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ORGANIZATION AND PROGRESS OF THE TENNESSEE HIGHWAY RESEARCH PROGRAM*

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In a report published in 1953 by the Highway Research Board of the National Research Council, a summary of highway research by state highway departments disclosed that there are five broad research organizational patterns which are in existence. The patterns were listed as (1) noncentralized research, (2) centralized coordinated research, (3) formal research, (4) joint research, and (5) contracted research. Noncentralized research was defined as that research undertaken by various units of the highway department without special organizational framework. Centrally coordinated research was stated as that research conducted by the various units of the highway department and coordinated by a research director. Formal research was defined as that research conducted by self-contained, centrally operated units officially designated or recognized as research units in the state highway departments. The fourth organizational pattern, joint research, was defined as that research conducted by organizations established and operated by joint effort and for the mutual benefit of the state highway department and the college or university. The fifth organizational pattern, contact research, was stated as that research contracted to other agencies by the highway department.

The Tennessee Highway Research Program is one of several research programs in the field of highway engineering which functions as a benefit to the state highway department and the state university or college. Tennessee, in 1951, was the fifth state to establish a highway research program under the joint research organizational pattern. The first state was that of Indiana, when in 1937, the Indiana State Highway Department made a formal agreement with Purdue University for a joint research program. The second endeavor was that of Kentucky in 1942. The third and fourth state highway departments to enter similar agreements were those of Florida and Virginia in 1947 and 1948, respectively.

The framework of the Tennessee Highway Research Program was, in all probability, being molded prior to 1951, but in April of that year a definite program was established with the passage of an enabling act by the General Assembly of the State Legislature. The act permits the Commissioner of Highways and Public Works to enter into a contract or contracts with the

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University of Tennessee "relative to the development and testing of new materials to be used in constructing and maintaining roads, bridges, and highways relative to the development of more economical methods of designing, constructing and maintaining roads, bridges and highways, and relative to the training of personnel in the fundamentals of highway engineering." On October 1, 1951, less than seven months after passage of the enabling act, the Tennessee Highway Research Program commenced operation.

The general activities of the Program are programmed by a six-man Advisory Council, consisting of three representatives of the Department of Highways and three of the University of Tennessee. The Council meets quarterly to consider and approve new research projects, to approve the Program budget, and to establish broad matters of policy. Technical and detail direction of the Program is invested in the Program Director.

The Program is housed in Perkins Hall and makes use of the facilities in the Department of Civil Engineering and the Engineering Experiment Station. It is administered for the University through the Engineering Experiment Station. The staff of the Program consists of the Director, research engineers, laboratory technicians, and part-time student assistants.

At the present time, there are five research projects in progress. These projects are designated as (1) a study and investigation of "local materials" within the state to determine methods and means of increasing their stability and workability when used as a base in highway construction, (2) a study of the causes of slipperiness in pavements to devise practicable remedies, (3) the durability of high early strength concrete, (4) a study of subgrade materials to determine suitable means of evaluating their usability, and (5) an investigation of calcium silicate slag as a potential aggregate.

The first project, "local materials," was authorized in October, 1951, for the purpose of investigating various chemical additives and mechanical methods of improving the stability and durability of existing materials for base construction. The problem is of considerable importance as in some sections of the state local materials exist which are not entirely suitable for base construction, but should be considered for use, as the cost of shipping suitable materials into the area is excessive. This condition prevails, to a great extent, in Middle and West Tennessee where chert and granular materials exist, but are not of sufficient quality to warrant their usage without qualifications.

Samples of the materials in this area were brought into the laboratory and subjected to durability and stability tests with and without attempts to increase their usability by adding varying percentages of different admixtures. The admixtures consisted of such materials as calcium chloride, calcium acrylate, lime flyash, portland cement, cutback asphalt (RC-2), emulsified asphalt, road tar (RT-5), and hydrated lime. Specimens were also molded from each basic material, with and without admixture, which had been blended with sand. All test specimens were subjected to wetting and drying, freezing and thawing durability tests and California Bearing Ratio, direct compression, and triaxial compression stability tests.

The results of this study, to date, have been to show the effect on durability and stability, based on varying percentages, of the several admixtures. They have also been used as a basis for authorization by the State Highway Department for the construction of a low percentage portland cement base in Middle Tennessee using a heretofore unsuitable chert material.

The second of the four research projects under investigation, also authorized in October, 1951, is a study of pavement slipperiness in Tennessee. This project has received considerable attention from the residents of this state as it embraces a problem which is known to all who drive in Tennessee. The highway officials expressed their grave concern of the problem by assigning it as the second project of the Program. The problem of pavement slipperiness does not confine itself to any particular locality or pavement type and is not, necessarily, directly associated with the present "high-speed" automobile age.

There are two generally accepted methods of determining pavement slipperiness or the relative "skid" or "non-skid" qualities of pavement surfaces. One of these is a small two wheel trailer pulled by some self-propelled vehicle. One wheel of the trailer can be locked and the drag which the trailer exerts on the towing vehicle (moving at a constant speed) can be measured and a relative coefficient of friction calculated. The other method is to use a more or less standard passenger vehicle which can be driven at a constant predetermined speed, onto the test section of pavement, the brakes locked, and the distance which the vehicle slides in coming to rest measured. Both such tests have been conducted in this study. Variables such as speed of test, type test tires, wet and dry surface conditions, and type aggregate, as well as others, have been investigated.

In an effort to reduce the influence of such variables as weather and traffic and to evaluate other variables such as surface age and type aggregate, the State Highway Department incorporated a "test section" between Rockwood and Spring City, Tennessee when resurfacing that section of State Route 29. In one lane of that pavement six different consecutive surfaces were constructed as follows:

Section A – 60 per cent limestone and 40 per cent sand
Section B – 50 per cent limestone and 50 per cent sand
Section C – 50 per cent limestone and 50 per cent slag
Section D – 100 per cent slag
Section E – 75 per cent limestone and 25 per cent slag
Section F – 75 per cent limestone and 25 per cent sand

This construction was completed in April, 1953 and each section has been tested at frequent intervals since that time.

As a result of the studies of pavement slipperiness, the Highway Department has altered its design of pavement surfaces to include constituents which tend to reduce pavement slipperiness.

The third principal investigation, assigned to the Program in September, 1953, is that of the durability of high early strength concrete. It was undertaken primarily to determine the effect on durability of using calcium chloride as an admixture for accelerating the early set or hardening of concrete.

At present, there are three generally accepted methods of obtaining high early strength concrete. These are (1) the use of a normal Type I cement at an abnormally high cement factor, (2) the use of Type III cement which is manufactured as a high early strength cement, and (3) the addition of an accelerator, usually calcium chloride, to a mix containing Type I cement at a normal cement factor. Present highway specifications in Tennessee permit the use of either of the first two methods. The effectiveness of the first method is dependent, to a large degree, on field control and that of the second method is dependent upon the availability on the Type III cement.

In studying this problem, a number of concrete specimens, 3x4 x 16-inch beams, have been made from each of 12 mixes.

These mixes are as follows:

Mix 1---------Type I cement, 5.8 sacks per yd. 0.58 water-cement ratio by weight.

Mix 2---------Type I cement, 7 sacks per yd. 0.40 water-cement ratio by weight.

Mix 3---------Type III cement, 5.8 sacks per yd. 0.58 water-cement ratio by weight.

Mix 4---------Same as Mix 1 with 1 per cent calcium chloride added.
Mix 5---------Same as Mix 1 with 2 per cent calcium chloride added.
Mix 6---------Same as Mix 1 with 4 per cent calcium chloride added.
Mix 7---------Same as Mix 4 with 5 to 6 per cent entrained air.
Mix 8---------Same as Mix 5 with 5 to 6 per cent entrained air.
Mix 9---------Same as Mix 6 with 5 to 6 per cent entrained air.
Mix 10--------Same as Mix 1 with 5 to 6 per cent entrained air.
Mix 11--------Same as Mix 3 with 5 to 6 per cent entrained air.
Mix 12--------Same as Mix 2 with 5 to 6 per cent entrained air.

It should be pointed out that additions of calcium chloride were calculated on the basis of available soluble calcium chloride rather than on the basis of weight of the commercial product. Percentages shown in the above tabulation are based upon the ratio of the weight of the soluble calcium chloride to the weight of cement in the batch.

The specimens have been undergoing durability tests which are of the freezing and thawing nature. Specimens have also been placed in an outdoor exposure lot for the purpose of subjecting them to normal variations in weather.

All specimens are periodically subjected to a non-destructive, dynamic test to determine the effect of the durability tests. In this test, the specimens are subjected to minute, continuous vibrations and their natural resonant frequency in transverse, torsional, and longitudinal vibration determined. From these frequencies, and the weight and dimensions of the specimens, its dynamic modulus of elasticity may be computed. Changes in these moduli are indicative of changes in the condition of the specimen.

The analysis of the data collected from this investigation has prompted the Program's Director to recommend to the State Highway Department that, "where such usage is indicated, present specifications be modified to permit the use of calcium chloride as an additive for obtaining high early strength cement." It has also been concluded, from present data, that an addition of 2 per cent calcium chloride to a concrete mix is not seriously deleterious with respect to resistance of the concrete to weather.

The fourth research project was approved by the Advisory Council in October of last year. It is primarily a study of sub-grade materials to determine suitable means of evaluating their usability. The sub-grade, in highway engineering, is generally defined as the supporting structure on which the pavement and its special courses rest.

The influence of the subgrade on pavement performance was somewhat obscure in the 1920's and much in the 1930's due to the over-design of the pavement and special courses. However, high concentrations of heavy loads, frequency of overloads, and increased vehicle speeds, occurring during and after World War II, have caused many pavements structural failures. Investigations by various state highway departments into the causes of these failures have brought into the light that, in general, some correlation exists between these failures and subgrade materials.

It is the intent of this study to devise methods of evaluating the suitability of various subgrade materials, in place or borrowed, for subgrade construction. The methods, in general, will incorporate the physical and strength characteristics of the materials as well as the influence of parent material, drainage, climate, and traffic.

It is hoped that as this study progresses it will assist the Engineers of the Highway Department in finding answers to such questions as:

What subgrade soils exist in Tennessee?

Where and to what extent do they exist?

What, if any, improvements or corrective measures are desirable on existing subgrade materials?

The Advisory Council of the Tennessee Highway Research Program at its 19th meeting, on January 31, 1956, authorized the fifth research project for the purpose of investigating calcium silicate slag produced by T.V.A. at Muscle Shoals, Alabama. The project, designated as HW-4 and entitled "Investigation of Calcium Silicate Slag as a Potential Aggregate," was established for the purpose of evaluating the slag as a fine aggregate for concrete or asphaltic mixes.

There are areas in middle Tennessee where fine aggregates for use in concrete and asphaltic mixes are not in abundance. On occasions, it has been necessary to ship suitable material into these areas from rather distant sources. This practice is not very desirable as unit prices are generally higher and undue construction delays develop from extended supply lines.

It has been considered good policy by the Tennessee Department of Highways and Public Works, in order to guard against undue construction delays and high unit prices to investigate all possible sources of local materials as to their suitability. This practice, while initially expensive, can prove to be a saving to the Department, for when engineering data are accumulated on materials in any one area a more economical construction program can be planned for that area. With this in mind, Research Project HW-4 was authorized for the purpose of investigating calcium silicate slag as a potential aggregate which would be available for use in the southern area of middle Tennessee.

There is also the possibility that the slag aggregate could be made available to other areas of Tennessee since the source is located on the Tennessee River where barge shipping is convenient. The material is a by-product of the electric furnace method of producing phosphate and is available in large quantities at a relatively low unit price.

Another possible use of the material is in the construction of pavement surfaces where non-skid qualities are desired. This would mean, however, that if the slag is acceptable as fine aggregate a skid test section would be necessary to evaluate its non-skid properties.

In view of the interest in using the slag as an aggregate in concrete as well as asphaltic mixes, it was decided to organize the project such that both uses could be investigated concurrently. In order to do this, the project was divided into an asphaltic concrete and a portland cement concrete section. A general work plan for each of the two sections is discussed in the following paragraphs.

The work performed in the asphaltic concrete section consists of designing asphaltic mixes using limestone, natural river sand, and slag in varying combinations as coarse and fine aggregate. The mix designs are tested for stability by three well known methods. Information is also collected on the density of the mixes as prepared by different compaction methods for the three stability tests.

The mix designs, in general, conform to Section 104 of the Tennessee Department of Highways and Public Works general specifications for an asphaltic concrete surface course. They also conform to the special provision which was added to the section since the printing of the general specification. It provides for a certain percentage of sand, generally between 30 and 40 per cent passing the No. 40 screen, to be included in the mix.

The asphalt content and combined graduation for the aggregates according to Section 104 and Special Provision of the State specifications are shown in Table I.

TABLE I

Combined Graduation		Asphalt (85-100 pen.)
Sieve Size	*% Passing*	
½	100	
4	64-76	
10	46-56	
40	19-27	
100	5-11	
		Per cent
		6.8 to 6.0

The design of the mixes are made using the combinations of coarse and fine aggregates and asphalt content ranges as shown in Table II.

TABLE II

Mix	Coarse Aggregate	Fine Aggregate	Asphalt Range %
1	Limestone	Limestone	4.0- 9.0
2	Limestone	Natural River Sand	7.0-11.2
3	Limestone	Calcium Silicate Slag	5.0-12.0

The stability of the various mixes is determined by the Marshall, Hveem Stabilometer-cohesiometer, and the Hubbard Field methods. A detailed description of the test procedures and compaction methods will be included in a later progress report.

In addition to the stability tests, the specimens, as prepared by the different compaction methods for the stability tests, are tested for density by an ASTM standard (D1188-53) and a pulse velocity technique. The density of each specimen is determined prior to the performance of the stability test.

The section on portland cement concrete consists of that phase of the project on the evaluation of concrete mixes. The mixes are designed with a constant water-cement ratio, coarse to fine aggregate ratio, and cement factor. Limestone and river gravel are used as coarse aggregates in combination with natural river sand, limestone, and calcium silicate slag as fine aggregates.

After a considerable number of trial mixes, a control mix design was established for the project. It is based on a water-cement ratio of 0.58, a cement factor of 6.0 sacks per cu. yd., and a percentage of coarse and fine aggregate of 60 and 40 respectively.

In general the fabrication and curing of the test specimens follow ASTM procedures. The aggregates at room dry temperature are mixed in proper proportions with cement and water in a 1.5 cu. ft. Lancaster tub mixer. At the end of the mixing period the slump of the mix is determined and if satisfactory the mix is cast into test specimens.

Test specimens are made from each mix as shown in Table III. Twenty-five are cast into 3x4 x 16 inch beams and twenty-five into 6 x 12 cylinders. All specimens are cast into steel molds with the aid of vibration and allowed to stand, covered with wet burlap, for a period of 20 to 24 hours. At the end of this initial curing period, the specimens are removed from the molds and cured in a moist room at 100 per cent R.H. and 73.4°F.

TABLE III

Mix No.	Coarse Aggregate (60%)	Fine Aggregate (40%)
1	Limestone	Limestone
2	Limestone	Natural river sand
3	Limestone	Calcium silicate slag
4	Gravel	Natural river sand
5	Gravel	Calcium silicate slag

In order to determine the effect of the various designs on the modulus of rupture and comprehensive strength, beams and cylinders are tested at the end of 7, 14, 28, 90, and 365 day curing periods. In general, the beam and cylinder tests conform to ASTM Designations C 192-55 and C 39-49, respectively.

The investigations involved in the two sections of the project are being conducted by graduate students under close supervision of the Program personnel. The information and data will be used by the students as material for their Master of Science theses.

The work performed in the asphaltic concrete section is under the direction of F. L. Holman, Jr. and S. M. El Rawi. The proposed title for each of their theses is as follows:

"An Investigation of the Effect of Calcium Silicate Slag Fine Aggregate on the Stability of Bituminous Paving Mixes" by Frank L. Holman, Jr.

"An investigation of Several Methods for Compacting Asphaltic Specimens and of a Pulse Velocity Technique for Evaluating Density Variation" by Salman Malik El Rawi.

The portland cement concrete section of the project is under the direction of M. Ahmed whose thesis title is proposed as follows:

"Effect of Electric Furnace Slag Sands on the Strength of Concrete" by Moizuddin Ahmed.

While progress, in this report, has been measured by the progress of the research work conducted, it should be remembered that another measure of progress is by the accumulation of facilities and equipment. The Program, since its inception, has continued to improve its testing and research facilities and has within its own organization or access through the Department of Civil Engineering a rather complete bituminous, concrete and soil laboratory.

The Tennessee Highway Research Program is still a relatively young organization in the field of highway research. The foregoing has outlined very briefly its organization and progress of current projects. There is every reason to believe that the Program will continue to expand and will contribute appreciably to the present knowledge of highway materials and to the improvement and expansion of the highway system of Tennessee.

Additional information on the Tennessee Highway Research Program and its projects has been published in the following bulletins and reprints of the Program. Copies are available on request.

Bulletin No. 1, April, 1955
"The Stabilization of Local Base Materials."

Reprint No. 1, April, 1955
"Pulse-Velocity Techniques and Equipment For Testing Concrete."

Reprint No. 2, September, 1955
"The Tennessee Highway Research Program—A Progress Report."

Reprint No. 3, December, 1955
"A Study of Pavement Slipperiness in Tennessee."