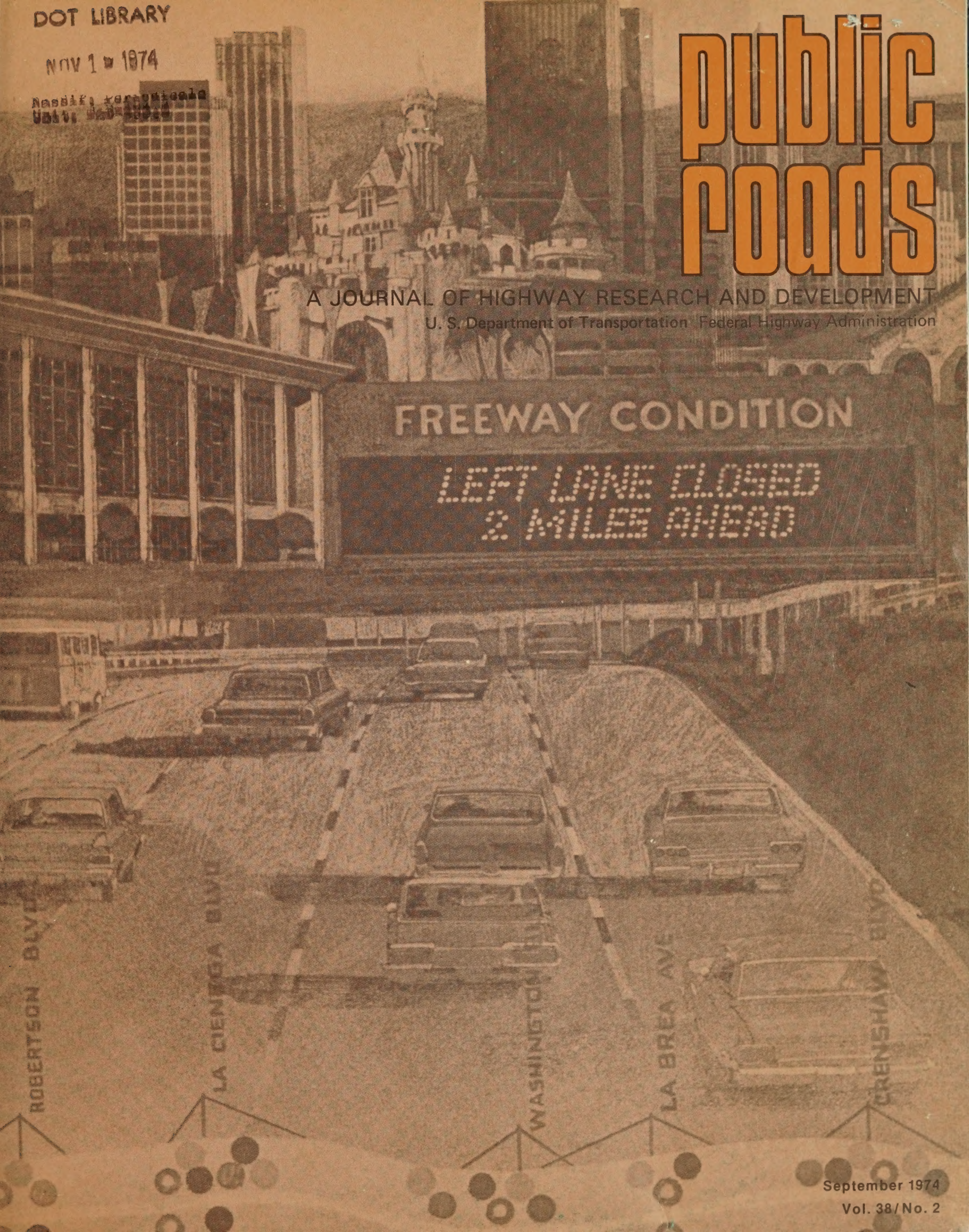
public roads

A JOURNAL OF HIGHWAY RESEARCH AND DEVELOPMENT
U. S. Department of Transportation Federal Highway Administration



September 1974
Vol. 38/No. 2

public roads

A JOURNAL OF HIGHWAY RESEARCH AND DEVELOPMENT

September 1974 Vol. 38/No. 2

COVER:

Artist's concept of Los Angeles and the State of California's Division of Highway's Experimental Traffic Control Program on the Santa Monica-San Diego Freeway. From an advertisement in the Great American Cities Series published by Phelps Dodge Industries, Inc. Artist: Robert A. Heindel. (Published with permission of Phelps Dodge Industries, Inc.)

IN THIS ISSUE

Articles

Departments

U.S. Department of Transportation
Claude S. Brinegar, *Secretary*

Federal Highway Administration
Norbert T. Tiemann, *Administrator*

U.S. Department of Transportation
Federal Highway Administration
Washington, D.C. 20590

Public Roads is published Quarterly by the Offices of Research and Development

Gerald D. Love, *Associate Administrator*

Public Roads, A Journal of Highway Research and Development, is sold by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, at $6.10 per year ($1.55 additional for foreign mailing) or $1.55 per single copy. Subscriptions are available for 1-year periods. Free distribution is limited to public officials actually engaged in planning or constructing highways and to instructors of highway engineering. A limited number of vacancies are available at present.
The Secretary of Transportation has determined that the publication of this periodical is necessary in the transaction of the public business required by law of this Department. Use of funds for printing this periodical has been approved by the Director of the Office of Management and Budget through March 31, 1976.

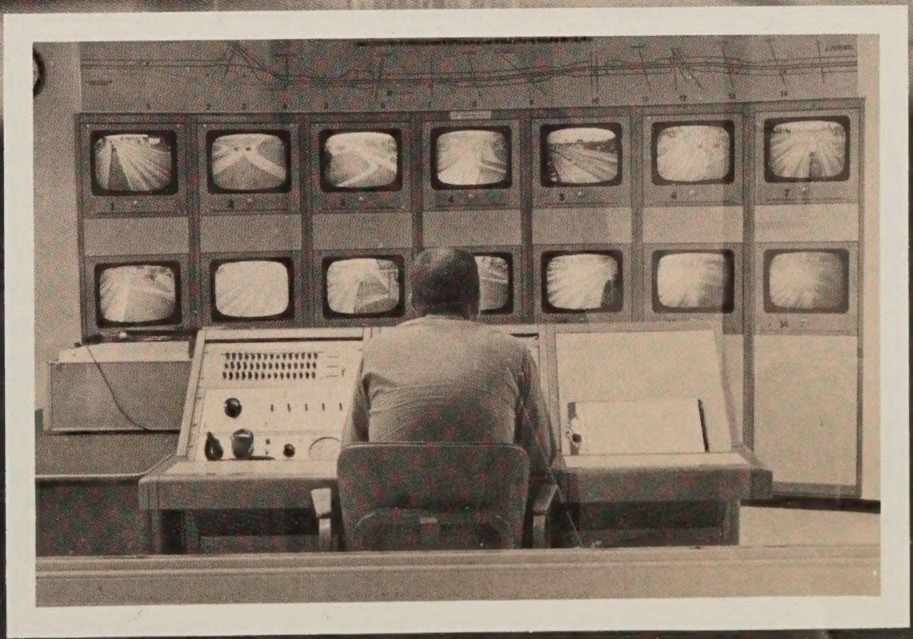
Development of a Traffic Control Systems Handbook

by Charles Pinnell, Dan Rosen, and Roy L. Wilshire

INTRODUCTION

Urban mobility depends to a great extent upon surface arterial street systems. Traditionally, the intersections of these urban streets—and other access points along their routes where heavy volumes of conflicting traffic must be interchanged—have been the most critical elements of the system, and traffic signals were usually provided at these locations. When traffic growth exceeded the capacity of the surface streets, networks of urban freeways were superimposed to (1) accommodate the longer through-trips, (2) provide for moving traffic, and (3) provide land access through interfaces with the arterial street network.

Continued growth in traffic demand in many urban areas has resulted in traffic congestion and a decreased level of service on both types of facilities. As congestion occurs, an obvious objective is to obtain maximum use of the existing facilities and thereby forestall expensive major additions to, or expansion of, the system.



It was in this environment that many agencies, both public and private, began searching for ways to improve and optimize traffic flow on urban streets and freeways. Many ways to achieve improved flow have been defined, including such techniques as one-way operation, reversible-lane operation, extensive on-street-parking prohibitions, proper allocation of signal green time, and minor regulation of influences which create disruptions in traffic flow, such as turning movements, truck loading, pedestrian interference, and restriction of access points. The effectiveness of traffic flow improvements possible through implementation of these basic traffic engineering measures has been demonstrated time and again by various research studies (*1-4*).[1]

[1]Italic numbers in parentheses identify the references on page 48.

TRAFFIC CONTROL SYSTEMS—A DYNAMIC FIELD

As a result of developing technology, new equipment—specifically the digital computer— is now available for the implementation of more sophisticated traffic control concepts. Components of typical systems are shown in figure 1. Such systems have been developed concurrently by many agencies, consequently there are several different control concepts and equipment configurations. Prospective users of these newly developed and developing systems must choose between concepts and techniques of control which are difficult, if not impossible, to compare. Often the prospective user lacks technical knowledge of—or is wary of—the computers and sophisticated communications techniques, which further complicates his choice.

Those familiar with modern computer and communication technology seem to speak a different language with a totally foreign vocabulary. The resulting confusion sometimes leads to an overly cautious approach and may even delay an action program which could prove advantageous.

HISTORY OF SYSTEM DEVELOPMENT

Urban street systems

The development of traffic control signal systems parallels the development and use of the automobile. The development of traffic control signal systems depended to a great extent on the technology used to develop railroad signal systems.

Interconnected signal systems were first used in 1917 in Salt Lake City where six intersections were manually controlled in a single system (*5*). In 1922 in Houston, 12 intersections were controlled as a simultaneous system from a central traffic tower—the first system to use an electric, automatic timer.

Six years later, in 1928, a flexible-progressive fixed-time system was introduced. At about the same time, traffic-actuated local controllers using pressure detectors were initiated. The fixed-time systems were quickly accepted, and widespread installation followed until they were common in almost every city in this country. Their success was probably due to (1) simplicity—almost any electrician could understand them, (2) reliability—rugged components were used, so with minimum maintenance they could be installed and forgotten, and (3) relatively low cost.

It was recognized that these fixed-time systems had limited flexibility. They could respond to traffic changes only as well as their operators could predict them and preset the systems to change on a time-clock basis. Predicting was difficult because of the efforts needed for data collection. Timing changes were avoided because of the effort required to go to each controller and make a change.

As a step toward advancing the state of the art, an analog computer control system was developed and installed first in Denver in 1952. This system attempted to apply some of the concepts of actuated isolated intersection control to signalized networks. Sampling detectors were used to input traffic flow data and the system could adjust its timing on a demand, rather than time-of-day, basis.

In 1960, a pilot study conducted in Toronto used a digital computer[2] [3] to

[2]An IBM 650 computer with about 2,000 words of drum memory—archaic by today's standards.

[3]The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

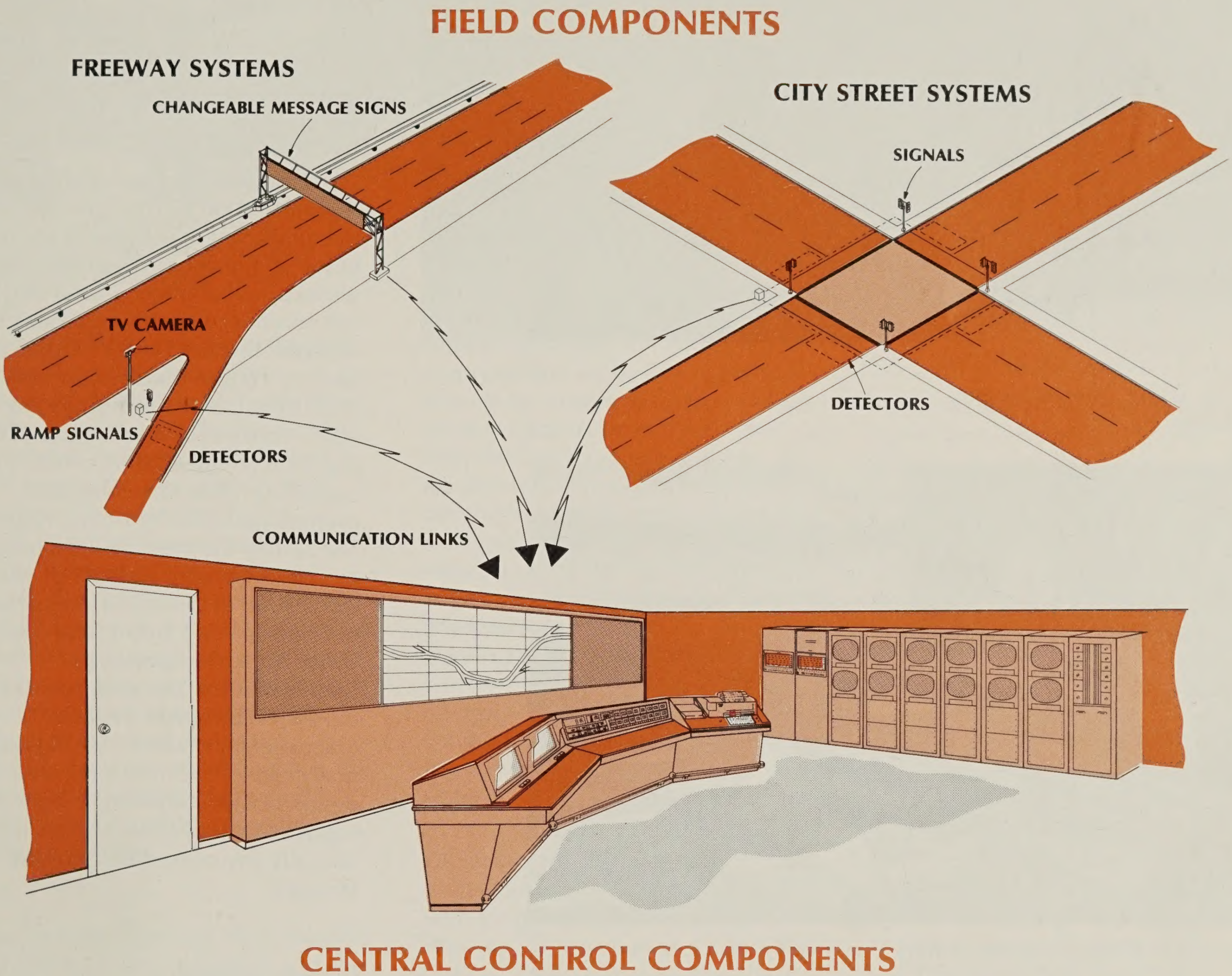


Figure 1.—Computer controlled traffic systems.

perform centralized control functions (6,7). A fortunate byproduct was the amount of surveillance data made available by this form of control. This control system approach was so encouraging that Toronto proceeded with full-scale implementation, placing 20 intersections on-line in 1963, expanding to about 900 intersections under computer control today.

IBM, encouraged by its evaluation of the market potential, began a cooperative effort in 1964 with the city of San Jose, Calif., to further develop a computer traffic control system (*8*). An IBM 1710 computer was used for this work. Control concepts developed and implemented in this project proved to be successful in significantly reducing stops, delays, and accidents.

Beginning in 1965, Wichita Falls, Tex., contracted with IBM for the delivery of an IBM 1800 process control computer to be used for traffic control. City and IBM programers then began a year-long effort to take the basic IBM 1710 programs from San Jose, re-code portions of them for the 1800 computer, refine certain of the control algorithms, and develop an operational traffic control software package. The system was placed in daily operation in October 1966, controlling 56 central business district intersections, later expanded to 78 controlled intersections. It now controls 85 intersections using 103 detectors.

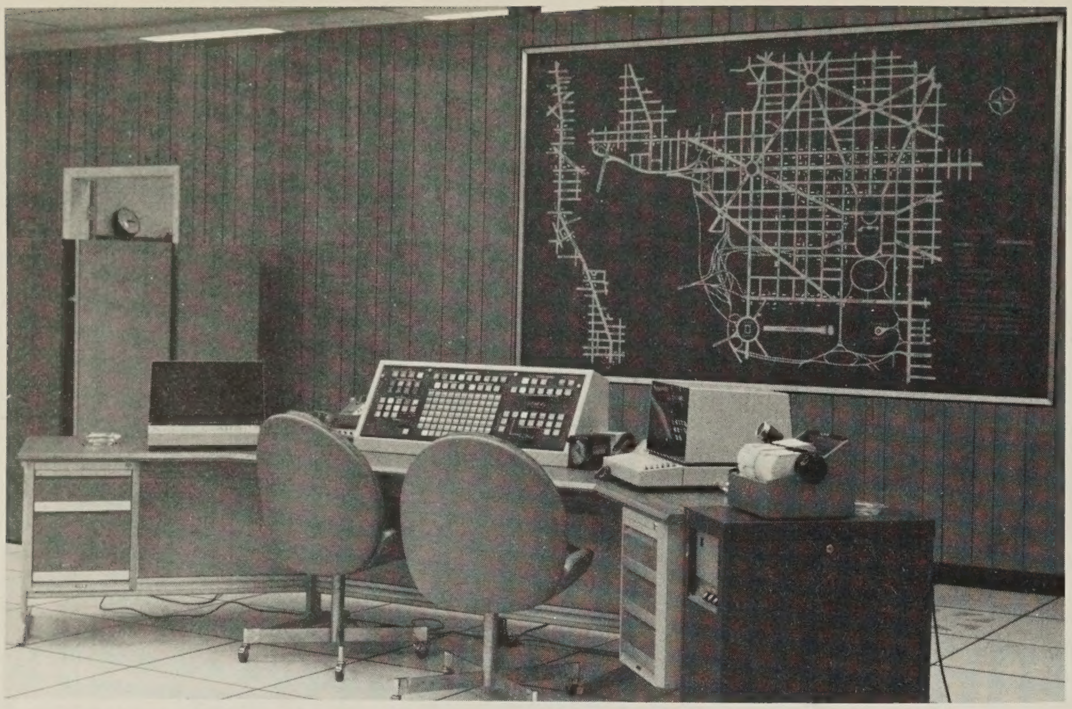


Figure 2.—Control room for the Urban Traffic Control System, Washington, D.C.

Figure 3.—Chicago control center.

Figure 4.—Chicago ramp signals.

San Jose, shortly thereafter, changed to the IBM 1800 computer, leading to the installation of similar systems in Austin, Portland, Fort Wayne, New York City, and Garland, Tex. (now under construction).

The U.S. Department of Transportation, Federal Highway Administration (FHWA) recognized the significant advantage of the state of the art represented by these early systems, and also recognized that their full potential was only beginning to be realized. In 1969, FHWA's Office of Research began the development of the Urban Traffic Control System (UTCS) project in Washington, D.C. (fig. 2) as an operational system to be used in developing, testing, and evaluating traffic control concepts. The system has been planned jointly by FHWA's Traffic Systems Division, the District of Columbia's Department of Highways and Traffic, and the Urban Mass Transportation Administration. The system has been developed by Sperry Systems Management Division (SSMD) and now controls 112 intersections. It is designed with sufficient flexibility and capacity to implement and evaluate virtually any conceivable control strategy.

Freeway systems

In urban street systems, considerable control experience had been developed over the years since signals became widely used. This was not the case for freeways. Freeways were designed as free-flowing limited-access facilities with little advance consideration given to the possibility of needing control systems. Ever-increasing traffic demands and the resultant congestion, however, forced attention on methods to improve freeway flow. Several studies were performed to investigate ways to improve freeway operation, of which the works of Moskowitz (*9*) and Keese, Pinnell, and McCasland (*10*) are representative.

Figure 5.—Map display room at traffic control center of Kanagawa Prefectural Police Department, Japan.

Figure 6.—Map display room at the traffic control center of Metropolitan Expressway Public Corporation, Japan.

The two earliest projects on freeway control were the Eisenhower Expressway project in Chicago (*11*)—figures 3 and 4—and the John Lodge Expressway in Detroit (*12*). In their early stages, the two projects were substantially different. The Eisenhower Expressway project emphasized an automatic control system. On the other hand, the John Lodge Fxpressway project emphasized closed-circuit television surveillance with intervention by human operators during incidents of an emergency nature. A variety of response mechanisms were studied, such as the closing of an entrance ramp or the dispatching of a patrol car to the scene of trouble.

Later, in both these and other projects that followed, an expressway and its entrance and exit ramps were viewed as a tree network. If the objective is to prevent congestion on any section of the freeway, the system must control the input on one or more of the input ramps during periods of peak demand.

One possible approach to freeway ramp control was given by Wattleworth and Berry (*13*). They considered a fixed origin-destination matrix for all points of the network and fixed rates of demand of entry. Under these assumptions, plus the tacit assumption of uniform mixing of the traffic streams at the entry points, maintaining the demand at all points of the network below a critical level is a problem in linear programing.

Another approach to freeway ramp control proposed by Drew (*14*) is to allow a car to enter a freeway only if there is a gap in the entrance lane large enough to accommodate it. A fair amount of work has been done in developing criteria and instrumentation for determining whether or not the observed gaps are large enough. Other approaches are oriented toward balancing the sizes of queues at the entrance ramps. Finally—under the label of *corrider control*—some work is underway to combine the surface streets and the freeway into an integrated control system.

These and other similar freeway surveillance and control systems—such as those on the Gulf Freeway in Houston, shown on page 41, and North Central Expressway in Dallas—have employed one or more of the following elements:

- Closed circuit television visual surveillance systems.
- Ramp metering systems for all or selected ramps.
- Lane control/advisory signing systems (See *Detroit lane control signals,* page 41).
- Traffic sensors located throughout the freeway for extensive surveillance and control use.
- Large map displays of the system under control (figs. 5, 6, and 7).

DEVELOPMENTS UNDERWAY

From a review of the brief history of surveillance and control systems, it is obvious that this is a dynamic field. Technological advances have made tools available at reasonable costs to virtually remove previous limitations of hardware flexibility. As a result, significant efforts are underway to advance the state of the art. Some significant developments underway are briefly discussed in the following paragraphs:

Urban street systems

Urban Traffic Control System (UTCS)—As previously discussed, this installation in Washington, D.C., is operational and has the capability for implementing and testing many potentially constructive control concepts. Priority control concepts for buses are included in this system. Although first generation software is now operational, second and third generation software is being developed to include real-time traffic pattern generation and a form of traffic prediction ability. In all of this work, transferability of concepts, techniques, and even programs is stressed. As a result, first generation software is being coded in FORTRAN to enhance its use by others.

Foreign system development—Development and operating experience with computer traffic control systems in other countries has also progressed rapidly. Some of the

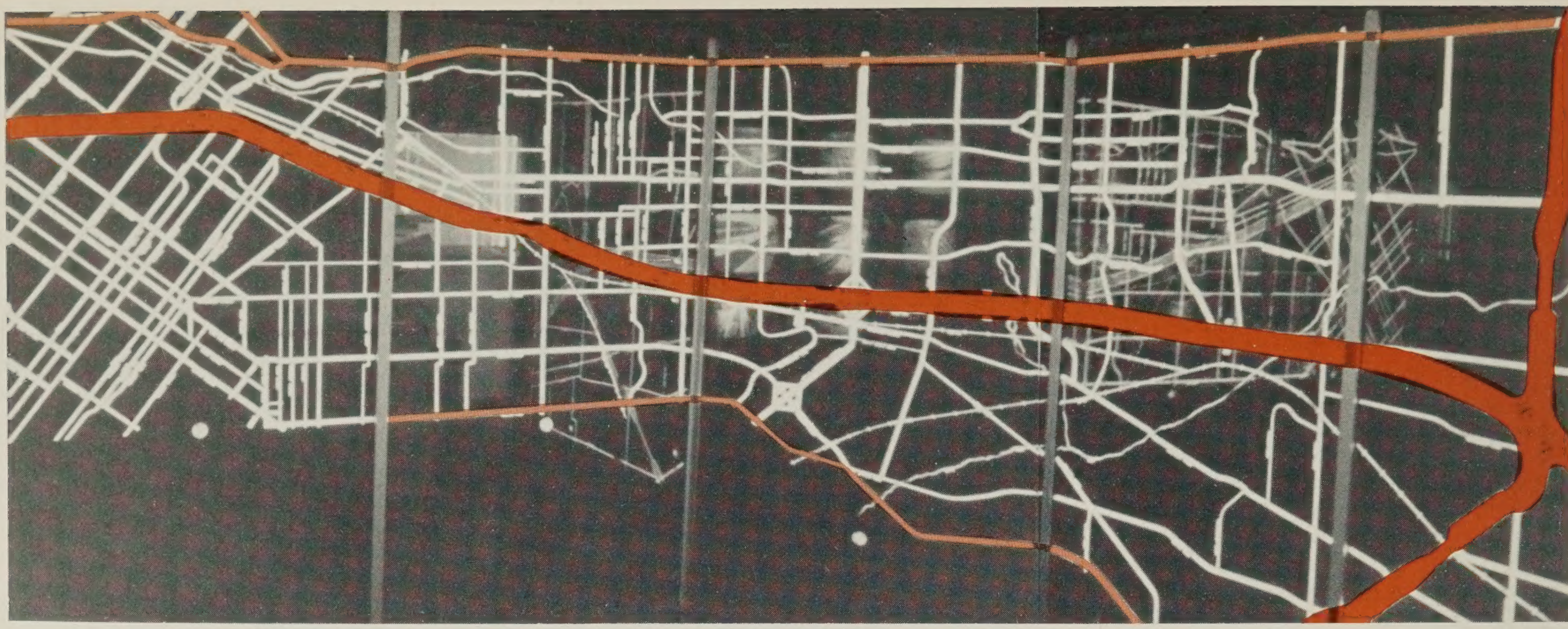


Figure 7.—The Dallas Freeway Corridor display.

more noteworthy advances have been made in the following cities: West London (*15-18*), Central London (*19*), Munich (*20-22*), Hamburg (*23*), Madrid (*24*), Glasglow (*25,26*), Tokyo, Sapporo, and Osaka.

NCHRP 3-18 (**1**)—Stanford Research Institute has conducted a research project entitled "Improved Control Logic for Use with Computer Controlled Traffic." The project developed an advance control concept, strategy, and computer program (*27*). It included development of an operational control program for calculating offset patterns for a network of signalized intersections that has the capability for independent and variable split adjustment. The project was started in mid-1971 and was completed in late 1973. San Jose's IBM 1800 system was used as the development and test site.

NCHRP 3-18 (**2**)—The Polytechnical Institute of Brooklyn is conducting research on a project, "Traffic Control in Oversaturated Street Networks." One of this project's objectives is to describe concepts of advanced traffic control techniques for improving the efficiency of traffic operation in oversaturated networks.

City of Baltimore—The City of Baltimore has been engaged for several years in the planning and design of a comprehensive traffic control system. Design of the system is now complete, a contract for installation of the system has been awarded, and installation of the system is in progress. This project has contributed and will continue to contribute extensively to the technology of computer controlled signal systems, local controller design, and application of advanced solid-state electronic technology to the traffic control field.

A report by Whitson, White, and Messer (*28*) is of immediate interest because it documents experiments with new control concepts for open networks. System operation and *two-way* progression were obtained while using multiphased actuated local control units capable of variable sequence phasing. The results showed remarkable improvements in system efficiency.

Freeway systems

Significant efforts are underway in the development and implementation of freeway surveillance and control systems. Interest in such projects is reflected by actions such as the creation, in May 1970, of a Task Force on Freeway Management by the Texas Highway Department.[4] Examples of specific projects underway include:

[4]Paper presented at HRB Freeway Operations Committee Meeting by Dale D. Marvel in Dallas, January 1972.

- North Central Expressway Corridor, Dallas
- Baltimore I-83
- Detroit City-wide System—65 miles (104.6 km)
- Los Angeles—incident reporting, mobile TV, ramp metering[5]
- Chicago—three freeways, 90 miles (144.8 km)
- Naples, Italy (*29*)

The FHWA published a comprehensive survey of freeway systems in 1973 (*30*), and a report on systems for the city street in 1972 (*31*).

This brief review of the traffic control field provides a background for pinpointing the following basic conclusions:

- There is a wide range of traffic control applications.
- New technology in the area of computer traffic control has developed and is still developing rapidly.
- There is a broad scope of research and development efforts in traffic control, ranging from practical applications to sophisticated and theoretical studies.

[5] The cover of this issue illustrates some of the concepts being employed on the Los Angeles system.

■ A wide range of costs and benefits has been calculated as indicated in tables 1 and 2.

HANDBOOK DEVELOPMENT—RESEARCH IMPLEMENTATION

A brief review of the developments in the traffic control field and an awareness of the need to implement effective traffic control techniques throughout the United States showed the necessity for a thorough study of the state of the art in traffic control and the preparation of a compendium of available technology, concepts, and practices. Such a compendium could foster understanding and widespread acceptance of existing and advanced traffic control techniques, leading to accelerated implementation and utilization of proven advances in traffic control system technology.

In recognition of this basic need in the traffic control field, the Office of Development, FHWA, has initiated a project to develop a *Traffic Control Systems Handbook*. The handbook will document basic principles of traffic surveillance and control system design and provide detailed examples and illustrations of the application of these principles.

The handbook is intended to serve many purposes and is designed for a wide range of users—primarily the practicing traffic engineer. The handbook will also be an important source document for consulting engineers, educators and students, and contractors engaged in supplying traffic surveillance and control systems.

The project to develop a *Traffic Control Systems Handbook* is an example of the increased emphasis on implementation on the part of the FHWA. The FHWA has supported major efforts in research and development related to the field of traffic surveillance and control. These efforts, along with those of other agencies, cities, and individuals, have produced significant technological developments. A major purpose of the handbook, therefore, will be to facilitate wide implementation of new traffic surveillance and control technology, decrease system installation costs, provide some standardization where appropriate, reduce system operating costs, and thoroughly document *first generation* systems as a foundation for encouraging continued advances in the state of the art.

Table 1.—Freeway system costs and benefits (*30*)

Location	Number of ramps	Annual net benefit	Equivalent uniform annual cost	Benefit/cost ratio
		Thousands of dollars	*Thousands of dollars*	
Atlanta	1	24.4	0.5	49.0
Minnesota	2	16.9	1.1	15.0
Los Angeles	6	325.0	[1]7.2	45.0
Detroit	8	675.0	49.6	14.0
Chicago	8	231.3	32.8	7.1
Houston				
Local digital-gap acceptance only	8	190.1	24.8	7.7
Local digital-full control	8	260.4	34.8	7.5
Central digital-full control	8	260.4	40.8	6.4

[1]Annual maintenance and operating costs estimated to be $200 per ramp.

Table 2.—City street system costs and benefits (*31*)

City	Type	Intersections	Control strategies: Time-of-day	System cost	Cost per intersection	Results, percent reduction: Travel time	Results, percent reduction: Delay
				Millions of dollars	*Thousands of dollars*		
New York	Arterial	433	Fixed time	0.7	1.6	20—40	
San Jose	CBD[1] grid and arterial	60	do	0.5	8.4		10—12
London	do	450	Fixed time Off-line optimization	1.3	13.0	9	...
Glasgow	CBD grid	80	do	0.8	10.0	12	
Toronto	do	864	Fixed time Variable split	4.0	4.7		8—37
Charleston, S.C.	CBD grid and arterial	90	Fixed time PR type	0.6	0.7	(2)	(2)
Washington, D.C. (UTCS)	do	111	Pattern recognition	4.5	41.0	(3)	(3)

[1]CBD = Central Business District. [2]Not known. [3]Evaluation not complete.

PROJECT SCHEDULE AND PHASES

The FHWA awarded a contract for handbook development, and an 18-month development period was begun in July 1973. The three major phases of the project are (1) *data collection*, (2) *handbook preparation*, and (3) *implementation*.

The handbook will be designed to cover the two basic system areas—freeways and urban streets. The coverage of freeway surveillance and control systems will range from simple isolated ramp metering to freeway corridor control to an urban freeway network. Coverage of urban street surveillance and control systems will range from signalized control of an isolated intersection to computer control of a large urban street network.

The *data collection* phase of the project will provide for library research, review of published reports, and the identification of sources of material and site locations of pertinent traffic control projects that are now operational or in the final development stage. The data collection effort will also include site visits, contacts with practicing traffic engineers, and the collection, analysis, and summary of all information pertinent to the development of the handbook.

The *handbook preparation* phase will first call for the development of a topic outline and a comprehensive format. Once the topic outline and the comprehensive have been selected, the specific handbook material will be prepared. Extensive draft review and editing are planned to insure the quality of the final product.

The *implementation* phase will provide for the development of a handbook implementation plan. This plan will include such items as training courses, workshops, and training aids. An initial workshop will be conducted as a test program and the results of this activity will be incorporated into the final recommendation on implementation.

A method for periodically updating the handbook will be developed. The finished handbook plus the training aids should provide an excellent package of pertinent technology in the traffic control systems field. This package, along with a program of implementation, should provide for the rapid translation of research and development efforts in traffic control technology into practicable solutions for traffic control problems throughout the United States.

REFERENCES

(*1*) Arthur A. Carter, Jr., "Increasing the Traffic-Carrying Capability of Urban Arterial Streets," (Wisconsin Avenue Study), *U.S. Department of Commerce, Bureau of Public Roads,* May 1962.

(*2*) Walter E. Pontier, Paul W. Miller, and Walter H. Kraft, "Optimizing Flow on Existing Street Networks," NCHRP Report 113, *Highway Research Board,* 1971.

(*3*) James H. Kell and Barnard C. Johnson, "Optimizing Street Operations Through Traffic Regulations and Control," NCHRP Report 110, *Highway Research Board,* 1970.

(*4*) Vergil G. Stover, William G. Adkins, and John C. Goodnight, "Guidelines for Medial and Marginal Access Control on Major Roadways," NCHRP Report 93, *Highway Research Board,* 1970.

(*5*) Gordon M. Sessions, "Traffic Devices—Historical Aspects Thereof," *Institute of Traffic Engineers,* 1971.

(*6*) Neal A. Irwin, "The Toronto Computer-Controlled Traffic Signal System," *Traffic Control Theory and Instrumentation,* Plenum Press, New York, 1965.

(*7*) L. Casciato and S. Cass, "Pilot Study of the Automatic Control of Traffic Signals by a General Purpose Electronic Computer," *HRB* Bulletin 338, 1962.

(*8*) "San Jose Traffic Control Study," Initial Report, *IBM Corporation,* March 1965.

(*9*) K. Moskowitz, "Research on Operating Characteristics of Freeways," Proceedings, *Institute of Traffic Engineers,* 1956.

(*10*) C. J. Keese, Charles Pinnell, and W. R. McCasland, "A Study of Freeway Operations," *HRB* Bulletin 235, 1960.

(*11*) A. D. May, "Experimentation with Manual and Automatic Ramp Control," *HRB* Record 59, 1964.

(*12*) E. F. Gervais, "Optimization of Freeway Traffic by Ramp Control," *HRB* Record 59, 1964.

(*13*) J. A. Wattleworth and D. S. Berry, "Peak-Period Control of a Freeway System—Some Theoretical Investigations," *HRB* Record 89, 1965.

(*14*) Donald R. Drew, "Traffic Flow Theory and Control," *McGraw-Hill,* 1968.

(*15*) "West London Traffic Scheme," *Traffic Engineering and Control,* January 1966.

(*16*) D. A. B. Williams, "Area Traffic Control in West London—Assessment of First Experiment," *Traffic Engineering and Control,* July 1969.

(*17*) R. Ham, "Area Traffic Control in West London—Vehicle Counting Detectors," *Traffic Engineering and Control,* August 1969.

(*18*) R. W. H. Attwood and D. H. Brantigan, "Computer Graphics for Area Traffic Control," British Computer Society, Data Fair 71, *Nottingham University,* Reference 127, March 1971.

(*19*) K. W. Huddart and M. J. H. Chandler, "Area Traffic Control for Central London," *Traffic Engineering and Control,* September 1970.

(*20*) Werner Bolke, "Munich's Traffic Control Centre," *Traffic Engineering and Control,* August 1967.

(*21*) Gerhard Pavel, "Centralized Computer Control of Traffic Signals," *Traffic Engineering and Control,* September 1967.

(*22*) J. A. Ferguson, "Developments in West German Traffic Control," *Traffic Engineering and Control,* August 1966.

(*23*) Dieter Ruhnke, "Collection and Evaluation of Traffic Volume Data for Traffic-Dependent Selection of Signal Plans in Hamburg," *Siemens-Review,* January 1969.

(*24*) Antonio Valdes and Sebastian de la Rico, "Area Traffic Control by Computer in Madrid," *Traffic Engineering and Control,* July 1970.

(*25*) John A. Hillier, "Glasgow's Experiment in Area Traffic Control," *Traffic Engineering and Control,* December 1965.

(*26*) John A. Hillier, "Equipment in the Glasgow Experiment," *Traffic Engineering and Control,* February 1968.

(*27*) "Improved Control Logic for Use With Computer-Controlled Traffic," Interim Report, NCHRP Project 3-18 (1), *Highway Research Board,* July 1972.

(*28*) Robert H. Whitson, Byron White, and Carroll J. Messer, "A Study of System Versus Isolated Control As Developed on the Mockingbird Pilot Project," *City of Dallas Computer Traffic Control System,* February 1973.

(*29*) Roberto Nenzi and Guido Anglisani, "Real-time Computer System Controls the Naples Tollway," *Traffic Engineering and Control,* February/March 1974, p. 470.

(*30*) Paul F. Everall, "Urban Freeway Surveillance and Control—The State of the Art," *Federal Highway Administration,* Revised Edition, June 1973.

(*31*) Charles R. Stockfisch, "Selecting Digital Computer Signal Systems," *Federal Highway Administration,* December 1972.

Gerald D. Love Becomes Associate Administrator for Research and Development of the Federal Highway Administration

Gerald D. Love has been named Associate Administrator for Research and Development by Federal Highway Administrator Norbert T. Tiemann. Mr. Love succeeds G.W. Cleven, who retired in December 1973. Charles F. Scheffey, who had been serving as Acting Associate Administrator in the interim, will continue as Director, Office of Research.

As Associate Administrator, Mr. Love will be the principal advisor to the Federal Highway Administrator on all research and development matters as they relate to FHWA missions, programs, and objectives. He will be responsible for program analysis and control and the administration of policy for the Offices of Research and Development.

Mr. Love's career with the Federal Highway Administration began in 1957. He comes to Washington from an assignment as Regional Administrator for Region 5, Homewood, Ill. Prior to that assignment, he served as Regional Administrator for Region 1, Delmar, N.Y. Various other positions have included service in the New York and New Hampshire Division Offices and a special assignment working on the Khmer American Friendship Highway in Phnom Penh, Cambodia. In 1968, Mr. Love was recognized by the U.S. Department of Transportation with a Sustained Superior Performance Award.

He is a native of Iowa and a graduate of Iowa State University where he received both Bachelor of Science and Master of Science degrees. He holds a certificate from Yale University Bureau of Highway Traffic. Mr. Love also attended Syracuse University and is obtaining his doctorate from Rensselaer Polytechnic Institute. Following his B.S. degree in 1949, he served on active duty with the U.S. Navy Civil Engineer Corps in the Pacific Theater. He is presently a captain in the Navy Civil Engineer Corps Reserve.

Mr. Love is a registered professional engineer in the States of New York and Iowa. He is a Fellow of the American Society of Civil Engineers and a member of the Institute of Traffic Engineers.

He and his wife, Jan, have five children: Laura, 21; Cynthia, 18; Gregory, 16; Linda, 13; and Geoffrey, 9. They reside in Vienna, Va.

Implementation/User Packages "how-to-do-it"

The principal tool for implementing research and development is the implementation/user package which provides "how-do-it" information to the potential user. The package converts research findings into practical tools. The packaging requirement is accomplished between the identification and promotion stages of implementation.

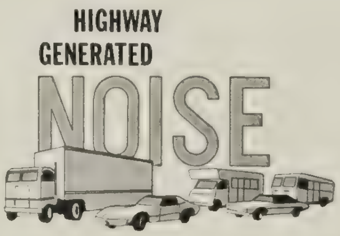
The following items are brief descriptions of selected packages which are actively being developed, or have been recently completed, by State and Federal highway units in cooperation with the Implementation Division, Offices of Research and Development, Federal Highway Administration (FHWA). Completed packages will be available from the Implementation Division unless otherwise indicated. Those placed in the National Technical Information Service (NTIS) will be announced in this department after an NTIS accession number is assigned.

**U.S. Department of Transportation
Federal Highway Administration
Office of Development
Implementation Division, HDV-20
Washington, D.C. 20590**

Packages Completed

Michigan Noise Model by FHWA Implementation Division

The State of Michigan has recently completed updating and expanding the original version of the noise prediction computer program which was based upon NCHRP Report 117. The original program was distributed to all of the State highway departments by the Federal Highway Administration in May 1972. This modified version incorporates the methodology contained in the new NCHRP Report 144. The current implementation effort includes conversion of the program from time-share mode to batch mode, program testing and evaluation, modification of user instructions to reflect the program conversion, and nationwide distribution.



Accident Investigation Sites by Texas Highway Department and Texas Transportation Institute

This report describes the Texas Highway Department's efforts to provide sites to conduct the police accident investigation at a remote location rather than at the accident site. The remote accident investigation site concept eliminates the *gaper-block* phenomenon, which persists as long as the accident, police, and wrecker vehicles are visible to the freeway motorist. Police officers report that the remote accident investigation sites improved traffic operations and eliminated lengthy traffic delays. The investigation site is not moved if a fatality has occurred, if a crime has been committed, or when photographs or measurements are needed.

The report describes applications, costs, and benefits on the Gulf Freeway in Houston and planned additional installations. Distribution has been made to the States and Federal Highway Administration field offices by the Offices of Research and Development, where a small number of additional copies are available on request. Copies are also available for $5.75 for paper copy and $1.45 for microfiche through the National

Vehicles moved to remote accident investigation site—minor city street.

Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22151 by requesting Stock No. PB 223583.

Directional sign indicating route to remote accident investigation site.

The following completed packages, announced in previous issues of *Public Roads,* are available from the Implementation Division.

Open Graded Bituminous Mixtures for Pavements

Concrete Structure Surface Coatings

Encapsulated Subgrades

Culvert Outlet Protection Program

Urban Traffic Control/Bus Priority Systems (UTCS/BPS) Brochure

Packages in Preparation

Inductive Loop Detector Operations Guide
by City of Los Angeles

The Department of Traffic, City of Los Angeles, has developed a systematic procedure for troubleshooting malfunctioning loop detector systems. The procedure is designed to isolate system malfunctions and determine their probable cause as quickly and easily as possible, keeping maintenance time and disruptions to traffic to a minimum. The package, containing a description of the troubleshooting procedure, discussions of loop detector operation and loop system characteristics, and suggestions for standard loop system performance criteria, will provide a practical guide for those involved with loop system operation and maintenance. The Federal Highway Administration will prepare and reproduce the Los Angeles report for widespread distribution.

Breakaway Barricades
by Nevada Department of Highways

Urban Traffic Control/Bus Priority Systems (UTCS/BPS) Hardware Specifications
by FHWA Implementation Division

Aerial Drainage Survey Computer Program
by Wyoming State Highway Department

Water in Pavements
by FHWA Implementation Division

The following are completed packages which were announced in previous issues of *Public Roads* and are now available from the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, Va. 22151.

Title	NTIS Accession Number	Paper Copy Price	Microfiche Price
Texas Crash Cushion Trailer	PB 231818	$3.00	$1.45
Bridge Rating and Analysis Structural System (BRASS)			
Volume I—System Reference Manual	PB 231890	5.50	1.45
Volume II—Example Problems	PB 231891	7.25	1.45

Asphalt *FINGERPRINTING*

by[1] Woodrow J. Halstead
and Edward R. Oglio

Under present conditions of crude oil shortages, the quantity of asphalt available for highway construction is likely to be reduced. The extent of reduction is still somewhat uncertain. Equally uncertain is the extent to which the quality of the available asphalt may be affected. Some States may be faced with the necessity of using materials from unfamiliar crude sources or even with modifying their specifications. For this reason, it appears that we should take a closer look at the usefulness of the system of cataloging and identifying asphalts that was developed under a Federal Highway Administration (FHWA) Research and Development Contract in 1971. Although the system is not completely definitive, nor foolproof, when properly employed it can provide valuable guidelines to those faced with evaluating the effects of specification changes or judging the acceptability of new materials. The final report of the research is published in Report No. FHWA-RD-72-18 and is available from the National Technical Information Service (*1*).[2] This article reviews some of the background and findings of this work as well as the rationale for the system. It is basically an abridgement of an article "Fingerprinting of Highway Asphalts," published by the Association of Asphalt Paving Technologists (AAPT) (*2*).[3]

INTRODUCTION

Studies of asphalt properties and behavior have been pursued for many years and have resulted in the production of a large quantity of information published in various papers and reports. The need for assembling, collating, and making this information available in an efficient manner had been recognized for some time. To satisfy this need, a data bank was set up in 1965. The bank consisted of a marginally punched set of cards containing property data accumulated in comprehensive surveys and studies of practically all asphalts produced in the United States in 1955-1956 and a broad spectrum of the 1963-1964 production. In addition to measured property data, the cards contain information on refinery, source of crude, and the general refining procedure used in processing each asphalt.

After the initial organization of the data bank, a considerable amount of additional data on asphalt fundamental properties and performance-related properties became available. An updating and expansion of the cards added information which reflected the properties of more recent asphalt types resulting from such modern

[1]Based on a paper presented at the 1972 annual meeting of the Association of Asphalt Paving Technologists, February 14-16, Cleveland, Ohio

[2]Italic numbers in parentheses identify the references on page 59

[3]The contribution of Dr Fritz S Rostler and Kay S Rostler who prepared the major part of the text of the AAPT article is gratefully acknowledged

production practices as blending of asphalts from several crudes, and use of combinations of refining methods.

Also, it was apparent that the usefulness of the data would be greatly increased by a rational, systematized procedure for classifying asphalts to permit locating identical asphalts and asphalts of similar behavior characteristics from a specific number of property parameters. It was envisioned that such a system would serve to positively identify an individual, *unknown* asphalt in a manner similar to the identification of an individual through his fingerprints. Such a system would make it possible to predict performance of asphalts independently of crude sources, or methods of refining—as has been necessary in the past. Consequently, a Federal Highway Administration (FHWA) contract to achieve these ends was awarded in 1971 and a full report of the work accomplished is available from the National Technical Information Service (*1*).

CATALOGING SYSTEM

The cataloging system developed contains three similar sets of chemical and physical property parameters designated as (1) *identity* parameters, (2) *fingerprint* parameters, and (3) *behavior* parameters. The sets differ principally with respect to the limits of the numerical values assigned to the parameters.

The *identity* parameters serve to group asphalts that are the same in all respects. The ranges for these parameters are the most restrictive, and essentially represent the variability of the test method used in determining an individual parameter.

The *fingerprint* parameters are intended to identify asphalts that are or were the same, but which may have had sufficiently different histories—overheating, storage-aging, etc.—prior to measurement of the parameters to mask their original identity. For this reason, the *fingerprint* parameters are somewhat less stringent than those used for the identity parameters.

The *behavior* parameters are the least stringent of the three sets and are intended to compare new or *unknown* asphalts with others in the bank with respect to performance-related characteristics. Asphalts placed in the same group by behavior parameters should be sufficiently similar to be interchangeable for highway construction.

The chemical compositional parameters used for the identification systems are the compositional fractions of asphalt as obtained by the acid-precipitation method. Past experience has shown that this procedure is a reliable method for determining asphalt composition. As is well known, compositional data are also available from determinations made with other analytical procedures utilizing liquid chromatography, gas chromatography, selective solvent extractions, etc. Since reliable acid-precipitation compositional data were available on more asphalts than were available from all other analytical methods combined, this procedure was considered the most useful one for the present purposes. This does not preclude the possibility of future work providing a different basis for cataloging asphalts by chemical characteristics.

The data bank and the identification systems developed in the study can be used for cataloging and storing additional information and research results as they become available. Thus, past and current data will be available for monitoring and evaluating research results and as an aid in developing realistic specifications. Also, the system makes it possible, as described in the report, to *predict* the behavior characteristics of new asphalts, within practical limits, on the basis of the system parameters.

Although the identification system has been operative for several years, its potential usefulness is yet to be realized. To date a relatively small number of researchers doing work in the asphalt field are *fingerprinting* the asphalts being used in their research. It appears, however, that present conditions are such that greater use of the system could provide significant benefits.

For example, by *fingerprinting* new sources of materials, States could get valuable predictive indications of its performance. Also, since present performance criteria are based on a somewhat limited spread of compositional differences in asphalts, data on new materials should ultimately provide a broader base for establishing limits in specifications. It may be possible to conclude that present requirements could be either broadened or made more restrictive on the basis of performance rather than on what is available.

DATA BANK

The asphalt data bank consists of individual file cards on asphalts previously studied and described in the literature. The largest group comprises the penetration-graded asphalts of a wide range of consistencies collected in 1954-1955 and extensively studied by the Bureau of Public Roads (BPR) (*3, 4*). Another large group consists of the viscosity-graded asphalts collected in 1964-1965 and studied by both the BPR and the Asphalt Institute (*5, 6*). Many specimens from each group have been included in as many as four or five subsequent studies by various investigators (*7-13*).

The card file has been set up on edge-notched 8- by 10 1/2-inch (203- by 266.7-mm) punched cards on each of which is printed a form designed to accommodate the most widely measured and most useful data on

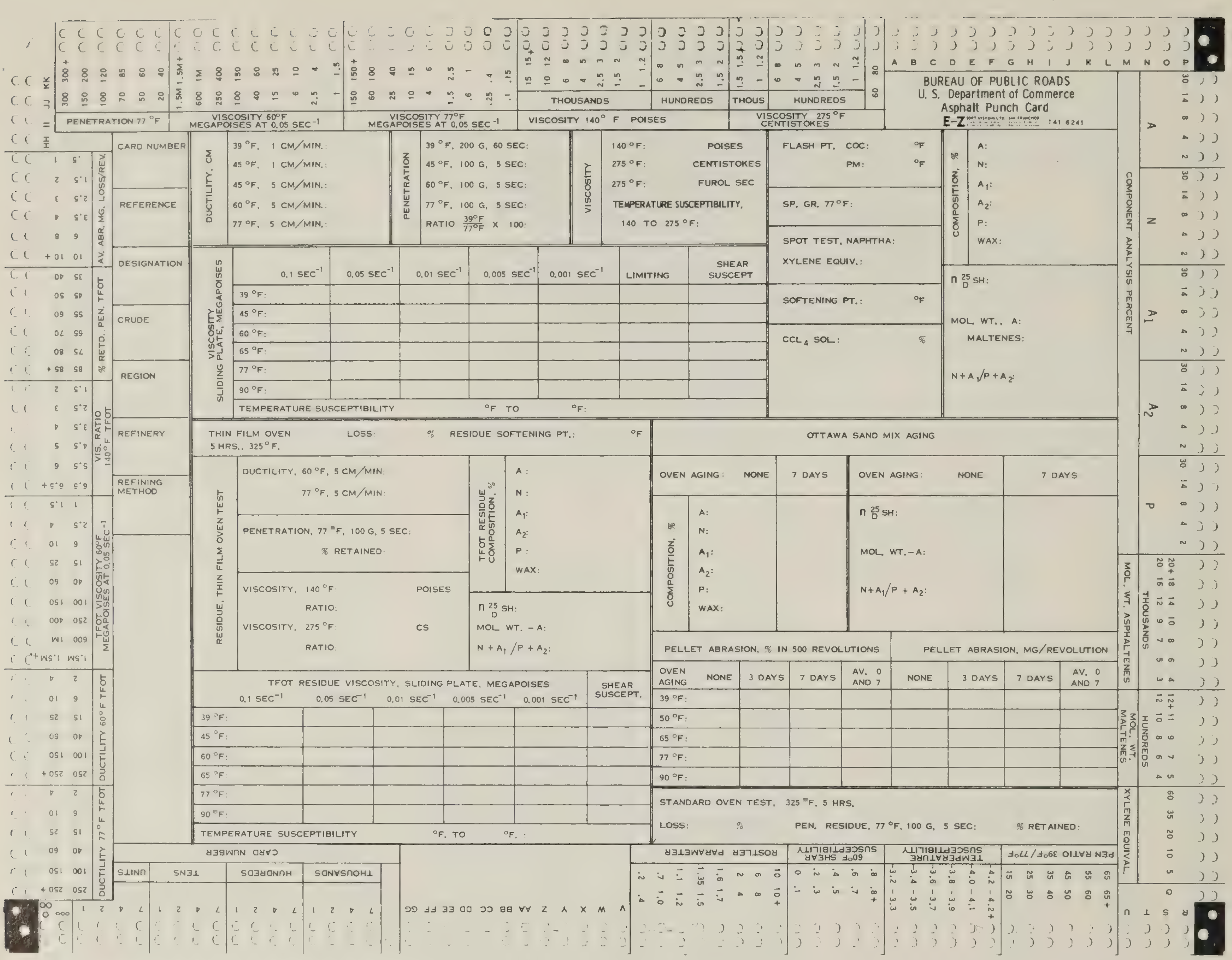


Figure 1.—Marginally-punched card used in data bank.

individual asphalts. A photograph of the card is shown in figure 1. The edge of the card is coded so that marginal notching makes it possible to retrieve cards from the file by the coded parameters identified in the frame around the edge. The file is hand operated, and cards are retrieved from the file according to coded properties and parameters by means of a sorting needle. The sorting technique is illustrated in figure 2. The mechanics of searching the card file are detailed in an instruction manual (*14*).[4]

[4]Data bank cards are available for purchase. Inquiries for details should be addressed to Chief, Materials Division (HRS-20), Office of Research, Federal Highway Administration, Washington, D.C. 20590.

THE THREE SETS OF PARAMETERS

It is well known that many asphalts of entirely different origin and chemical composition can meet the same specification requirements, such as penetration, viscosity, ductility, etc. Such data are therefore not sufficient for establishing identity of individual products. The three sets of parameters were based not only on the results of this study, but also of many preceding studies, and represent fundamental chemical and physical properties of the asphalts. Limits for each parameter are set, which determine whether asphalt specimens compared are identical, were probably once identical, or merely match in behavior. These sets of parameters—*identity, fingerprint,* and *behavior*—are presented in table 1.

Identity parameters

The selected *identity* parameters establish identity of an asphalt to the extent that two specimens having the same numerical values (within the limits of experimental error) for the same parameters are definitely the same in every respect, i.e., they are identical. The ranges for matching asphalts as to identity, therefore, are essentially the limits of repeatability of the tests being used. The corollary from this is that two asphalts of the same identity characteristics will behave alike in every respect, when used in the same manner. However,

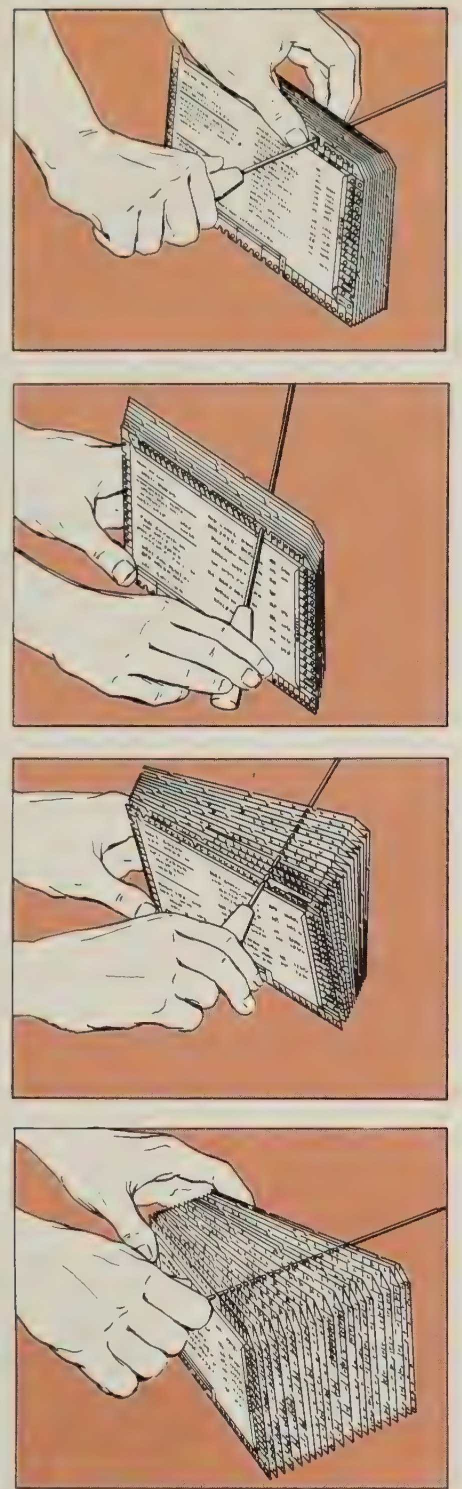


Figure 2.—Data cards and sorting procedures.

Table 1.—The three sets of parameters

Measured characteristics	Range of results for matching[1]		
	Identity	Fingerprints	Behavior
Composition of asphalt			
Asphaltenes(A) . . . . percent . .	2	3	5
Nitrogen bases (N) . . . . do	2	6	. . .
First acidaffins (A_1) . . . . do	2	. . .	. . .
Second acidaffins (A_2) . . . . do	2	. . .	. . .
Paraffins (P) . . . . do	2	2	. . .
Ratio, $(N+A_1)/(P+A_2)$	. . .	0.2	(2)
Ratio, N/P	. . .	. . .	(2)
Wax, 1 percent	. . .	. . .	(2)
Refractive index, fraction P	0.002	0.003	. . .
Logarithm of asphalt viscosity in poises at 140° F (60° C)	0.1	0.3	(2)
Penetration, 77° F (25° C), 100g, 5 sec . . . . percent . .	8	20	(2)
Logarithm of maltenes viscosity:			
At 77° F (25° C) . . . . poises . . .	0.4	0.4	(2)
At 140° F (60° C) . . . . do	0.2	0.2	(2)
At 275° F (135° C) . . . centistokes . .	0.1	0.1	. . .
Molecular weight of asphaltenes . . . . percent . .	25	25	. . .
Weight loss in Thin Film Oven Test . . . . do	0.2	0.2	(3)
Pellet abrasion loss, average of unaged and 7-day aged . . . mg/revolution . .	0.4	(2)	(2)

[1]When the test results agree within the range indicated, the asphalts are considered to *match* for the characteristic.

[2]Five to nine groups sometimes with different ranges and with some overlapping established. See original report (*1*) for details.

[3]Separated into two groups; 1.0 or less and greater than 1.0.

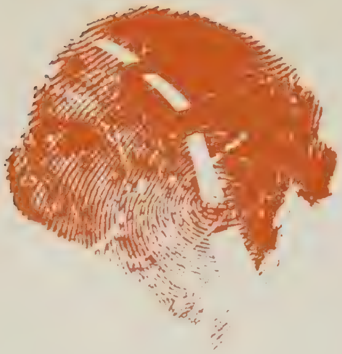
this does not preclude that two asphalts of different identity characteristics can give the same performance in laboratory tests or in service on the road. It is also possible that pavements made with the same asphalt will behave differently because of factors unrelated to the asphalt.

Fingerprint parameters

The term *fingerprints* is used to depict in one word the type of characterization. The fingerprints of an asphalt are the parameters which detect resemblance of specimens closely enough to classify them as originally identical. Fingerprints differ from the identity parameters principally in that some of the limits of the numerical values are less restrictive, to allow for changes which may have occurred in storage, shelf aging, or manipulation of specimens, e.g., heating for the withdrawal of samples for test. The property most affected by shelf aging or other manipulation is consistency as measured by either penetration or viscosity. Under the same conditions, asphalts matching in fingerprints may not behave identically in all respects, but their behavior should be similar.

Behavior parameters

Behavior parameters are concerned only with performance of an asphalt. Asphalts need not be identical, or ever have been identical, to give an equivalent performance in service and in laboratory performance tests. In establishing the behavior parameter only those characteristics are included that have been shown to influence properties of the asphalt related to its performance. For most of the characteristics the full ranges of



expected values were broken into groups that overlapped. Consequently, a given asphalt may be at the high end of one grouping and the low end of another. Thus, in its present state of development, use of this system requires some degree of subjective judgment. Despite these shortcomings, it is this set of parameters that could be of greatest benefit under the present circumstances—where States may be required to use asphalts from new or unfamiliar sources. Generation of the needed test data on new asphalts to compare with asphalts of known performance should be very useful to anyone faced with the necessity of evaluating the risks in using untried materials.

RATIONALE FOR SELECTION

Details of the rationale underlying selection of the specific parameters and limits for each of the characterizing systems are given in the full report and will not be repeated here. However, a discussion of the basic test data employed and the rationale for its selection is summarized briefly.

Chemical composition. The method of expressing composition is the acid precipitation method in which the constituents are grouped as follows:

A—asphaltenes (the portion insoluble in pentane)

N—nitrogen bases (the portion that reacts with 85 percent sulfuric acid)

A_1—first acidaffins (the portion that reacts with 98 percent sulfuric acid)

A_2—second acidaffins (the portion that reacts with fuming sulfuric acid)

P—paraffins (the unreactive portion—saturated hydrocarbons)

In developing the parameters the ratio of the more reactive constituents, $N+A_1$, to the least reactive constituents, $P+A_2$, is considered a key factor relating to the durability of the asphalt. The ratio, N/P, has also been introduced as a factor in the *behavior* system.

Wax content is an additional measure of composition, defining those individual components having crystalline structure. This additional characteristic is particularly useful in defining the nature of the two components A_2 and P.

The refractive index of fraction P identifies the paraffins by the chemical structure and is specific for the three types of paraffinic hydrocarbons, cycloparaffins (naphthenes), isoparaffins (branched), and straight chain hydrocarbons (*15, 16*). The refractive index of the paraffins fraction has been chosen as an accurately reproducible value definitive for an asphalt and its source.

Asphalt viscosity at 140° F (60° C) has been chosen as an identifying characteristic as asphalt behavior is influenced not only by chemical reactivity of the components but also by consistency.

Penetration at 77° F (25° C) has been used as an additional measure of consistency, both because it is descriptive of consistency at this temperature and because grading asphalts by penetration has long been in use, and is thus a characteristic with which all asphalt technologists are familiar. The combination of penetration at 77° F (25° C) and viscosity at 140° F (60° C) provides a good description of asphalt consistency, and the interrelation of the two is an innate characteristic of an asphalt.

Viscosity of the maltenes at the three temperatures—77° F (25° C), 140° F (60° C), and 275° F (135° C)—is a very specific characteristic of this portion of the asphalt. Maltenes viscosity is a useful identifying characteristic largely because of the prevalence of a multitude of asphalts with similar penetrations and asphalt viscosities. The 85 to 100 penetration asphalts included in this study, for instance, differed at 77° F (25° C) less than sevenfold in asphalt viscosity, while their maltenes viscosities varied over four hundredfold from the lowest value of 300 poises to the highest value of 130,000 poises.

Molecular weight is an indigenous property of the asphaltene fraction. Even though not found to exert any great influence on asphalt behavior, molecular weight of the asphaltenes is an identifying numerical value which assists in defining an asphalt.

Weight loss is an important characteristic of a commercial asphalt in the same sense as is the solids content of an emulsion or a cutback asphalt, and determines the proportion of the material which will evaporate during mixture processing and will not remain to serve as binder in the asphalt pavement. The test result, however, is influenced by the gain in weight due to oxidation of the asphalt. Hence, the reported test result may not always equal the actual amount of volatile matter lost.

The *pellet abrasion test* has been used to detect abnormal behavior of an asphalt caused by use of additives. A rubberized asphalt, for instance, often shows much better abrasion resistance than an unmodified asphalt of the same composition, as determined by the fractional analysis. This performance test has therefore been included specifically to detect the presence of an additive which might result in higher abrasion resistance than predicted from the fractional composition.

SPECIAL CONSIDERATIONS FOR FINGERPRINTS

The requirements are different for fingerprinting an asphalt than for establishing identity. The fingerprinting parameters are intended only to establish that specimens analyzed have sufficient features in common to have originally been identical, even though they may have undergone minor changes as a result of shelf aging or other past history.

The property most affected in shelf aging and during heating for liquefying samples is consistency. Limits for permissible differences in penetration and asphalt viscosity are therefore broader than those used in establishing identity.

Minor changes during aging also occur in composition as measured by the fractional analysis. The limits set for fingerprinting take into account these expected changes in composition.

The properties least affected by shelf aging are the refractive index of the paraffins fraction and maltenes viscosity. Limits for these two parameters have therefore been set to be nearly the same as for identity. It was an important finding that, while asphalt consistency can change considerably during storage, maltenes viscosity changes very little. Consequently, maltenes viscosity was chosen as a significant fingerprint parameter. Data are presented in the original report illustrating this fact.

The changes in chemical composition which can occur with shelf aging were also demonstrated. Paraffins (*P*) content remained virtually unchanged. A moderate increase was found in asphaltenes (*A*) and a moderate change occurred in second acidaffins (A_2). Considerably greater changes occurred in the most reactive maltenes fractions, the nitrogen bases (*N*) and the first acidaffins (A_1). Data reflecting these changes in a great number of specimens retained in storage served to establish the limits set up for composition parameters for the fingerprinting system.

SPECIAL CONSIDERATIONS FOR BEHAVIOR PARAMETERS

The behavior parameters were developed by establishing five to nine overlapping groups, sometimes with different ranges, for most of the parameters. The special grouping and details concerning each parameter are given in the full report. Briefly, the major considerations in selecting the behavior parameters are as follows:

Composition parameters

The exact amounts of specific chemical components, although important for identification purposes, are relatively unimportant in determining behavior of asphalts. Most important is the combined effect of the two more reactive components (N, A_1) to the two less reactive components (P, A_2) in the maltenes as expressed by the parameter $(N+A_1)/(P+A_2)$. In a number of previous studies this parameter has been shown to be a decisive factor in embrittlement of asphalts upon aging, as measured by the pellet abrasion test and in field performance (*7, 8, 11, 17, 18-20*). A South African study reported by Jamieson and Hattingh (*20*) is of particular significance, since it verifies the general validity of the parameter for asphalt currently used in that country. These asphalts had not been investigated when the parameter was derived.

The contract study demonstrated that the introduction of the parameter N/P, which is the ratio of the most reactive component of the maltenes to the least reactive one, increases accuracy in predicting asphalt behavior. For most commercial asphalts the two parameters run parallel. If, however, either *N* or *P* is unusually high, behavior will not follow the pattern predicted from the ratio $(N+A)/(P+A_2)$. This second parameter (N/P) has therefore been introduced as an additional behavior parameter based on chemical composition. The significance of this parameter has been examined by an analysis of data on more than two hundred asphalts in the data bank.

The wax in the asphalt was shown in the study to be related to the type of asphalt behavior measured by low temperature ductility tests. However, sufficient data have not yet been obtained to assure that the suggested limit of ± 1 percent is of general validity. Additional data are needed to establish exact limits.

A ± 5 percent limit for the asphaltenes content is used as a behavior parameter and represents a broadening over the fingerprinting parameter taking into account that asphaltenes content, although not itself a critical factor in performance, has an effect on viscosity as a bodying agent. Asphaltenes content is thus by implication a rough indication of maltenes viscosity and is useful for characterizing asphalt when maltenes viscosity data are lacking.

Consistency

Two consistency parameters have been used—viscosity at 140° F (60° C) and penetration at 77° F (25° C). It is well established that products within the same 140° F (60° C) viscosity grade are more similar in flow characteristics during construction than products of the same 77° F (25° C) penetration grade. Accordingly, the characterization of an asphalt as belonging to one (or in some instances two) of nine viscosity groups at 140° F (60° C) is the primary identification of the asphalt by consistency in a manner similar to that used in specifications for viscosity graded asphalts. Grouping of asphalts in nine 77° F (25° C) penetration groups provides a measure of consistency at ambient temperatures to supplement the viscosity at high service temperatures provided by the 140° F (60° C) viscosity. The use of both parameters together provides information regarding the temperature susceptibility of the asphalt. Some overlapping of the groups for both viscosity and penetration now exists because of the uncertainties in the borderline regions.

Maltenes viscosity

Maltenes viscosity at the two temperatures—77° F (25° C) and 140° F (60° C)—has been shown to have a considerable bearing on performance. The value for viscosity at 275° F (135° C) has not been included since there is too little difference in 275° F (135° C) viscosity among various maltenes to justify use as a parameter. Viscosity at 77° F (25° C) and at 140° F (60° C) of the maltenes fraction of an asphalt in a given consistency range is the primary factor regulating the amount of asphaltenes needed in an asphalt as a bodying agent.

Thin Film Oven Test

The weight loss in the Thin Film Oven Test (expressed as *1 percent or less* and *greater than 1 percent*) was a useful characteristic for detecting an asphalt of poorer performance than that predictable from its composition parameters (7). One percent is the limit frequently used in specifications. When loss exceeds this amount, abnormal hardening is likely to occur.

Pellet abrasion

Abrasion test results are included in the behavior characteristics for the same reason given for inclusion of this parameter among the fingerprint and identity parameters. If the performance of an asphalt in the pellet abrasion tests is better than predicted from the maltenes composition parameters, the asphalt should be suspected of containing an additive such as rubber.

VALIDITY OF THE SYSTEM

To determine whether the characterizing system and its respective parameters were operative, a total of 11 asphalt specimens were supplied to the contractor as unknowns for characterization and identification.

Seven of the unknown asphalts were taken from storage containers that had been stocked from 3 to 13 years. Two of these seven unknowns had never been logged into the data bank. Three had been tested and logged into the bank, under their actual code numbers, prior to storage. Two were originally the same asphalts but had been stored in separate containers. The other four unknowns were blends of other asphalts in the data bank.

All data needed to compare the unknowns with themselves and with asphalts in the data bank were measured and are reported in the full report. The report also gives details of the sequential sorting procedures used to identify the unknowns.

In general, the contractor's search (sorting) was carried out by eliminating non-matching asphalts successively by each parameter. None of the asphalts in the data bank matched the unknowns with respect to all parameters in the *identity* series. The changes in composition and consistency were large enough to indicate that they could no longer be considered identical to the original asphalts as judged by the data in the bank.

A comparison of the asphalts by *fingerprint* parameters correctly matched the five unknowns to their counterparts in the data bank—including the two unknowns that were the same asphalt—correctly concluded that unknown 2 was not in the bank; and indicated that unknown 3 (which had never been logged) might be similar to three asphalts already in the bank. However, this similarity was not considered conclusive since some parameter data were lacking on the three data bank asphalts.

The remaining four unknowns (the blends) were *newer* asphalts which had been logged into the data bank and had been in storage for a comparatively short length of time (approximately 1 1/2 years). A run-through of the data bank using the *identity* parameters resulted in a correct identification of each.

The validity of the *behavior* parameters was checked by comparing three pairs of asphalts with respect to behavior parameters and to performance-related laboratory tests such as ductility and penetration at low temperatures, abrasion loss, temperature susceptibility, etc.

As indicated previously, the purpose of the behavior parameters is to identify or group those asphalts that can be expected to perform alike in service, within the limits of normal experience and expectations. Asphalts that match in *identity* parameters will be alike in all respects, but others differing in one or more *identity* characteristics may match in overall behavior. It is shown in the report that the three pairs of asphalts matching in *behavior* parameters also matched in the performance-related laboratory tests. Other data provided in the report show that the pairs were not identical asphalts, since they did not match in chemical composition and other chemical indexes.

SUMMARY AND CONCLUSIONS

The work performed in the study was primarily to create a frame to catalog available information with provisions for incorporating future data and a means for predicting performance of asphalts from numerical values measured on specimens of asphalt cements. Those objectives were accomplished.

A data bank has been set up which constitutes a reference file, making a store of information on known and well defined asphalts easily available to future investigators. The full potential of this file will have to be developed through use and through expansion of the file to include future research results on additional asphalts.

Based on extensive study of the information in the data bank, criteria have been set up in the form of parameters for (1) determining identity of an asphalt, (2) fingerprinting, and (3) predicting behavior.

There are many utilitarian applications besides research purposes for matching or identifying asphalts by the three sets of parameters. A rather prosaic application might be to determine whether two lots of asphalt delivered to a job, and supposed to be the same asphalt, are, in fact, the same. The *identity* parameters will answer this question. *Behavior* parameters could determine whether a second lot of material, even though not the same asphalt, could be expected to give the same performance. The *fingerprints* will tell whether or not the asphalt was once the same, but altered by overheating.

Another application for identifying by the system is in correlating and monitoring research results. If an asphalt or asphalts used in one study can be shown to be identical, or to have once been identical, to asphalts used in another study, results can legitimately be combined and their usefulness enlarged. Conversely, if asphalts in one study are not the same as in another, only limited comparisons can be made. The data bank can also be used by researchers to select asphalts for specific studies.

Finally, it was demonstrated that asphalts matching in the selected behavior characteristics are equivalent for practical purposes as measured by tests related to performance. Under present circumstances if *new* asphalts or asphalts not normally used by a State can be shown to match in behavior parameters with asphalts of proven performance records, such new materials could be used with much greater confidence. Differences in performance might also be explained and predicted from differences in the numerical values of the parameters.

REFERENCES

(*1*) F.S. Rostler and K.S. Rostler, "Fingerprinting of Highway Asphalts—A Method for Cataloging and Identifying Highway Asphalts," Final Report, FHWA-RD-72-18, *U.S. Department of Transportation, Federal Highway Administration*, November 1971, available (Stock No. PB210058) from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22151.

(*2*) F.S. Rostler, K.S. Rostler, W.J. Halstead, and E.R. Oglio, "Fingerprinting of Highway Asphalts," *Asphalt Paving Technology*, vol. 41, 1972.

(*3*) J.Y. Welborn and W.J. Halstead, "Properties of Highway Asphalts—Part I, 85-100 Penetration Grade," Proceedings, *Association of Asphalt Paving Technologists* (*AAPT*), vol. 28, January 1959.

(*4*) J.Y. Welborn, W.J. Halstead, and J.G. Boone, "Properties of Highway Asphalts—Part II, Various Grades," Proceedings, *AAPT*, vol. 29, January 1960.

(*5*) J.Y. Welborn, E.R. Oglio, and J.A. Zenewitz, "Viscosity-Graded Asphalt Cements," *Public Roads*, vol. 34, No. 2, June 1966, pp. 30-42, and Proceedings, *AAPT*, vol. 35, February 1966.

(*6*) V.P. Puzinauskas, "Evaluation of Properties of Asphalt Cements with Emphasis on Consistencies at Low Temperatures," Proceedings, *AAPT*, vol. 36, February 1967.

(*7*) F.S. Rostler and R.M. White, "Composition and Changes in Composition of Highway Asphalts, 85-100 Penetration Grade," Proceedings, *AAPT*, vol. 31, January 1962.

(*8*) W.J. Halstead, F.S. Rostler, and R.M. White, "Properties of Highway Asphalts—Part III, Influence of Chemical Composition," *Public Roads*, vol. 34, No. 2, June 1966, pp. 17-29, and Proceedings, *AAPT*, vol. 35, February 1966.

(*9*) J. Skog, "Setting and Durability Studies on Paving Grade Asphalts," Proceedings, *AAPT*, vol. 36, February 1967.

(*10*) A.W. Sisko and L.C. Brunstrum, "The Rheological Properties of Asphalts in Relation to Durability and Pavement Performance," Proceedings, *AAPT*, vol. 37, February 1968.

(*11*) B.A. Vallerga, R.M. White, and K.S. Rostler, "Changes in Fundamental Properties of Asphalts During Service in Pavements," Final Report, Contract No. FH-11-6147, *Office of Research and Development, U.S. Bureau of Public Roads*, January 1970.

(*12*) R.J. Schmidt and L.E. Santucci, "A Practical Method for Determining the Glass Transition Temperature of Asphalts and Calculation of Their Low Temperature Viscosities," Proceedings, *AAPT*, vol. 35, February 1966.

(*13*) F. Moavenzadeh, "Asphalt Fracture," Proceedings, *AAPT*, vol. 36, February 1967.

(*14*) "Instruction Manual for Use of the Asphalt Punch Card File Revised 1971," Originally prepared by Materials Research and Development, Inc., under contract FH-11-7188, for the *Bureau of Public Roads, Federal Highway Administration, U.S. Department of Transportation*, November 1971.

(*15*) F.S. Rostler and R.M. White, "Determination of Hydrocarbon Type of Petroleum Products," *Rubber Age 70*, March 1952.

(*16*) ASTM Designation D 2006—70, "Standard Method of Test for Characteristic Groups in Rubber Extender and Processing Oils by the Precipitation Method," 1970 Annual Book of ASTM Standards, Part 28, Rubber; Carbon Black; Gaskets, *American Society for Testing and Materials*, Philadelphia, Pa.

(*17*) R.M. White, W.R. Mitten, and J.B. Skog, "Fractional Components of Asphalts—Compatibility and Interchangeability of Fractions Produced from Different Asphalts," Proceedings, *AAPT*, vol. 39, February 1970.

(*18*) F. Zube and J. Skog, "Final Report on the Zaca-Wigmore Asphalt Test Road," and discussion by R.M. White, Proceedings, *AAPT*, vol. 38, February 1969.

(*19*) W.J. Gotolski, S.K. Ciesielski, and L.N. Heagy, "Progress Report on Changing Asphalt Properties of In-Service Pavements in Pennsylvania," and discussion by R.M. White, Proceedings, *AAPT*, vol. 33, February 1964.

(*20*) I.L. Jamieson and M.M. Hattingh, "The Correlation of Chemical and Physical Properties of Bitumens with Their Road Performance," (Paper No. 659), Proceedings, *Australian Road Research Board*, vol. 5, Part 5, Ramsay, Ware Publishing Pty. Ltd., North Melbourne, 1970.

Our Authors

Charles Pinnell is President of Pinnell-Anderson-Wilshire Associates, Inc., Dallas, Tex. He has an extensive background in traffic and transportation research and development and has authored numerous technical articles and reports. Prior to entering the consulting field, Dr. Pinnell held positions with the Texas Highway Department and Texas Transportation Institute and was a senior faculty member of Texas A&M University.

Dan Rosen is a highway engineer in the Implementation Division, Office of Development, Federal Highway Administration. He manages development efforts in the traffic engineering area and is the FHWA contract manager for the Traffic Control Systems Handbook. Prior to joining the Implementation Division, Mr. Rosen was with the Traffic Systems Division, Office of Research. He is a graduate of the FHWA training program.

Roy L. Wilshire is Executive Vice President, Pinnell-Anderson-Wilshire Associates, Inc., Dallas, Tex. For 5 years Mr. Wilshire was Director of Traffic and Planning for the city of Wichita Falls, Tex., where he developed and implemented one of the pioneering efforts in the United States for the control of traffic signals by a digital computer.

Woodrow J. Halstead is Chief of the Materials Division in the Office of Research. He was first employed by the Bureau of Public Roads in 1935 and, with the exception of 2 years in the Navy during World War II, has spent his entire career with the Federal Highway Administration in the field of research on highway materials and the development of test methods. He has been active in national technical groups concerned with asphalt testing and research such as the Association of Asphalt Paving Technologists, Transportation Research Board, and the American Society for Testing and Materials.

Edward R. Oglio, now retired, is one of the country's leading asphalt technologists. He was employed as a highway research engineer by the Federal Highway Administration from 1957 until his retirement in July 1973. Earlier he spent 21 years at the National Bureau of Standards, where he was supervisor of their asphalt testing laboratory at the time of his transfer.

George W. Ring is a highway research engineer in the Structures and Applied Mechanics Division, Office of Research. Since he came to the Federal Highway Administration in 1956, his work has included research in the fields of structural design of pavements, soil mechanics, and the structural design of pipe culverts. He has recently participated in a series of workshops across the country on "Water in Pavements," conducted jointly by the FHWA Offices of Research, Development, Engineering, and Highway Operations.

Richard L. Sharp is the Director of the Bridge Division in FHWA Region 8, Denver, Colo. He was the contract manager for the FHWA administrative R&D contract with the Wyoming Highway Department on the development of the Bridge Rating and Analysis Structural System. Mr. Sharp is currently serving as the contract manager for the BRASS Maintenance Service contract. He has a broad background in the design and construction of highway bridges.

Webster H. Collins, highway engineer in the Implementation Division, Office of Development, is the senior implementation manager in the area of structural engineering. He is involved with translating structural research findings, including traffic barrier systems, into operational use. He is experienced in the area of structural design and has a broad background in the development of highway engineering computer application programs.

Richard W. Smith is a highway research engineer in the Materials Division, Office of Research, Federal Highway Administration. His research background and experience on bituminous and portland cement concrete materials have led him to his present position where he is responsible for the administration of a number of research activities in the skid accident reduction area.

James M. Rice has been a research engineer in the Materials Division, Office of Research, Federal Highway Administration, since 1962. His career in the asphalt paving field spans over 25 years and includes employment with the National Crushed Stone Association and the Natural Rubber Bureau. His current research efforts are directed toward the mechanical properties of asphalt paving mixtures and the skid resistance and wear resistance of pavement surfaces.

Stewart R. Spelman is a highway research engineer in the Materials Division, Office of Research, Federal Highway Administration. He has extensive experience in research on design of bituminous paving mixtures and is responsible for conducting and coordinating research in this area under the Federally Coordinated Program for Research and Development. He is an active member of ASTM, being involved in work related to test methods for bituminous mixtures.

John G. Viner has been the Chief of the Protective Systems Group, Structures and Applied Mechanics Division, Federal Highway Administration, since September 1970. For the past 10 years he has been engaged in research, having been associated with the development of impact attenuators since 1967, and prior to that having conducted structural vibration research for the Naval Ship Research and Development Center.

Charles M. Boyer is a bridge engineer in the Bridge Division, Office of Engineering, Federal Highway Administration, where he has been involved with bridge design since 1958. From 1967 until June 1973 he was a structural research engineer in the Structures and Applied Mechanics Division, Office of Research, where he worked on bridge design details and impact attenuator research.

Seasonal Strength of Pavements

by [1] George W. Ring

To minimize seasonal fluctuations in the support capacity of pavements due to frost action, methods used to date include insulation of the subgrade, use of mechanical or chemical soil modifiers, replacement of frost susceptible soils, and control of water through drainage measures.

The problem is presented and various solutions are discussed, with emphasis on improved drainage. The author suggests using insulated underdrains for removing water in the pavement structure during the period when some of the subgrade remains frozen.

INTRODUCTION

Highway engineers have recognized since Taber's experiments in 1929 (*1*)[2] that increased pavement roughness can be caused by the formation and growth of ice lenses in foundation soils and pavement layers. Subsequent research and field experience have not only validated Taber's explanation of this phenomenon, but have shown that there is a considerable loss of pavement strength when the ice thaws. Many other factors related to cold temperatures contribute to weakening of pavement elements. Some of these factors are:

- Increased moisture content caused by reduced evaporation during the winter.
- Increased moisture content caused by migration of water to the cold zone.
- Decreased density of the soil-water system associated with increased moisture content. (Actual soil density may increase due to dehydration during freezing.)
- Temporary inhomogeneity of clay soils and water caused by the formation of ice lenses in the soil-water system.

Many of the factors causing weakened subgrades also apply to soil-aggregate base courses and subbase courses, especially when they contain even small amounts of material finer than No. 200 sieve (0.074 mm). Other factors important to the strength loss of pavements in freezing environments are:

- Water trapped in the top of a pavement structure when thawing of the ice progresses downward from the pavement surface.
- Reduced intergranular friction in granular base courses resulting from pore pressures generated by daily thermal expansion of air due to solar heating in partially saturated materials (*2*).
- Lessened strain tolerance of chilled asphaltic concrete (AC) surface courses, although not necessarily a strength loss (the AC may actually be stronger), results in lessened ability of the surface to accommodate base course deflections.

During a temporary loss in support, a few heavy loads can greatly shorten the service life of a pavement. About 25 States make allowance for frost in their pavement design or take special steps to reduce the frost susceptibility of subgrade materials (*3*).

---

[1] Presented at the Symposium on Frost Action on Roads held at the Norwegian Road Research Laboratory, Oslo, Norway, October 1-3, 1973.

[2] Italic numbers in parentheses identify the references on page 68.

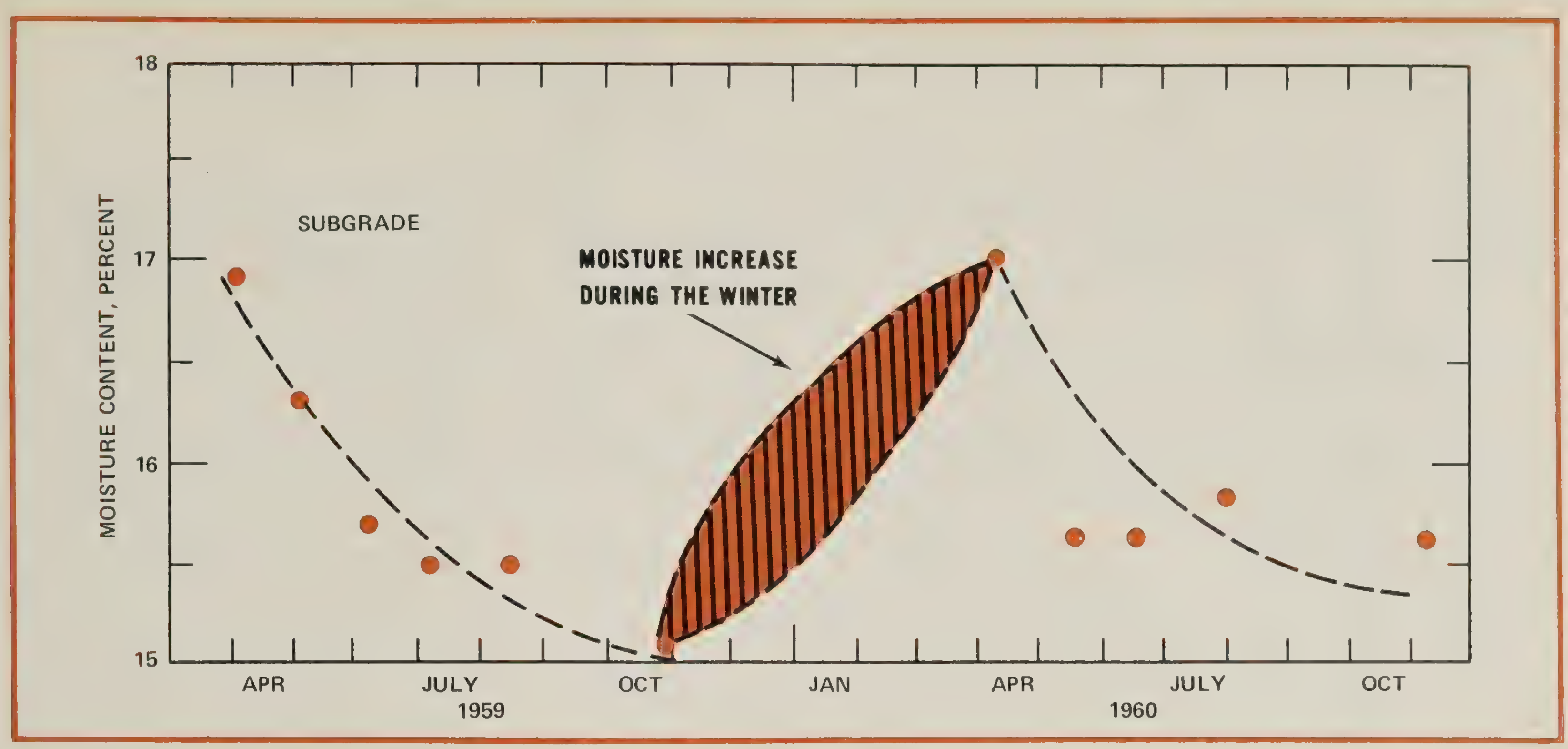


Figure 1.—Seasonal subsurface conditions, loop 1 (4).

INCREASED MOISTURE CONTENT OF THE SUBGRADE

Increases in subgrade moisture during the winter are a primary reason for the increased deflections and reduced load capacity during the spring. Field moisture measurements of silty clay subgrade at the 1958-1960 American Association of State Highway Officials (AASHO) Road Test shows a cyclic seasonal fluctuation of as much as 2 percent moisture content (fig. 1). As shown in figure 2, this 2 percent subgrade moisture variation can result in a reduced strength (CBR) of from 50 to 100 percent.

Subgrade density

Density of the AASHO Road Test embankment soil was about 3 lbs/ft^3 (48.3 kg/m^3) less during the spring thaw period. This reduction in density from the fall value can be attributed partly to the increase in moisture and partly to the expansion of water on freezing. Although the change in density is small, it can account for a decrease in the strength of the subgrade from a CBR of 60 to a CBR of 48 at 10 percent moisture, as shown in figure 2.

Similar reductions in strength caused by changes in density and moisture were also reported for the subbase and base course at the AASHO Road Test (4).

Entrapment of melt water over frozen layers

Melt water trapped in the pavement structure can create a very critical condition. This has been briefly mentioned in the literature, but very little data has been accumulated.

PORE PRESSURE DUE TO THERMAL EFFECTS

Studies made at the Bureau of Public Roads, now Federal Highway Administration (FHWA), Test Track at Hybla Valley, Va., show that expansion of air in the air-water

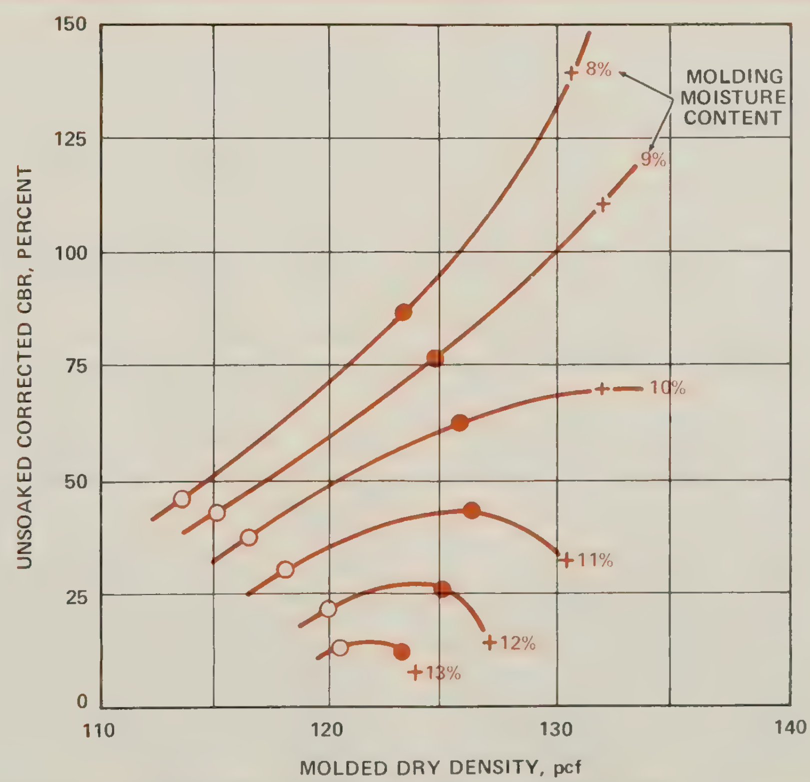


Figure 2.—CBR tests on subgrade soil (5).

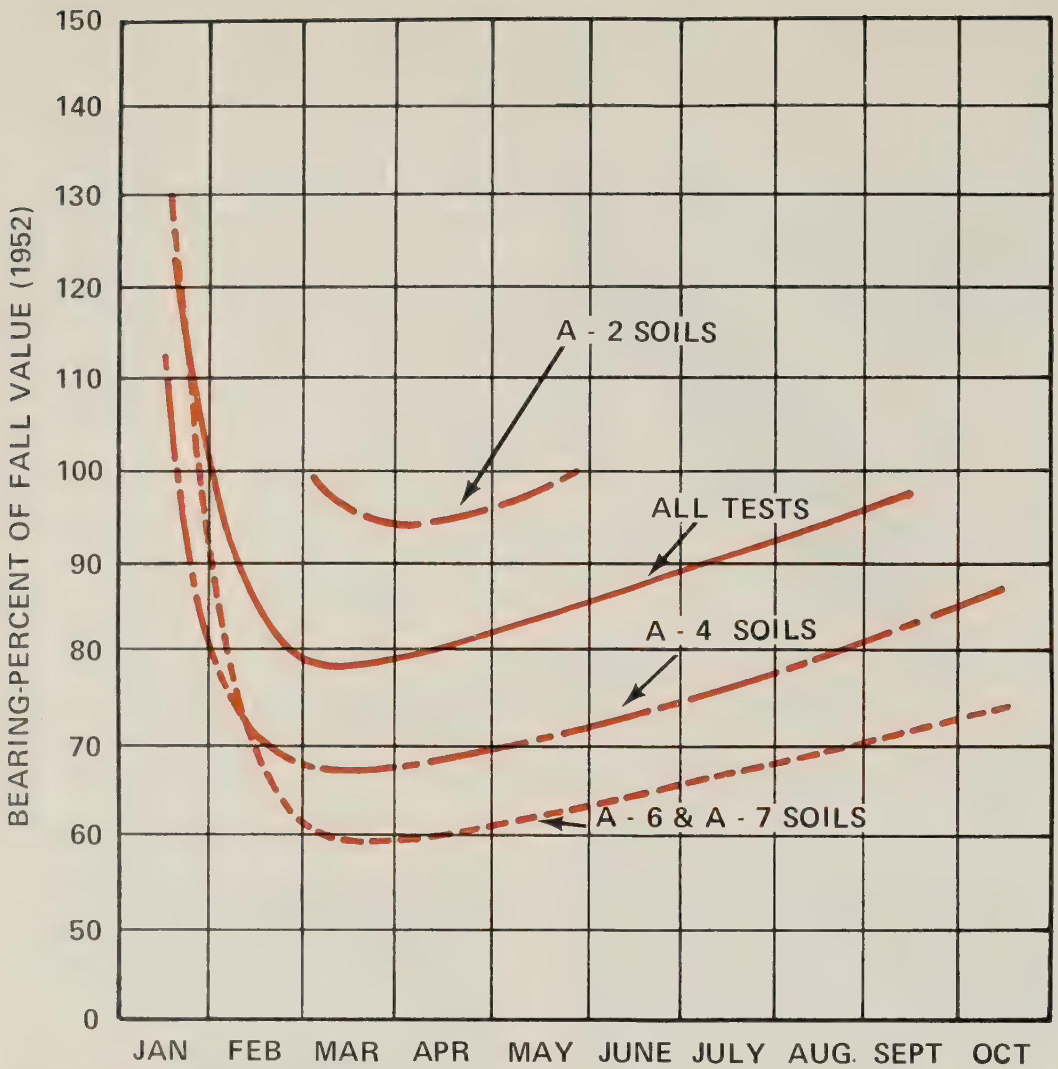


Figure 3.—Seasonal changes in bearing capacity (6).

system of partially saturated pavements undergoing daily warming cycles can generate pore pressures which reduce inter-granular friction of granular base courses (2). As a result, pavement strength may be greatly reduced during the warming cycle until early afternoon. Conversely, there is a strength gain when the pavement cools later in the evening. Although this phenomenon is not directly related to frost action, it can occur during the thaw period when water content in the pavement structure is high.

MEASUREMENT OF SEASONAL STRENGTH OF PAVEMENTS

Detection and measurement of seasonal strength loss in pavements has been accomplished primarily through static or nearly static bearing tests on the subgrade through holes cut in the pavement surface. A few static bearing tests have been conducted on the pavement surface.

Plate bearing (sometimes repeated), CBR, and the North Dakota Cone have been used extensively to measure subgrade strength (or weakness) during the thaw period. In the Northern States, spring subgrade strengths have been measured from 30 to 100 percent of the fall bearing value, with 55 to 80 percent reported most often. Typical plots of seasonal subgrade strength as measured by plate bearing are shown in figure 3.

Fewer studies have been made on the seasonal strength of the entire pavement system. Those which have been conducted have been primarily with plate bearing and the Benkleman Beam testing techniques. Linell (7) reports that the bearing capacity of pavement systems is constantly changing through the seasons of the year. Based on evaluations from both deflection measurements and performance observations, flexible pavements have only one-third of the strength exhibited during the fall season, while rigid pavements often retain two-thirds of their fall strength. Linell attributed the greater strength retention of rigid pavements to their lesser dependency on the subgrade for support.

Small scale laboratory strength tests have been conducted on undisturbed samples of the subgrade and on samples remolded to duplicate the subgrade moisture and density conditions found under weakened pavements. These tests confirm both the large changes in strength which occur as a result of small changes in moisture and density, and those large changes in strength that occur during ice-melting.

Although increased deflection is well documented, few corollary studies of actual pavement performance in terms of roughness and cracking associated with seasonal strength loss have been made. Recent promising developments in dynamic methods for rating pavements, such as the Road Rater and the Dynaflect[3] have had only limited application in the study of seasonal strength of pavements. The most comprehensive study using dynamic methods to evaluate frost effects on the seasonal strength of pavements was conducted in Illinois and Minnesota during the winter of 1968-69. Conclusions from this study indicated that the Dynaflect was better suited for detecting seasonal changes than the Benkleman Beam, plate bearing, and a curvature meter test (8).

It should be anticipated that with dynamic devices much more can be learned in the future about the seasonal and daily changes in the strength of pavement systems. There is very little literature on critical strength condition measurements over 24-hour periods.

[3] The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

Table 1.—Evaluation of additives as frost modifiers[1]

Additive	Required concentration	Cost per pound	Cost per kg	Field use	Evaluation as frost modifier
	Percent	*Dollars*	*Dollars*		
Void pluggers and cement					
in situ polymerization (calcium acrylate)	> 5	>0.50	> 0.23	Difficult to control polymerization.	Poor.
Resins	> 1	0.01—0.15	0.004—0.07	Other than cure requirements, no special problems.	Promising.
Portland cement	> 4	[2]0.01—0.02 [3]0.06—0.12	0.004—0.01 0.03—0.05	No special problems.	Interesting to poor.
Natural fines	> 6	0.00—0.02	0.00—0.01	Probably unusual mixing and processing problems.	Interesting.
Aggregants					
Polymers	> 1	0.12—1.00	0.05—0.45	Moderate mixing and processing problems expected.	Interesting to poor.
Cations	> 0.5	0.02 and up	0.01 and up	No special problems expected.	Very promising.
Dispersants	> 1	0.05—1.00	0.02—0.45	No special problems.	Do.
Waterproofers	> 0.5	0.25—2.00	0.12—0.90	Need for high degree of drying.	Promising.

[1]After Lambe (*11*).
[2]Cement.
[3]Additives.

METHODS FOR MINIMIZING SEASONAL CHANGES IN PAVEMENT STRENGTH DUE TO FROST ACTION

Where existing roads are weakened by spring thaw and reconstruction funds are limited, some States reduce the maximum allowable axle load during the thaw period. Because this restriction is difficult to enforce, many States have strengthened their pavements on major routes so that no restriction is needed. However, strengthening existing pavements results in over-strength pavements for a large part of the year. As a result, a large part of the additional investment is used only during the spring thaw.

It is usually more economical to design and construct pavements initially so that seasonal strength changes are minimized. Methods used to date include:

- Insulation of the subgrade.
- Chemical additives to reduce frost susceptibility.
- Excavation of frost susceptible materials and replacement with non-frost susceptible materials.
- Control of water through drainage.

Insulation of the subgrade

Studies have shown that granular materials are poorer insulators than other soil-aggregate materials (9). In experimental installations designed to insulate frost susceptible subgrades, many States have placed layers of expanded plastic foam between the subgrade and overlying granular layers of subbase. Where drainage is adequate, the plastic foam is effective in limiting frost penetration. For example, during the winter in Ontario, Canada, with a freezing index of 2,600 degree days, 2 inches (50.8 mm) of foamed plastic reduced frost penetration from 5.41 ft (1.65 m) in uninsulated conditions to only 2.5 ft (0.76 m) under the insulated areas (*10*). Use of the foam required special placement techniques and an overlying depth of material for the pressure distribution of construction and design wheel loads. Deflection of the foam-insulated pavement system is anywhere from 0.25 to 0.5 in. (6.4 to 12.7 mm) greater than deflection of an untreated area. Also, the plastic should extend outside the pavement to protect the edges of the pavement from heat loss through the shoulders.

Icing of pavements over insulated subgrades has occasionally been a safety problem. Very recently, manufacturers of some proprietary insulation materials in the United States have requested a waiver of liability from the State highway departments for any claims that might result from the use of their product. Since some accidents have occurred because of icing of the surface under certain moisture and temperature conditions, some of the States have suddenly become very reluctant to incorporate these proprietary materials for insulation purposes.

Chemical additives to reduce frost susceptibility of soils

Extensive laboratory and limited field experience have shown chemical additives to be effective in reducing the frost susceptibility of subgrade soils (*11*). Additives can usually be classified into one of four different types: (1) Void fillers and cements, (2) aggregants, (3) dispersants, and (4) waterproofers, according to their action on the soil. The most promising are resins, cation aggregants, dispersants, and waterproofers, as shown in table 1. Well-graded soils respond best to treatment, making the use of additives attractive for modifying dirty gravels, sandy clays, and silty sands. Uniform silts and plastic clays were the least responsive. As with all soil modifiers, obtaining a uniform mixture of modifier with the soil can present problems, especially when the soil is a wet clay.

Excavation and replacement of frost susceptible materials

Although granular materials are not particularly good insulators, replacement of frost susceptible material with clean, granular backfill is the most popular and usually most successful method for reducing both heaving and loss of strength during the thawing period. The method reduces both overall heave and differential heave, and, if drainage is adequate, results in retention of strength. Replacement is generally to a depth of from 50 to 100 percent of the depth of frost penetration. On high type roads where granular materials are plentiful, replacement is often to 100 percent of frost penetration. The granular material is apparently effective because it reduces the supply of capillary water to the frost zone and permits better drainage of surface water entering the pavement system. In areas of high precipitation, and in areas with either ground-water seepage problems or a high water table, it is therefore important when specifying frost free materials to require a low percentage of material finer than 0.001 in. (0.02 mm), and to require no more than 0.04 in. (1.0 mm) heave per day when the soil is subjected to a laboratory frost susceptibility test proposed by the U.S. Army Corps of Engineers (CREEL) (*12*). According to CREEL, to control frost heave, the amount of material finer than 0.001 in. (0.02 mm) should be no more than 1 1/2 to 3 percent for granular, well-graded sands and silty sands, and no more than 10 percent for uniform sandy soils.

Research on criteria for frost susceptibility is being studied further by the Pennsylvania, Massachusetts, and New Hampshire highway departments under current projects sponsored by the FHWA.

Control of the water supply through drainage measures

Methods to reduce frost action through control of temperature (insulation), modification of frost susceptible soils, and replacement of frost susceptible soils are effective only when adequate drainage is assured to minimize movement of water into the frost zone and to drain melt-water from above the frozen zone. In many problem cases, good drainage alone will result in a high percentage of retained bearing capacity during the spring thaw. The following special drainage measures are effective:

- Drain open-graded layers.
- Drain water trapped in ledge (rock) cuts.
- Provide deep side ditches to help lower the water table.
- Drain seepage layers, especially those which are exposed when the roadway is perpendicular to contours.
- Provide drainage for seepage layers under side hill fills.
- Place underdrains in shaded areas where frost penetration is deeper.
- Drain low points of subbase materials.
- Raise the pavement grade in high water table areas.
- Place underdrains in wet cuts unless the soil is pure silt or clay, in which case, undercut and backfill.

The major problem in designing drainage for pavements in cold areas is keeping the drainage system from being blocked by ice. Pipe outlets placed low in side ditches often remain frozen when melt-water under the pavement needs an outlet. Wherever possible, outlets should be placed in the side of the embankment at least 1 ft (305 mm) above the ditch invert. Gate flaps on pipe outlets may delay ice blockage by keeping cold air out of the pipe.

Differential heaving over shallow drains has been a problem in some States. This is generally attributed to the cold-air chimney effect in the pipe. Placement of small pipes at least 2 ft (610 mm) below the pavement surface reduces the differential heaving.

Because of the sequence of freezing from above and then thawing from above and below, drainage problems are created by the block of ice left between the lower and upper thawed zones. In climatic areas where the frost penetration is deep and ground water seepage is a problem, it is the author's opinion that a two-layer drainage system is needed in the roadway. One layer should be placed below the deepest frost penetration to drain ground water seepage, reducing both free water and capillary water. Another layer should be placed high in the pavement system to drain water from thawing ice in the upper layers of the pavement during warm spring days. This top drainage layer could consist of an asphalt-treated, open-graded drainage layer as part of the pavement structure, as advocated in a report recently prepared for the FHWA under an administrative contract (*13*). A distinctive feature of this system is the high permeability of the open-graded layer—0.12 to 0.28 in./s (0.003 to 0.007 m/s)—and the use, where necessary to prevent intrusion, of a filter layer of sand or fibrous material both above and below the open-graded layer. This graded filter drainage system has been quite successful in draining ground water seepage in warm, high rainfall areas of California. One of the installations has been placed in a colder climate and its performance is under observation.[4] When this type of shallow drainage is placed in very cold areas, particular attention should be paid to parts of the drainage system which might

[4]FHWA HP&R Research Project, California D-2-1, "Open Graded Asphalt Treated Drainage Blanket," *California Department of Transportation*, Sacramento, Calif.

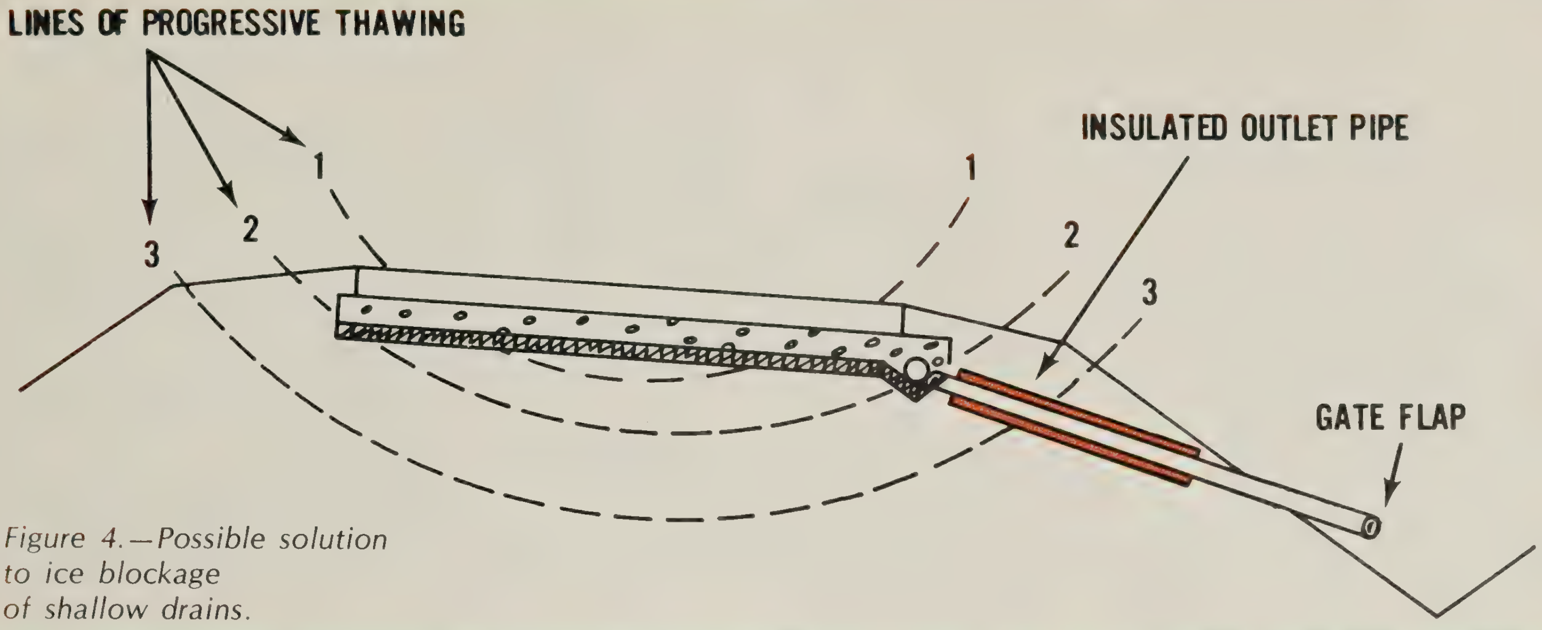


Figure 4.—Possible solution to ice blockage of shallow drains.

remain frozen while that part under the pavement thaws. For example, ice in outlet pipes under the shoulder will probably thaw last because of snow cover on the shoulder or less heat-absorbing surfacing material. This ice could temporarily block the drainage of melted ice water under the pavement. Although it is not covered in the FHWA report "Guidelines for the Design of Subsurface Drainage Systems for Highway Structural Sections" (*13*), it is the author's opinion that the problem of ice blockage in cold sections of the drainage system can be alleviated through the use of pipes made of a high heat conducting material and surrounded by a good insulator (fig. 4) in those areas remaining frozen the longest. This type of construction could provide sufficient heat flow from the warm areas under the pavement to the cold areas under the shoulder and maintain an open drainage system during the critical thaw period. Typical gradations and permeabilities of the open-graded drainage layer and granular filter materials for the layered drainage system are shown in figure 5. This type of pavement drainage will also handle infiltration of rain and melted snow from the surface during warm weather (*13*).

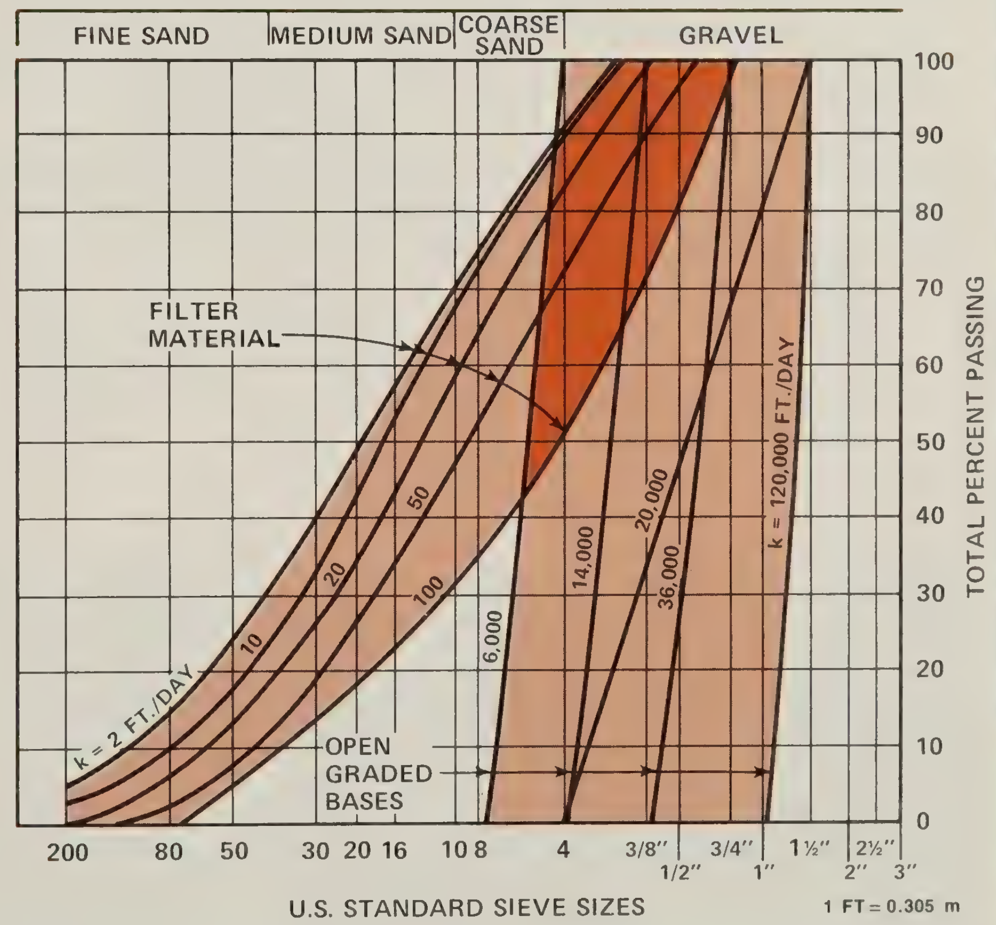


Figure 5.—Typical gradations and permeabilities of open-graded bases and filter materials (13).

SUMMARY

The supporting strength of pavements is constantly fluctuating as a result of environmental influences. In cold climates, the critical strength period occurs during the spring thaw. Pavement structures must be designed to support heavy wheel loads during their weakest period or the change in subgrade and pavement strength must be minimized by either modifying or replacing frost susceptible materials and, above all, by assuring adequate drainage of both the subgrade and the pavement structure.

REFERENCES

(*1*) S. Taber, "Frost Heaving," *Journal of Geology,* vol. 37, 1929, pp. 428-461.

(*2*) E. S. Barber and G. P. Steffens, "Pore Pressures in Base Courses," Proceedings, *Highway Research Board,* 1958.

(*3*) C. J. Van Til, et al., "Evaluation of AASHO Interim Guides for Design of Pavement Structures," NCHRP Report 128, *Highway Research Board,* 1972.

(*4*) "Pavement Research," The AASHO Road Test, Report 5, Special Report 61E, *Highway Research Board,* 1962.

(*5*) J. F. Shook and H. Y. Fang, "Cooperative Materials Testing Program at the AASHO Road Test," Special Report 66, *Highway Research Board,* 1961.

(*6*) "Report of Committee on the Load-Carrying Capacity of Roads as Affected by Frost Action," Bulletin 96, *Highway Research Board,* 1955.

(*7*) K. A. Linell and J. F. Haley, "Investigation of the Effect of Frost Action on Pavement Supporting Capacity," Special Report No. 2, "Frost Action in Soils," *Highway Research Board,* 1952.

(*8*) F. H. Scrivner, R. Peohl, W. M. Moore, and M. B. Phillips, "Detecting Seasonal Changes in Load-Carrying Capabilities," NCHRP Report 76, *Highway Research Board,* 1969.

(*9*) "The WASHO Road Test," Special Report 22, Part 2, "Test Data, Analyses, Findings," *Highway Research Board,* 1955.

(*10*) E. Penner, M. D. Oosterbaan, and R. W. Rodman, "Performance of City Pavement Structures Containing Foamed Plastic Insulation," Record 128, *Highway Research Board,* 1966.

(*11*) T. W. Lambe, "Modification of Frost Heaving Soils with Additives," Bulletin 135, *Highway Research Board,* 1956.

(*12*) K. A. Linell and C. W. Kaplar, "The Factor of Soil and Material Type in Frost Action," Bulletin 225, *Highway Research Board,* 1959.

(*13*) H. A. Cedergren, J. A. Arman, and K. H. O'Brien, "Guidelines for the Design of Subsurface Drainage Systems for Highway Structural Sections," *Federal Highway Administration,* Washington, D.C., 1972, available (by stock No. PB 220116) from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22151.

PRICE INCREASE FOR ***PUBLIC ROADS***

Effective with the March 1974 issue, the annual domestic subscription rate for ***Public Roads*** was increased to $6.10 ($1.55 additional for foreign mailing). The price increase is attributed to an increase in the number of pages and additional color, as well as rising printing, labor, and paper costs and new postal rates for 1974.

The Federal Highway Administration produces the magazine. The Superintendent of Documents, U.S. Government Printing Office, establishes subscription rates and conditions of sale.

Bridge **R**ating and **A**nalysis **S**tructural **S**ystem

by Richard L. Sharp
and Webster H. Collins

The Bridge Rating and Analysis Structural System (BRASS) is a set of 45 computer programs with documentation designed to aid in the long range structure inventory and appraisal of bridges along the Nation's highways. The present 45 programs evolved from a series of bridge design and analysis programs developed by the Wyoming Highway Department during 1967-1972. Structural review and load rating capabilities were added to the bridge design and analysis programs to form the bridge rating system. This additional work was sponsored by the Implementation Division, Office of Development, Federal Highway Administration (FHWA), through one of its administrative contracts.

The BRASS programs are written in the FORTRAN IV computer programing language and were developed on an IBM 360 Model 40 computer.[1] With a minimal data requirement, the system's programs assist in the analysis of the loading and structural characteristics of a highway bridge, furnishing aggregate and detailed estimates of dead load and live load stresses and a rated level of structural service (fig. 1). The programs are easily executed and not constrained by the characteristics of their host computer, are flexible and user oriented, adhere to uniform bridge design standards, and will work for any State highway organization. Complete documentation of the programs, including example problems and program diagnostic aids, is available to the rating system user from the U.S. Department of Transportation, Federal Highway Administration (HNG-30), Washington, D.C. 20590.

[1]The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

Figure 1.—BRASS in use.

Capabilities exist in the system for designing, reviewing, and load rating a wide variety of highway bridges. The system will accommodate the following types of bridges (both simple span and continuous): Timber, welded steel plate, composite welded steel plate, rolled steel beam, composite concrete-steel beam, steel I-beam (both welded and riveted), cast-in-place concrete slab, concrete T-beam, concrete box girders, concrete box culverts, concrete and steel rigid frame structures including slant leg structures, and hybrid girders (figs. 2-5). It will accommodate up to 18 continuous spans. The system will handle vehicles with any selected axle spacings and axle loads. It can handle vehicles with varying numbers of axles—up to a maximum of 24 axles. In addition, the system accommodates the standard AASHTO type loads. For these loads, it automatically handles the variable axle spacing and provides maximum live load moments at critical points.

Between February and April 1973, the Office of Development sponsored training workshops on the bridge rating system. These workshops were conducted jointly by personnel from the Wyoming Highway Department and FHWA's Region 8 and Wyoming Division Offices. These training workshops were designed to assist FHWA and State highway bridge engineering personnel in the use of the programs. Five separate workshops were held across the Nation in which more than 150 bridge engineers were trained in the use of the system.

Immediately after the workshops, 25 State highway agencies requested copies of the BRASS programs. In response to their requests, a magnetic computer tape was sent by Wyoming to each State. This tape contained the FORTRAN IV source code statements for the 45 programs as developed for the IBM 360 computer under the disk operating system (DOS).

Figure 2.—Analysis and rating of cast-in-place and prestressed concrete bridges are in the system's scope.

After receiving the initial tape containing the BRASS programs, many States requested the rating system be converted to run on the IBM 360 computer under the full operating system (OS). Accordingly, the Implementation Division requested FHWA's Computer Services Division to convert the rating system from DOS to OS. This conversion was accomplished from June through September 1973. Following this conversion, some revisions and certain improvements to the system were made during October by the Wyoming Highway Department. These revisions and improvements were forwarded to FHWA's Computer Services Division who made a second conversion of the system from DOS to OS. Wyoming sent a single magnetic tape of this new version of the bridge rating system to the 25 State highway agencies having already requested BRASS. This distribution of the modified system was accomplished by December 1, 1973.

Further testing will be done by the States using the latest version of the system. This additional testing will undoubtedly raise questions concerning either program results or OS problems and these will have to be resolved. Also, since this system is new and complex, it is expected that users will discover problems in the system and will require assistance. Corrective measures and answers to user problems must be developed by one who is thoroughly familiar with the internal features of the system. Accordingly, the Implementation Division is sponsoring a contract to provide a maintenance service whereby users may contact a contractor for help with problems discovered in the system. The Wyoming Highway Department—developer of the system—is serving as the maintenance contractor. At the end of this contract maintenance service, FHWA's Bridge Division, Office of Engineering, will provide any future service which may become necessary.

As mentioned earlier, the bridge rating system may be obtained from FHWA's Bridge Division on request. In response to such requests a BRASS Implementation Package will be sent. This package contains complete documentation and a single magnetic tape, on which are the FORTRAN IV source code statements for the 45 programs. The documentation includes the BRASS Reference Manual which details the coding of bridge structural and loading data for processing and also contains test data which allow the recipient to implement and execute BRASS without extensive collecting or coding of data. These test data provide output examples and serve a tutorial function.

Instructions on how to install the bridge rating system on a local IBM 360 computer will be sent with the implementation package. Any agency receiving BRASS will be kept informed regarding its use, modification, and improvements.

Figure 3.—BRASS may be used to check design calculations and to rate new bridges.

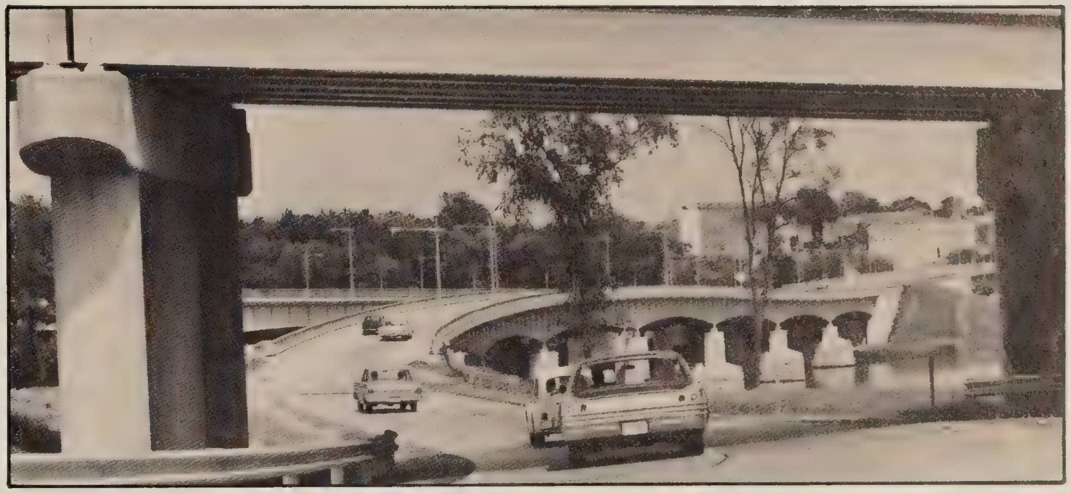


Figure 4.—BRASS analyzes and rates bridges with rolled and fabricated members.

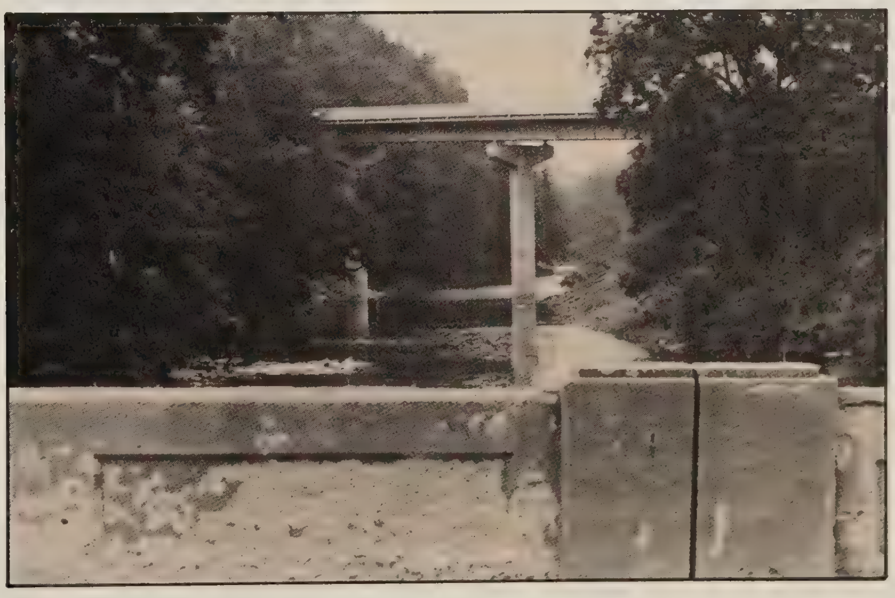


Figure 5.—The system calculates section properties for damaged members.

Design of Open-Graded Asphalt Friction Courses

by[1] Richard W. Smith, James M. Rice, and Stewart R. Spelman

The new design technique described in this article was developed by the Office of Research, Federal Highway Administration (FHWA), and is offered as a logical approach to the design of open-graded asphalt friction overlays. It provides a means to overcome with reasonable assurance some of the past difficulties encountered in design, construction, and field performance. The overall simplicity of the methodology and the low capital investment in required laboratory equipment contributes to its suitability for acceptance on a national level.

The described method has been used successfully on several FHWA Region 15 demonstration projects. It is believed that the method provides technological improvements over other existing methods, and its use is recommended for immediate experimental application. Assistance and instruction in the use of the procedure are available to interested agencies through the FHWA Region 15 Demonstration Project 10.

INTRODUCTION

Most of the highway community is familiar with the type of overlay commonly referred to as an *open-graded plant mix seal coat*. According to most available reports, this type of surfacing evolved from the conventional chip seal surface treatment which is used primarily to seal and maintain aged, but otherwise structurally sound, pavements. It is what its name implies—a chip seal aggregate mixed hot in a plant with a relatively high percentage of asphalt cement and placed to a compacted depth of 5/8 to 3/4 of an inch (16 to 19 mm) by an asphalt paver. The history and extent of plant mix seal usage has been adequately discussed and documented in the literature (*1-8*).[2] Some of the benefits which have been associated with the use of plant mix seals are:

- Improved skid resistance at high speeds during wet weather.
- Minimization of hydroplaning effects during wet weather.
- Improved road smoothness.
- Minimization of splash and spray during wet weather.
- Minimization of wheel path rutting.
- Improved visibility of painted traffic markings.
- Improved night visibility during wet weather (less glare).
- Lower highway noise levels.
- Retardation of ice formation on surface.

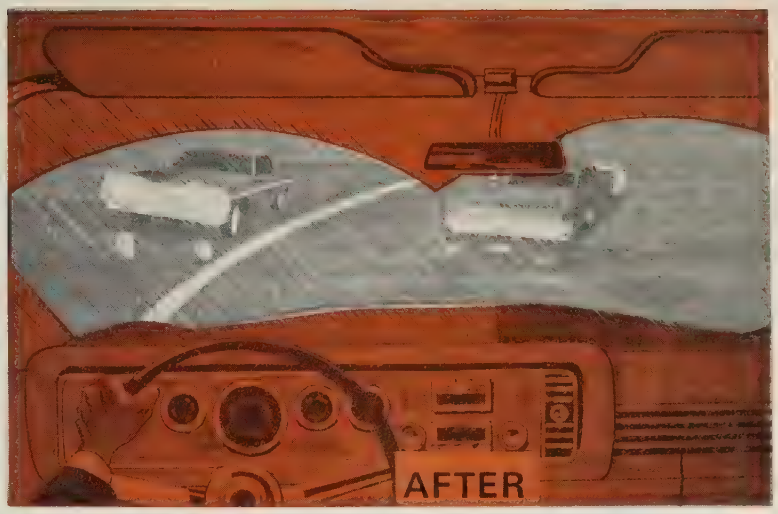
In spite of these benefits, the use of plant mix seals has not been very extensive because of a number of uncertainties and problems involved in their design and construction. The FHWA has recently initiated an all-out effort to overcome the problems which prevent the motoring public from receiving the benefits associated with this type of surfacing material.

THE PROBLEM

The greatest discernible difficulty in this effort was that current design practice was not well defined. In most instances, the only design criteria available were limits on the aggregate gradation and ranges of values for asphalt content which were based primarily on field experience. Existing methods of design seemed to rely either on surface treatment concepts or on the application of routine design methods that are generally only suitable for dense, cohesive type mixtures. The open-graded plant mix seal, however, does not fit into either category.

[1] This article is an abridgment of "Design of Open-Graded Asphalt Friction Courses," by R. W. Smith, J. M. Rice, and S. R. Spelman, which is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22151, PB No. 227479.

[2] Italic numbers in parentheses identify the references on page 77.



OPEN-GRADED ASPHALT FRICTION COURSE CORRECTS POOR NIGHT VISIBILITY DURING RAINY WEATHER

The main design consideration that created problems appeared to be the determination of the percentage of asphalt cement to be used. The amount was usually selected by conducting a series of asphalt drainage tests on trial mixtures at various percentages of asphalt. The basis for this design approach was simply the requirement that a sufficient quantity of asphalt cement be made available for the formation of a seal on the existing road surface, but not so much as to cause excess drainage, segregation, or handling problems during construction. The undesirable aspect of selecting asphalt content in this manner is that the *drainage test temperature* is made the controlling factor rather than, more properly, the inherent properties of the material constituents or of the resulting mixture.

When asphalt content was selected by the use of more advanced equipment, such as the Marshall or Hveem apparatus, it was found that stability and flow were quite insensitive to variations in asphalt percentage. Selecting the asphalt content on the basis of optimizing stability and flow did not provide definitive results.

The selection of asphalt content by either drainage tests or mechanical tests requires considerable engineering judgment. Using either of these methods, it is quite possible for the mixture to contain too little asphalt, which would create a raveling condition, or too much asphalt, which would create a flushing condition.

A DIFFERENT APPROACH

In the course of our analysis of the problem, it became evident that highway engineers have been using open-graded plant mix seals for two distinct purposes: (1) Maintenance of aged and weathered pavement surfaces, and (2) specifically for the improvement of pavement friction. Since the latter purpose is the primary concern of the FHWA, we thought it desirable to advance the open-graded plant mix seal still further, into the *open-graded asphalt friction course*. Referring to the previous discussion, an open-graded asphalt friction course might best be considered a plant mix seal without the excess asphalt cement which forms the seal.

Although this distinction may seem relatively minor, it does greatly reduce the difficulty that is encountered in mixture design and pavement construction. Using this concept, a more definite design procedure can be established without sacrificing any of the benefits. It is still important, however, to provide a watertight seal at the interface with the existing pavement system to prevent water infiltration. It is recommended that the existing surface be treated separately from the new surfacing material with a tack coat. If the existing surface is porous and dry, a prime coat should be applied. If it is flushed, the excess asphalt should be removed.

The design procedure, then, is based on the concept that the open-graded asphalt friction course consists predominantly of a narrowly-graded coarse aggregate fraction—defined here as the material that is retained on a No. 8 (2.36 mm) sieve—with a sufficiently high interstitial void capacity to provide for a relatively high asphalt content, a high air void content, and a small fraction of fine aggregate—defined as that material passing a No. 8 (2.36 mm) sieve. The coarse aggregate fraction provides the structure of the composite mixture while the fine aggregate fraction acts primarily as a filler within the interstitial voids and as a stabilizer for the coarse aggregate fraction.

Material requirements

The highway community is now cognizant that pavement skid resistance is not only a function of the larger scale texture or macrotexture, but also of the small scale texture or microtexture which can barely be felt by touch. In a typically dense-graded asphalt mixture, the pavement macrotexture is provided by the coarse aggregate, while the microtexture can be provided by both the coarse and fine aggregates. In the open-graded asphalt friction course, however, the coarse aggregate fraction must provide the necessary microtexture without assistance from the fine aggregate. For this reason, it is very important that this be considered when selecting the coarse aggregate. A number of aggregates derive their excellent microtexture properties through the process of attrition, but in some cases this can be excessive in terms of abrasion loss requirements. A compromise might, therefore, be required between friction and abrasion properties.

It is recommended that relatively pure carbonate aggregates or any aggregates known to polish be excluded from the coarse aggregate fraction—material retained on No. 8 (2.36 mm) sieve. In addition, the coarse aggregate fraction should have at least 75 percent by weight of particles with at least two fractured faces and 90 percent with one or more fractured faces. The abrasion loss (AASHTO T 96) should not exceed 40 percent.

The attainment of the required drainage and macrotexture properties (see fig. 1) is more or less implicit with adherence to the following recommended limits on the aggregate gradation which have been borrowed largely from field experience (9):

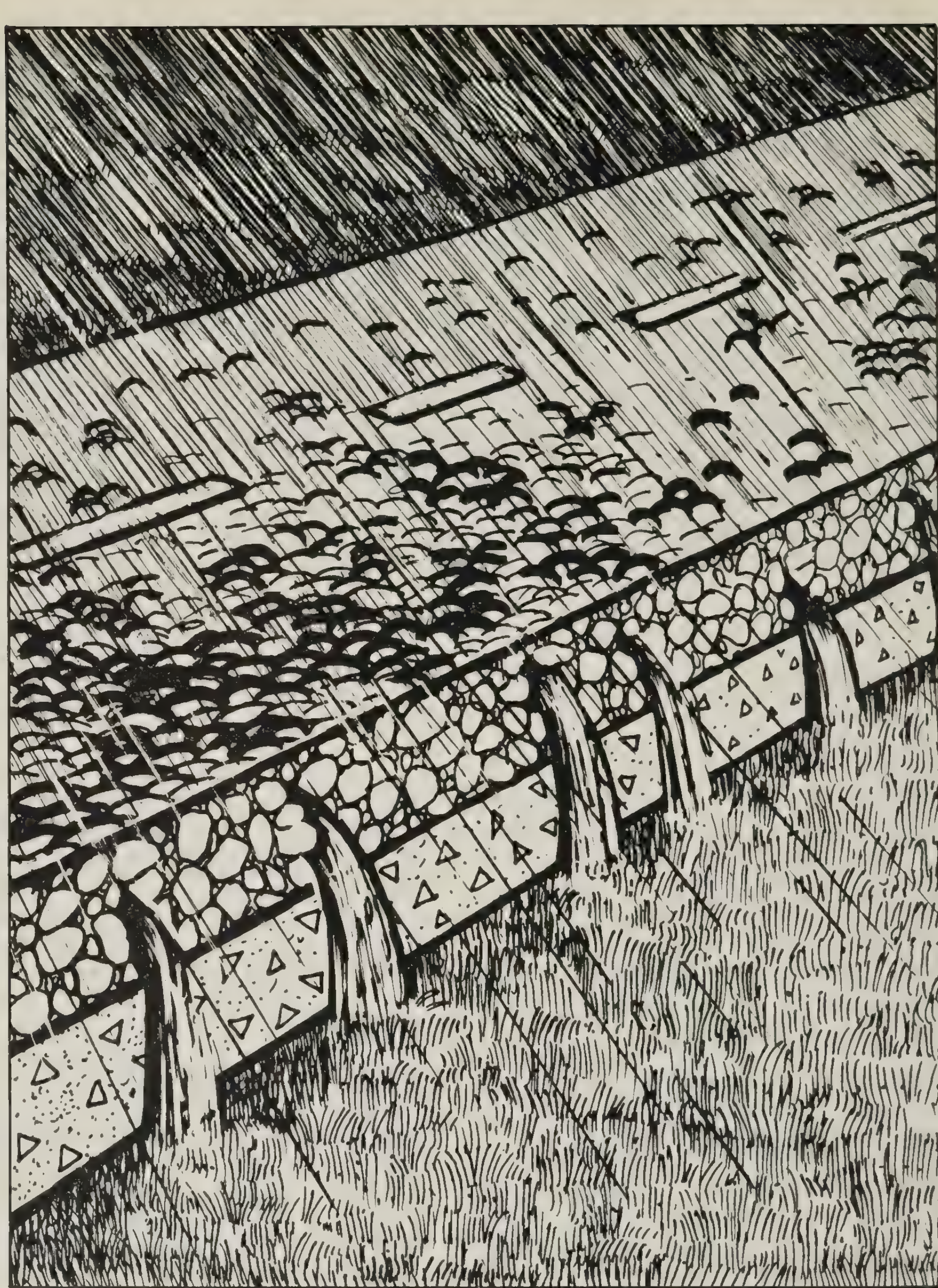


Figure 1.—Functional concept of open-graded asphalt friction course.

U.S. sieve size	Percent passing
3/8 inch (9.5 mm)	100
No. 4 (4.75 mm)	30—50
No. 8 (2.36 mm)	5—15
No. 200 (75 μm)	2—5

Limits which are given for the No. 8 (2.36 mm) sieve are intended primarily as a guide. The overriding consideration which actually dictates the maximum limit is that all material finer than this limit must fit within the interstitial voids of the composite forming material—that retained on No. 8 (2.36 mm) sieve. The uniformity of the aggregate grading between the No. 8 (2.36 mm) sieve and the No. 200 (75 μm) sieve is an important factor affecting the quantity that can be used, as are the shape characteristics (roundness and sphericity) of the coarse aggregate fraction. The importance of including at least some fine-sized aggregate cannot be overemphasized, as its primary purpose is to provide a *chocking action* for the stabilization of the coarse aggregate fraction. Consequently, minimum requirements have been provided. Limits which are given for mineral dust—passing No. 200 (75 μm) sieve—help to assure some degree of uniform grading of the fine aggregate, as well as to control the asphalt drainage characteristics of the mixture by effectively increasing the viscosity of the asphalt cement.

The suggested grade of asphalt cement to be used is AC-10 or AR-40 of AASHTO M226-73I. These grades should be considered a tentative starting point because test results obtained from the design process may indicate an advantage or a necessity to alter the asphalt grade.

Asphalt content

The method of selecting the asphalt content consists of two steps. The first is to conduct a measurement of the surface capacity (K_c) of the predominant aggregate size fraction—

material retained on No. 4 (4.75 mm) sieve. Surface capacity includes absorption, superficial area, and surface roughness—all of which affect asphalt cement requirements (*10*).

The second step is to compute the required asphalt content from an established simple linear relationship obtained from field experience on similar mixtures (*5*):

$$\text{Percent asphalt} = {}^{3}2.0(Kc) + 4.0$$

Asphalt content so determined is based on weight of total aggregate. A basic difference between this design procedure and its predecessors is that this value for asphalt content is to be considered final in that no further adjustments are to be made based on asphalt drainage characteristics, stability, or any other criteria. However, after the subject report had been distributed, a refinement for asphalt content was found necessary for mixtures containing certain types of aggregates such as expanded clays and shales. Although the original formula undoubtedly accounted for small variations in aggregate specific gravity because it was based on field experience, it cannot be used for mixtures in which the apparent specific gravity of the aggregate is markedly different from 2.65. Therefore, it is suggested that a corrected asphalt content be calculated by the formula:

Corrected percent asphalt

$$= \frac{\text{percent asphalt} \times 2.65}{\text{apparent specific gravity of aggregate}}$$

The corrections will be relatively insignificant for most aggregates other than the lightweight expanded clays or shales.

[3] Other equations which have been used are: FOA = 1.5 (Kc) + 3.5 and FOA = 1.5 (Kc) + 4.0 by California and Colorado, respectively.

Void capacity of coarse aggregate

A portion of the procedure covers the measurement of the interstitial void capacity of the coarse aggregate fraction—material retained on No. 8 (2.36 mm) sieve—of the proposed gradation. This information is obtained by conducting a vibratory unit weight determination (*11*). The desirable feature of this test is the high degree of densification achieved without causing a significant amount of aggregate degradation. This test provides an indication of the minimum level of interstitial voids that will exist in the coarse aggregate fraction of the friction course after long-term densification under high traffic volumes—assuming no aggregate degradation. In essence, the compactive characteristics of the coarse aggregate fraction are determined not only by the gradation, but also by particle sphericity and roundness. The essential components of this test are illustrated in figure 2. The main element shown is an electromagnetic vibratory rammer with a frequency of 3,600 Hertz and a mass of 25 pounds (11.34 kg).

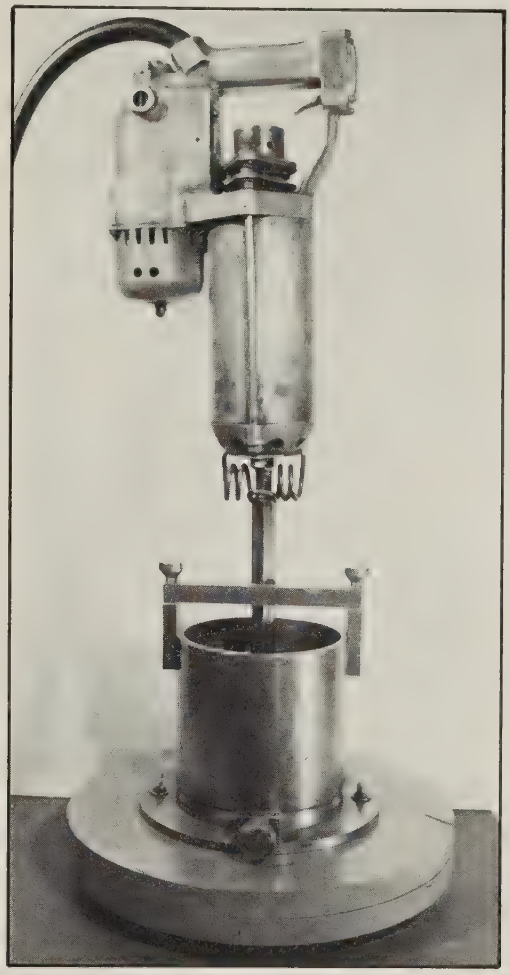


Figure 2.—FHWA vibratory compaction apparatus (11).

Optimum content of fine aggregate

The optimum content of the fine aggregate fraction is that amount which can fit within the interstitial voids of the coarse aggregate fraction, while at the same time allowing a sufficient portion of the interstitial voids for the asphalt cement and for a minimum quantity of air voids. The maximum quantity of fine aggregate is limited not only by absolute volume requirements, but also by the particle-size distribution of the fine aggregate (i.e., the fine aggregate has its own interstitial void system). An implied requirement of the design method is that the interstitial void system of the coarse aggregate fraction will not be made greater by the addition of the fine aggregate fraction. This insures an internal void system with large-sized voids for water drainage purposes. The assumption is made that the above requirement will be satisfied provided that the fine aggregate fraction is limited to a maximum of 15 percent by volume of the total aggregate (or by weight if the coarse and fine aggregate fractions are of the same specific gravity).

A minimum air void content of 15 percent is recommended for design purposes to insure adequate subsurface water drainage. It is this condition which gives the mixture its desirable features. Information supporting the criterion of 15 percent is scarce; however, it has been shown that for approximately the recommended aggregate grading (Marshall samples compacted at 50 blows per side yielded air void contents of 15.6 percent) the resulting water infiltration capacity of the mixture when compacted to a pavement thickness of 1 in. (25.4 mm) proved to be sufficient (*12*).

The fine aggregate content may be expressed in general terms by the following relationship on a percentage by volume basis:

Fine aggregate passing No. 8 (2.36 mm) sieve

= Void capacity (VMA) retained No. 8 (2.36 mm) sieve

— Design asphalt content

— Design void content

+ Asphalt absorption by aggregate

The above expression has been translated into a quantitative mathematical equation and included as part of the design procedure. As an alternate to using the equation, a simplified nomograph (fig. 3) is also provided which is applicable for a wide range of materials. Neither the equation nor the nomograph includes a correction for asphalt absorption since it is assumed to be negligible in most cases.

Optimum mixing temperature

The optimum mixing temperature is based on the concept that the aggregate should be heated hot enough to be reasonably dry to facilitate coating and adhesion, yet not be so hot as to reduce the viscosity of the asphalt binder to a level which facilitates drainage and segregation of the asphalt from the aggregate during transit from the mixing plant to the job site. The recommended target mixing temperature is in the range that will corrrespond to asphalt cement viscosities of 700 to 900 centistokes. A simple test is provided in the procedure to investigate the drainage characteristics of the design mixture. This consists of maintaining a sample of the mixture in a glass container at the mixing temperature for a prescribed period, and then observing for drainage. The purpose of this test is not to determine asphalt content as has been done in the past, but rather to determine the mixing temperature at which the recommended quantity of asphalt may be used. If asphalt drainage occurs at a mixing temperature which is too low to provide for adequate drying of the aggregate, an asphalt of a higher grade should be used (AC-20 or AR-80).

Resistance to effects of water

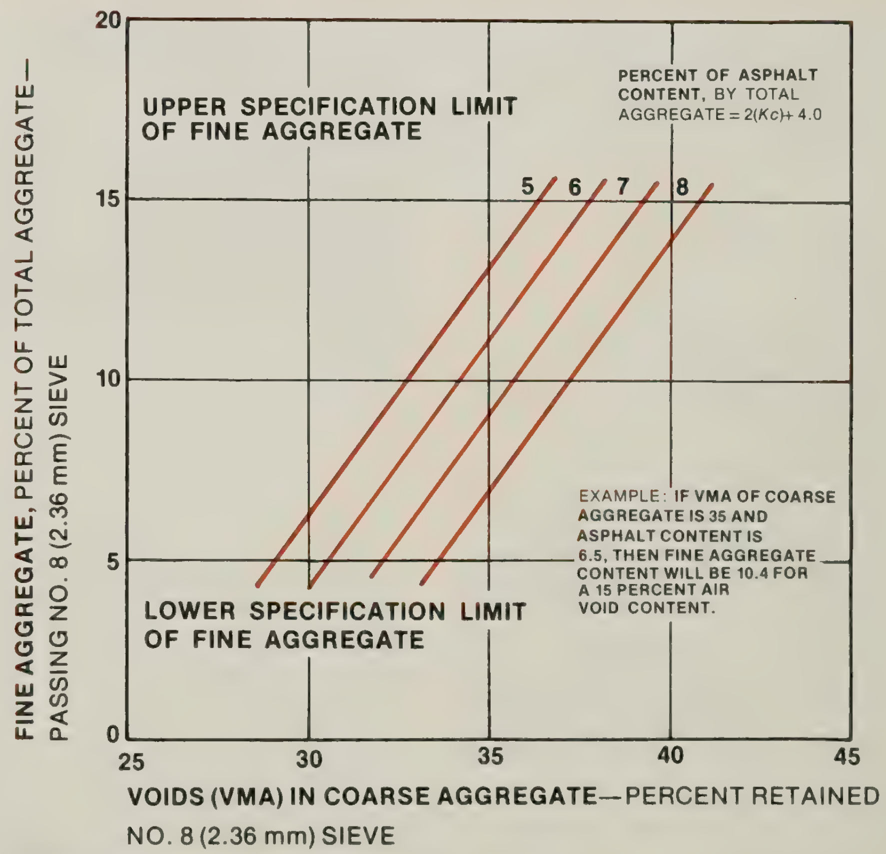
The accessibility of the interior of the open-graded asphalt friction course to water makes it important to investigate the tendency to lose strength in the presence of moisture. The criterion of strength is not believed to be as important as the criterion of retained strength.

The Immersion-Compression Test (AASHTO T 165 and T 167) is required for this investigation. A molding pressure of 2,000 psi (13.79 MPa) is used rather than the specified value of 3,000 psi (20.68 MPa) to eliminate most aggregate degradation during compaction. Accordingly, the index of retained strength is specified as a 50-percent minimum—as contrasted to a 70-percent minimum for dense-graded mixtures molded at 3,000 psi (20.68 MPa)—after a 4-day immersion in 120° F (48.89° C) water. Additives may be used to promote adhesion and to provide adequate retained strength.

EXTENT OF USAGE

The procedure which has been outlined is relatively new. However, in the course of conducting an initial investigation, it was possible to apply the procedure to the design of plant mix seals which were recently

Figure 3.—Determination of optimum fine aggregate content.



ASSUMPTIONS USED IN DERIVING CHART:
SPECIFIC GRAVITIES OF COARSE AND FINE AGGREGATES = 2.65.
SPECIFIC GRAVITY OF ASPHALT = 1.00.
AIR VOID CONTENT = 15.0 PERCENT.

constructed under the auspices of the FHWA Region 15 Demonstration Project 10, in the States of New Hampshire, Minnesota, Michigan, New York, and Kentucky. These after-the-fact designs compared quite well with the designs recommended by FHWA Region 15 personnel, which were based on the Colorado procedure (*8*). A comparison of aggregate gradation and asphalt content results and a more complete listing of pertinent information obtained by this procedure are provided in the subject report. In the Kentucky and the New York designs, some 3/8- to 1/2-in. (9.5- to 12.7-mm) material was permitted. It is believed that a relatively small quantity of this size in the range of 5-10 percent will not significantly affect the desired mixture properties and is therefore allowable. This provision would permit the more economical use of standard sizes of aggregates.

As a result of the favorable comparison, the procedure was applied to the design of mixes for a demonstration project in Mississippi. This turned out to be especially challenging as three separate job-mix designs were requested, each containing various combinations of aggregate—crushed gravel, expanded clay (synthetic aggregate), and slag (phosphate type). These mixture designs were successfully placed in October 1973. Although it is too early to draw any conclusions regarding performance, it has been reported that all three sections are maintaining good skid numbers, excellent drainage qualities, and very satisfactory riding qualities.[4]

Since the Mississippi project, a number of interested agencies have requested assistance and instruction in the use of this procedure through the FHWA Region 15 Demonstration Project 10. As a consequence, other successful demonstrations using mixtures designed by this procedure have been completed in Ohio and Iowa. Similar projects are being scheduled in Pennsylvania, Kansas, West Virginia, Delaware, Hawaii, Montana, and Washington.

[4] Paper by T.C. Paul Teng "Research and Evaluation of Hot Bituminous Plant Mix Seal Course," Mississippi Asphalt Paving Seminar, April 1974.

CONCLUSIONS

The authors believe that the design procedure described in the preceding paragraphs is a substantial technological improvement over other existing methods used to design open-graded asphalt mixtures. This opinion is based on several considerations.

First is the simplification of the usual process required to select asphalt content. Although the value determined is still based largely on field experience, asphalt requirements are desirably dependent on the effects caused by different types of aggregates. Furthermore, the relationship used to compute asphalt content seems to provide for as high an asphalt content as used anywhere in practice. The use of this relatively large amount of asphalt is facilitated by requiring and providing for adjustments in mixing temperature and grade of asphalt cement, if necessary.

Second is the provision for the investigation of the compaction characteristics of the coarse aggregate. This step verifies whether adequate space is available in the composite structure for the required amount of asphalt, air voids, and a sufficient but limited quantity of fine aggregate. Essentially, the properties and characteristics of the aggregate to be used dictate how the aggregate shall be graded (within limits) in order that the desired mixture characteristics are achieved.

Third is the knowledge that the application of this procedure would have averted the use of a mix design that was responsible for a rather extensive incidence of asphalt flushing of an open-graded plant mix seal coat placed in the Washington, D.C. area in 1969. Evaluation of the actual mix design by the proposed new procedure indicates that insufficient void space was available in the coarse aggregate for the quantities of fine aggregate and asphalt cement that were used. Further improvements in the procedure are contemplated as results of current research efforts become available. However, the procedure in its present form is recommended for immediate application.

REFERENCES

(*1*) William L. Eager, "Construction and Performance of Plant Mixed Seal Coats," Proceedings, *American Association of State Highway Officials,* 1967, pp. 235-246.

(*2*) Gordon A. McKenna, "Plant Mix Seal Coats Used in Region Seven (FHWA)," *Federal Highway Administration, Office of Engineering,* distributed by Circular Memorandum, May 1968.

(*3*) W. R. Lovering, "Open-Graded Asphalt Mix—Pros and Cons," *Roads and Streets,* December 1961, p. 84.

(*4*) Doyt Y. Bolling, "Open-Graded Plant Mix Surface Courses in the Washington (D.C.) Area," Conference on Skid Resistant Surface Courses, Arlington, Va., *Federal Highway Administration,* Report No. FHWA-RDDP-10-1, July 1970.

(*5*) Robert A. Bohman, "Open-Graded Plant Mix Seals," Conference on Skid Resistant Surface Courses, Chicago Heights, Ill., *Federal Highway Administration,* Report No. FHWA-RDDP-10-2, September 1971.

(*6*) John A. Mills, "A Skid Resistance Study in Four Western States," Special Report 101, *Highway Research Board,* 1969, pp. 3-17.

(*7*) Wade B. Betenson, "Plant-Mixed Seal Coats in Utah," Asphalt Paving Technology 1972, *The Association of Asphalt Paving Technologists,* pp. 664-684.

(*8*) B. A. Brakey, "Design, Construction, and Performance of Plant Mix Seals," Proceedings, *American Association of State Highway Officials,* 1972, pp. 177-195.

(*9*) "Open Graded Plant Mix Seals," *Federal Highway Administration, Office of Engineering,* distributed by Notice, May 1973, p. 13.

(*10*) "Method of Test for Centrifuge Kerosene Equivalent Including K-Factor," Test Method 303-E, *California Department of Transportation.*

(*11*) D. G. Fohs, J. R. Blystone, and P. C. Smith, "A Vibratory Compaction Test Method for Granular Materials," *Federal Highway Administration,* Report No. FHWA-RD-72-43, November 1972, available through the National Technical Information Service, Springfield, Va., 22151, PB No. 221008.

(*12*) R. W. Smith, "Influence of Permeance on Asphalt Concrete Hardening," *The Pennsylvania State University,* December 1971.

Report on Accident Experience with Impact Attenuators —A Best Seller

by John G. Viner and Charles M. Boyer

The final report on "Accident Experience with Impact Attenuation Devices" (*1*)[1] is now available. The report examines 393 accidents involving impact attenuators (also called crash cushions) which were reported in conjunction with the National Experimental and Evaluation Program Project No. NEEP-4, "Impact Attenuation Devices," administered by the Federal Highway Administration's Office of Highway Operations. An interim report on this study was published in the October 1971 issue of *Public Roads* (*2*).

Accident reports used in this study were received on the Fibco impact attenuator,[2] the Hi-Dro Cushion, the Steel Drum attenuator, the TOR-SHOK, the Dragnet, and the Vermiculite Concrete barrier. The data involved 188 locations, mostly at elevated gores.

Some 68 of these accidents involving impact attenuators were judged likely to have resulted in death or serious injury had the attenuator not been present. In these 68 accidents, 5 resulted in fatalities and 12 in injuries requiring hospitalization. Thus, in 75 percent of these cases, accident severity was reduced from probable fatalities or hospitalizing injuries to accidents involving only minor injury or property damage. In these 68 major accidents, vehicle overturns occurred in six cases.

[1]Italic numbers in parentheses identify the references.

[2]The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

For impact attenuators installed in gore areas, 4.1 accidents per site per year were reported in this study. In many of these installations the attenuator was installed in front of an existing parapet nose which reduced weaving room, perhaps thereby increasing the number of accidents that occurred. In new construction and in some existing gores, the gore can be designed (or rebuilt) so that the attenuator occupies essentially the same space as a conventional bridge parapet nose, alleviating this problem. Provision of such space in the design of elevated exit ramps, together with the installation of an impact attenuator, is now required on all Federal-aid projects (*3*).

Data on vehicle heading angle and point of impact in an attenuator accident, the range of reported installation and maintenance costs, and a summary of all reported accidents are given in the final report (*1*). The report may be obtained for $3.75, paper copy and $1.45, microfiche (PB 224995/1AS) from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22151.

REFERENCES

(*1*) J. G. Viner and C. M. Boyer, "Accident Experience with Impact Attenuation Devices," Final Report FHWA-RD-73-71, *Federal Highway Administration,* April 1973.

(2) John G. Viner, "Experience to Date with Impact Attenuators," *Public Roads,* vol. 36, No. 10, October 1971, pp. 209-218. Subsequently published in the *Transportation Engineering Journal of ASCE,* vol. 98, No. TE1, Proc. Paper 8747, February 1972, pp. 71-87.

(3) "Use of Crash Cushions on Federal-Aid Highways," FHWA Instructional Memorandum 40-5-72, *Federal Highway Administration,* HNG-32, November 8, 1972.

New Research in Progress

The following items identify new research studies that have been reported by FHWA's Offices of Research and Development. These studies are sponsored in whole or in part with Federal highway funds. For further details, please contact the following: Staff and Contract Research—Editor; Highway Planning and Research (HP&R Research)—Performing State Highway Department; National Cooperative Highway Research Program (NCHRP)—Program Director, National Cooperative Highway Research Program, Transportation Research Board, 2101 Constitution Avenue, N.W., Washington, D.C. 20418.

FCP Category 1—Improved Highway Design and Operation for Safety

FCP Project 1A: Traffic Engineering Improvements for Safety

Title: Guidelines for Uniformity in Traffic Control Signal Design Configurations. (FCP No. 51A1514)
Objective: Prepare guidelines for optimum traffic control signal design configurations at intersections and mid-block crossings. This must include considerations of cost and user response in terms of observance, safety, and efficiency. Only special operation techniques for special configurations will be considered.
Performing Organization: KLD Associates, Inc., Huntington, N.Y. 11743
Expected Completion Date: July 1976
Estimated Cost: $300,000 (NCHRP)

FCP Project 1B: Remedial Driving Techniques for Freeways and Interchanges

Title: Remedial Driving Techniques for Freeways and Interchanges. (FCP No. 31B1762)
Objective: Determine problem freeway segments, identify associated improper and proper maneuvers, and develop remedial measures to improve drivers' performance.
Performing Organization: Institute for Research, State College, Pa. 16801
Expected Completion Date: May 1975
Estimated Cost: $161,000 (FHWA Administrative Contract)

FCP Project 1C: Analysis and Remedies of Freeway Traffic Disturbances

Title: Data for Development of Incident Detection Algorithms. (FCP No. 31C3514)
Objective: Provide real-time traffic data on freeway incidents stored on magnetic tape. Obtain data at various volume levels on three-, four-, and five-lane freeways with different geometrics. Provide documentation for each incident characterizing its severity, type, and time of occurrence.
Performing Organization: California Department of Transportation, Los Angeles, Calif. 90020
Expected Completion Date: December 1975
Estimated Cost: $275,000 (FHWA Administrative Contract)

FCP Project 1F: Energy Absorbing and Frangible Structures

Title: Modifications for Achieving High Performance Barriers. (FCP No. 31F1152)
Objective: Develop new concepts for low-cost impact attenuators that are low in maintenance, have multi-hit capability, utilize minimum space, and are high performance in design.
Performing Organization: Eyring Research Institute, Provo, Utah 84601
Expected Completion Date: June 1976
Estimated Cost: $139,000 (FHWA Administrative Contract)

FCP Project 1H: Skid Accident Reduction

Title: Improvement of Utility of a Highway-Vehicle-Object Simulation Program for Highway Application. (FCP No. 31H2232)
Objective: A detailed users manual of the present HVOSM program will be established. The existing programs will be improved for efficient utilization by highway personnel as well as extending the present capability using previously developed results.
Performing Organization: Calspan Corporation, Buffalo, N.Y. 14221
Expected Completion Date: December 1975
Estimated Cost: $115,000 (FHWA Administrative Contract)

Title: Texture Measurement System Development. (FCP No. 31H3222)
Objective: Performance evaluation of laser system for texture measurement under operational conditions. Investigation of wavelength diversity as measure of skid resistance at varying speed. Delivery of road test model of laser-sensor package.
Performing Organization: Naval Ordnance Laboratory, Silver Spring, Md. 20910
Expected Completion Date: May 1975
Estimated Cost: $86,000 (FHWA Administrative Contract)

Title: Frictional Requirements Necessary to Reduce Skidding Accident Frequencies (FCP No. 31H4022)
Objective: Analysis on present data base and models for frictional demand of pavements. Design skidding tests to complete the data base. Semi-empirical modeling of skidding phenomena and establishing frictional requirements leading to an operational methodology.
Performing Organization: JRB Associates, Inc., La Jolla, Calif. 92037
Expected Completion Date: April 1975
Estimated Cost: $159,000 (FHWA Administrative Contract)

FCP Project 1N: Motorists' Direction and Information Systems

Title: Motorist Response to Highway Guide Signing. (FCP No. 51N1012)
Objective: Identify, develop, and critique candidate measures of driver response to highway guide signing and develop a means for validating the most promising measures and conduct such a validation.
Performing Organization: Biotechnology, Incorporated, Falls Church, Va. 22042
Expected Completion Date: January 1976
Estimated Cost: $250,000 (NCHRP)

FCP Project 1O: Aids to Surveillance and Control

Title: Structural and Geometric Design of Highway-Railroad Grade Crossings. (FCP No. 41O1042)
Objective: Develop implementable, structural, and geometric design criteria for highway-railroad grade crossings.
Performing Organization: Texas Transportation Institute, College Station, Tex. 78701
Funding Agency: Texas Highway Department
Expected Completion Date: August 1977
Estimated Cost: $170,000 (HP&R)

FCP Category 2—Reduction of Traffic Congestion, and Improved Operational Efficiency

FCP Project 2B: Development and Testing of Advanced Control Strategies in the Urban Traffic Control System

Title: UTCS/BPS Software Support. (FCP No. 32B2512)
Objective: (1) Integrate advanced traffic control strategies with the UTCS-1 simulation; (2) test advanced traffic control strategies; (3) convert housekeeping software associated with the second generation software into FORTRAN IV; and (4) code, integrate, and test third generation software.
Performing Organization: Honeywell, Inc., Hopkins, Minn. 55343
Expected Completion Date: December 1975
Estimated Cost: $581,000 (FHWA Administrative Contract)

FCP Category 3—Environmental Considerations in Highway Design, Location, Construction, and Operation

FCP Project 3F: Pollution Reduction and Visual Enhancement

Title: Erosion Control During Highway Construction. (FCP No. 53F1592)
Objective: Assess methods of erosion control currently in practice; develop a manual recommending techniques to reduce erosion; identify research needs in the research area.
Performing Organization: Utah State University, Logan, Utah 84321
Expected Completion Date: October 1975
Estimated Cost: $175,000 (NCHRP)

Title: Establishment and Management of Vegetation in Highway Environments. (FCP No. 43F1732)
Objective: Establish habitat restrictions and develop procedures for establishing plants for erosion control. Develop methods for controlling unwanted plants.
Performing Organization: Texas Transportation Institute, College Station, Tex. 77840
Funding Agency: Texas Highway Department
Expected Completion Date: August 1978
Estimated Cost: $150,000 (HP&R)

FCP Category 5—Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety

FCP Project 5D: Structural Rehabilitation of Pavement Systems

Title: Pavement Evaluation. (FCP No. 35D1022)
Objective: Develop methodology for the determination of a pavement's structural adequacy taking into account the load-carrying capability, serviceability, and remaining life of the structure.
Performing Organization: Texas Transportation Institute, College Station, Tex. 77843
Expected Completion Date: February 1977
Estimated Cost: $204,000 (FHWA Administrative Contract)

Title: Reconditioning Heavy-Duty Freeways in Urban Areas. (FCP No. 55D2172)
Objective: Develop a new technology for reconstituting and/or replacing all or part of the pavement structure on a heavily traveled urban freeway so that the finished product has a design service life equal to or greater than that of the original pavement, including restoration of riding and non-skid characteristics.
Performing Organization: Texas A&M Research Foundation, College Station, Tex. 77843
Expected Completion Date: October 1975
Estimated Cost: $100,000 (NCHRP)

FCP Project 5F: Bridge Safety Inspection

Title: Acceptance Criteria for Electroslag Weldments in Bridges. (FCP No. 55F2112)
Objective: The fracture and fatigue crack growth behavior of the heat-affected zone and various areas within the fusion zone of electroslag weldments will be studied. The influence of base material (A36 and A588 steel) plate thickness (1- and 4-inch) as well as numerous process variables are included in the experiment design.
Performing Organization: U.S. Steel Corporation, Monroeville, Pa. 15146
Expected Completion Date: April 1976
Estimated Cost: $200,000 (NCHRP)

Title: Determination of Tolerable Flaw Sizes in Full Size Bridge Weldments. (FCP No. 35F2132)
Objective: Experimental determination of the tolerable fatigue crack size in bridge girders and gusset plated truss connections. Correlation of experimental results with analytical determination of stress intensity factor and measured material toughness.
Performing Organization: Lehigh University, Bethlehem, Pa. 18015
Expected Completion Date: December 1975
Estimated Cost: $245,000 (FHWA Administrative Contract)

FCP Category 6—Development and Implementation of Research

FCP Project 6C: Traffic Engineering

Title: Traffic Responsive Ramp Control Through Use of Micro Computers. (FCP No. 46C1173)
Objective: Evaluate the use of micro computers as traffic responsive ramp controllers. Work includes development of both hardware and software considering both cost and functional capability.
Performing Organization: California Department of Transportation, Sacramento, Calif. 95814
Expected Completion Date: December 1976
Estimated Cost: $122,000 (HP&R)

FCP Project 6Z: Implementation of Research Projects

Title: Implementation of Research. (FCP No. 46Z1733)
Objective: Special efforts to insure that the results of research and development projects are brought into operating practice.
Performing Organization: New York Department of Transportation, Albany, N.Y. 12226
Expected Completion Date: May 1975
Estimated Cost: $87,000 (HP&R)

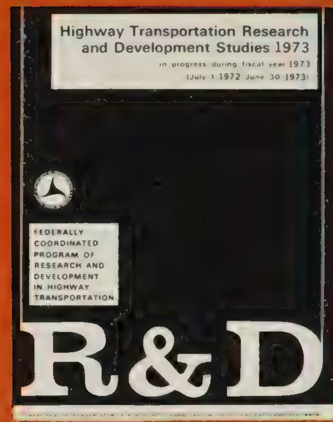
New Publications

Motor Carrier Safety Regulations provides, in one publication, the applicable motor carrier safety regulations for motor carriers operating in interstate or foreign commerce. This is a revised issue of the regulations, including amendments through October 1, 1973, parts 390 through 397. There are sections on qualifications of drivers, driving of motor vehicles, parts and accessories necessary for safe operation, notification, reporting, and recording of accidents, hours of service of drivers, inspection and maintenance, transportation of hazardous materials, and driving and parking rules.

This publication may be purchased for $1.20 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock Number 5004-00010).

Part VI, Traffic Controls for Street and Highway Construction and Maintenance Operations, of the Manual on Uniform Traffic Control Devices has been reproduced as a separate publication to meet the needs of traffic control standards for construction, maintenance, and utility work areas in the United States. **Part VII, Traffic Controls for School Areas,** of the Manual has also been published separately for the special demand of uniform traffic control standards in school areas throughout the Nation. Both standards are applicable to all public roads regardless of type or class, or agency having jurisdiction in accordance with Federal legislation.

Part VI on Construction and Maintenance Operations may be purchased for $1.25 (Stock Number 5001-00065) and Part VII on School Areas for 75 cents (Stock Number 5001-00067) from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.



Highway Transportation Research and Development Studies 1973 presents a complete inventory of the research and development studies approved, in progress, or completed during fiscal year 1973. The report contains individual vignettes for all research and development studies that are supported and aided by the Federal Highway Administration's Offices of Research and Development, Bureau of Motor Carrier Safety, and selected planning research studies from the Offices of Planning.

This publication is intended primarily for the information and guidance of Federal and State personnel concerned with highway-related research, particularly those in the Federal Highway Administration (FHWA) and other agencies within the U.S. Department of Transportation (DOT), and those in State highway departments or departments of transportation. It will be useful also to other Federal and local government personnel, to highway-oriented and vehicle-oriented trade, professional, and research organizations, and to members of the general public interested in or concerned with research in highway transportation.

This publication may be purchased for $4.50 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock Number 5003-00157).

Highway Research and Development Reports Available from National Technical Information Service

The following highway research and development reports are for sale by the National Technical Information Service, Sills Building, 5285 Port Royal Road, Springfield, Va. 22151.

Other highway research and development reports available from the National Technical Information Service will be announced in future issues.

STRUCTURES

Stock No.

PB 226625 Analysis of Overhead Cable-Supported Roadway Sign.
PB 226884 Development of Louvered Signs to Reduce Wind Load.
PB 228329 An Investigation of the Load-Carrying Capacity of Drilled Cast-in-Place Concrete Piles Bearing on Coarse Granular Soils and Cemented Alluvial Fan Deposits.
PB 228680 Field Measurements of Lateral Earth Pressures on a Pre-Cast Panel Retaining Wall.
PB 228681 Condition of Longitudinal Steel in Illinois Continuously Reinforced Concrete Pavements.
PB 228720 Fill Stabilization Using Non-Biodegradable Waste Products—Phase I.
PB 228786 Barrier VII: A Computer Program for Evaluation of Automobile Barrier Systems.
PB 229401 Design Variables for Cut Slopes.
PB 229509 Evaluation of Stud Welding System for Aluminum Highway Signs.
PB 229611 Live Load Stresses in a Straight Box-Girder Bridge.
PB 229720 Skid Test Trailer Calibration.
PB 229885 Computer Evaluation of Automobile Barrier Systems.
PB 229922 Feasibility Study and Preliminary Design of a System for Rapid Evaluation of Rational Pavement Designs.
PB 229938 An Analysis of Dynamic Displacements Measured Within Pavement Structures.
PB 229948 Load Distribution in a Composite Steel Box-Girder Bridge.
PB 230449 Probabilistic Design Concepts Applied to Flexible Pavement System Design.
PB 230847 The Rehabilitated AASHO Test Road, Part I—Materials and Construction.
PB 230940 Analytical Problems in Modeling Slurry Wall Construction.
PB 230942 Investigation of Dynamic Stresses in Highway Bridges—An Interim Report.
PB 231173 Development of Guidelines for the Design of Subsurface Drainage Systems for Highway Pavement Structural Sections.
PB 231178 Evaluation of Existing Bridge Expansion Joints.
PB 231202 Proceedings of a Symposium on Downdrag of Piles.
PB 231219 A Study of the AASHO Road Test—Final Summary Report; Phase 2—Evaluation and Application of the AASHO Road Test Results.
PB 231326 Correlation of Pavement Behavior and Performance Between the University of Illinois Test Track and the AASHO Road Test.
PB 231350 Pavement Design and Performance Study; Phase B—Deflection Study: Interim Report No. 5, Nuclear Measurement of Subgrade Moisture.
PB 231998 Creep and Shrinkage Study of Concrete Made from Hawaiian Aggregates—Phase II.

MATERIALS

Stock No.

PB 228330 Application of Electro-osmosis to Marginal Soils.
PB 228679 The Effect of Sodium Chloride on the Corrosion of Concrete Reinforcing Steel and on the pH of Calcium Hydroxide Solution—Interim Report.
PB 228975 Technical Control of Sulfate Waste Materials at the Transpo '72 Site.
PB 228976 Structure Backfill Testing.
PB 228982 Behavior of Shrinkage-Compensating Concretes Suitable for Use in Bridge Decks—Interim Report, Phase I.
PB 228993 Investigation of Lime Slurry to Control Absorptive Aggregates Used in Asphalt Concrete.
PB 229744 Traffic Stripes and Formed-in-Place Delineators.
PB 229811 Electrical Resistivity Techniques.
PB 230951 Arkansas Waste in Municipal Areas Suitable for Highway Construction or Maintenance—Final Report.
PB 230953 The Location and Potential Highway Use of By-Products in Arkansas—Final Report.
PB 230986 Experimental Cathodic Protection of a Bridge Deck.
PB 230990 Bridge Deck Membranes—Evaluation and Use in California—Interim Report.
PB 231000 First Progress Report on Concrete Experimental Test Sections in Brazos County, Tex.
PB 231021 Wet Night Visibility—Interim Report.
PB 231208 Accelerated Environmental Testing.

PB 231243 Paint Characterization by Electrical Techniques.

PB 231388 Refinement of Moisture Calibration Curves for Nuclear Gage.

PB 231649 Failure Modes and Required Properties in Asphalt-Aggregate Cold Mix Bases.

PB 231908 Evaluation of Interior and Exterior Latex Paints.

PB 231965 Design Considerations for Asphalt Pavements.

PB 231979 Skid Resistance and Wear Properties of Aggregates for Paving Mixtures.

TRAFFIC

Stock No.

PB 228421 Freeway Operations Study—Phase III. The FREQ3 Freeway Model.

PB 228423 Optimization Techniques Applied to Improving Freeway Operations.

PB 228516 Meaning and Application of Color and Arrow Indications for Traffic Signals—Final Report and Appendices.

PB 229333 Diagrammatic Guide Signs for Use on Controlled Access Highways: Volume II—Laboratory, Instrumented Vehicle, and State Traffic Studies of Diagrammatic Guide Signs.

PB 229886 The Improved Effectiveness of Traffic Signal Systems: Conventional Signal Network Timing Strategies.

PB 229903 Information Lead Distance Studies—Electronic Route Guidance Systems.

PB 230047 Computer Control of the Wayside-Telephone Arterial Street Network.

PB 230448 The Improved Effectiveness of Traffic Signal Systems: Effects of Changes in Signal Operation on Traffic Flow.

PB 230760 Network Flow Simulation for Urban Traffic Control System—Phase II.
Vol. 1—Technical Report.

PB 230761 Vol. 2—Program Documentation for UTCS-1 Network Simulation Model, Part I.

PB 230762 Vol. 3—Program Documentation for UTCS-1 Network Simulation Model, Part II.

PB 230763 Vol. 4—User's Manual for UTCS-1 Network Simulation Model.

PB 230764 Vol. 5—Applications Manual for UTCS-1 Network Simulation Model.

PB 230996 Right Turn on Red.

PB 231042 Feasibility Investigation of Audio Modes for Real-Time Motorist Information in Urban Freeway Corridors.

PB 231051 Cost Effectiveness Evaluation of Freeway Design Alternatives—Freeway Operations Study, Phase III.

PB 231077 Development of a Model for Predicting Travel Time on an Urban Freeway.

PB 231086 Dallas Corridor Frontage Road Evaluation Plan.

PB 231161 Progress Toward a Freeway Corridor Model—Freeway Operations Study, Phase III.

ENVIRONMENT

Stock No.

PB 228517 Summary and Assessment of Sizes and Weights Report.

PB 229334 Evaluation of a Method of Fog Dispersal by Ionization.

PB 229605 Hydraulic Performance of Pennsylvania Highway Drainage Inlets Installed in Grassed Channels (Type H, Type 4-ft and 6-ft).

PB 229610 Lensed Rail Lights for Pavement Illumination.

PB 229835 Procedures and Materials for Roadside Development in Montana. Interim Report: Dryland Sodding with Native Grasses for Permanent Erosion Control.

PB 230995 Hydraulic Performance of Bridges—Efficiency of Earthen Spur Dikes in Mississippi.

PB 230999 Species Recommended for Highway Plantings Selected from a Natural Vegetation Survey in the Panhandle of Nebraska.

PB 231074 Stabilizing Disturbed Areas During Highway Construction for Pollution Control.

PB 231104 A Minimum-Cost and Environmentally-Safe Program of Herbicide Maintenance for Indiana Roadsides.

PB 231387 Manual of Procedures for Conducting Studies of the Desirable Limits of Dimensions and Weights of Motor Vehicles.

PB 231583 A Simplified Procedure for Computing Vehicle Offtracking on Curves.

PB 231889 Colorado Tunnel Ventilation Study.

IMPLEMENTATION

Stock No.

PB 228448 Determination of the Feasibility of Using Southern Pine Veneer Log Cores as Posts for Fencing Highway Projects—Final Report.

PB 228449 An Investigation into the Gradation Variability of Aggregate Used in Bases.

PB 228473 Modern Concepts for Density Control.
Phase I: Bituminous Wearing Courses.

PB 228511 Tunnel Cleaning Method.

PB 228572 Construction Control of Rigid Pavement Roughness—Final Report.

PB 228656 Recordation of Quantities of Materials Incorporated in Base and Pavement Plant Mixtures—Final Report, Phase II.

PB 229824 Microwave Heating for Road Maintenance.

PB 230381 Modification and Calibration of the Illinois Skid Test System.

PB 230497 Skid-Resistant Characteristics of Experimental Bituminous Surfaces in Illinois.

PB 231018 Variation of the Results of Routine Concrete Tests Using Standard and Accelerated Curing Methods.

PB 231159 Modern Concepts for Density Control—Phase II: Granular Base Courses.

PB 231382 Variations in Portland Cement Concrete Construction in Nebraska.

PB 231552 Modern Concepts for Density Control—Phase III: Embankment Materials.

PB 231818 Texas Crash Cushion Trailer.

PB 231890 Bridge Rating and Analysis Structural System (BRASS).
Vol. I.—System Reference Manual.

PB 231891 Vol. II—Example Problems.

PLANNING

Stock No.

PB 228997 Studies of Optimal Models of Interchange Development Through Land Use Regulation and Control.

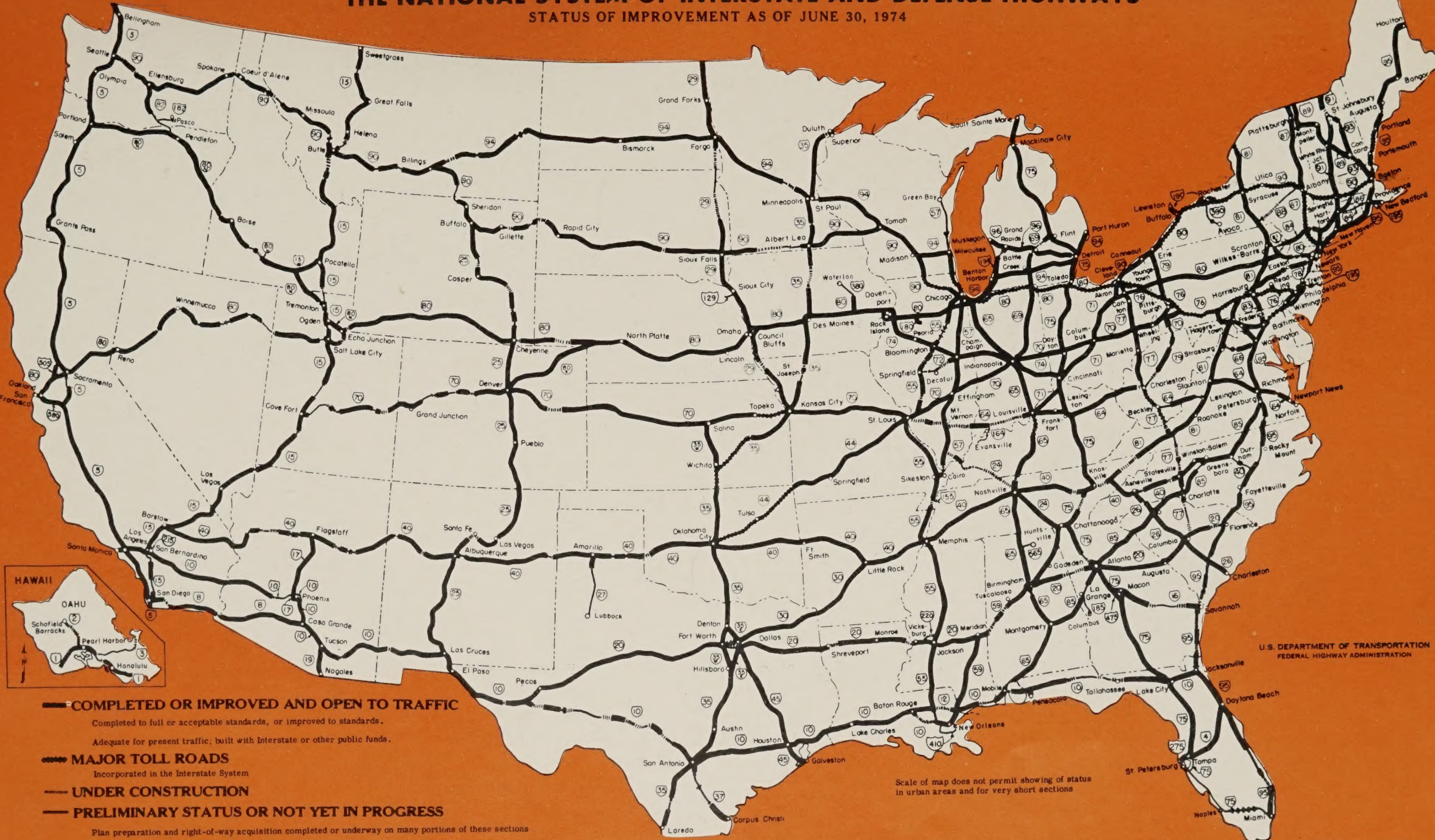
PB 231168 Test and Evaluation of Data from the Standard Package of Census Data for Urban Transportation Studies.

PB 231594 Design of an Information System for Continuing Transportation Planning in the Albuquerque Metropolitan Area.

*U.S. Government Printing Office: 1974—620-830/4

THE NATIONAL SYSTEM OF INTERSTATE AND DEFENSE HIGHWAYS

STATUS OF IMPROVEMENT AS OF JUNE 30, 1974



COMPLETED OR IMPROVED AND OPEN TO TRAFFIC

Completed to full or acceptable standards, or improved to standards.

Adequate for present traffic; built with Interstate or other public funds.

MAJOR TOLL ROADS

Incorporated in the Interstate System

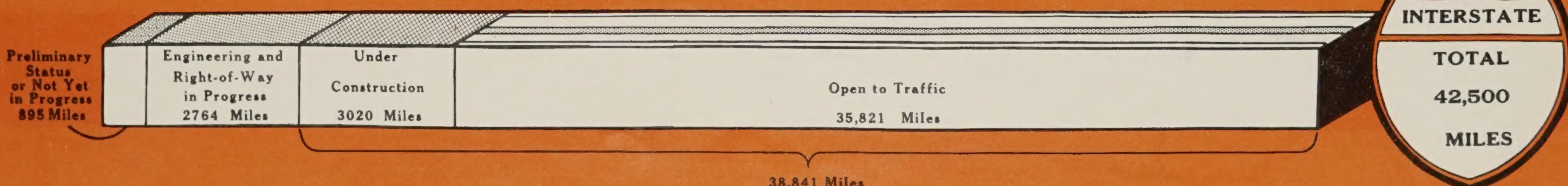
UNDER CONSTRUCTION

PRELIMINARY STATUS OR NOT YET IN PROGRESS

Plan preparation and right-of-way acquisition completed or underway on many portions of these sections

Scale of map does not permit showing of status in urban areas and for very short sections

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION



United States
Government Printing Office
Public Documents Department
WASHINGTON, D.C. 20402

Official Business

in this issue

public roads

A JOURNAL OF HIGHWAY RESEARCH AND DEVELOPMENT