INTRODUCTION

Each year at Road School, the planning committee has suggested that one of the topics at the opening general session should be a brief summary of several of the research projects which were active during the current year in the Joint Highway Research Project. As a result, 15 of our current projects will be reviewed in this report.

The 15 researches to be discussed are from 40 that have been active during 1975-76. Much of the material has been originally authored by the principal investigators conducting the projects and they, of course, are due any acclaim which their words create.

Our research is directed at solving or at helping solve problems encountered by the Indiana State Highway Commission and other agencies responsible for highways. We seek ways to prolong life of pavements, provide improved safety for motorists, minimize congestion, do things at less cost, move traffic more efficiently, etc. About half of our projects are funded totally for direct costs by the Indiana State Highway Commission. The other half utilize highway planning and research funds from federal aid for a portion of the costs with the matching portion from other highway commission funds. Purdue University provides on all projects for costs commonly referred to as overhead.

One objective of each project, in addition to providing new knowledge about a particular problem in transportation, is to obtain implementation of the results. In some cases initial implementation is obtained before the project is completed. This is achieved by maintaining close contact during the research with personnel in the highway commission who are involved with the problem area and who are in a position to apply the results as quickly as possible. For many of the projects we have a formal advisory committee composed of our investigators and one person each from the highway commission and the Federal Highway Administration Division office.
The brief review of each of the research studies which follows will typically include a discussion of the problem being researched, how we are attacking the problem and, where progress permits, some of our findings.

IMPROVING EMBANKMENT DESIGN AND PERFORMANCE

Before one constructs the pavement it is necessary to prepare the subbase and this often requires the construction of sizeable embankments. (See Figure 1.) In designing such embankments, the design engineer has to prepare specifications which will produce an embankment which will behave as he desires. Natural soils and compaction processes are inherently variable and produce compacted soils which are not uniform.

Figure 1. Construction of Embankment Results in Variability in Characteristics of Compacted Soils and Difficulty in Prediction of Engineering Behavior of the Embankment.

How, then, can the designer produce the performance he wants in the product? How can he allow for the variability which exists? What might be done at the specification level to produce the desired behavior more efficiently?

One of our research projects is attempting to assess the effects of variability on the predictability of the engineering behavior of Indiana compacted soil. Secondarily, we are hoping to isolate the relative impor-
tance of the various field compaction variables which produce the variability in the finished embankment.

To attack this problem we have accumulated results of field compaction from the literature and from the files of ISHC. Then, we analyzed these data statistically in an effort to establish trends and relationships.

With the assistance of ISHC personnel, we also have become involved in two current field projects. We tested the borrow soil in the lab, then field sampled and tested the same soils as they were placed during construction. Again, the data were analyzed statistically to develop prediction relationships for field strength and variability.

Finally, we are simulating postconstruction environmental changes in the soil by soaking operations. Testing will then be done on the soaked samples and the results will again be analyzed.

Findings to date show a large variability in the results of compaction. We as yet have not been able to isolate the major causes but we have obtained trend-type relations for as-compacted dry density and its variability as functions of equipment, energy, and soil. Better quantitative, credible relationships will require better defined data, especially about equipment and its operation on the job, which we are now seeking.

From the field projects and associated testing, we have developed a basis for better prediction of field properties. This should permit the designer to know better the kind of tolerances required in his specifications to produce the strength and variability he needs to obtain an embankment which provides excellent service for years to come.

DESIGN AND CONSTRUCTION GUIDELINES FOR SHALE EMBANKMENTS

Another project is also concerned with the pavement foundation material and specifically embankments. Shale is the most common sedimentary rock and is often encountered in construction. It is thus desirable to use shale as much as is practical. But shale is often described as a "problem" embankment material and traditionally considered by many to be almost useless. The fine-grained structure of shale makes it intrinsically more difficult to study and analyze than other rocks, and the fact that many shales are too "hard" to test conventionally as soils and too "soft" to test conventionally as rocks restricts their rational use.

In Indiana, shales are often encountered in building highways, especially in the southern part of the state. Use of some shales, however, has led to serious problems in some embankments on I-74 in southeastern
Indiana. (See Figure 2.) This is one reason research is directed toward formulating design and construction guidelines for shale embankments. These guidelines are to permit the engineer to predict the behavior of a shale from the results of relatively simple laboratory tests.

Figure 2. An Embankment Failure on I-74 in Southern Indiana with Shale Materials.

Varying shale properties make it desirable to first classify shales by means of their differing expected behaviors. Some shales degrade readily in the process of excavation, hauling, and placement. Others appear more durable as they remain as large chunks during construction but may settle seriously due to slaking if placed so that relatively large voids are present. A third class of shales performs satisfactorily as rock-fill. It is obvious that failure to correctly predict these differences in the shale being used can be unsafe on one hand or overly conservative on the other.

The Joint Highway Research Project in an earlier study developed a classification system for shales based on three simple tests. (See Figure 3.) Work has continued to improve the limits used to establish the various categories. For example, the condition of shale pieces following the slake durability test can be used to identify a shale as belonging to one of three types. Type I is virtually unchanged; Type II becomes large and small pieces; and Type III is all small pieces.

Currently, Indiana shales are being evaluated relative to their ability to resist mechanical breakdown as experienced in the construction
process. Strength tests are being performed on specimens composed of discrete shale pieces with the expectation of developing long-term design parameters.

![Proposed Classification of Shales for Embankment Construction](image)

Figure 3. Proposed Classification of Shales for Embankment Construction.

**ANALYSIS OF HARDENED CONCRETE FOR ADMIXTURE CONTENT**

Although we have been using Portland cement concrete for many years and are well aware that air entrainment in concrete will minimize surface scaling, we still find concrete which scales badly. The deteriorated curb in Figure 4 is a good example.

When such deterioration occurs, the question always arises as to whether the proper amount of admixture to provide air-entraining had actually been added and retained in the concrete.

The available analytical methods to provide answers to this problem are completely inadequate. The purpose of one of our investigations is to develop methods that will be generally applicable to a wide variety of admixtures and that will be quantitative enough to permit the decision of whether or not the required dosage was used.

The method chosen for trial is high-pressure liquid chromatography. In this technique the admixture is extracted from powdered concrete by some solvent and then is passed through a column containing an
adsorptive solid. The various substances in solution are separated by differential adsorption on the column and are then detected and plotted by a refractive index analyzer as they are washed off the column by another solvent. If the research is successful, we will have the ability to tell with certainty if hardened concrete contains the specified amounts of admixtures.

Figure 4. An Example of Deterioration of a Curb Resulting from Concrete Surface Scaling.

IMPROVEMENT OF NONDURABLE AGGREGATES

Another problem common to many areas of Indiana, especially close to urban areas where much aggregate is required, is that the supply of good aggregates is getting scarce. If we permit use of aggregates with poor freeze-thaw characteristics, the result will be deterioration of pavements as shown in Figure 5 for a location on I-69. Initial distress was several years in developing but then grew rapidly over the next year until maintenance was necessary. Within about two years major deterioration occurred. Many aggregates of marginal durability, such as those used in this section, would be very useful if they could be treated before use to beneficiate them and block their undesirable actions to freezing. This is another problem on which we are working.

Since the susceptibility of an aggregate to difficulty in freezing is intimately associated with its pore structure and the way that structure gains and holds water, Phase I of this project consists of the measure-
ment of the pore size distribution of a suite of aggregates by the methods of mercury intrusion porosimetry. Pores are measured from sizes of about 1/32 in. down to about 1/ten millionth of an inch. Aggregates with both good and bad field performance are being used. The results will be correlated with field performance and with the results of absorption, specific gravity, and soundness tests, and with laboratory freezing tests.

When the harmful pore sizes are identified, methods to treat the aggregates to beneficiate them will be studied in a second phase. The goal of course is to develop methods which will enable the use of easily available aggregate materials that cannot now be used because of freezing climates. Results would provide very great economic advantages.

COMPACATION OF REINFORCED CONCRETE
BY INTERNAL VIBRATION

Another problem area often encountered in pavement construction is the difficulty of determining the effectiveness in the field of consolidation of the wet concrete. One of our current projects has already investigated and reported on methods of obtaining better consolidation. A second phase of this study is now evaluating the effectiveness of a nuclear gauge in measuring the consolidation. (See Figure 6.) It is a probe type gauge and a direct path reading is made to determine the
Figure 6. Measuring Concrete Consolidation with a Nuclear Gage.
density of the wet concrete. The method has proved promising and these gauges may be used on at least some highway commission projects this year.

USE OF LOW-POROSITY CEMENT CONCRETE

One of our responsibilities in addition to finding solutions to current problems is to evaluate possible uses of new materials. One such new material is a new variety of cement. The new cement is ground Portland cement clinker to which no gypsum is added. The set is controlled by added sodium lignosulfonate plus sodium bicarbonate.

The resulting cement is much more fluid at a given water content than ordinary Portland cement. Consequently, it can be mixed with much lower water contents than normal—0.20 or 0.25 water:cement ratio, rather than 0.4 or 0.5. Because of the low water content, the hardened cement is much less porous than ordinary hardened cement. Strength gain is more rapid and much higher strengths can be secured. Furthermore, the durability of the resulting concrete should be improved, and its shrinkage reduced, meaning less cracking. Also, the permeability to water and to salt should be less, meaning much less tendency to corrode reinforcing steel in bridge decks.

However, because of the unusual response of the cement in the wet state there are problems with mix design and possibly with handling of the wet concrete that need to be solved. Figure 7 shows the fluid ap-

Figure 7. Low-Porosity Cement Paste Is Fluid.
pearance of the cement paste—this is mixed at a water:cement ratio (by weight) of 0.24. The cement paste is a thin watery "soup" rather than a thick buttery material, even at this low water content.

A rough comparison of the strength and rate of strength development of one series of low-porosity cement concrete as against that of a reasonably typical "ordinary" Portland cement concrete is shown in Figure 8. The "ordinary" concrete has about 6000 psi at 28 days—this is pretty good "ordinary" concrete. The low-porosity cement concrete not only is much stronger at 28 days, but it reaches high strength much sooner. Note that it has almost 8000 psi strength in three days, more than the "ordinary" concrete has in a month.

![Figure 8. Comparison of Strength and Rate of Strength Development of "Low-Porosity" Concrete and "Ordinary" Concrete.](image)

Low-porosity cement (and concrete made from it) is more expensive than ordinary cement, and there may be other problems. However, so far we are finding reasonable success with it, and hope to have some interesting results within the next six months or so.
EFFECT OF FILM THICKNESS, VOIDS, AND PERMEABILITY ON ASPHALT HARDENING IN ASPHALT MIXTURES

Research in bituminous mixtures and pavements is also always in progress. One of these is concerned with asphalt hardening.

A durable asphaltic mixture offers long-term resistance to weathering and gives good performance without abnormal ravelling and cracking of the paving surface. If the asphalt in an asphaltic mixture hardens, however, it will result in the disintegration and fracture of the pavement surface. (See Figure 9.) This project is investigating the factors that control such asphalt hardening. There is a general belief that less hardening occurs in denser mixes. This may not be true as the thickness of the asphalt coating on the aggregate pieces is also of importance. Therefore, a laboratory study was undertaken to examine the influence of permeability, voids, and the thickness of asphalt coating on asphalt hardening in asphalt mixtures.

Limestone aggregate and a 200-250 penetration grade asphalt were used in the study. Specimens from both single size and graded mixtures were prepared. They were then subjected to permeability measurements followed by alternate cycles of accelerated weathering and creep testing. After the weathering and testing cycles, percent accessible void measure-
ments were made for each specimen using four different techniques. Finally, the asphalt was recovered from each specimen and its penetration determined.

The results (shown in Figure 10) indicated that for single size mixtures the ratio of the thickness of asphalt coating on the aggregate pieces to permeability is the best predictor of the mixture's resistance to asphalt hardening. For graded mixtures the concept of the thickness of asphalt coating breaks down and permeability alone was found to be the best predictor of the mixture's resistance to hardening. The permeability was found to be closely related to accessible air voids obtained by hand pumping techniques. A comparison between the penetration test results of the recovered asphalt from asphalitic mixtures and their corresponding creep test results indicate that the creep test is a measure of asphalt hardening. Therefore, this test can be employed to measure progressive asphalt hardening in asphalitic mixtures. These findings will be useful in evaluating asphalt hardening in porous friction courses in current efforts to provide better skid resistance surfaces.

<table>
<thead>
<tr>
<th></th>
<th>SINGLE SIZE MIXTURES</th>
<th>GRADED MIXTURES</th>
</tr>
</thead>
<tbody>
<tr>
<td>VOIDS</td>
<td>UNSATISFACTORY</td>
<td>SATISFACTORY</td>
</tr>
<tr>
<td>PERMEABILITY</td>
<td>LIMITED</td>
<td>BEST</td>
</tr>
<tr>
<td>FILM THICKNESS FACTOR PERMEABILITY</td>
<td>BEST</td>
<td>NOT APPLICABLE</td>
</tr>
</tbody>
</table>

Figure 10. Prediction of Asphalt Hardening.

THE EFFECTS OF BOTTOM ASH UPON BITUMINOUS SAND MIXTURES

The diminishing supply of high quality natural aggregate for use in bituminous construction has had many detrimental effects associated with it. Among these are an increasing number of skid prone surfaces, lack of structural stability, and higher construction costs. Concurrently, the depletion of the nation's oil reserves has directed attention toward the use of coal as an energy source, while concern over environmental protection has made it difficult to dispose of the ash by-product.

The availability of ash and the condition of inadequate natural aggregates may offer an opportunity for the improvement of the overall
performance of a bituminous paving mix with respect to skid resistance and structural stability. It may be possible to utilize a marginal aggregate in bituminous pavement construction by adding bottom ash. This would not only improve overall performance, but allow use of local materials, thus saving transportation costs involved in shipping quality aggregates.

A laboratory study conducted on six bottom ash sources obtained throughout the state of Indiana attempted to physically characterize the materials. One such material is shown in Figure 11. Mixtures of river sand, limestone, and two of the six sources of bottom ash were evaluated to determine the effect of the ash upon the performance of the mineral aggregate when incorporated in a bituminous paving mixture.

Two characteristic ash classes were noted. One did little to improve the skid resistance or the structural stability. The second class improved skid resistance but did not improve stability. However, both classes of ash aided in maintaining stability when tested in the soaked condition. Possibilities for use in bituminous mixtures do exist.

Figure 11. An Example of One Coal Ash.

MAINTENANCE METHODS FOR CRC PAVEMENTS

Late in the 1960's, the Indiana State Highway Commission constructed many miles of continuously reinforced concrete (CRC) pavement. The purpose of this undertaking was to provide the state with
“low maintenance” pavements. However, by 1972 severe distress was noted on certain sections of CRC pavement in the interstate system as well as the primary system. The Joint Highway Research Project was asked to investigate the causes of the distress and to make recommendations relative to designs that might be adopted to correct the situation.

During the field investigation which has been conducted over the past three years, it was found that about one-third of the mileage of CRC pavements within the state have experienced severe distress. Among the significant factors that were found to influence the performance of this type of pavement were (a) subbase type, (b) use of preset steel on chairs, (c) an insufficient amount of steel, and (d) properties of the concrete itself.

Up to the present time the principal method of maintaining this pavement is to patch it with concrete. The pavement is cut with a saw to expose the steel. New steel is then tied to the old steel; new concrete is poured and a patch which restores the continuity of the pavement is applied. This method of repair, however, is expensive and the highway commission requested an investigation of other techniques for maintaining this type of pavement.

A cooperative project was therefore set up with ISHC to investigate various methods of repair. A test section was established on I-65 south of Indianapolis since this road contained all the features found to affect performance.

The maintenance types constructed last fall included, among others, construction of concrete shoulders on certain sections of the test pavement. (See Figure 12.) Holes were drilled in the edge of the pavement and tie bars were fixed in place using epoxy. Concrete was then poured and rumble strips were constructed on the completed shoulder to discourage travel. The purpose of this type of maintenance is to determine if tying a concrete shoulder to the existing pavement will cut down on deflection a sufficient amount to prevent breakup.

Another method of maintenance that was investigated consisted of bituminous undersealing used in conjunction with overlaying with asphalt and also just by itself. Asphalt was pumped under the pavement to fill the voids that were known to exist under the pavement.

Still another method investigated was use of drainage systems at the edge of the pavement. These drains, shown in Figure 13, are intended to minimize water on the top of the subbase.

Other maintenance methods being investigated include overlays of bituminous asphalt of various thicknesses, bituminous patches, and concrete patches. The final results of the study will not be known for
several years since it will be necessary to observe and measure the performance of the test methods over that period of time.

Figure 12. One Method of Repairing Continuously Reinforced Concrete Pavements Being Researched Is Adding a Concrete Shoulder to Reduce Pavement Deflection.

Figure 13. Construction of a Drainage System along the Pavement Edge is Being Studied as a Maintenance Technique for CRC Pavements.
BRIDGE VIBRATION STUDIES

In the highway bridge research area we are planning an analysis of the stresses in some of the new segmental bridge structures in Indiana and we are also conducting a study of bridge vibrations.

Analytical, experimental, and survey data are being correlated in an attempt to improve results of bridge design where human response to vibration may be important. In many rural areas, vibrations may be of secondary importance—perhaps present designs could be even more flexible. Urban bridges used by pedestrians, on the other hand, may need additional vibration control to allow satisfactory performance.

This cooperative project between Purdue and the Indiana Highway Commission’s Research and Training Center is to develop field and analytical data which permit rational design for vibration control. Personnel of the Research and Training Center have obtained considerable data (see Figure 14) and it is currently being analyzed by University and R and T Center personnel.

DEVELOPMENT OF TECHNIQUES FOR PLANT ESTABLISHMENT

The roadside too has many opportunities for research as problems here also abound. The construction of highways brings about many
changes in the natural soil conditions that exist along a highway after construction. These changes include removal of top soil; deep cuts creating new slopes which often have subsoil on their surfaces; compaction of soil due to heavy equipment use; and finally the use of poor quality fill soils. The results of these changes are very poor soil conditions for plant growth, both for plant establishment by seeding on the roadside and the establishment of landscape plants. Failure to establish plantings on slopes results in erosion (See Figure 15) soil loss,

Figure 15. An Example of Soil Erosion due to Failure of Roadside Plantings.
and general bad appearance. Sod often will not hold and the slope is lost. Also, landscape plants fail to grow properly and often become maintenance problems as well as presenting a poor appearance to the public.

To minimize these problems, we have been conducting through the Department of Horticulture of Purdue's School of Agriculture studies to determine which plants should be used on the often poor soils of the roadside. Techniques for establishment were also investigated. Nitrogen-fixing plants, plants that are able to utilize nitrogen from the air, are logical plants to consider for establishment on impoverished soils. Legume cover crops such as the clovers, crown vetch, and alfalfas were investigated as possible plants for establishment on slopes. Their use as cover plants on slopes where initial seedlings had failed to establish were also investigated.

Woody plant establishment was also studied. Direct seeding of trees and shrubs failed, but the use of root cuttings and seedlings were successful with sumac.

The obvious benefit to the highway from such research is that where plant cover on the roadside has failed, some new seedling mixtures may be found that will insure more certain success and the need for continual reworking of some slopes will be reduced. The result will be more slopes like the one in Figure 16 where the solution was

![Figure 16. An Example of Successful Slope Development Where Appearance is Good and Maintenance Low (Clover, Alfalfa, and Crown Vetch over Tall Fescue).]
legume plants (clover, alfalfa, and crown vetch) over a base of tall fescue.

AN EVALUATION OF THE TRAFFIC ENGINEERING FUNCTIONS IN THE SMALL MUNICIPALITIES OF INDIANA

A number of research studies are also in progress in the operations area but I will detail only one. Three others—RTOR, truck accident rates, and evaluation of the 55 mph speed limit—are of considerable interest and a report on each will be issued in mid-1976. The project in this area to be reviewed was concerned with an evaluation of the adequacy of traffic engineering in small communities. One important aspect of this function concerns the proper use of traffic control devices. These devices are important not only from the traffic safety standpoint and the liability problem but also they are required by federal safety standards to be properly used on all classes of roads and streets with the possible penalty that a portion of the federal funds for highways would be withheld.

Most of our cities in Indiana are small, less than 50,000 people. Only five percent of our towns and cities greater than 2,000 have over 50,000 population and 70 percent of them have between 2,000 and 10,000 people. This evaluation of how the traffic engineering function was being performed, therefore, was of the less than 50,000 population cities.

Through a mailed questionnaire, personal contacts, and a traffic control device survey in 26 cities, the quantity, quality, and the administration of the traffic engineering function were evaluated.

During the field study, many nonstandard and poorly maintained signs were found. I am not certain what the speed limit is on the sign shown in Figure 17. They must have had only the very short post available for the speed limit sign shown in Figure 18—it's only 17 inches above the ground. In fact, large numbers of nonconformance to standards were found in the 26 cities studied and are summarized in Figure 19.

It was alarming to find that many who had the responsibility for traffic engineering functions in some of these cities:

1. Did not know a standard uniform manual existed.
2. Did not know how to perform simple traffic engineering functions.
3. Did not know what the city was required by Indiana statutes to do.
Figure 17. Speed Limit? Your Guess Is as Good as Anyone's.

Figure 18. Speed Limit Sign Only 17 Inches above the Ground Instead of the Required 5 Feet.
<table>
<thead>
<tr>
<th>Nonconformance</th>
<th>Absolute Frequency</th>
<th>Percentage of All Signs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mounted height less than seven feet</td>
<td>745</td>
<td>71.9</td>
</tr>
<tr>
<td>Nonreflectorized</td>
<td>257</td>
<td>24.8</td>
</tr>
<tr>
<td>Nonstandard color</td>
<td>201</td>
<td>19.4</td>
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<tr>
<td>Nonstandard secondary message on sign face</td>
<td>193</td>
<td>18.6</td>
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<td>Nonstandard location</td>
<td>28</td>
<td>2.7</td>
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<tr>
<td>Nonstandard application</td>
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<tr>
<td>Nonstandard shape</td>
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<tr>
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</table>

Figure 19. Traffic Signs and the Nonconformances Found in 26 Indiana Cities.

Clearly much needs to be done in many of our small communities to improve the operations of our highway and street facilities.

A METHODOLOGY FOR EVALUATING THE IMPACT OF RAILROAD ABANDONMENT ON RURAL HIGHWAYS

Another research project just completed developed a methodology for evaluating the impact of railroad abandonment in Indiana on our highway system. Under the provisions of the Regional Railroad Reorganization Act of 1973 a large portion of the railroad trackage in Indiana is expected to be abandoned. The exclusion of about 1,400 miles of active, light-density railroad trackage in the state from the ConRail network would cause the loss of rail transportation to several areas. (See Figure 20.) This situation will obviously create an impact on the rural highway network in Indiana.

A methodology was developed to estimate the impact of railroad abandonment on rural highways and bridges. The evaluative methodology can be employed for assessing the public costs associated with a highway's providing equivalent service to a railroad facility which is being considered for abandonment. With regard to highway pavements, formulas were developed which express the impact of rail service discontinuance on rural highways in terms of additional thickness of asphaltic concrete overlay which would be required.
Figure 20. Indiana Will Lose Many Miles of Low-Volume Railroads. Research Developed Methodology to Evaluate the Effects of Such Abandonment on Highways.

The methodology was applied to two affected areas within Indiana. The major finding was that railroad service discontinuance on the North Vernon to Madison branch line would result in an equivalent need of up to 0.60 inches of additional asphaltic concrete overlay for affected highway sections in Jennings, Jefferson, and Scott counties. The additional highway cost of rail abandonment of this line was determined to be $145,200 over the next ten years.

TREATMENT OF SANITARY WASTES AT INTERSTATE REST AREAS

Another of our projects is the treatment of sanitary wastes at rest stops. Location of rest stops on the interstate system of highways can be difficult because of the need for water supply and wastewater disposal. The ability to supply the quantity of water needed and the capability to treat the wastewater generated to an acceptable level for stream discharge have been difficult problems. If a stream is not available it has been impossible to locate a rest stop in the vicinity.

The objective of this research project was to look at two types of wastewater treatment systems that could solve these problems. The first of these was a wastewater treatment system of the activated sludge
variety in which all treatment was carried out inside of a nylon filter bag. Several years of testing had shown this type of treatment-filter system capable of producing an effluent better than that required by any of the state or federal regulatory agencies. The second type of system involved taking this high-quality effluent, decolorizing it with activated carbon, and deusing it to flush the toilets in the rest stop. This type of system thus has no liquid discharge to the environment because evaporation losses exceed the fresh water contributed by drinking and hand washing. The other distinct advantage of both of these types of treatment systems is that they require minimum space and thus can be housed in the rest stop building, materially cutting land needs and climatic difficulties with treatment plant operation.

One such rest stop of each type has now been in operation on I-65 near Lebanon for several months. The performance of the recycle and nonrecycle systems has been good, but, as expected, some difficulties in startup of the systems have been experienced. As shown in Figure 21, the water used in the recycle system is approximately ten percent of that in the nonrecycle system. The effluent quality from both systems has been better than that required by state and EPA standards from the treatment units which have operated satisfactorily.

A few treatment units have had problems with holes in the nylon fabric filter bags and the performance of these units has been less than desirable but these problems are rapidly being corrected. Several other minor problems on the recycle system were encountered because of small pieces of carbon and solids which caused malfunction of the flush-o-meter valves. These malfunctions caused an imbalance in water usage which, after correction, meant that extra water had to be added to the system because some had been discharged into the emergency tile field connected to the system. The high water use shown on Figure 21 during the period from November 3 through January 26 reflects these difficulties. As you will note from the rest of the data on the figure, the difficulties have been corrected. The results of this research look very promising. The waste disposal and water supply problems of rest stops may be largely solved.

FUNDAMENTAL STUDIES IN PORTLAND CEMENT CONCRETE

I have briefly reported on 14 of our 1975-76 research projects. Each of the ones discussed were directed at a specific problem area of current interest to the state highway commission and local highway authorities. We also do some basic research and as the final project I want to report
Figure 21. Thorntown Rest Stop Water Usage, Recycle, and Nonrecycle Systems.
briefly about one of these—our fundamental studies in Portland cement concrete. In this research, our investigators are seeking knowledge about the structure of hardened Portland cement concrete and how that structure influences behavior, especially fracture and the propagation of cracks.

A variety of methods have been used to look at the structure, but we have been most successful with scanning electron microscopy. The recent work has been an extended look at how the structure develops at the point of contact between the cement paste and sand or gravel aggregate surfaces—this is the critical zone in terms of concrete failure.

Some of the work has been done using glass microscope slides as simulated aggregate surfaces—this is convenient because there is a flat surface to look at, and because the glass surface spontaneously separates from the hardened cement on drying. Everything we have seen with glass we have also seen with mortars and concretes, only it is more difficult to define and to show clear pictures.

The first thing that develops is that a “skin” of lime, very thin, is laid down immediately on the surface of the glass (or the aggregate grain). When the hardened cement “pops off” the surface on drying, some of the skin stays with the glass (or aggregate) but most of it comes off with the hardened cement. The skin hides the details of the cement, but the observer can look through “windows”—places where the skin stayed with the aggregate—and see the details of the cement structure. Let me take you on a short trip into the structure of concrete.

Figure 22 shows such a window. You are looking down onto the hardened cement, mostly covered with the skin or film but there is a window to see through into the cement structure. There is also a tear in the skin.

Figure 23 was taken through such a window and shows what hydrating cement grains look like. This is more or less normal, and happens all through the hardened cement paste, not only near the aggregate.

Figure 24 shows an abnormal mode of hydration that we were the first in the world to discover. It takes place mostly near the aggregate contact. The cement grain forms a coating around itself, then proceeds to dissolve inside the coating, leaving a partly or completely hollow shell. The dissolving cement is the bright, shiny rounded grain in the middle of its shell. You can only see this if the shell is broken so you can see inside, as it is here.

One of the things we have been most concerned with is the onset and propagation of cracks. Figure 25 shows a narrow crack forming
Figure 22. A Window through the Skin of Hardened Cement Permits Looking into the Cement Structure.

Figure 23. Hydrating Cement Grains as Normally Seen.
Figure 24. An Abnormal Mode of Cement Hydration.

Figure 25. Initial Formation of a Crack in Cement Mortar.
in the contact zone right next to a flat piece of aggregate in a mortar, at very low load. The last state in concrete crack development soon follows when the crack widens under applied load, and the concrete fails.

CONCLUDING STATEMENT

There are 25 additional projects, each one designed to develop new knowledge, which will be helpful in wisely attacking the many problems which not only exist in transportation, but which are ever increasing as we move into new and unknown fields. We are interested in developing research in areas where new knowledge is needed and we seek suggestions.

The Joint Highway Research Project has a typical staff of about 50 part-time personnel, part-time in the sense that they are also involved in teaching or in taking courses as graduate students. We have about 20 regular staff members and they are the principal investigators who guide the research.

We sincerely appreciate the fine cooperation and support we have received for the past 40 years from the Indiana State Highway Commission and from the Federal Highway Administration. We publish much of our research in technical papers to national organizations so that it is available to the profession throughout the world. Copies are usually available from our offices at Purdue University.

Our goal is seeking better ways to plan, design, construct, maintain, and operate better transportation facilities and to use transportation to improve the quality of life.