

# Eighteen-Year Progress Report on the Highway Research Program at Purdue

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## INTRODUCTION

The growth and progress made in the operation of a business enterprise are of interest to the stockholder, patron, and public. It is customary for each business to prepare reports of progress.

The Joint Highway Research Project has always operated in a similar manner and has used various technical papers and bulletins, annual reports, and the Highway Extension News to report research data and accomplishments.

It has been customary to present specific progress in research to the Purdue Road School. A report of the aims and activities of the Joint Highway Research Project was presented to this body in 1940 (3)\*. A similar report, which summarized ten years of highway research at Purdue, was submitted in 1945 (12). These periodic reports of progress were supplemented in 1950 when a report on the pay-off in highway research was presented (79).

The accomplishments since 1950 have been so numerous and important that it has become necessary to present an up-to-date summary report of progress in highway research at Purdue.

Research as a major factor in achieving progress has been demonstrated well in recent years. In fact, most of the great advances in the field of technology are due directly to research. Every successful industry recognizes the importance of the search for new knowledge, for new products, new uses, and the quest for improvement in their present commodities. Large corporations invest as much as 2% of their income in research and development. Today's civilization is,

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\* Numbers in parentheses refer to references in the attached bibliography.

in part, a product of the research of the past; civilization of tomorrow will be influenced markedly by the research of today.

The great demands for transportation and the importance of transportation to the economy of the nation, the state, and community require that transportation systems be adequate, efficient, economical, and safe. This is a serious challenge—one that will require the maximum energies of every highway man and the cooperation of every citizen.

The means for providing and maintaining a modern highway system is not a finished business—much remains to be learned about highways.

It has been said that the development of the highway has not kept pace with the development of the motor vehicle. This indicates the need of more effective planning and design, improved methods of finance, improved methods of construction, more economical techniques of maintenance, more efficient means of traffic operation, and safer means of travel.

In recent years, the great increases in highway travel and the large sums of money required to construct modern highways have resulted in a greater emphasis upon highway research and development. The Federal Government expends considerable funds on studies, plans, and research for the highway systems. Many state highway departments, universities, industrial and commercial companies, and national and local organizations have also contributed materially. The State of Indiana has contributed its share. For many years research has been an important activity of the State Highway Department of Indiana.

### HISTORICAL

This activity began in 1936 with the establishment of the Joint Highway Research Project at Purdue University. Although the budget for the Project has always remained only a fraction of one per cent of the total state highway budget, a considerable amount of research has been completed or is in progress covering a wide variety of highway problems. The Project was the pioneer in state highway-university co-operation, and has served as a model for the development of similar organizations in many states.

The Joint Highway Research Project is sponsored by the State Highway Department of Indiana and Purdue University. The legislative act authorizing the Research Project requires the allocated money to be expended for the conduct of highway research, the holding of the annual Purdue Road School, the dissemination of highway in-

formation, and for highway extension. The Highway Department contributes the "out-of-pocket" finances while the University provides the physical plant and administration. An Advisory Board which includes members from each unit guides the research activities.

The organization was established as a result of an agreement between the Chairman of the State Highway Commission of Indiana and the Dean of the Schools of Engineering at Purdue University. During the first year the Commission budgeted \$25,000 for research and on March 11, 1937 the organization was established by an act of the State Legislature which permitted the Commission to allocate up to \$50,000 annually for the operation of the research organization. In 1949 the legislature revised the 1937 act, to raise the permissive amount the Highway Department may allocate to the University. The offices and laboratories are located in the Civil Engineering Building at Purdue University.

### PRESENT ORGANIZATION

Close coordination is maintained with the Highway Department through the Advisory Board. The Board outlines policy, receives and recommends projects, receives reports on projects, approves release of research data, and recommends to the Highway Department and the University the quarterly funds to be allocated. Through their intimate contact with the program of research, the Highway Department



Fig. 1. The Advisory Board during one of the day-long sessions. This group meets once each month to review proposed programs, reports of progress, and budgets.

members are able to guide the research endeavors toward the most pressing Indiana highway problems and to apply quickly the knowledge gained.

This Board is composed of five division heads of the Highway Department and six members of the staff of the School of Civil Engineering. The present membership is: J. R. Cooper, J. T. Hallett, F. F. Havey, W. H. Sorrell, C. E. Vogelgesang, P. F. Chenea, J. M. Hayes, R. E. Mills, B. H. Petty, R. B. Wiley, and K. B. Woods. See Figure 1.

The Highway Research Project is a unit in the Engineering Experiment Station and is administered by the Head of the School of Civil Engineering, who also serves as Director. At the present time there are seven research divisions, each of which is administered by a full-time staff member. These divisions are as follows: Soils, Concrete and Rigid Pavements, Bituminous Materials and Flexible Pavements, Airphoto Interpretation, Chemical, Traffic, and Economics and Administration. These divisions are the scene of graduate work and the area of research programs, and most of them are the source of educational courses at the graduate and undergraduate level. At the present time, the staff of the Project includes 24 full-time employees and 15 half-time graduate research assistants. From 50 to 75 undergraduates are employed on a part-time basis to assist on research projects.

One important advantage in having the Highway Research Project located at Purdue is the availability of professional engineering counsel from the various schools and divisions of the University. Highway Research has been facilitated through the use of the many facilities of the University and through the assistance of the staff outside of the Highway Research Project. Academic areas contributing to the highway research program include the Department of Chemistry, the Schools of Mechanical, Chemical, and Electrical Engineering, the Department of Agronomy, the Department of Mathematics including in particular the Statistical Laboratory, the Electronics Services, the Heat Transfer Laboratory, and Engineering Mechanics. The School of Civil Engineering has, of course, contributed a great deal to the programs by way of staff and facilities from Structures, Soil Mechanics, Sanitary Engineering, and Materials Testing.

The University has provided seventeen thousand\* square feet of floor space for the research laboratories and offices. In addition, the organization makes full use of the facilities of the general Business Offices of the University, particularly Accounting and Purchasing,

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\* Allocated as follows: Concrete Laboratory and Shop 3900 sq. ft.; Bituminous 2900; Soils 1500; Chem. Lab. 550; Transportation 1050; Airphoto 5800; General Office 1300.

while the Head of the School of Civil Engineering and the Director of the Engineering Experiment Station serve the organization without pay.

### SCOPE AND PURPOSE

The purpose of this paper is to review the major accomplishments of the Joint Highway Research Project. Brief mention will be made of the material contained in previous progress reports, but major emphasis will be given to accomplishments since 1950.

The accomplishments will be discussed under the following topics:

1. Design and Construction
2. Materials and Specifications
3. Maintenance
4. Economics, Administration, Finance, Traffic, and Safety
5. Research Contracts and Related Activities
6. Extension and Dissemination of Information
7. Engineering Education

The paper is concluded with a summary of the most important accomplishments of the Joint Highway Research Project and a section on "Looking Ahead."

### RESEARCH CONTRIBUTIONS IN DESIGN AND CONSTRUCTION

Some of the more important work completed by the Highway Research Project has been in the field of design and construction. Although special programs are rarely set up for the specific purpose of developing information for design and construction, nevertheless the end result is very frequently applicable to the highway areas.

#### *Soils Manual*

One of the most far reaching and important developments of the Joint Highway Research Project has been the work on the engineering characteristics of the soils of Indiana. This work was released in 1943 as Engineering Experiment Station Bulletin No. 87 (10). The research consisted of combining the geological and pedological information available in Indiana with newly developed engineering characteristics of the soil materials for most of the soil areas of the State. The completed bulletin contains an engineering soils map of Indiana and presents the engineering characteristics of about 130 major soil materials, presented in profile and work-description form.

This engineering-soils manual of the State has been used extensively for the solution of many problems of highway design and construction and particularly for the location of materials of construction and for

correlating such highway problems as frost heave, rigid-pavement pumping, and the thickness requirements for flexible pavements with type of soil. Since the release of the bulletin several states have developed similar soils manuals for use by their respective Highway Departments. Although the value of this work is more or less intangible, the benefits to the Highway Department and to the State at large are important and the results will continue to pay dividends.

#### *Explorations*

Closely related to the production of the soils manual has been the development of new and important techniques for determining subgrade and foundation conditions for paving and bridge projects. As more consideration is given to the foundation material on which pavements are placed, the research in this area becomes extremely important. It is now known that a pavement cannot be economically and adequately designed unless the characteristics of the soil on which the pavement is to be placed are known. This not only necessitates information about the surface soil but also, in the case of foundations for large structures, requires knowledge of the subsoil conditions—sometimes to considerable depths.

#### *Airphotos*

The most significant of these newly developed techniques has been the use of aerial photographs for predicting engineering soil conditions (10, 30, 36, 37, 38, 42, 239). Many years of highway research on the correlation existing between airphoto patterns and the characteristics of Indiana soils has been supplemented by large Engineering Experiment Station research contracts with outside agencies (Civil Aeronautic Administration (176); The United States Air Force; the Corps of Engineers through the Army Map Service, District Office at St. Paul, Minnesota, and the Waterways Experiment Station at Vicksburg, Mississippi) through which literally thousands of airphoto patterns of soils have been studied and catalogued for Indiana as well as for the rest of the United States, Canada, Alaska and many foreign areas. Out of these several large research programs have come the development of the science of airphoto interpretation as well as procedures for producing soil maps (Figure 2) of Indiana counties (46, 53, 69, 70, 73, 101), the use of the strip map techniques for evaluating soil conditions along a relatively narrow strip of a proposed highway or turnpike location (77, 94), and the use of low-altitude strip airphotos which have been used in some states in road and bridge location surveys (45), and have been used in Indiana for making condition surveys of existing pavements.

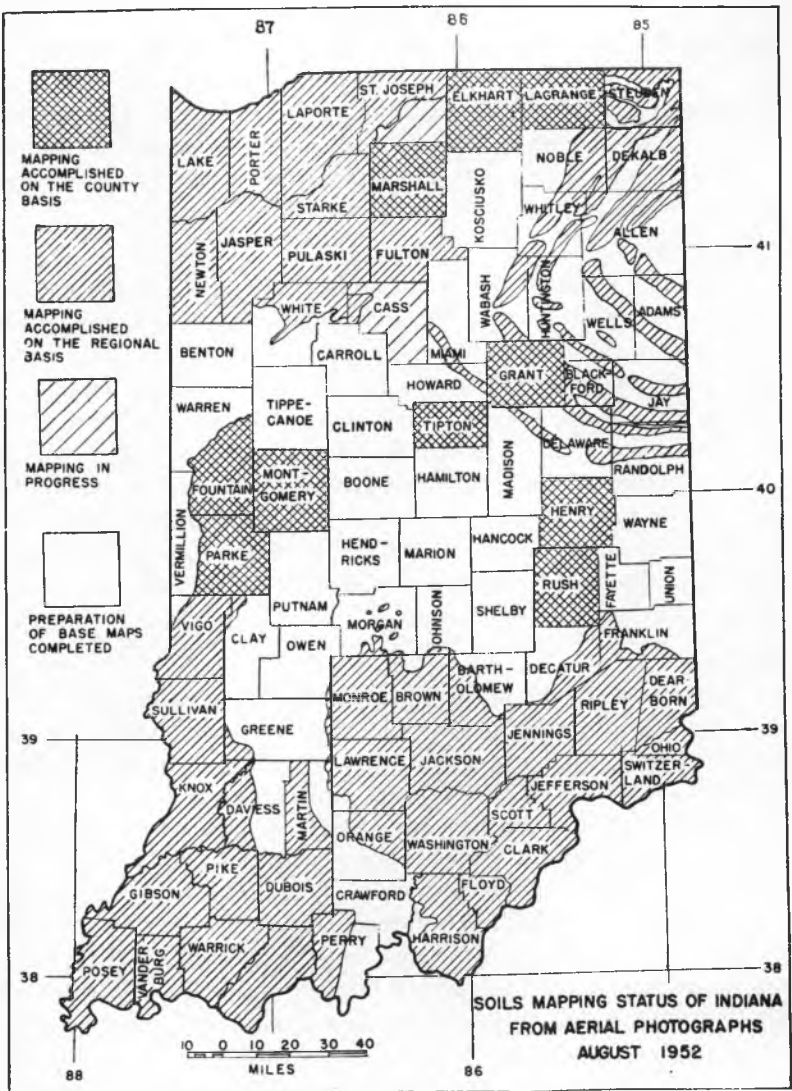


Fig. 2. Status of Indiana soils mapping program is illustrated on the map of the state.

As a result of the combined research in this airphoto field, carried on mostly by the Highway Research staff at Purdue, it is now possible for trained personnel to use airphotos, not only for the selection of the best routes and sites for highways, turnpikes, airports, and other engineering structures, but also to predict the general soil profile

with respect to engineering characteristics of soils and to locate granular materials for use in construction. The results of this important research have affected and will continue to yield important savings in many design and construction aspects of the engineering programs carried on by the State Highway Department of Indiana, the Toll Road Commission, and the counties in the state.

### *Foundation Explorations*

Additional work in the field of soil exploration includes special research done for the Bridge Bureau of the Highway Department for foundation explorations through the use of resistivity procedures (106, 111). Known electric currents are induced in a foundation site and the amperage and voltage drop between several points are measured at the surface and are recorded. Note Figure 3. These data are then used to predict the nature and depth of the various layers of different

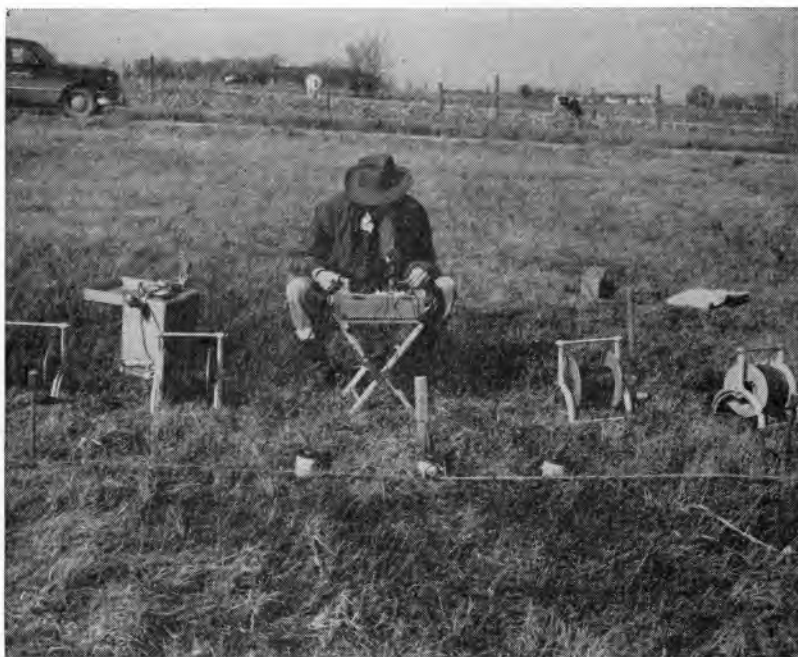


Fig. 3. Resistivity testing setup used for determining quickly and accurately the foundation conditions for bridge footers. (31733)

soils. The use of this method is rapid, comparatively easy, generally accurate, and much more economical than coring methods. This study developed procedures for using the method in Indiana and provided



the Bridge Bureau with design data for several sites. The work completed to date also indicates application in determining the depth of peat bogs.

### *Drainage Maps*

Another project in the development of soils maps has been the use of airphotos for producing county drainage maps showing drainage channels in very fine detail (52, 185, 189, 215, 221). In the absence of adequate information on the topography of the State, the drainage reports have had wide application, not only for the Highway Department and the Toll Road Commission, but also for a number of other agencies including the Flood Control Commission, Planning Commissions, and the Conservation Department. This project has been underway for many years and will be completed within the next eighteen months (78 Indiana counties have already been mapped as shown in Fig. 4). A published set of these county maps will be made available to engineers and others throughout the state in the near future. The monetary value of this type of project, too, is intangible. Nevertheless such developments pay dividends many times in excess of the original cost of the research, particularly with respect to determining the size of waterway openings for bridges and culverts. One failure alone of a highway or county bridge, caused by use of an inadequate bridge opening, which in turn resulted in the use of inadequate drainage data, could more than pay the cost of the entire mapping programs of all the counties in the State. When the results of research can be shown in tangible form, such as these, it is apparent immediately that research laboratories have a well-established function in the affairs of any highway department.

### *Rigid Pavement Studies*

Included with those projects which have high monetary value to the Highway Department is, and continues to be, the reasearch work done in Indiana on the pumping of rigid pavements (Figure 5) as related to the type of soil and the intensity and repetition of load (31, 35, 49, 55). Also the maintenance procedures developed for handling the problem and the design concepts which have evolved are of significant economic importance. Performance surveys made in 1943 and again in 1947 showed that about 500 miles of pavements were damaged or distressed by pumping.

Considerable research effort on this subject, performed at the request of the Advisory Board, has made possible the development of new and adequate designs. The loss to the State in damaged pave-

ments amounts to many millions of dollars, but it is pertinent to note at this time that structural failures of new rigid pavements have occurred only rarely in Indiana since new designs were adopted in

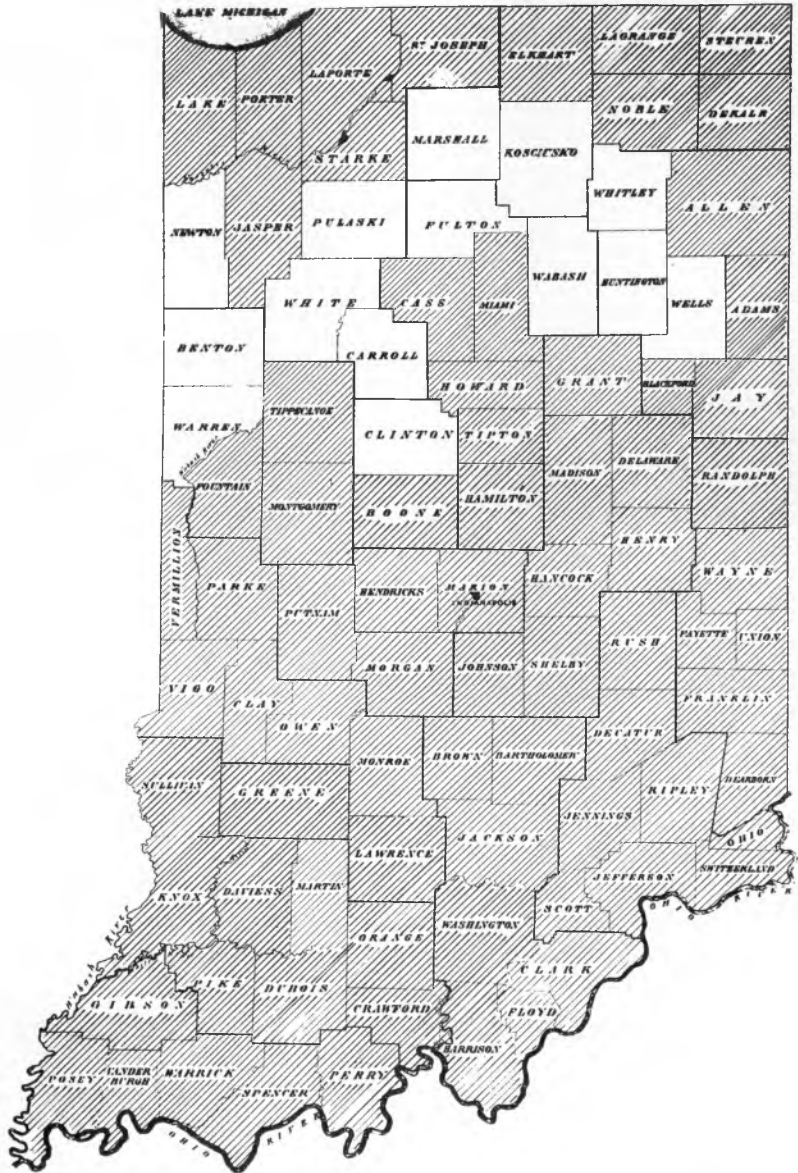


Fig. 4. The Indiana county drainage mapping program is nearing completion. This project has been under way since 1944.



Fig. 5. This view shows a "water squirt"—a new and serious highway problem known as "pavement pumping." (4713)

about 1946 as a result of research efforts (90). It should be emphasized strongly that this is no small research accomplishment—the development of new designs and a completely adequate solution to a problem which had been costing an estimated \$500,000 a year.

Research work continues in this field on additional performance surveys, study of various pavement-design techniques, the use of continuous reinforcement, and the use of filter and other types of base courses (48, 49, 349). Recently initiated projects in the field of rigid-pavement design include studies of pavement strains (which indicate stress) in the pavement, through the use of strain gages embedded in the concrete. As a result of unpredictable changes in the intensity and magnitude of loads, it has been considered extremely important by the Advisory Board of the research organization not only to maintain the present tempo of this research activity but also to expand it.

On the U.S. 41 test road cooperative research is being conducted by the Project, the State Highway Department, and the Bureau of Public Roads on the relative support characteristics of nine different

subbases. A determination of the stresses of rigid pavements is also receiving attention.

### *Flexible Pavements*

With respect to flexible pavements, the research organization has indeed been active for a long period of time (1, 8). Early and important work covered studies of the aggregate gradation (5) and bitumen-content requirements for surface-treatment work and for low-cost roads (7). Rock asphalt, as a surface material for primary roads, was studied extensively (6).

Very important contributions have been made in recent years in basic studies of bituminous-concrete test methods (Figure 6) and design criteria (81, 89, 104, 113). These studies are still active and much remains to be done in this field of endeavor. More recently, interest has been concentrated on the rutting of bituminous mixtures (Figure 7) as related to design of the mix, the type of load causing rutting, and the thickness of bituminous-aggregate overlay. Work in this area is already occupying the attention of a portion of the research staff. See Figures 8 and 9.

In addition, methods of flexible pavement design (25) have been studied intensively. Field studies of base and subgrade rutting failures of flexible pavements, have been made also. It is emphasized that the laboratory work already completed in the area of both thickness design for flexible pavements and strength design of bituminous-aggregate mixtures would be enhanced by the construction and observation of a fairly large number of test sections located on the state highway system throughout Indiana (43, 81, 87).

### *Bridge Studies*

The Project is also assisting the State Highway Department in other research of a design character. A study of the stresses in various structural members of a steel bridge over the Yellow River is currently under way and will be reported in the near future.

Related to the quality of aggregate for portland-cement concrete pavements has been a large-scale condition survey of portland-cement concrete highway structures throughout the State (Note Figure 10). This study was requested by the Highway Department's Engineer of Bridges. It is now known that the quality of aggregate has a less important bearing on the performance of these structures than do factors of design, construction, and maintenance and the report being submitted to the Highway Department at the present time will carry, among other recommendations, the use of air entrainment in all bridge

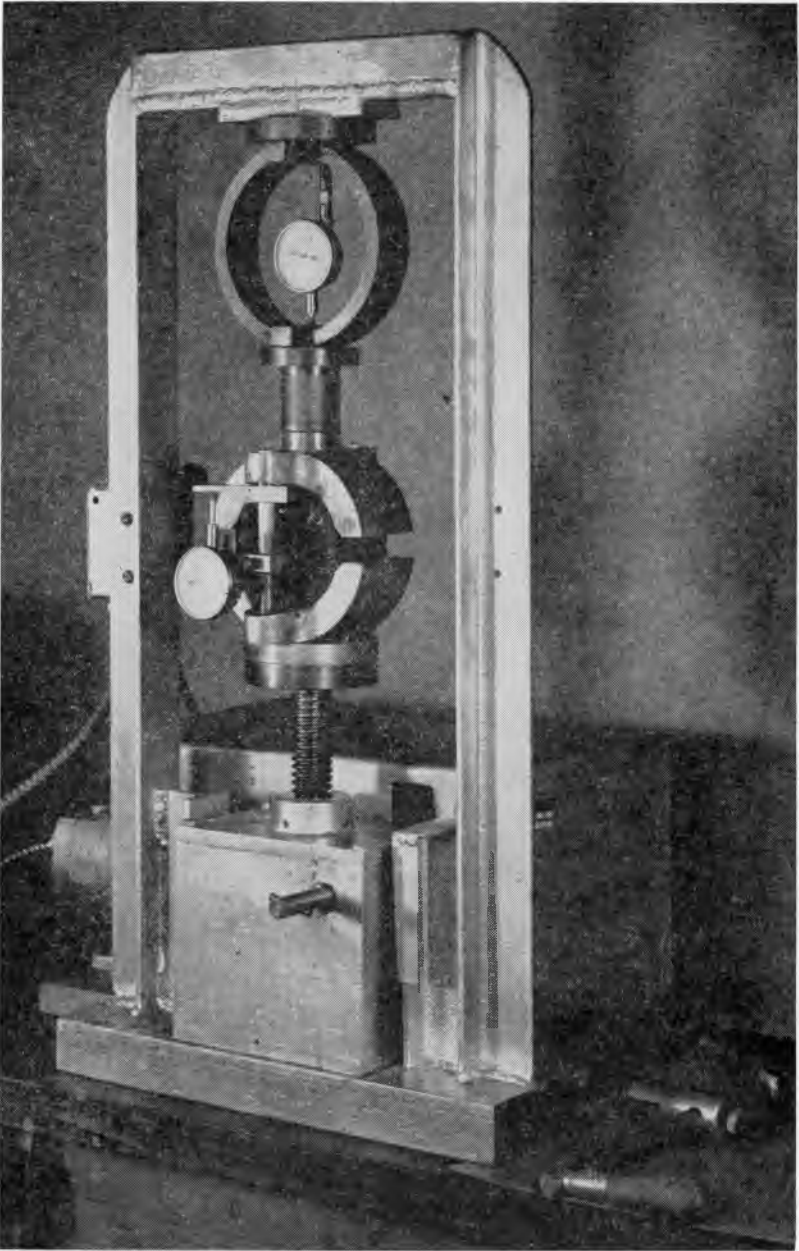


Fig. 6. Laboratory studies of strength tests of bituminous-aggregate mixtures are carried on in the Joint Highway Research Project Bituminous Laboratory with the use of the stability apparatus pictured here. (18406)

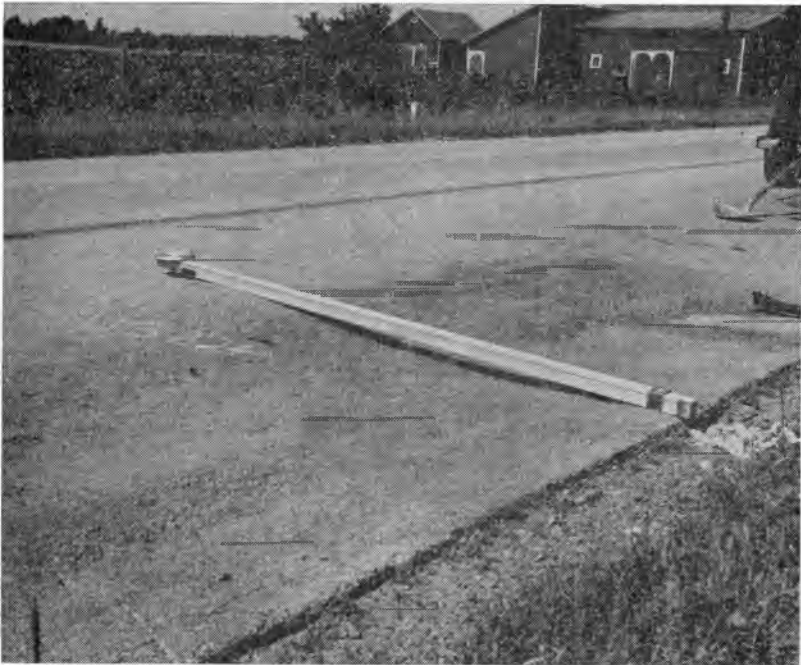


Fig. 7. One of the many flexible pavement studies is illustrated in this view showing serious rutting of bituminous surface on U. S. 224. (22665)

super-structures. It is expected that considerable ultimate savings will be effected through increased life and decreased maintenance of structures by the adoption of this and other recommended changes in design, construction, and maintenance procedures. For example, the cost of repair amounting to 25 to 50 thousand dollars for a single structure will pay for a considerable portion of the entire yearly highway research budget, if this repair bill can be saved through design changes made possible through research.

#### *Engineering Investigations*

The Highway Department frequently uses the research facilities to determine design criteria. For instance, the Project's Soils Laboratory has been used extensively to determine California Bearing Ratio values of the subgrade soils for both the U.S. 41 and 31 test sections. Likewise the Bituminous Laboratory has been of material assistance in supplying design-of-mix data for the bituminous sections of the test project on U.S. 31 (113). On two occasions, moving pictures have been made by the staff of the Research Project to record specific design



Fig. 8. This view shows one method of obtaining cores of bituminous concrete resurfacing for laboratory tests. (34787)

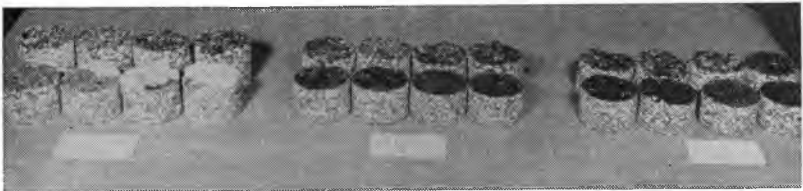


Fig. 9. Studies on resurfacing of portland cement concrete with bituminous concrete have been carried on for many years—comparison of cores taken from rutted pavement—in-wheel-track are on left, between-wheel traffic are on right. (34765)

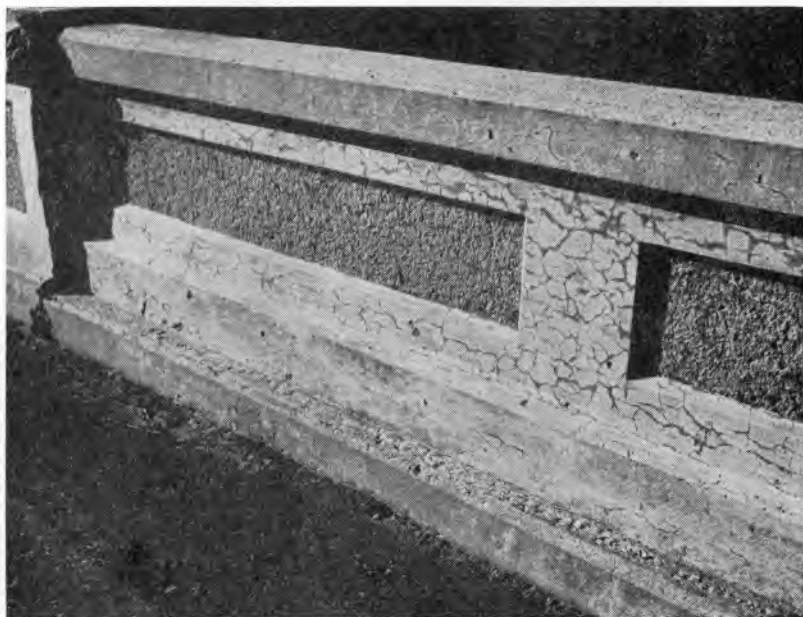


Fig. 10. Deterioration of a bridge structure. Note the pattern cracking—a sure sign of deterioration. (22613)

and construction details in connection with field tests conducted by the Highway Department.

### MATERIALS AND SPECIFICATIONS

The highway research organization has been very active in the field of materials research and in assisting the Highway Department in the development of adequate specifications. Results of research in this field may have an important bearing on the economic aspects of highway construction because the development of information for use in specifications can have far-reaching effects in improving the quality of completed structures in resolving apparent inequalities between material types and broadening the use of present materials as well as developing and applying new materials.

#### *Aggregates for Concrete*

One of the early projects on Materials and Specifications was the study of chert as a deleterious constituent of aggregates (9). Field observations had shown that chert was causing difficulty in pavements and structures alike. Several years of laboratory work established that chert varied in quality almost directly with its porosity. As a result,



it was possible to develop specifications for aggregate which limited the amount of this type of deleterious material by defining specific gravity ranges (9, 21). One of the important contributions of the staff to the knowledge of concrete aggregates was the work done on rigid-pavement blow-ups (Fig. 11) and the correlation of this phenomenon with the quality and type of coarse aggregate used in the concrete mix (50, 59, 64, 66, 68, 78). The first report on this subject was released in 1945 (39) and received the award of the Highway Research Board of the National Research Council for the outstanding highway research paper presented that year. The report had two important influences with respect to the highway systems of Indiana, namely, (a) the data were used by the State Highway Department to prove that expansion joints were not required on most rigid-pavement projects, which change in design has resulted in an estimated annual savings of between \$100,000 and \$200,000 a year—an amount equal to or higher than the present highway research budget (79 p. 91); and (b) the work has resulted in a series of laboratory experiments which, in the end, caused the abandonment of certain sources of supply of poor quality coarse aggregates or in improved quarrying procedures for better utilization of materials available. The savings accumulated as a result of this later work amounts to many thousands of dollars each year. Development of a standardized acceptance test for aggregates is currently underway as a result of the findings of these studies. This is another case where the results of research are paying handsome dividends and also another reason why the State Highway Department of Indiana has been able to supply the motoring public with one of the finest highway systems in the country. Another study has demonstrated that deleterious particles in gravels can be separated by heavy media techniques (97, 253). Work is currently underway to establish proper specific gravity values for use in acceptance testing of aggregates. See Figure 12. It has been established in other areas of the country that the treatment of gravel aggregates, by methods of heavy media separation, will improve considerably the durability of concrete made with certain gravels.

Other studies have shown that the durability of concrete in which inferior materials must be used for economic reasons can be improved in some cases by the use of air entrainment or by drying the aggregate prior to use (59, 66). Any drainage that can be used to help keep the concrete from absorbing water later also is helpful in improving durability.

In addition to these materials studies, the staff is continuing the work on field surveys to establish accurately the quality of aggregate from sources in Indiana. A newly installed automatic freeze-thaw

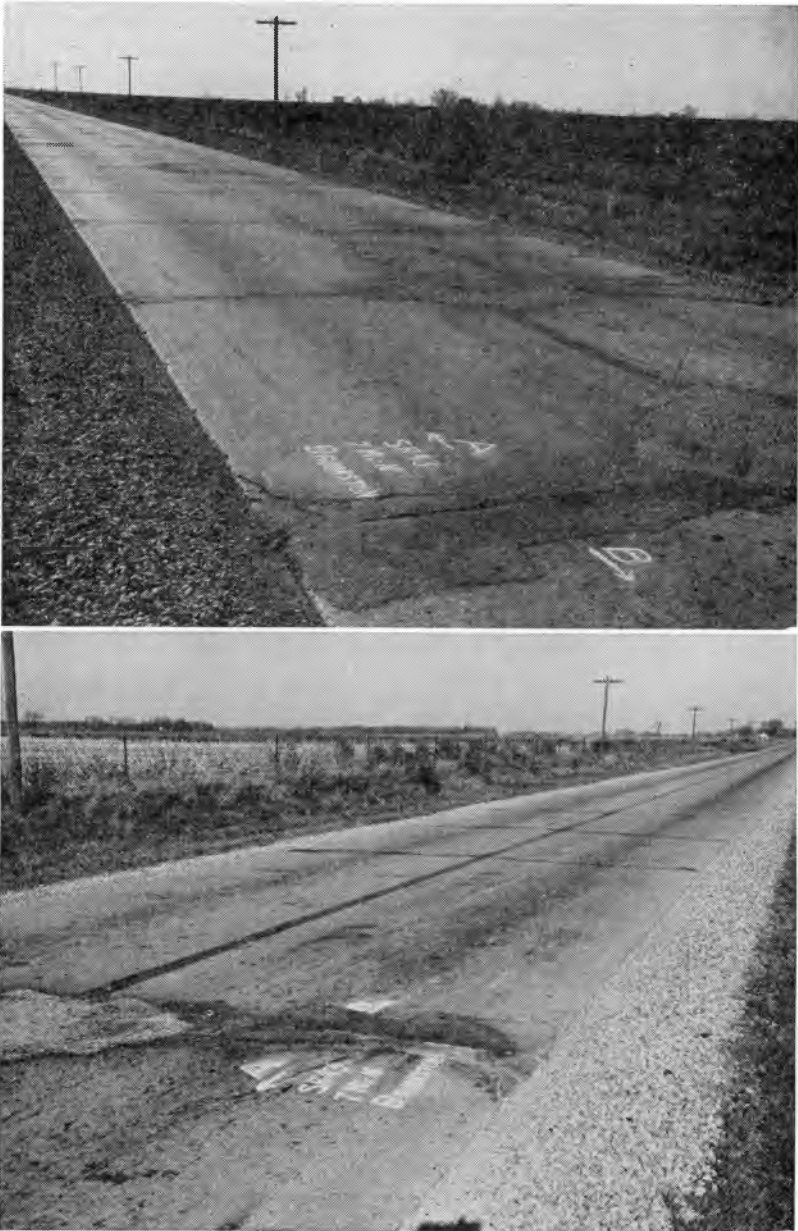


Fig. 11. These combined views show the effect of coarse aggregate on performance of portland cement concrete pavements. The photos show the contrasting performance on opposite sides of a construction joint at which the coarse aggregate was changed from 9-1S to 79-1G. All other materials are the same for both sections of pavement. (19663, 19665)

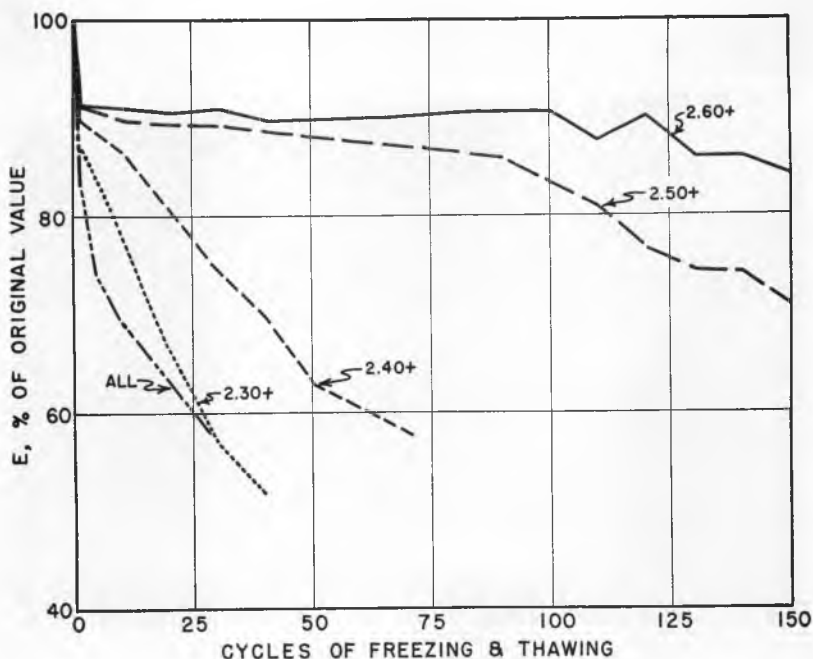


Fig. 12. Improvement of concrete durability in freezing and thawing by removal of lightweight particles of aggregate is illustrated in this chart. The figures on the curves show the minimum specific gravity values of gravel aggregate used in the laboratory tests. (31676)

machine is available to supply the State Highway Department quickly with data on newly opened quarries and gravel pits. In addition, some important laboratory work is underway on the amount, shape, and size of the pore systems in various classes of aggregates. Chemical reactivity of aggregate with chemical constituents of cements (Fig. 13) is also being studied in connection with materials and materials specifications. (Figs. 14 and 15.)

#### *Aggregate for Bituminous Mixtures*

In the bituminous field, many data have been obtained that contribute to the knowledge of aggregate characteristics as they affect bituminous concrete. These include among the early studies the characteristics of adhesion of bituminous materials and crushing resistance (5, 19). The work has already proved of value to the State Highway Department and the research could be expanded in the years ahead. Important application of these new data includes, in particular, the development of specification requirements for the percentage of crushed



Fig. 13. General view of the Joint Highway Research Project Chemical Laboratory. (14899)

material needed for various types of bituminous-aggregate mixtures. Important information has been given the Highway Department from time to time on the effect of gradation on the strength of bituminous-aggregate mixtures (149, 244, 275, 317), an important area of research since strength requirements vary with changes in traffic volume and load intensities. A thorough study has been made of the possible use of Indiana's sands (67) and sandstones (71), particularly for low-cost roads in areas where the quantity of good-quality aggregates is limited. The study of aggregate shape is developing into one of the important projects of the research laboratory and has resulted in the recently released report showing the effect of the shape of aggregate on the stability of the bituminous aggregate mixtures (255).

It should be emphasized that much of the work on materials is of long range and of a basic nature. Fundamental studies are the only foundation on which applied research can be built. Research in highway materials is no exception. Even though it is difficult to show the tangible benefits of some of this work and they are frequently rather long term, they are nevertheless very real and such studies are of prime importance.

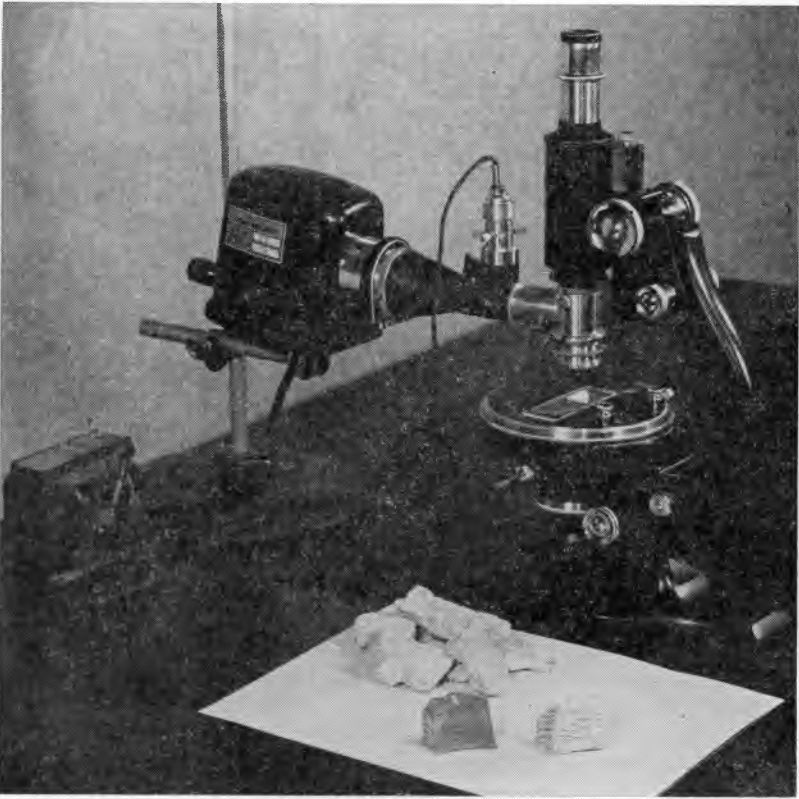


Fig. 14. This view shows the petrographic microscope used for study of aggregate. (7688)

### *Traffic Paint*

In the field of traffic paint the research laboratory has supplied the Highway Department with both field and laboratory data from time to time on the quality of traffic paint (23, 33). This research points up the need for better specifications for traffic paint and also shows the possibility for developing better traffic paints (Fig. 16). The availability of staff and facilities to handle a project of this character is an important asset to the Highway Department.

### *Base Courses*

The work on the gradation and quality of binder soil of soil-gravel mixes used for base courses has been outstanding (48). The results of this study have been used by New Jersey and New York and the major results are being incorporated in present design practices and specifications of the State Highway Department of Indiana.

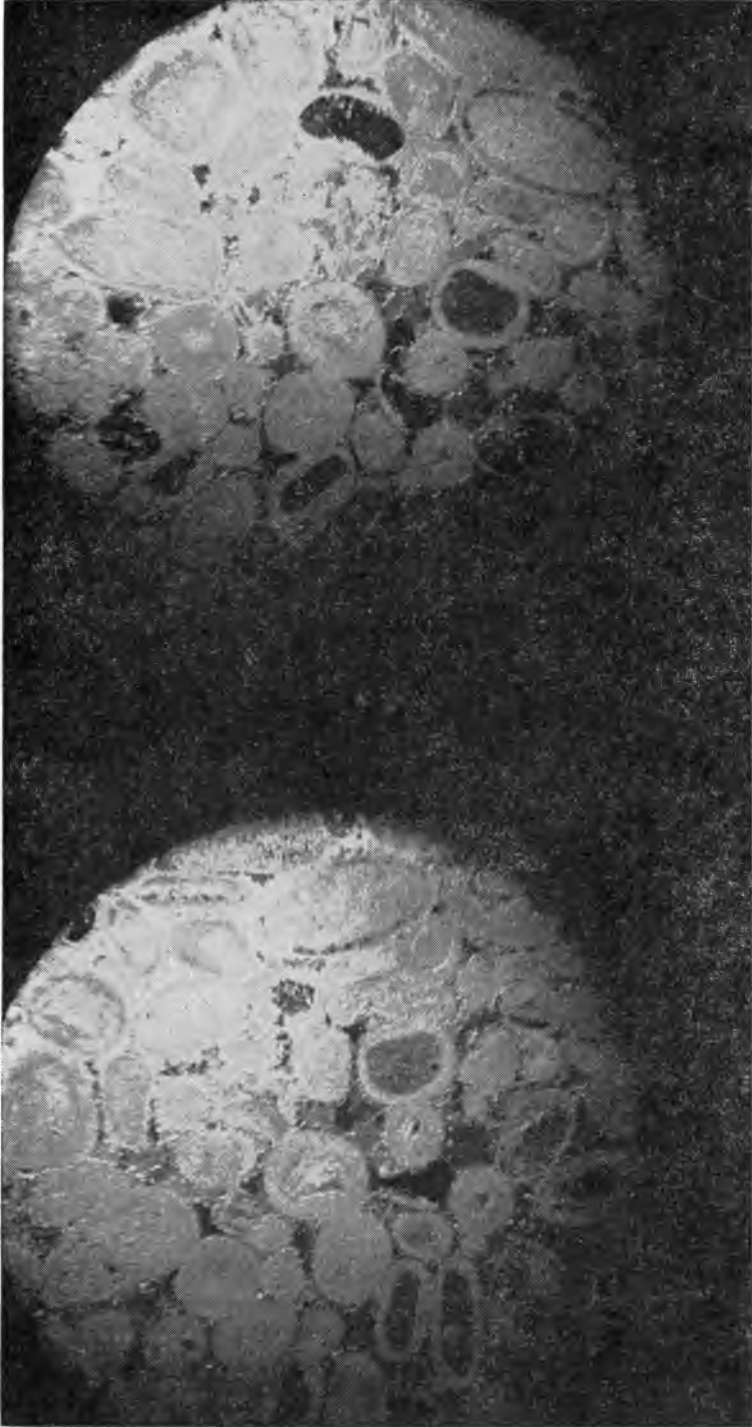


Fig. 15 This illustration is a picture of a thin section of oolitic limestone as seen through a microscope. (23297)



Fig. 16. Field testing of traffic paints for the Highway Department is illustrated in this view. Note the wide range in quality of the various paints being tested. (3265)

### MAINTENANCE

An important part of the work in the research laboratories has been for and at the request of the Department of Maintenance. As a result of the constantly increased mileage of new construction and with the never-ending increases in traffic volumes and loads, maintenance costs are bound to increase. This field, therefore, is one which deserves special attention.

### *Research Reports*

Since most of the efforts of the Joint Highway Research Project have been directed toward the solution of existing problems, it follows that almost any type of research report is of interest to the Maintenance Department. For instance, the field surveys and laboratory work on blow-ups was used to develop a resurfacing program directed toward the salvage of pavements which were in distress for known and specific reasons. Many other research reports, such as field surveys of rigid pavement pumping, have been used similarly (151, 171).

### *Spring Break-up Surveys*

Of particular value to maintenance has been the 1943 survey of spring break-up of flexible and rigid pavements. The study showed that about 1,500 miles of flexible pavements were either destroyed or were severely distressed during this particular spring, and information was made available to the Department with respect to the various causes of spring break-up together with recommendations for minimizing the problem.

### *Surface Treatments*

Some of the early work in maintenance was on surface-treatment construction which included in particular research data on optimum gradation and bitumen content of bituminous-aggregate mixtures (5, 8, 19). One large test road was constructed by the Maintenance Department in co-operation with the staff and Advisory Board and a great deal of important engineering data were obtained during the 10-year life of these field tests (43). In addition, stabilization with the use of various chemicals has received a great deal of attention and several test roads have been built and detailed records obtained upon the performance of these various treatments. This type of research, is also of considerable importance to the counties.

### *Pavement Pumping*

In recent years the rigid-pavement-pumping problem has received serious consideration and both laboratory and field experiments have been used to develop the best maintenance procedures to correct or retard the pumping action. Included have been the use of cement slurry or hot bituminous materials pumped under the deflecting rigid pavement slab (56, 57). Note in Figures 17 and 18.

### *Overlays*

Through test sections and long-term performance surveys the staff, at the request of the Advisory Board, has been able to develop





Fig. 17. Crew undersealing pumping pavements with extremely hot bituminous material. This maintenance operation has made possible the salvage of many miles of high-type pavement in Indiana. (18839)



Fig. 18. Undersealing placed under pumping pavements. Note bituminous material under rigid pavement. This maintenance operation has proven quite successful in retarding the pumping out of subgrade soils from beneath rigid pavements. (18333)

representative data covering the performance of types of overlays including both rigid (85) as well as flexible ones (87). The information from such surveys is placed in the hands of the Highway Department engineers and changes in designs and construction procedures can be incorporated on relatively short notice.

### ECONOMICS, ADMINISTRATION, FINANCE, TRAFFIC, AND SAFETY

The status of the several forms of transportation has been given attention recently by the staff (13) and analyses have been made of problems of finance, legislation, management and organization, and of the county-road problem in Indiana. The need for more effective planning and administration was shown to be a problem of major concern by many of these studies (82, 109). A comparative analysis of local road practices in three abutting counties of Indiana, Michigan, and Ohio has been made and criteria have been suggested for the establishment of more effective county road administration (107).

#### *Highway Department Organizations*

Recently, a study of state highway organization and salary scales in representative states was prepared. The advantages and disadvantages of the several types of highway administration were listed. See Fig. 19. Emphasis was placed on the evident fact that adherence to effective policies of wage administration and personnel practices is essential if public service is to compete favorably with private enterprise for qualified engineering personnel.

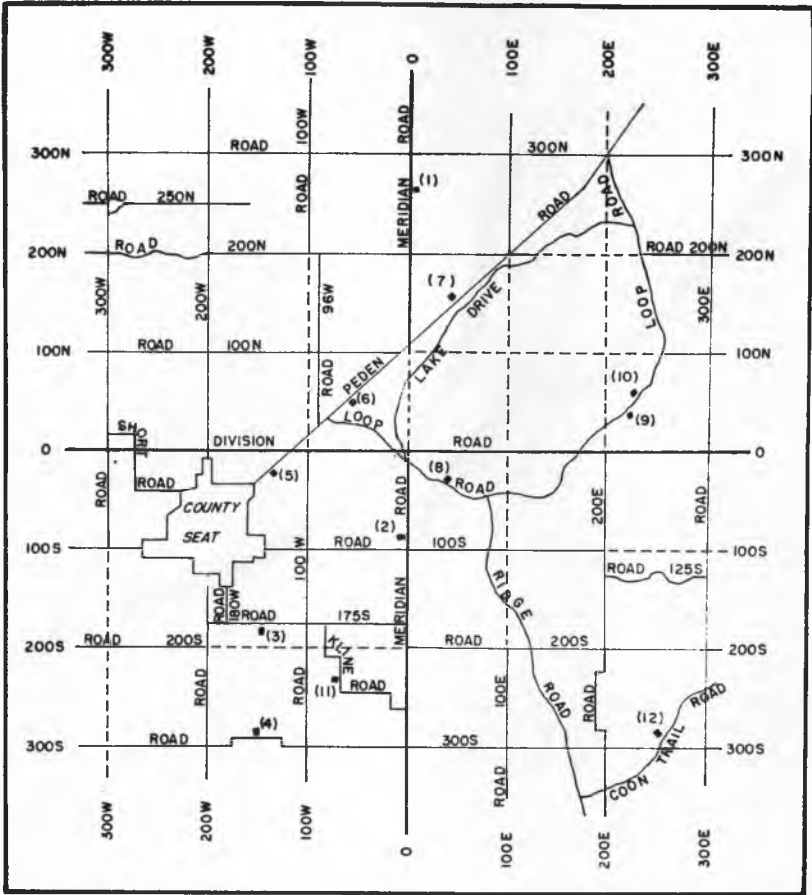
#### *Finance*

Studies of the factors affecting highway finance have given a better insight into the highway spending of the past and have suggested methods of allocating the great financial costs that the highway system presently demands. The classification of roads and streets and the development of sufficiency rating procedures is currently being studied and will, when complete, provide techniques for better planning of highway construction and maintenance.

#### *Road Identification*

A method for identifying county roads and numbering rural homes was prepared and made available to county officials of the State (257). See Fig. 20. The necessity of such a method was well known and had received considerable study by various organizations and individuals. The study was made in the hope of establishing uniformity





- |                              |                                       |
|------------------------------|---------------------------------------|
| (1) 263N MERIDIAN ROAD       | (7) 15N 43E PEDEN ROAD (0E)           |
| (2) 88S MERIDIAN ROAD        | (8) 28S 39E LOOP ROAD (0E)            |
| (3) 144W ROAD 175S           | (9) 39N 222E LOOP ROAD (0N)           |
| (4) 151W ROAD 300S           | (10) 51N 230E LOOP ROAD (0N)          |
| (5) 21S 134W PEDEN ROAD (0S) | (11) 238S 69W KLINE ROAD (175S)       |
| (6) 52N 56W PEDEN ROAD (0W)  | (12) 285S 252E COON TRAIL ROAD (300S) |

Fig. 20. This chart shows an example of road and house designations proposed for use by the Joint Highway Research Project for Indiana counties. (33493)

in the method used by the 92 counties so that easy identification would be possible throughout the State.

#### *By-Pass Studies*

In the area of traffic engineering and highway planning, many valuable studies have been completed or are being made. A study of

the uses, effects, and control of by-passes has received nation-wide recognition and has indicated the methods which should be employed in locating and maintaining these facilities for full use with maximum benefits for their entire life (Fig. 21). A determination of the num-

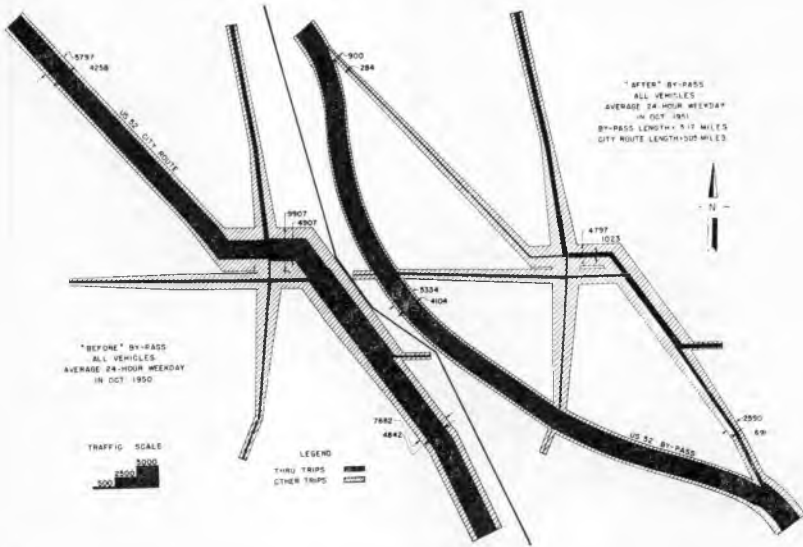


Fig. 21. This graph shows traffic volumes "before and after" construction of a by-pass performed at Lebanon, Indiana, by the Joint Highway Research Project for the State Highway Department of Indiana. (31335)

ber and type of vehicles which use a new facility has also proved valuable in determining the use that would be made of other suggested highways and has promoted planning of the proper facilities (109).

### *Traffic Surveys*

During the past three years, the research staff has co-operated with the Metropolitan Area Traffic Survey Unit of the State Highway Department in the planning, conduct, and analysis of comprehensive traffic surveys in six cities of Indiana (Fig. 22). Three of these studies have been made almost completely by Joint Highway Research Project staff and have provided adequate information for the development of a complete highway, street, and parking plan for these cities. The data collected from these surveys also have been used to develop new methods and procedures for collecting and analyzing traffic information that provides for more efficient, economical, rapid, and thorough use. Some of the most important of these have been the use of sampling procedures in origin-destination surveys (117), the adaptation of roadside interviewing to inside-the-city use, a comparison of the postcard and the home-



Fig. 22. This view illustrates the costly delays which occur frequently at railroad grade crossings. Traffic problems such as this are being studied by the Joint Highway Research Project in several Indiana cities. (30219)

interview methods of origin-destination surveys (15), and the determination of parking demand (Fig. 23), in order to reduce the cost of future surveys of this nature.

A comprehensive study of the characteristics of traffic will, when complete, provide valuable information for the highway planner and designer. A continuing traffic speed study, underway for the past 15 years, has proved valuable to engineers, administrators, enforcement officials, and legislators. The Project has also assisted the Statewide Highway Planning Section of the Department by collecting the speed data in the annual Truck-Weight-Speed study for the Bureau of Public Roads.

#### *Skid Resistance*

The Project is also participating extensively in several Test Road studies of the State Highway Department. Portions of the study of



Fig. 23. Data for research and planning are being obtained through origin and destination surveys as illustrated in this view. (23448)

the bituminous-concrete and portland-cement concrete test sections on U.S. 31 near Columbus have been assigned the Project. Skid-resistance and the lateral placement characteristics of traffic on the two types of pavements are being investigated.

For several years, skid tests have been performed on many pavements in Indiana. This study was initiated to evaluate the skid resistance qualities of various types of surfaces because of certain or reported "slick pavement conditions." A comprehensive study of this matter is under way.

### *Road Roughness*

At the request of the Highway Department, a Road Roughometer is being constructed at the University and, after calibration and the installation of previously developed recording equipment, will be used by the Department for comparison of smoothness characteristics of new surfaces and for determination of resurfacing needs on old pavements. Note equipment illustrated in Fig. 24.

The economic aspects of future research in highway traffic, safety, finance, and administration are almost unlimited—in the years ahead research in these areas will have far-reaching importance.

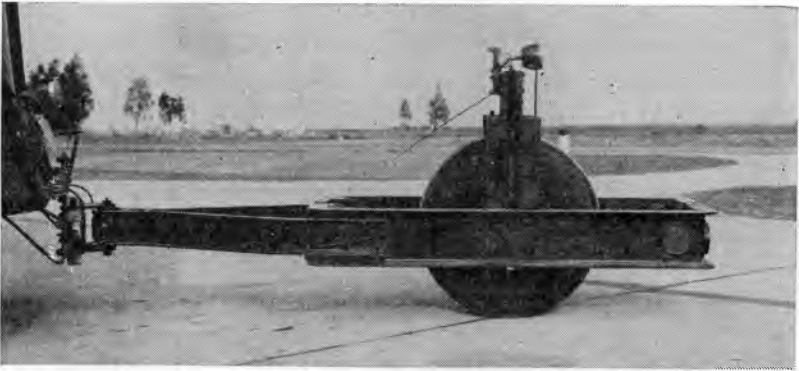


Fig. 24. A Road Roughometer measuring device similar to the one pictured above is being constructed by the Joint Highway Research Project for use by the State Highway Department of Indiana in an effort to construct and maintain pavements with "smooth riding" characteristics. (19548)

#### RESEARCH CONTRACTS AND RELATED ACTIVITIES

The accomplishments of the research staff over a period of many years tends to attract outside research as well as new graduate students to Purdue. Although the State has no financial interest in most of the outside studies, the benefits are important as the results of these researches are made available. See in particular reference Nos. 14, 42, 61, 80, 84, 93, 102, 103, 112, 176, 207, 210, 214, 220, 234, 235, 242, 261, 263.

The total annual amount of these contracts is now more than \$200,000—an amount considerably greater than the annual highway research budget, while the total for the past ten years is well over a half-million dollars. These highway and outside contract funds complement each to their mutual benefit, and at no expense to the Project.

##### *Graduate Research*

The graduate student body in the highway area has gradually increased in number until there are now about sixty graduate students in this and related areas. Many of them are sent to Purdue or are financed by governmental units, industry, and others and their thesis projects often supplement the highway-research program in developing research data of value to the state. Several dozen such projects have been completed over the 18-year life of the highway research organization, and these results have always been made available to the Highway Department through the Advisory Board. See in particular the



following references to theses: Nos. 274, 293, 311, 326, 329, 336, 339, 342, 346, 349, 350, 352, 355, 359, 360, 365, 366, 372, and 374. In addition a large portion of the highway research of the Project has been done by half-time graduate research assistants.

#### *Soil Stabilization Studies*

More important, perhaps, have been the non-highway research contracts coming to the University which have been assigned to the Highway Research Staff. The results of these researches have contributed to the solution of Indiana problems at no cost to the Project.

Outstanding studies of this character are the large-scale and long-term soil stabilization research programs financed by the National Lime Association, the Calcium Chloride Institute, the Bakelite Corporation, and government contracts with the Civil Aeronautics Administration and more recently the Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi. In addition to the current work on stabilization being done for the Bakelite Corporation, there is also a large government contract covering the study of frost action in base courses for rigid pavements. It is anticipated that results from this work will contribute significantly to Indiana base-course problems. Conversely, data already developed in Indiana should enhance the base-course study.

#### *Turf for Berms*

An extensive study initiated by the State Highway Department of Indiana in the form of some field tests and followed up by the Corps of Engineers by both laboratory and field tests, covered the requirements for growth of turf on granular shoulders. Most of this work was done cooperatively with the Agronomy Department of Purdue.

#### *Concrete Waterproofing*

A long-term research project which has been under way for the American Association of Railroads is a study of methods and materials for waterproofing concrete railroad bridges. The published reports of Indiana studies, particularly on aggregates, are pertinent to this railroad study and at the same time the results of this contract work can be applied to highway structures in Indiana.

#### *Rubber-Bituminous Mixtures*

A very interesting project on rubber-asphalt has been completed by the research staff for the Army Air Force at Wright Field under another Engineering Experiment Station contract. Rubber is being used in increasing amounts throughout many sections of the country as an additive with bituminous-aggregate mixtures and this laboratory study

has developed some significant data. Also, current work in this area includes tar-rubber combinations.

#### *Airphoto Interpretation*

The work on airphoto interpretation, mentioned previously, is important because of the large-scale projects which have been completed for the Civil Aeronautics Administration, the Corps of Engineers under the District Engineer, St. Paul, as well as later work for the Waterways Experiment Station at Vicksburg. Currently, some very important work is being done for the Army Air Force under a contract dealing with many important details of photography related to airphoto interpretation work. Additional current studies include "A Study of Desert Terrain" for the Waterways Experiment Station, and the preparation of manuals for the Army Map Service.

#### *Membership in Technical Societies*

Staff contacts with professional organizations have been important in bringing to Indiana the ideas and results of major researches from other universities and other highway departments. Included are the American Society of Civil Engineers, the Association of Asphalt Paving Technologists, the American Railway Engineering Association, the American Society for Testing Materials, the American Concrete Institute, the Institute of Traffic Engineers, the Highway Research Board, and the American Road Builders Association.

#### *Outside Contacts*

Personnel of the Joint Highway Research Project have been granted leaves of absence without pay to engage in activities of national importance. On one occasion, the construction of a very large airbase outside the continental United States, 10 members of the Purdue staff were granted such leaves. All but one of these men received their training and conducted their research through the facilities offered by the Joint Highway Research Project. Others have played an important part in the planning and actual construction of highway systems of foreign countries. Thus, the techniques developed at Purdue have found application to engineering problems all over the world.

## EXTENSION AND DISSEMINATION OF INFORMATION

#### *Schools and Conferences*

One of the most important elements of any research organization is the method used to release its findings. Research results, no matter how important in themselves, will never provide the benefits which are

potential unless they are made available to those who can use them. Those who initiated the legislative act authorizing the Project wisely acknowledged this by providing for the annual Purdue Road School and highway extension work. For forty years highway information has been disseminated at this important conference to those in the highway field who have an interest in obtaining new ideas.

The benefits accruing from the Road School are numerous and varied. One important item is the opportunity the school offers for road and street officials and employees to familiarize themselves with materials, methods, and equipment so that they can better serve their constituents. Beneficial exchanges of ideas result from meetings of city, county, and state road men and material and equipment men. An understanding of "the other fellow's problems" has resulted in more harmonious relationships and has reacted to the benefit of the taxpayers of this state.

The Traffic Control Conferences similarly disseminate traffic and safety information and promote more efficient operation of our roads and streets. There have been two short courses for Airphoto Interpretation. These were attended by representatives of government agencies, military services, highway departments, universities, industry and foreign countries.

#### *Extension Activities*

Highway and traffic information is also disseminated to the various areas of the state through extension activities. The members of the Staff of the School of Civil Engineering and the Highway Research Staff are always available to discuss highway problems. Members of these staffs have made many trips to almost every city and county in the state to discuss problems of administration, construction, maintenance, traffic and finance. A monthly issue of "Highway Extension News," containing many items of value to highway improvement, finds its way into the hands of almost every highway official in the state.

#### *Publications*

Various publications of the Project also serve to spread valuable highway information. Proceedings of the Road School are published after each School and contain the most important material presented. Bulletins of the University are published whenever a particular study merits the dissemination of a large volume of data. Condensed results of the most important projects are published as reprints from publications where they were first presented. Over 100 such reprints have been made available since the Project began—50 in the last four years for an

average of one per month. The Directory of State, County, and City Highway Officials is published annually and has rendered considerable service to the highway industry.

#### *Traffic Engineering Services*

Within the past year the highway-extension activities of the Project have been broadened to include traffic engineering and highway planning. A unit known as Traffic Engineering Services provides advice on these subjects to cities and counties of the state at their request and expense. Projects presently under way by this unit include classification of county roads in one Indiana county, the dissemination of information on a comprehensive traffic survey made by the State Highway Department, and advice on parking and major thoroughfare problems in three Indiana cities.

#### *National Research Committees*

The results of many investigations are made available to the nation through the activities of several members of the staff on national Research Committees of several organizations. Much research material is reported at the annual meetings of these organizations and is published in their proceedings. Members of the staff also have contributed papers at road schools and highway conferences throughout the nation as well as to many other highway groups.

### ENGINEERING EDUCATION

The shortage of qualified engineers is well known and has been of special concern to the State Highway Department of Indiana. In recent years the state has been unable to attract any great number of young men into the highway field. This has been true partly because there have been too few engineers to fill the demands. At the undergraduate level it has been necessary to train the student in the basic principles of engineering and to leave the specialization to summer or part-time employment, after-graduation employment, or to advanced study. As a result, one of the major sources of supply of engineers for the highway field has been those students who were employed by the Project on a summer or part-time basis and those who elected advanced study in the field of highway engineering.

During the past four years approximately 350 individuals have been employed for part-time in the several highway research laboratories and have become intimately acquainted with some of the highway research programs. During the entire 18-year period the number of such students totals over 1,000. During the past four years 39 men have

received the M.S. degree and three the Ph.D. degree in highways and related areas, and 17 men are currently doing work in highways, including a research project for an M.S. or Ph.D. degree (Figure 25).



Fig. 25. The results of research and development are used in the training of others as illustrated in this classroom view.

The totals for the 18-year period include about 130 men who have received or are expecting to receive advanced degrees in the highway field at Purdue.

Most of these men enter the highway field after graduation and their services are of direct benefit to the highway programs. As an example of the benefits of this program, the part-time employment in the Traffic and Transportation area of the Project has resulted directly in five graduate engineers accepting employment with the State Highway Department of Indiana after graduation and in three others entering the Purdue Graduate School to major in highways. Several other graduates accepted employment with various city traffic and street departments. An analysis of 116 staff men who have received advanced degrees at Purdue in highways or in related areas, 61 are employed in 22 universities, 23 are with consulting and industrial firms, 15 are with highway or city engineering departments, 11 are foreign with employ-

ment conditions unknown, 7 are with governmental units, 3 are in the military service, 3 are classified as "miscellaneous," and 3 are deceased.

The existence of the research program in highways and the opportunity for young graduates to engage in this research are undoubtedly the major reasons why the graduate program in highway engineering at Purdue has attracted a large number of students from all over the world. The research is thus conducted at a reasonable cost by outstanding personnel. The benefits to the state, moreover, include the training of these personnel. This benefit is one of the most important contributions of the Project to the state and if the potential were fully utilized would provide the state with a large number of extraordinarily well qualified engineers.

In addition, the highway programs at Purdue attract many teachers of highway engineering who take teaching leave from their schools to work on advanced degrees.

### LOOKING AHEAD

While accomplishments of major importance have been recorded by the Joint Highway Research Project during the 18 years of its existence, there remain many unsolved highway problems to be attacked by it and other research agencies throughout the country. With motor vehicle registration showing an annual increase of some three million cars, trucks and busses, highway departments will be faced with many new problems for years to come. Research will provide the answers to most of them.

Currently, our State Highway Department expenditures total 45 to 50 million dollars annually. In addition, our county highway departments spend approximately 24 million dollars, and our city and town street departments spend some 12 million dollars annually. The savings to the Highway Department alone, as a result of the research effort, now amount to many times the annual cost of research, while continued effective research is vital in insuring adequate returns from this total annual highway disbursement of over 80 million dollars in Indiana.

### SUMMARY

This presentation covers a review of the activities and accomplishments of the Joint Highway Research Project from the time it was established in early 1936 to April, 1954—a period of 18 years. Reference is made to material published on this subject in 1939, in 1946, and in 1950, but special emphasis is given to the achievements from early 1950 to the present time.

Special mention is given to those projects which have made possible the saving of considerable sums of money to the State Highway Department of Indiana and to the state at large. However, the use of the staff and the research facilities by the Highway Department for current projects and the intangible benefits to the state through the educational facilities for highway research men, the Road School, highway extension, and the use of hundreds of undergraduate students in completing research programs, are also important. Some mention is made of important advantages of conducting highway research at the University because of the availability of University facilities and non-highway staff. The contract research work for other agencies is very important, because a great deal of it contributes to the work of the State Highway Department of Indiana at no expense to the state.

### *Financial Savings*

In summary, the past four years have proved, just as did the preceding 14 years prior to 1950, that the State Highway Department of Indiana and the citizens of the state and the nation are receiving large dividends on their annual investment in the Joint Highway Research Project. Many projects are producing dividends each year which exceed the total annual expenditures. For example, the bridge deterioration survey just completed shows the need for minor changes in design and construction which, if made, will materially increase the life of bridges and decrease maintenance. Large ultimate savings can result. As a second example, the recent recommendations relating to by-passes have resulted in a decision by the state to use the authorized limited access provisions of state statute. The savings from this decision are reflected not only in savings to the State Highway Department through the establishment of a facility that will be adequate for 20-25 years instead of 10-15, but in large annual benefits to the using motorist, the adjoining landowner, and the community.

In short, the knowledge gained from research is permitting those of us in the highway field to emerge from the shadows of the unknown into the light of highway progress. It is enabling us to maintain a highway system in good condition, even with inadequate funds. It is enabling us to progress toward a solution of what may be the No. 1 domestic problem of the nation. It is enabling us to keep Indiana high in the development and maintenance of a modern highway system. There is only one question that should be asked: "Are we spending enough on highway research?"

*Important Achievements*

Listed below are probably the 15 most important accomplishments of the Joint Highway Research Project:

1. One of the most important findings of the Project is the result obtained from the field survey work, showing correlation between blow-ups and source of coarse aggregate. Large-scale studies on the characteristics of aggregates have shown it to be advisable to eliminate generally expansion joints in rigid pavements, excepting under special situations. The annual savings in construction costs alone from this one change are equal to a large portion of the research budget each year.
2. The research on the quality of coarse aggregate is saving the State Highway Department many thousands of dollars yearly. The ultimate goal in this work is to develop specifications for coarse aggregates used in portland cement concrete which are sufficiently rigid to rule out all poor-performing materials, at no great increase in the overall cost. As a service to the Department, the installation of a new automatic freezer is important. This equipment makes possible the rapid evaluation of materials of unknown quality so that the Highway Department can judge rather quickly almost any supply of coarse aggregate in the state through their highway research facilities.
3. Because of the lack of adequate state mapping, the work on the development of Indiana county drainage maps has proved extremely important to the Bridge Bureau of the Highway Department, the Toll Road Commission, the Indiana Flood Control Commission, the Conservation Department, many railroad companies, consulting engineering firms, and many other organizations and agencies. Seventy-eight of the 92 counties of Indiana have been mapped to date.
4. Development of engineering soil maps through the use of air-photo interpretation techniques has made possible the use of much smaller field forces for soil borings and subgrade soil-survey work, and also has made possible the development of regional designs for both rigid and flexible pavements in the State of Indiana. The basic development of the new science of airphoto technique for identification of soils is one of the major contributions of the organization.
5. The special service work for the State Highway Department of Indiana has been of considerable importance in the bituminous-



concrete design tests and various types of specialized soil tests for the test sections on U. S. No. 31 near Columbus, Indiana, and soil tests for test sections on U. S. No. 41 in northern Indiana. In addition the research laboratories prepared moving pictures demonstrating design and construction features of these roads. Also, the facilities of the Highway Research Project are being used to develop deflection-measuring devices for use in evaluating the performance of the test sections on U. S. No. 41 and for other special work in the state. A roughometer is being developed for use by the Construction Department in evaluating road-roughness characteristics of pavements. The staff is always available to assist the Department on many types of engineering investigations.

6. In the field of traffic engineering, the research staff has maintained a continuous record of traffic speeds since 1939. Data produced from these studies have been used in part for establishing trends and for formulating the traffic speed laws of Indiana. This information has wide use in cross-sectional design of highways and pavements. Currently, skid resistance of various types of pavements is being determined and these data will have application in the design of the surface textures of various types of pavements to reduce skidding and, therefore, accidents.
7. Some of the economic studies made by the research organization have been badly needed, particularly studies of by-passes which show trends in property values both in cities as well as alongside the newly constructed improvement. Traffic-flow studies have been made by the staff in cooperation with and for the Metropolitan Area Traffic Survey unit. The staff has been able to help organize and complete the surveys as well as analyze the data and prepare reports for the cities of Richmond and Logansport. Similar studies have been made for Lebanon, Kokomo and Huntington.
8. Perhaps one of the most important contributions of the organization has been the employment of both undergraduate and graduate students. A total of about 1,000 undergraduates have been aided in obtaining their undergraduate degrees during the past 18 years, while about 130 graduate students have been helped in obtaining M.S. or Ph.D. degrees. A large percentage of these men continue their interest in highways and related fields.

9. On the basis of dollar value, one of the most valuable projects completed by the research organization has been the long-time study of pavement pumping in Indiana. This problem has attracted the attention of highway engineers, economists, legislative bodies, and many other groups of individuals. The results of the work have led to a strengthening of Indiana truck-weight laws, and important material has been given the State Highway Department covering the maintenance of pumping pavements through the use of cement-slurry or hot bituminous materials pumped under moving slabs. Many field observations of the performance of the various corrective procedures have been made available to the personnel of the State Highway Department of Indiana. Finally, the design of rigid pavements for roads carrying heavy traffic and for turnpikes has been given special consideration by the research staff, with the net result that the present designs of the Department are adequate for the current loads.
10. In very recent months a field survey of many of the important highway structures in the State has been made by the staff. Special emphasis has been given to the weathering of these structures and it has been found that the exposure conditions resulting from the use of certain design features as well as certain construction and maintenance procedures have sometimes developed unsatisfactory performance. Improvements can be made in these factors for reinforced concrete structures, and the net savings per year will be considerable. If the life of only one structure can be doubled the cost of research for this particular activity will have been paid for many years.
11. In the field of flexible pavements some very important data have been collected over a period of 18 years covering first, work on aggregate gradation and bitumen content for use in surface treatments, and more recently for bituminous concrete used as overlays on primary roads subjected to extremely heavy wheel loads. Currently, the subject of rutting on some of these pavements is receiving special emphasis both through the use of field surveys as well as laboratory analysis of specimens obtained in both failed and unfailed sections of the pavement. A very important project has just been completed on the influence of the shape of aggregate on the stability of bituminous-aggregate mixtures. This work will have important use in specifications for coarse and fine aggregate with special refer-

ence to the percentage of crushed material required for various qualities of bituminous concrete. Thickness design requirements for base and surface courses of flexible pavements continues as an important research project.

12. Both laboratory and field experiments have yielded important results in the field of traffic paints. The performance of traffic paint is dependent not only upon the quality of the ingredients, but also upon the method of application. Since about half the total cost of traffic lines is labor for application, it follows that improvements which can be made in the quality of the paint used for the line will have far-reaching economic benefits.
13. The chemical and physical properties of aggregates used in portland cement concrete for structures and for portland cement concrete pavements have been studied extensively during the past several years to determine the relation between the quality of aggregate and the amount and type of pore system as well as chemical reaction which may take place between certain types of aggregates and currently used cements. The results of this work are already being used in aggregate specifications and improvements can be expected in the future.
14. Work in the field of soil stabilization and base courses has yielded some very important results. Data released in 1946 on the gradation and quality of binder soils have had wide application in Indiana as well as in such states as New Jersey and New York where the results of the research have been used directly in the development of specifications.
15. The use of the highway research facilities for engineering education merits special emphasis. The research laboratories are used to develop data of great importance to Indiana. At the same time this information has been obtained economically by the use of undergraduate and graduate students working under a skeleton staff of engineers. Many of these graduates now hold high positions in highway departments and other research organizations.

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LIST OF BULLETINS, REPRINTS, PUBLISHED  
PAPERS, AND THESES  
of the  
JOINT HIGHWAY RESEARCH PROJECT  
January 1936-April 1954

## HIGHWAY RESEARCH BULLETINS

1. "Adhesion of Bituminous Films to Aggregates," by Owen R. Tyler, Engineering Bulletin of Purdue University, *Research Series No. 62*, Vol. 22, No. 5, September, 1938.
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  309. "Regional Drainage Patterns of Indiana." A thesis submitted to the faculty of Purdue University by Merle Parvis in partial fulfillment of the requirements for the degree of Civil Engineer, June, 1947.
  310. "The Application of Aerial Strip-Photography to Highway Engineering." A thesis submitted to the faculty of Purdue University by Jean Edwin Hittle in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, June, 1947.
  311. "Soils of Jamaica, B. W. I., Their Formation and Engineering Characteristics." A thesis submitted to the faculty of Purdue University by Frederick Barker Hill in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, June, 1947.
  312. "Effect of Air Entrainment on the Durability Characteristics of Concrete Aggregates." A thesis submitted to the faculty of Purdue

- University by Sterling Lowe Bugg in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, February, 1948.
313. "Traffic Speed and Lateral Placement Investigation at a Highway Bridge." A thesis submitted to the faculty of Purdue University by Warren Sturtevant Quimby in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, February, 1948.
  314. "Airphoto Interpretation of Soils and Drainage of Rush County, Indiana." A thesis submitted to the faculty of Purdue University by Charles R. McCullough in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, February, 1948.
  315. "Airphoto Interpretation of Soils and Drainage of Henry County, Indiana." A thesis submitted to the faculty of Purdue University by William S. Pollard, Jr., in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, February, 1948.
  316. "Comparison of the Thermal and Moisture Expansion of Concrete and Stone." A thesis submitted to the faculty of Purdue University by Nung Yuen Lu in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, February, 1948.
  317. "A Study of the Influence of Aggregate Gradation on the Stability of Bituminous Mixtures." A thesis submitted to the faculty of Purdue University by Gifford Eugene Rogers in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, June, 1948. This study was financed by the Standard Oil Company of Indiana under Fellowship No. 1.
  318. "Concrete Durability as Affected by Coarse Aggregates." A thesis submitted to the faculty of Purdue University by Harold Sinclair Sweet in partial fulfillment of the requirements for the degree of *Doctor of Philosophy*, June, 1948.
  319. "The Effect of Pavement Width on Road Usage." A thesis submitted to the faculty of Purdue University by Richard Allen Overmyer in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, August, 1948.
  320. "Airphoto Study and Mapping of Southeastern Indiana Sandstone-Shale Materials." A thesis submitted to the faculty of Purdue University by Frank K. Dawson in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, August, 1948.



321. "Airphoto Interpretation and Mapping of South-Central Indiana Limestone Soils." A thesis submitted to the faculty of Purdue University by Cecil James VanTil in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, August, 1948.
322. "Engineering Evaluation of Northwestern Indiana Moraine, Lacustrine, and Sand Dune Airphoto Patterns." A thesis submitted to the faculty of Purdue University by Merritt McGregor Davis in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, February, 1949.
323. "Airphoto Interpretation of the Illinoian Glacial Drift Soils in Southeastern Indiana." A thesis submitted to the faculty of Purdue University by John C. Stevens in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, February, 1949.
324. "Suitability of Indiana Dune, Lake and Waste Sands for Bituminous Pavements." A thesis submitted to the faculty of Purdue University by James M. Rice in partial fulfillment of the requirements for the degree of Master of Science in Engineering, February, 1949.
325. "Durability of Good and Poor Coarse Aggregate in Air-Entrained Concrete." A thesis submitted to the faculty of Purdue University by Jack B. Blackburn in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, February, 1949.
326. "A Master Plan for Purdue University Airport." A thesis submitted to the faculty of Purdue University by Robert C. Richert in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, June, 1949. (Special E. E. S. Project.)
327. "The Effect of Restraint on the Durability of Concrete Aggregates." A thesis submitted to the faculty of Purdue University by Laurence C. Pendley in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, June, 1949.
328. "Solubility Studies of Indiana Limestone." A thesis submitted to the faculty of Purdue University by William Lee Dolch in partial fulfillment of the requirements for the degree of Master of Science, June, 1949.
329. "Annotated Bibliography on Soils Stabilization." A thesis submitted to the faculty of Purdue University by Rattan C. Sharma

- in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, June, 1949.
330. "A Study of the Use of Sandstone in Bituminous Surface Courses." A thesis submitted to the faculty of Purdue University by C. T. Metcalf in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, June, 1949.
  331. "Effect of Lime Upon the Engineering Characteristics of Soils." A thesis submitted to the faculty of Purdue University by Lu I Cheng in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, August, 1949.
  332. "Airphoto Interpretation and Engineering Evaluation of Northwest Indiana Sands." A thesis submitted to the faculty of Purdue University by A. Morgan Johnson in partial fulfillment of the requirements for the degree of *Doctor of Philosophy*, August, 1949.
  333. "Determination of Pore Size of Four Indiana Limestones." A thesis submitted to the faculty of Purdue University by Fulton Keller Fears in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, February, 1950.
  334. "Influence of Fine Aggregates on Concrete and Mortar Durability." A thesis submitted to the faculty of Purdue University by Joe Garland Higgs in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, February, 1950.
  335. "A Laboratory Study of the Stability of Bituminous Mixtures." A thesis submitted to the faculty of Purdue University by Chih Chung Chen in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, February, 1950.
  336. "A Study of the Compaction Characteristics of Cohesive Soils." A thesis submitted to the faculty of Purdue University by Robert Youse Bush in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, June, 1950.
  337. "Public Opinion Survey Methods as Related to Traffic Engineering." A thesis submitted to the faculty of Purdue University by John E. Baerwald in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, June, 1950.
  338. "An Annotated Bibliography on Traffic Volume Studies and Origin-Destination Surveys." A thesis submitted to the faculty of Purdue University by Robert E. Barkley in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, June, 1950.

339. "Prediction of Trafficability in the Big Delta, Alaska Area, Based on Aerial Photographs." A thesis submitted to the faculty of Purdue University by Robert E. Clark in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, August, 1950.
340. "Determination of Thermal Diffusivity of Indiana Limestones." A thesis submitted to the faculty of Purdue University by Ralph G. Fox, Jr., in partial fulfillment of the requirements for the degree of Master of Science, August, 1950.
341. "A Laboratory Study of the Durability Characteristics of Lime-Soil Mixtures." A thesis submitted to the faculty of Purdue University by Shangee Yihwa Wang in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, August, 1950.
342. "Numerical Solutions of Steady and Transient Flow of Artesian and Water-Table Wells." A thesis submitted to the faculty of Purdue University by Abd-el-Aziz Ismail Kashef in partial fulfillment of the requirements for the degree of *Doctor of Philosophy*, January, 1951.
343. "Application of Triaxial Testing to the Design of Flexible Pavements." A thesis submitted to the faculty of Purdue University by Charles R. Lowrie in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, January, 1951.
344. "Correlation of Soil Test Data with Airphoto Patterns for Trafficability Study." A thesis submitted to the faculty of Purdue University by James R. Shepard in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, January, 1951.
345. "Adaptability of the Soniscope for Measuring Setting Time of Concrete." A thesis submitted to the faculty of Purdue University by Eldridge A. Whitehurst in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, January, 1951.
346. "Annotated Bibliography of Bituminous Mixtures and Construction." A thesis submitted to the faculty of Purdue University by Mohammed Hassan Zarrabi in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, January, 1951.
347. "The Effect of Highway Shoulders on Traffic Operations." A thesis submitted to the faculty of Purdue University by Edwin R.

- Lang in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, June, 1951.
348. "Procedures for Making Preliminary Soils and Drainage Surveys from Aerial Photographs." A thesis submitted to the faculty of Purdue University by Robert D. Miles in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, June, 1951.
349. "Effectiveness of Granular Bases for Preventing Pumping of Rigid-Type Pavements." A thesis submitted to the faculty of Purdue University by Carl Edgar Vogelgesang in partial fulfillment of the requirements for the professional degree of Civil Engineer, June, 1951.
350. "The Compressibility of Two Compacted Clays." A thesis submitted to the faculty of Purdue University by Harold C. Woodsum, Jr., in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, June, 1951.
351. "A Road Roughometer." A thesis submitted to the faculty of Purdue University by Harry Thanos in partial fulfillment of the requirements for the degree of Master of Science in Electrical Engineering, May, 1951.
352. "A Comprehensive Program of Frozen Ground Research." A thesis submitted to the faculty of Purdue University by Charles W. Lovell, Jr., in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, August, 1951.
353. "Determination of the Non-Durable Constituents of Indiana Gravels." A thesis submitted to the faculty of Purdue University by Eduards Venters in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, August, 1951.
354. "An Economic Evaluation of the Kokomo, Indiana, By-Pass." A thesis submitted to the faculty of Purdue University by Harold L. Michael in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, August, 1951.
355. "Use of Field, Laboratory and Theoretical Procedures for Analyzing Landslides." A thesis submitted to the faculty of Purdue University by Hiram Gordon Larew in partial fulfillment of the requirements for the degree of Master of Science, August, 1951.
356. "Annotated Bibliography on Snow and Ice Removal." A thesis submitted to the faculty of Purdue University by Frank P. Stainback, Jr., in partial fulfillment of the requirements for the degree of Master of Science, August, 1951.

357. "Airphoto Study and Boundary Delineation of Southwestern Indiana Shale-Sandstone-Soil Materials." A thesis submitted to the faculty of Purdue University by James H. McLerran in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, January, 1952.
358. "The Application of Sampling Techniques to Highway Surveys." A thesis submitted to the faculty of Purdue University by Irwin Miller in partial fulfillment of the requirements for the degree of Master of Science, February, 1952.
359. "Shearing Resistance of Partially Saturated Clays." A thesis submitted to the faculty of Purdue University by Gerald A. Leonards in partial fulfillment of the requirements for the degree of *Doctor of Philosophy*, February, 1952.
360. "Outline of Research for Field Studies of Piles in Permafrost." A thesis submitted to the faculty of Purdue University by John A. Pihlainen in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, June, 1952.
361. "Strength and Dynamic Properties of Concrete." A thesis submitted to the faculty of Purdue University by Gerald Batchelder in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, June, 1952.
362. "Annotated Bibliography and Exploratory Tests on Rubber-Asphalt." A thesis submitted to the faculty of Purdue University by John A. Havers in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, June, 1952.
363. "Airphoto Pattern Study of the Erie Lobe Recessional Moraines in Indiana." A thesis submitted to the faculty of Purdue University by Katsuyoshi Nishimura, in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, August, 1952.
364. "Comparison of Two Methods of Internal Origin-Destination Surveys: Home Interview and Controlled Post Card." A thesis submitted to the faculty of Purdue University by James Herbert Kell, in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, August, 1952.
365. "Analysis and Classification of Airphotos as Related to Soil Trafficability." A thesis submitted to the faculty of Purdue University by Donald D. Litt, in partial fulfillment of the requirements for the degree of Master of Science in Engineering, August, 1952.
366. "A Review and Annotated Bibliography of the Structural Design of Concrete Highway Pavements." A thesis submitted to the

- faculty of Purdue University by Burjor K. Choksi, in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, December, 1952.
367. "Sonic Studies of Bituminous Mixtures." A thesis submitted to the faculty of Purdue University by Kanwal S. Bawa, in partial fulfillment of the requirements for the degree of Master of Science, January, 1953.
368. "An Investigation of the Properties Measured by the Marshall Test." A thesis submitted to the faculty of Purdue University by John F. McLaughlin, in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, January, 1953.
369. "Airphoto Boundary Delineation of Loess or Loess-like Soils in Southwestern Indiana." A thesis submitted to the faculty of Purdue University by Kendall Moulthrop, in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, January, 1953.
370. "Application of Airphoto Interpretation Techniques in Determining Runoff from a Selected Watershed." A thesis submitted to the faculty of Purdue University by Pai Tao Yeh, in partial fulfillment of the requirements for the *degree of Ph.D.*, January, 1953.
371. "Investigation of the Freezing-and-Thawing Characteristics of Soil-Calcium Chloride Mixtures." A thesis submitted to the faculty of Purdue University by Oktay Korman, in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, January, 1953.
372. "An Exploratory Study of the Effects of Rubber Additives on Bituminous-Aggregate Mixtures." A thesis submitted to the faculty of Purdue University by James Dusenbury, in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, May, 1953.
373. "Engineering Subsurface Explorations by the Earth-Resistivity Method." A thesis submitted to the faculty of Purdue University by C. Robert Lennertz, in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, May, 1953.
374. "The Use of Bituminous Resurfacing In Highway Maintenance and Improvements." A thesis submitted to the faculty of Purdue University by George B. O'Connor, in partial fulfillment of the requirements for the degree of Master of Science, August, 1953.