FHWA RIGID PAVEMENT RESEARCH PROGRAM - A HISTORICAL REVIEW

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This paper presents an overview of the Federal Highway Administration's past, present, and future research activities dealing with all aspects of rigid pavement design and rehabilitation. Historically, FHWA and its predecessor, The Bureau of Public Roads, has played a major role in rigid pavement research. A brief review is made of historical research activities and the development of the present FHWA research program. The paper includes work currently being done as a part of the Federally Coordinated Program, 5J - Rigid Pavement Systems Design, 5D - Structural Rehabilitation of Pavement Systems and 5E - Pavements for Zero-Maintenance.

Research was one of the principal missions of the first national highway program in the United States and is, in fact, the oldest continuous Federal highway activity. The scope of federally conducted or assisted research encompasses all of the Federal highway programs and every facet of highway transportation --as a national resource and as a principal force in the social and economic well-being of the people and Government.

Early History

The history of highway research in the Federal Government began with the establishment of the Office of Road Inquiry (ORI) in the Department of Agriculture in 1893. Prior to that date, there had been numerous investigations and experiments, but they were primarily scattered and isolated events. With the creation of the ORI, whose primary mission was to investigate the best methods of roadmaking and to assist in disseminating this information, a formal, organized research program began. In 1894, the ORI issued nine bulletins on such subjects as State laws, roadbuilding materials, and railroad rates for hauling those materials. Demonstration trains, originally known as "Good Roads Trains," travelled throughout many parts of the Nation in the 1890's. These trains were fitted with construction and roadbuilding machinery and equipment as well as section models of macadam and other types of road construction.

States, local authorities, railroad companies, and the manufacturers of earth-handling and roadbuilding machinery also cooperated in building short sections of quality roads to demonstrate good road building practices. The emphasis was on drainage surface course and maintenance. Local material and manpower were used under the general supervision of Federal engineers. Sometimes on "Good Roads Day," as many as 500 local farmers would take a walking tour of a demonstration section being In 1910, the annual report of the Office of Public Roads reported that 55 object lesson and experimental roads had been completed during the fiscal year.

Although information on specific research activities in the early 1900's is rather fragmentary, the most substantial continuing effort was testing large numbers of samples of highway materials, including aggregate, cement, soil, asphalt, and tar. A Federal laboratory was established in 1900 for mechanical and chemical investigation of these materials. The result of the tests were analyzed to obtain a general overview of the characteristics of available materials and their suitability for roadbuilding purposes. Samples were sent in from all areas of the country and were tested free of charge until 1924, when it was announced that materials would no longer be tested for the general public.

In addition, statistical and economic evaluations were made in 1910 of the effect of road improvements on communities. Some work was also undertaken on coatings and coverings for iron and steel corrosion. In 1911 there were some object lesson projects on culverts, and a bulletin was published on highway bridges. Rather than attempting to outline here a large number of technical advances, several broad historical

milestones can be summarized. (1) The research mission of the Federal agency was clearly established, and, later, Federal funds were specifically earmarked for research. (2) A major research journal, Public Roads, was founded. (3) The cooperative and joint-participation concept with the States and industry was established. (4) The initial concentration on material and surfaces was rapidly expanded into areas such as structures, economic consequences, and the impact of traffic and trucks.

Federal Aid for Research

The first sustained fiscal support for highway research was authorized by section 21 of the Federal Highway Act of 1921. The foundation for the Federal-aid State highway planning and research program was laid with the enactment of the Hayden-Cartwright Act of 1934. Section 11 of the Hayden-Cartwright Act specified with the approval of the Secretary of Agriculture, not to exceed 1-1/2 per centum of the amount apportioned for any year to any State ... may be used for surveys, plans, and engineering investigations ...." Under this authorization, some States, with the delegated approval of the Bureau of Public Roads, initiated research activities, mostly in the area of physical materials of the highway.

The Federal-Aid Highway Act of 1944 contained for the first time the term "research" in addition to planning. Thus, the States at their option and with the approval of Public Roads could use a portion of the 1-1/2 percent planning funds for research. Funds not used for planning or research could revert to the construction program. With the enactment of the Federal-Aid Highway Act of 1962, the 1-1/2 percent funds were restricted as of fiscal year 1964 to research and planning purposes only. If they were not used during their availability period, these funds would lapse.

To further encourage the States to increase their research and planning efforts, the 1962 Highway Act authorized, beginning with fiscal year 1964, the use of an additional one-half of 1 percent of sums apportioned for each fiscal year for planning and research, but this was optional. The initiative to conduct such efforts rests with the State highway departments.

The Federal-Aid Highway Amendments Act of 1963 expanded the law to include development under the research and planning section. The Act specified that the 1-1/2 percent funds would be available, among other purposes, "... for research and development, necessary in connection with the planning, design, construction,and maintenance of highways and highway systems ...." The intent of Congress was that development would be an integral part of the overall research and development program and that this provision would stimulate the States to play a more active role in the development phase.

Public Roads Magazine

The Federal-Aid Road Act of 1916 authorized a 5-year road program which had barely begun when the United States entered the European War. Looking forward to the resumption of the road program after the war, Director Logan W. Page of the Office of Public Roads and Rural Engineering foresaw the need for a journal devoted to the publication"... of the results of researches, experiments and studies of those connected with this Office, and of highway officials of the various States ...." and also "... for the dissemination of such information as the officials of the various States may desire to spread for the benefit of their contemporaries."

The first issue of the new publication, named Public Roads, appeared May 1918. It provided the State highway officials with a welcome forum for the discussion of current problems. The first issue brought the industry up-to-date by summarizing motor vehicle licensing laws and fees for registration and operators'licenses. This wartime issue also urged highway builders to conserve scarce fuel by proper attention to the firing of boilers and the careful use of steam in road machines and in quarrying. An entire issue (June 1918) was devoted to the catastrophic road breakups caused by heavy trucking during the 1918 spring thaw. The May 1919 issue dealt with the social and economic benefits of using convict labor on the public roads. When the Government distributed the huge surpluses of military equipment to the States, Public Roads ran articles on how to take care of the equipment and convert it to civilian highway use.

Public Roads published the resolutions adopted by the American Association of State Highway Officials (AASHO) at its annual meetings of December 1918, 1919, and 1920, and also the papers read at those conventions. In effect, it was the official journal of AASHO until that organization launched its own publication, American Highways in 1922.

Within a year of its first issue, Public Roads was an important voice of the young highway industry, with a long waiting list of would-be subscribers. In fiscal year 1920, the authorized monthly circulation was raised to 4,500 copies, but hundreds of requests for the magazine had to be refused. Budgetary cuts reduced the circulation to 4,000 copies per month for fiscal year 1921, and, without explanation, publication was suspended altogether after the December 1921 issue.

Public Roads resumed publication in March 1924, with the return of better times. However, the magazine was no longer a forum for the administrative and technical problems of the States, this function having been assumed by American Highways after Public Roads ceased publication. Instead, the new Public Roads was exclusively a house research journal, and all of its contributors were engineers, scientists, and economists of the Bureau of Public Roads. As the Bureau's research activities expanded, Public Roads published papers dealing with every aspect of highway research--finance and taxation, the economics of transport systems, the properties of soil and road materials, the management of the construction operations by contractors, the c characteristics of highway traffic, the strength of road slabs, and many others. Public Roads was the original publisher of many landmark papers in highway research. Most notable of these was

"Interrelationship of Load, Road and Subgrade" by C. Hogentogler and C. Terzaghi (Public Roads, May 1929) which laid the foundations of subgrade soil classification and marked a turning point in studies of subgrade soils.

The highway researchers of the twenties, thirties, and forties were breaking new ground. Often progress in a particular field of research depended on the invention of new instruments to measure what had never been measured before. A continuous stream of such instruments issued from the Bureau of Public Roads' instrument laboratory for nearly 40 years--the Goldbeck Pressure Cell for measuring pressures under pavements; the electric-eye and road-tube traffic counters; and Benkelman Beam for measuring deflections in pavements under load; and many others. Information about most of these devices first searched the scientific world through the pages of Public Roads.

Publication has continued without interruption from March 1924 down to the present, although the frequency of issues has varied widely. Through the years, Public Roads again expanded to include articles on highway research and development from sources outside of the Bureau of Public Roads.

Federal-State-Industry Cooperation

The historic association between Federal highway researchers and their counterparts in the States is considered unique in Federal Government programs, past and present. Over the years, all of the States have conducted research in cooperation with Public Roads and contributed in countless ways to the program described here. One other important accomplisment in this longstanding Federal-State partnership has been the establishment of strong, viable research staffs, facilities, and programs in the States.

In the last two decades, considerable cooperative research has also been undertaken on an international scale. A notable example is the continued involvement of FHWA in a number of research committees of the Organization for Economic Cooperation and Development (OECD). Their efforts have been particularly directed toward research for safer highway design and improved traffic operations. Since 1964, FHWA Roads has also worked with the International Road Federation in the collection and dissemination of information through a worldwide annual inventory of research and development activities.

Materials and Structures

In the early period of highway construction in the country, an understanding of the physical behavior of the major materials was developed primarily by trial and error, which led to the development of criteria and tests based, to a great extent, on empirical relationships. Much of the early research work consisted of testing large numbers of samples of highway materials to determine the essential characteristics of available materials and their suitability for roadbuilding purposes.

Soils

In the very early stages of the roadbuilding industry, little of a scientific nature was known about soils as road materials other than that clay soils were sticky and sadly lacking in vehicle support when wet and that very sandy soils, while having fair performance when wet, were highly unsatisfactory when dry. Thus, the first effective modification of soils for unpaved roads consisted of adding sand to clay soil and clay to excessively sandy soils in a more or less "cut-and-try" system.

Most of the experiments up until 1920 were concerned with dust prevention and road surface preservation. Then, in 1920, the Bureau of Public Roads began investigations "to obtain accurate scientific information regarding the characteristics of soils which affect their bearing value." At about the same time, several State highway departments established soil-testing units and each attacked the problem in its own way. However, through exchange of information at conferences and through American Society for Testing and Materials (ASTM), AASHO, and HRB, a soil classification system and standard soils tests were developed could be improved by the addition of portland cement, lime or bitumen, and that calcium and sodium chlorides were effective dust palliatives. During World War II, the Soils Laboratory collaborated with the Engineer Board, Fort Belvoir, Virginia, in the evaluation of chemicals for soil stabilization. Beginning in 1954, and continuing until about 1970, the Bureau in cooperation with the chemical industry evaluated about 50 chemicals for soil stabilization.

Cement and Concrete Materials

The name "portland cement" comes from an "artificial" cement patented by Joseph Aspdin in England in 1824. Aspdin kept his process a secret, although many others tried to duplicate this product. In 1845, L. C. Johnson developed a product based on high temperature calcination that was essentially "portland cement" as we know it today. Portland cement was first manufactured in the United States in 1871."

Today's refined knowledge of concrete design and utilization is the product of a number of organizations, such as American Concrete Institute, American Society for Testing and Materials, Portland Cement Association, State highway departments, and the Bureau of Public Roads. In particular, BPR played an important role in developing knowledge of the relationship of concrete's various components to concrete strengths and other characteristics and in developing better tests and specifications for the product. In addition, BPR performed studies which established the quantitative relation between some aggregates and the alkali content of cements and determined the value of fly ash in concrete to control the damaging alkali aggregate reactions as well as serve as a replacement for part of the cement. Other research assessed the sulfate resistance of various concretes and the relation of such resistance to cement composition. Air entraining agents to prevent freeze-thaw damage were also evaluated.

Aggregates

The simplification, standardization, and uniform application of aggregate gradations has been a major effort since 1936. This work led to the early adoption of a simplified practice of specifying sizes of coarse aggregate for concrete. In 1962, Public Roads encouraged the States and other agencies to adopt simplified procedures for aggregates used in bituminous construction. The recommendations included the development and adoption of standard aggregate sizes in graphical form.

In 1928 studies were made of concrete containing rounded gravel coarse aggregate versus the angular material produced by crushing ledge stone or large-size waterworn gravel. This research determined that crushed stone is generally preferred for paving work because of the superior strength of the resulting concrete.

Research on concrete freezing and thawing was also being conducted at this time. Public Roads research led to the development of new concrete specifications requiring denser and more durable types of coarse aggregate. Other research in this area included the development of air-entrainment techniques and the establishment of a list of acceptable air-entrainment admixtures.

New Analytical Techniques

During the late 1940's and early 1950's, Public Roads pioneered in the application of sophisticated instruments to help solve materials problems. Infrared spectroscopy was developed to identify the nature and understand the behavior of chemical admixtures for concrete, mineral composition of aggregates, and other highway materials. An infrared spectrophtometer was acquired in the late 1950's and was successfully applied to analyzing, classifying, and regulating the use of certain admixtures for concrete, such as water reducers, hardening retarders, and air-entraining chemicals. These materials were of such complex chemical nature that they had defied earlier less sophisticated methods.

Concrete Pavement Research

Following World War I, a prime objective of the State and Federal highway program was to reconstruct the surfaces and pavements of main highways which had received widespread damage from the greatly increased traffic of heavy trucks with solid rubber-tired wheels. The light surfaces, designed for horsedrawn or other light vehicles, failed under the impact of the heavier vehicles. Road test data were needed to determine the supporting capability of the various subgrade soils, the stresses induced in rigid and flexible pavements by the impact of motor vehicles, the effects of expansion and contraction of road surfaces caused by variations in temperature, the wear of traffic upon pavement surfaces, the distribution of loads upon bridges, and many other factors. To solve some of these problems, the Bureau of Public Roads and the States initiated a series of road tests.

The Arlington Road Test. The first road test was initiated in 1918 at BPR's Experimental Farm in Arlington, Virginia, to measure qualitatively the impact forces of various wheel loads. The tests, conducted with Army trucks equipped with solid rubber tires, were on concrete, brick, and bituminous slabs on circular tracks. The early tests indicated the major effect of wheel impact forces and led to further studies with more refined measuring instruments and the inclusion of pneumatic tires.

The Bates Road Test. For the Bates Road Test, the Illinois Division of Highways constructed 68 test sections, including six types of pavement on 2 miles of road and, with the assistance of BPR engineers, conducted tests on them from 1920 to 1923. Trucks were operated with controlled wheel loads that were progressively increased from 2,500 to 13,000 pounds. The test data gave the pavement type and thickness required for a specified loading and showed the need for control of wheel loads. A direct result of this study was the use of a thickened edge concrete pavement.

The Pittsburg Road Test. Between 1921 and 1922, another road test was conducted in Pittsburg, California, to determine the efficiency of both reinforced and plain concrete pavements of variable thickness and designs on certain types of subgrade soil. The test was conducted by the Columbia Steel Company on an elliptical track 560 feet in length containing 13 concrete pavement test sections. Much new information was learned, particularly concerning the effectiveness of longitudinal joints in preventing longitudinal cracking.

The combined findings from these three contemporary road test studies led to major advances in pavement design practices. The relations were determined between concentrated wheel loads and the thickness of several common types of pavement, which were directly usable on new highway plans. From the range of wheel loads studied, highway officials were able for the first time to reach agreement on the use of a 9,000-pound maximum value as the economic standard for highway pavement designs. More directly evident to the public was the abrupt phasing out of solid-rubber tires on trucks because of their high impact destruction on all types of pavements. Within a few years after 1926 the use of pneumatic tires became universal. Also, these studies made evident the need for amplified research on soil support values to attain better pavements.

Road Test One--Maryland. In 1949 the Interregional Council on Highway Transportation originated a test road study on a 1.1-mile section of highway south of La Plata, Maryland. The study and report was a cooperative effort of 11 eastern States, the District of Columbia, Public Roads, truck manufacturers, the petroleum industry, the Department of Defense, and HRB. The objective was to obtain data, for use both in vehicle weight regulations and in pavement design, on the relative effect of four different axle loads on the existing concrete pavement (two lanes), then in excellent condition.

Test trucks with 8,000- and 22,400-pound single axle loads were operated on adjacent lanes and trucks with 32,000- and 44,800-pound tandem axle loads operated on the other pair of lanes. Nearly 338,000 single axle truck passes were made and about half as many of the tandem axle.

The data on the progressive pavement deterioration, evidenced by cracking, internal structure failure, and joint depression, showed that damage was proportionate to axle loads. Significant data also were reported concerning soil support features and stresses at various points in the pavement slab.

The AASHO Road Test. After the WASHO Road Test, which was concerned with flexible pavements, the American Association of State Highway Officials (AASHO), in agreement with the Bureau of Public Roads, decided to conduct a comprehensive national test to obtain data on all significant variables. In 1955, AASHO sponsored and requested the Highway Research Board to direct this test. The purpose was to study the performance of pavement and bridge structures of known characteristics under moving loads of known magnitude and frequency.

This $27 million project, located near Ottawa, Illinois, was financed by the highway departments of the 48 States, Hawaii, the District of Columbia, and Puerto Rico. Financial support was also provided by the Bureau of Public Roads, the Automobile Manufacturers Association, the petroleum industry, and the American Institute of Steel Construction.

The Department of Defense furnished the heavy vehicles and drivers for their test run operations. In addition, there were many services and contributions by the automotive, petroleum, tire, cement, and steel industries.

The test road consisted of about 7 miles of two-lane pavements, half of concrete and half bituminous. The roadways included 16 short-span bridges. There were 836 separate test sections located in six loops which varied in length from 2,000 to 6,600 feet. The test sections had selected factorial combinations of surface, base, and subbase thicknesses. Axle loads differed on each loop and varied from 2,000-pound single to 48,000-pound tandem; truck trailer units were included. Full-scale tests started in November 1958 and terminated in November 1960. A total of 1,114,000 axle loads had been applied to the pavements and bridges surviving at the last date.

The project produced a reservoir of facts long needed for the development of a more refined and scientific design of pavements and short bridges.

Many articles have been published documenting the Bureau of Public Roads' research on portland cement concrete pavements. Among the earliest was a study in 1919 on the behavior of concrete slabs. The measured curling and warping movements of the slab were evaluated, in addition to the effect of wheel loading, and a thickness design formula based on the corner break was developed. This was followed in 1926 by Dr. H. M. Westergaard's theoretical analysis of slabs on an elastic medium. There followed a period of detailed studies by Bureau of Public Roads' researchers lasting until 1936 to verify and expand his results into a comprehensive design procedure, published as The Structural Design for Concrete Pavements, which remained the basic guide for a decade or more.

Experimental roads continued to be built to test new concepts in concrete pavement. In 1921, the Bureau of Public Roads built the first experimental continuously reinforced concrete pavement near Washington, D.C., where many of the basic principles related to that type of pavement were developed. In 1937 the Bureau, in cooperation with the Indiana State Highway Department at Stilesville, began an extended field test of continuously reinforced concrete pavement, which now comprises a significant portion of the Interstate System mileage. The BPR also worked with industry in 1957 to produce the first U.S. prestressed concrete highway pavement, and, subsequently, built a 3,200-foot experimental section of pavement at Dulles International Airport in 1971.

Research was also performed on reinforcing materials for concrete pavement. Bond studies in 1926 on steel reinforcing bars of various shapes and types of deformation included pullout tests to evaluate the contribution of the different types of bar deformation to the load-carrying capability of concrete slabs. The superior performance of several specific types of bars was established. In addition, results in 1958 of an extensive laboratory study of the performance of load transfer dowels in concrete pavement joints had an immediate effect in pavement design. Recommended dowel bar lengths and diameters for effective load transfer were widely adopted and are still in use today.

Nationally Coordinated Programs

In the early 1960's several significant events led to dramatic changes in the concept and activity of highway research. Enlarged research and development legislative authority was enacted in 1962 and made effective beginning with fiscal year 1964. There were growing problems for highway transportation along with population growth, urban concentration, and changing national priorities and goals.

One major legislative change was the requirement that 1-1/2 percent highway planning and research (HPR) funds must be used for planning and research purposes. No longer was there an option of using this money for construction. This requirement ensured the strength and vitality of federally aided planning and research programs in the States. Another event was the organizational separation of planning and research in the Bureau of Public Roads late in 1961. Research and development finally became a formal separate program in the Bureau.

At the same time, there was high interest and strong urging from scientists and technologists in the Department of Commerce and elsewhere to push the Bureau of Public Roads beyond its historic materials and physical research and undertake so-called "soft" research in operations, human factors, systems analysis, safety,society, and the environment. Research programing and management could no longer be a loose collection of a number of separate, isolated, totally unrelated studies. The problems were too complex and the resources too small. Comprehensive, integrated, and balanced research was the only answer.

Starting in 1963, a multidisciplined task force reviewed a wide range of problems and opportunities for solution in the human, physical, environmental, and public policy fields. This culminated in the creation of "A National Program of Research and Development for Highway Transportation," which officially began in 1965.

If the National Program could be summed up in three words, they would be coordination, concentration, and flexibility. The Federal Highway Administrator called it a program to coordinate and concentrate our efforts on the most urgent problems with flexibility, responsiveness, and recognition of local and regional problems. The program consisted of detailed work plans and problem statements for each; it served as a stimulus and guide for R&D efforts to develop and apply solutions rapidly.

The National Program was directed to three issues of highest concern--highway safety, urban transportation, and reduction in the costs of construction and maintenance. These issues were important because of the considerable human losses and $10 billion annual costs of accidents; the increasing problems of congestion, pollution and adverse socioeconomic impacts; and the critical need to optimize technological processes and cost.

In 1970, when the National Program was 5 years old, FHWA initiated a new, nationally designed and coordinated program for highway research and development called the Federally Coordinated Program of Research and Development in Highway Transportation (FCP). The FCP was specially designed to meet the needs of the customer--highway program managers and operating personnel in State and local agencies as well as the general public. It was also designed to be particularly responsive to urgent new problems in the environment, energy and resource conservation, utilization of waste, the integration of multi-transportation goals, and increasing the efficiency of the present system.

The current program of the FCP in concrete pavement research is divided into three major, although related, subcategories: (1) Rigid Pavement Systems Design, (2) Premium Pavements for Zero-Maintenance, and (3) Structural Rehabilitation. Of the above three subcategories, the latter deals with investigations specifically related to the developments of methods and procedures for rehabilitating the vast inventory of highways which are in need of or will shortly be in need of repair. On the other hand, the second deals with the design of pavements which, under heavy traffic, would not incurr large expenditures for maintenance with the resulting long user delays. The first item deals primarily with the development of new analytic tools which would enable one to optimize the design features of rigid pavements. A general description of each subcategory is given below.

5J - Rigid Pavement Systems Design

A recent survey of the rigid pavement mileage of the Interstate system revealed many deficiencies. The number of defects encountered was alarming, and they, for the most part, seemed to be due primarily to poor drainage or jointing practices. Investigations are underway to identify these practices and to determine adequate economical alternatives.

Typical research studies are concerned with such subjects as blow-ups, joint sealing, load transfer, subbases, drainage, steel patterns, concrete thicknesses and strength, joint movements, shoulders, construction techniques, pavement repair, longitudinal cracking, crack patterns, corrosion of hardware, faulting, curing, bridge approaches and joints, terminal joints, pavement expansion, overlays, and pavement performance.

A tremendous amount of research has been conducted in the past under this project and its predecessor, Elimination of Rigid Pavement Defects, in the National Program for Research and Development in Highway Transportation. In past years, the project has encompassed a large number of HP&R studies. The findings of many of these studies have had local interest and have resulted in changes which were immediately adopted by the sponsoring States. In many cases, they resulted in a State making changes in slab lengths, pavement thicknesses, types and sizes of load transfer devices, increased laps of reinforcing steel, terminal joints on continuously reinforced concrete pavements (CRCP), etc. Other coordinated studies have produced findings that were mutually beneficial to all the States and have formed the basis for policy endorsed by the Federal Highway Administration. Often a study which was initiated to investigate an isolated problem of local concern has proven to be the first indication of a problem that was widespread in the Nation.

Examples of current research are:

1. The Portland Cement Association (PCA) has completed an evaluation of portland cement concrete (PCC) pavements under an FHWA administrative contract. The evaluation was to find reasons for similarly designed pavements giving widely different performance. In conducting the investigation, PCA made detailed surveys on 86 pavement projects in seven States. These pavements were generally under 15 years of age, were both plain and doweled, and were conventionally or continuously reinforced.

Some of the more important recommendations include increased use of dowels for load transfer, short joint spacing, sawed or formed koint depths of D/4 for transverse and D/3 for longitudinal, a tied concrete shoulder or widened outside lane, and good sub-drainage. The results of the study are contained in a 35 mm slide presentation, which is available from the Implementation Division and in a Technology Sharing Publication, FHWA-TS-78-202.

2. Administrative contract DOT-FH-11-9568 was awarded to Resource International, Inc. in March 1979. The objective is to develop a new, practical, and implementable procedure for the structural design of rigid pavements, based on mechanistic principles and fundamental material properties.

This study is a major thrust in the task on design concepts and is to develop design procedures for rigid pavements which will predict the accumulative distress due to externally and internally applied forces. The procedures must utilize mechanistic models, fundamental material properties, and provide for joints, voids, and other discontinuities in the system. The models and material properties should, if possible, be

compatible with the newly developed systems for flexible pavement design. The procedures should be able to predict various forms of distress and must be amenable to a rigorous economic analysis for life cycle or Zero-Maintenance planning. This study will not include prestressed concrete pavements, but will include all other types of rigid pavements. Work is continuing and is scheduled for completion next year.

3. Administrative Contract DTFH61-80-C-00052 was awarded to Construction Technologies Laboratories, Skokie, Illinois in April 1980. This study will develop improved load transfer devices and methods for analyzing joints and cracks in rigid pavements and will optimize their design, construction, and performance. It will be involved with the development of analytical techniques to model pavement discontinuities, the determination of the effects of traffic load and environment on joint behavior, and the development and optimization of improved methods of load transfer across joints.

Proposed research in this project includes a study on improved systems for subbase and subgrade and mechanistic models for pumping, and another study for the field verification of rigid pavement design methodology.

5E - Premium Pavements for Zero-Maintenance

The technical objective of this project is to provide pavement design procedures that determine whether higher initial investments are justified by reduced maintenance, and to exploit modern materials and design methodology in developing "Zero-Maintenance" (Z-M) pavements.

The main impetus for this project has come from the concern expressed by many highway agencies that their major traffic arteries are deteriorating rapidly and prematurely under exceptionally heavy traffic volumes. An example of such a roadway is the Dan Ryan Expressway in Chicago which was repaved with difficulty after only about 10 years of traffic. When maintenance is performed, it is expensive and often of inferior quality because of the difficult working conditions which are created while the traffic flow is maintained.

The aim of this project is to define what conditions (traffic, environment, geometry, etc.) dictate the use of improved pavement structures, and to develop procedures for the design and construction of long-lasting maintenance-free surfaces. An economic analysis model is the backbone of this project.

The other major aspects of the project include (a) development of design procedures to upgrade conventional pavements thus increasing their lifespan, (b) development of new and innovative pavement types, and (c) exploration of new materials which would possess equivalent or better structural properties than those available today, would be economical, and possess the quality of being energy efficient.

Examples of contract research conducted under the project are summarized below:

1. The system EAROMAR ("Economic Analysis of Roadway Occupancy for Maintenance and Rehabilitation") was developed by Byrd, Tallamy, McDonald, and Lewis to evaluate the economic impacts associated with roadway occupancy by work crews. The initial EAROMAR procedure is described in the four volume final report for study FHWA-RD-76-13, 14, 15, and 16. It was determined at the FCP review conference that this basic framework needed to be updated and modified.

2. In order to accomplish the above modifications, a contract was awarded to CMT, Inc. This contract effort is nearing completion and is being evaluated through an implementation effort with the Massachusetts Department of Highways to develop Zero-Maintenance justification for reconstruction of U.S. Route 128 in Boston.

3. The U.S. Army Corps of Engineers conducted a study whose objective was to evaluate the potential of new materials for use in premium pavements. Results concluded that there were no miracle products which could be a panacea, but that by judiciously combining several of the promising materials to yield the desired properties, it was possible to develop Z-M pavement systems. The findings were carefully reviewed and aided in determining the current direction of the "new materials" aspects of the project. The final report, "Identification of Candidate Zero-Maintenance Paving Materials," was distributed as two volumes--Report Nos. FHWA-RD-77-109 and 110.

4. As a result of the above effort, a second effort was the award of a contract to PCA to study means for improving portland cement concrete by using super water-reducing admixtures that modify the concrete properties. Interim results indicate that use of the admixtures will increase compressive strength, flexural strength, and rate of strength gain while decreasing drying shrinkage and permeability. Current work is concentrating on development of optimum mixing procedures, hauling, and placement techniques.

5. The first interim report from a contract awarded to the University of Illinois is published as Report No. FHWA-RD-76-105, "Zero Maintenance Pavements: Results of Field Studies on the Performance Requirements and Capabilities of Conventional Pavement Systems," April 1976. This report represents the data and findings accumulated during a nationwide field evaluation of five types of pavements that may have Zero-Maintenance potential: plain portland cement concrete (PCC), standard reinforced PCC, continuously reinforced PCC, flexible, and composite. The final report, "Design of Zero Maintenance Plain Jointed Concrete Pavement," was published in two volumes: "Volume I - Development of Design Procedures" and "Volume II - Design Manual," Reports No. FHWA-RD-77-111 and 112, which develop and document the JCP-1 computer program.

6. The goal of a contract with Austin Research Engineers is the development of a manual for the design of Z-M flexible and composite pavements. The manual includes identification and classification of the pavement materials and design procedures for the selection of pavement configurations using wheel loads and environmental factors and material and construction specifications necessary to achieve a Z-M pavement.

7. An interim report from a contract awarded to Dames and Moore has been distributed as Report No. FHWA-RD-77-76, "Unique Concepts and Systems for Zero Maintenance Pavements," July 1977. This state-of-the-art report included a survey of the literature on potential concepts for Z-M pavements and recommended several new concepts for continued study and detailed design analysis. An anchored pavement design model received extensive and detailed analysis for correlation of analytical and model test results.

8. The objective of a contract awarded to Portland Cement Association is to investigate the potential of prestressed pavements to serve as Z-M pavements and to develop design/construction techniques. An interim report was distributed as Report No. FHWA-RD-77-8, "Technological Review of Prestressed Pavements," December 1976.

9. A contract entitled "Environmental Effects for Zero-Maintenance Pavements" was awarded to the University of Illinois and has as its objective the development of models and procedures to account for those environmental influences which most significantly affect the behavior of our highway pavements. The project will concentrate on environmental influences which significantly affect pavement performance without traffic.

5D - Structural Rehabilitation of Pavement Systems

The objective of this project is to provide design and construction methods and better criteria and measurement for more timely and improved rehabilitation of pavement systems.

It is concerned with (a) the development of measuring systems and methodology for determining the structural adequacy and serviceability of the pavement system and the optimum timing for its repair or rehabilitation, (b) the development of materials and methodology for pavement repair and rehabilitation, (c) the formulation of design criteria and theory, and (d) the utilization of standard evaluation and design methodology in the development of a predictive type pavement management system. Life cycle costing of the entire system must be considered. This project is also concerned with the pavement effects due to changes in vehicle size, weight, and configuration of load assemblies.

Examples of research studies in this project are:

1. In conjunction with the First Annual FCP Review Meeting held in September 1973 in San Francisco, California, a Pavement Rehabilitation Workshop was held. The deliberations of the workshop covered the broad field of pavement rehabilitation application to both highway and airfield pavements. Individual workshop sessions were concerned with specific areas of the overall field. State-of-the-art papers presented and working sessions dealt with the following: (1) Evaluation of Pavement Serviceability, (2) Structural Evaluation of Highway and Airport Pavements, (3) Rehabilitation Planning, (4) Design of Flexible and Rigid Overlays, (5) Miscellaneous Rehabilitation Methods, and (6) New and Innovative Rehabilitation Strategies and Materials. The workshop proceedings including an evaluation of the current state-of-the-art and a recommended research framework have been published. The workshop was conducted by the Transportation Research Board under contract to FHWA. Proceedings of the workshop are published in FHWA-RD-74-60.

2. An Administrative Contract, DOT-FH-11-8264, "Pavement Evaluation," was awarded to Texas A&M Research Foundation in December 1973. The objective of this study was to develop methodology for the determination of a pavement's structural adequacy for use in pavement rehabilitation. The study involved two phases. In the first phase, pavement evaluation methodology was reviewed and evaluated, and in the second phase, prototype equipment necessary in the procedure was developed, and the method evaluated through a field verification. Equipment which showed reasonably good prospects for success was an acoustical crack detector for use on flexible and rigid pavements and the duomorph, a space-age sensor used to measure elastic and viscoelastic moduli of the surface layers. A prototype of the duomorph was developed and is being evaluated further. Results have been published in FHWA-RD-75-78.

3. In June 1974, a contract, DOT-FH-11-8544, was awarded to Austin Research Engineers. This study, "Pavement Rehabilitation Design Procedures," was to develop pavement overlay thickness design procedures for the rehabilitation of all common pavement types and to develop design procedures for eliminating or reducing the reflection cracking of pavement overlays. The contract involved three separate phases: Phase I - "Flexible Pavements - Overlay Design" - an overlay design procedure for flexible overlays over flexible pavements based on multilayer theory was developed; Phase II - "Rigid Pavements - Overlay Design" - overlay design procedure(s) for rigid and flexible overlays of rigid pavements were developed; Phase III - "Reflection Cracking" - design procedures, construction methods, and material specifications were developed to eliminate or greatly reduce the serious problem of reflection cracking of pavement overlays. Each phase involved the development of a users manual and a verification of the design procedure. Published reports include FHWA-RD-75-75 and FHWA-RD-77-66 and 67.

4. Contract DOT-FH-11-9142, entitled "Pavement Rehabilitation by Means Other Than Overlays," was awarded to Texas A&M in September of 1976. In many instances thicker overlays cannot be used for pavement strengthening. Rehabilitation methods by means other than overlays must be developed. Several approaches were investigated. These include strengthening of weak layers within the pavement structure as well as other innovative approaches. The objective of the study was to explore the feasibility of various innovative techniques to be used to rehabilitate pavements without having to resort to thick overlays and to develop these techniques to the point where they could be field evaluated. Systems for the rapid repair and patching of all types of pavements were developed along with adequate design procedures as a part of the contract. Particular emphasis was placed on repair and/or replacement of joints in rigid pavements. Results of this study are published as FHWA-RD-78-108 and 109.

5. Contract DOT-FH-11-9175, "Improving Subdrainage and Shoulders of Existing Pavements," was awarded to the University of Illinois in September 1976. This research is concerned with methods for minimizing the infiltration of surface water into the structure of existing pavements and methods to drain water that does infiltrate and become trapped. Impermeable curtains (water stops) will be considered as well as improved joint and crack sealing. Subsealing and injection stabilization are not considered as a part of this study. Insertion of lateral drainage systems are included with longitudinal drainage systems to provide adequate outlets for entrapped water. The research also concerns the shoulder structure as it affects drainage, differential frost heave, and support of encroaching loads. Differences in thermal expansion and contraction and thermal conductivity of pavement and shoulder materials are to be considered relative to their effects on infiltration of surface water. Although the research effort is aimed at rehabilitation of existing pavements, recommendations also applicable to the design of new pavements should be identified. Draft reports have been reviewed and results published.

6. Administrative Contract DOT-FH-11-9393, "Relating Pavement Distress to Serviceability and Performance," was awarded to Austin Research Engineers in January 1978. This study will develop a meaningful relationship between the occurrence of pavement distress to serviceability and performance and to develop a model for these relationships that can be used in a predictive pavement design and management system. The work is involved with the quantification of a most difficult relationship--that of distress to performance and serviceability. It includes an understanding of pavement distress, and identification of the individual and combined effects of the distress on the primary response of the pavement, and the effects of various maintenance and rehabilitation strategies on the distress and performance. Pavement management needs distress and performance information and the relationship between the two in order to be effective. A draft report is being reviewed and will be published.

7. Delon Hampton Associates was awarded contract DOT-FH-11-9518, "Pavement Rehabilitation by Means Other Than Overlay--Second portions of the operational system for highway pavements. The study will include the development of pavement distress identification methods, pavement ratio procedures and the quantification of required pavement maintenance and rehabilitation requirements.

Summary

This foregoing material has briefly covered the history of FHWA research in rigid pavement design, construction and rehabilitation and a brief look at current and future programs. A much more extensive coverage of current and future programs may be obtained by writing the authors at the Office of Research, Structures and Applied Mechanics Division, HRS-14, Federal Highway Administration, 400 7th Street, S.W., Washington, D.C. 20590.