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# public roads

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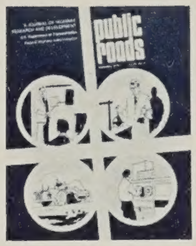

**COVER:**
Artist's conception of some of the elements involved in research and development.




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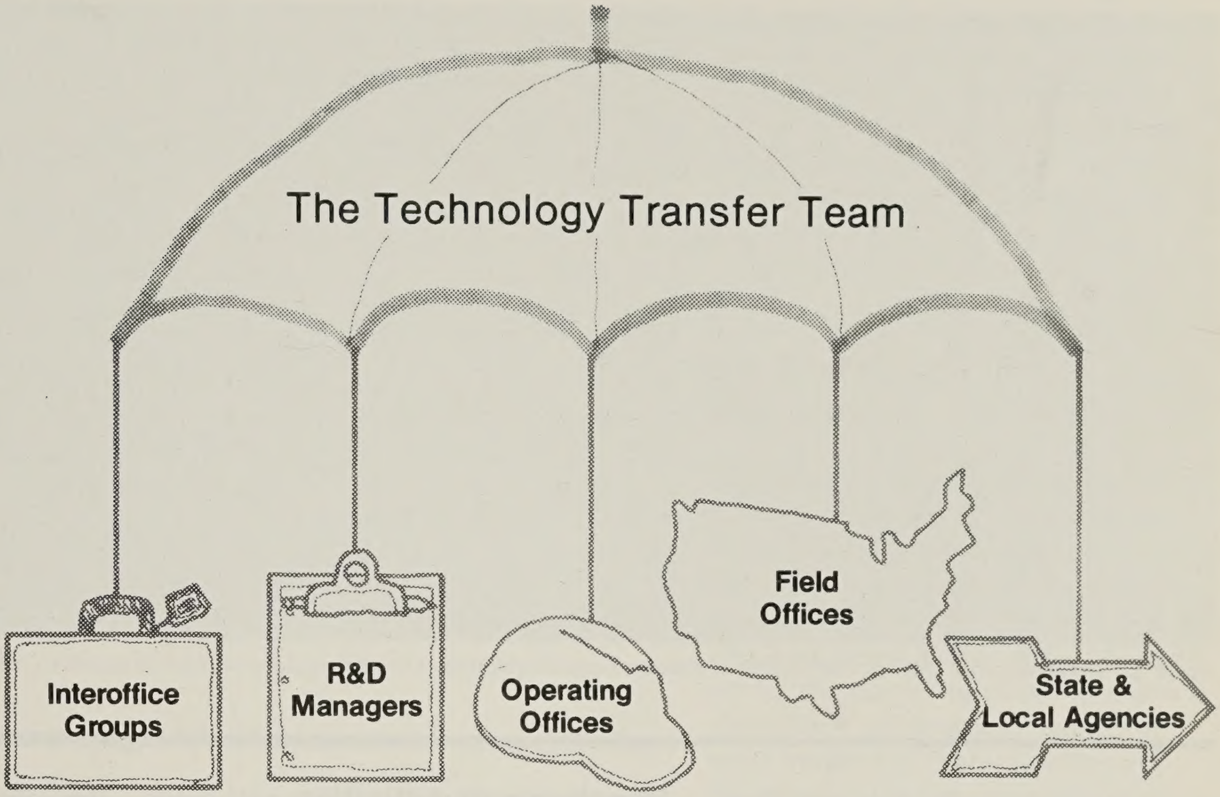



# Getting Research Into Practice

by Gerald D. Love

## Introduction

Usually the results of research are accepted and respected. However, some additional activities often must be performed as a part of the process of getting research into practice. Before the result is fully utilized and the benefits begin, a planned, deliberate, and adequate development and technology transfer effort is needed. New ideas simply do not sell themselves; they need help.

Some followers of highway research and development (R&D) programs believe that the process of development and technology transfer is something relatively new. This widespread impression probably arises from the fact that the Federal Highway Administration (FHWA) was restructured in 1970 to form an Office of Development and Implementation Division totally committed to a single mission—putting the results of research into practice. The pre-1970 structure of the Offices of Research and Development is shown in figure 1; the current structure is shown in figure 2. Also, in the late 1960's and early 1970's, FHWA established a demonstration program (Region 15 Demonstration Projects) and education program (National Highway Institute) to go along with its experimental projects program to create a family of technology transfer activities. This article describes these present programs and includes some history and a discussion of the future. It concentrates on work under the Offices of Research and Development even though technology transfer involves many other FHWA offices which will be identified briefly.

Despite the relatively recent reorganization, the process of technology transfer has been a part of the R&D process since FHWA and its predecessor agencies were first given the mission to coordinate highway R&D more than 80 years ago. The first Federal roads agency mission was deceptively simple: find out how to build better roads and tell other people how to do it. That happened in 1893, and the agency enthusiastically accepted its two-part mission. Not only did they find out how to build better roads, they demonstrated experimental sections and devised novel ways to "tell other people how to do it" as well. One of the first of these "implementations" was to put laboratory models of sections of new-design roads on trains and move these exhibits wherever there was interest in seeing them. The first section started on its travels about 1900 (fig. 3). The "Good Roads Trains," as they came to be known, continued exhibiting new developments in highway technology for approximately 10 years.

Through the years, the application of research results in highway transportation has been extensive. Table 1 shows a sample list of some of the items resulting from research that have made major contributions to transportation. Short descriptions of recent innovations are presented later in this article.

## FHWA Program

Currently in FHWA, the two-part mission is generally expressed as (1) development/implementation, and (2) technology transfer. The two parts generally follow in sequence between

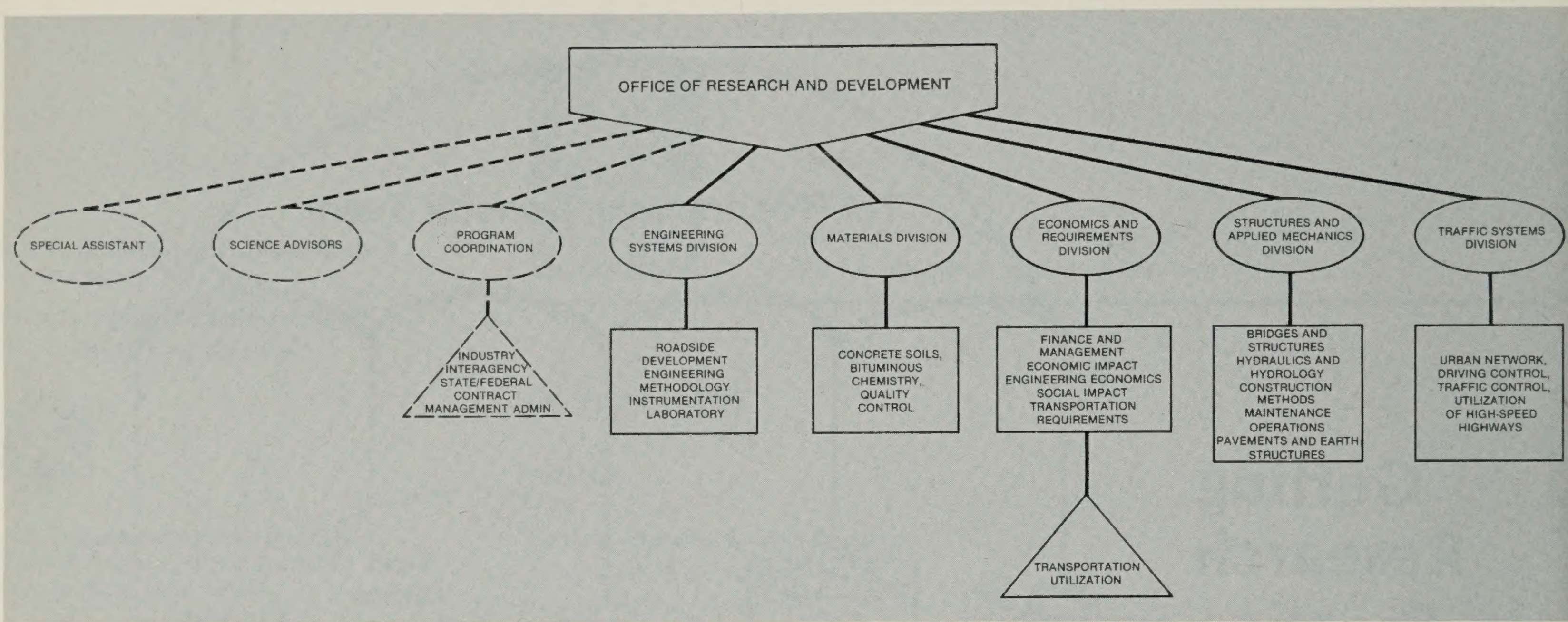



*Figure 1.—Organizational chart of the Offices of Research and Development in 1969.*

research and practice. They are often intermingled but will be treated separately in this article for simplicity.

The new program, charged with transforming technology transfer from a "hit-or-miss" basis to a planned procedure, soon found that a logical, organized approach was needed badly. The FHWA staff given this responsibility structured the new technology process into six important steps:

- Identification.
- Planning.
- Packaging.
- Promotion.
- Evaluation.
- Adoption.

The place or role of each step is summarized in figure 4 and described in detail later in this article.

## Development Activities

Development generally refers to activities that take place between research and technology transfer. It is the second step in a new technology evolution that includes research, development, technology transfer, and adoption.

At the outset, this goal was met by including development/implementation as an element of the Federally Coordinated Program of Highway Research and Development (FCP). This was done for a number of reasons; the most important include the following:

- Many of the fruits of research were not being used.
- FHWA was transitioning from the National Program of R&D for Highway Transportation (1965–1969) to the FCP concept, and involvement of the many jurisdictions was needed.
- State R&D programs were paying off more than ever before; a single, coordinating organization responsible for merchandising these results was necessary.
- An organization was needed to followup on introduced items to assess the value of the program in real terms, such as benefits realized.

Of course, there are many definitions of the word "development," but in the context of this discussion, we emphasize three purposes or objectives:

- To evolve.
- To make clear.
- To make usable.

In FHWA, following the guidance provided by these three objectives, the progression from research to application includes a large number of activities such as identifying, assessing, testing, evaluating, modifying, improving, preparing, documenting, prescribing, specifying, building, and finally, "telling someone else." All of these can be lumped together as *development,* with the reservation that there is no single prescription for the process.

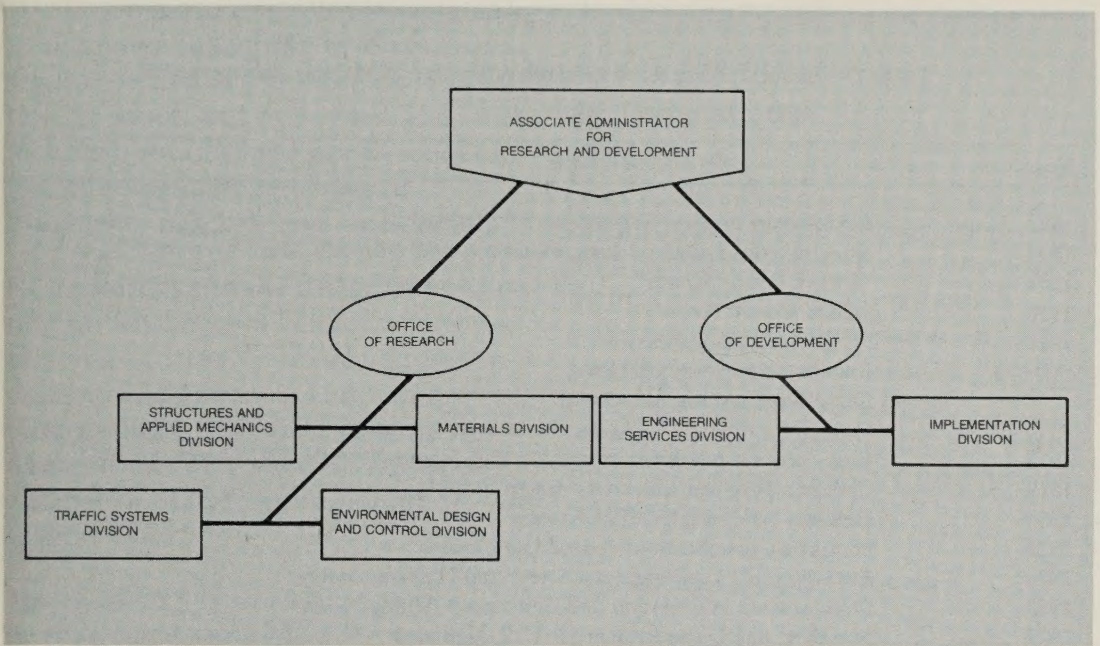



*Figure 2. — Present structure of the Offices of Research and Development.*

## Development process

As mentioned earlier, the total process of applying new technology in FHWA has been divided into six stages: (1) identification, (2) planning, (3) packaging, (4) promotion, (5) evaluation, and (6) adoption. The development process primarily deals with the first three of these stages but is heavily dependent on the last three.

## Identification stage

Very briefly, the identification process involves (1) finding and defining new technology, (2) assessing its usefulness and potential, and (3) making the first determination to go forward. Each of these steps is important. The sources of new technology are unbounded; in FHWA we look to the field, to State and local constituents, and to the outside just as we look to research. Defining is important because a clear understanding of exactly what the new product is and what it does is essential to all involved. Confusion and misunderstanding of product purpose have been problems in the past.

Assessment sometimes may be a simple determination of merit or value to those concerned at a specific time. More often, however, studies, reviews, new determinations, and meetings, all requiring considerable time, are needed for the parties involved to reach a conclusion. In addition, one of the most important characteristics of development is the involvement of others, particularly the constituency.

This involvement means that major development determinations are made by a group rather than a single person. In FHWA, the group can involve up to six elements representing research, development, operating offices, field offices, users, and the public. This involvement of others is essential because the purpose of development is to make something for someone else. Experience has demonstrated that development has been successful largely by getting and keeping everyone in the act.

The final step in identification is the decision to proceed with subsequent development and technology transfer or to reject, defer, or return to an earlier phase. Of course, these determinations may not be a clear-cut yes or no. They certainly are not irrevocable and they are reviewed many times as the effort progresses.

*Figure 3. — The Good Roads Train.*

## Planning stage

The second major stage of development is planning. A key to FHWA's success in using new technology is planning and organizing to do the job. Getting new technology into shape and into practice cannot be left to chance, to someone else, or to wishes and promises. It must be planned and conducted in a known and deliberate manner.

Planning comprises several efforts: gathering information and knowledge, consolidation and preparation of the plan or strategy, and plan coordination and expansion which involves the concerned parties and develops resources and schedules.

The plan should be complete, practical, and understandable. It should cover the entire spectrum of activities as final goals of adoption and should not just cover pieces. It should contain detailed steps, milestones, alternatives, and requirements.

## Packaging stage

This is the principal activity of the development/implementation program in FHWA. In fact, packaging and development are almost synonymous. This stage includes the entire spectrum of activities that is required to prepare new technology for use. It can vary widely from combining, translating, testing, and evaluating to refining, documenting, specifying, and disseminating. Packaging is trying it out, putting it all together, and turning out a product in the best form and the best style.

Most of this development work is performed by contractors or through arrangements with States, field offices, and other Federal agencies. Sometimes it is a specified part of the overall research effort and user documentation is prepared with the research reports.

**Table 1.—Historic examples of research utilization in highway transportation**

| Year | Example |
|---|---|
| 1893 | First agency mission—dissemination of research |
| 1894 | Nine bulletins issued on laws, materials, and railroads rates |
| 1903 | "Object Lesson Roads" |
| 1910 | "Good Roads Trains" |
| 1911 | "Object Lesson Culverts" |
| | Bulletin on highway bridges |
| | Centerline marking introduced |
| | Standard guidelines for use of bituminous materials |
| 1915 | First concrete pavement of considerable length (24 miles [38.6 km]) |
| 1919 | Concrete pavement thickness design formula |
| 1920 | Highway soils classification system |
| 1923 | 88 asphalt specifications consolidated into 9 |
| 1924 | First National Conference on Street and Highway Safety |
| 1925 | Standardized information and directional signing |
| 1927 | Standard numbering system for U.S. highways |
| | National manual on traffic control devices |
| 1934 | Effect of traffic control devices on safety and efficiency |
| 1935 | Rainfall intensity and frequency relations developed |
| | Soil compaction and moisture density requirements established |
| 1936 | Comprehensive design procedure for concrete pavements |
| 1939 | Design based on vehicle hill-climbing and passing ability |
| 1940 | Publication of "Transition Curves for Highways" |
| 1941 | Driver behavior and highway capacity relations developed |
| 1942 | Braking performance of motor vehicles |
| 1944 | Adoption of 12-ft (3.7 m) lane width |
| 1950 | Effect of vehicle and highway characteristics on truck operator and efficiency |
| 1953 | Value of full control of access developed |
| 1955 | Stop sign changed from yellow to red |
| 1959 | Comprehensive maintenance management system |
| 1965 | Concept of impact attenuation devices developed |
| | Freeway surveillance and control adopted after work in Detroit, Chicago, and Houston |
| 1967 | Breakaway sign and light posts adopted |
| 1970 | Significant utilization of electronics in communications, data processing, and traffic control |
| 1973 | Maintenance management training curriculum developed |

A wide variety of tasks may be performed under packaging:

- Translating research reports.
- Development of hardware.
- Computer programing.
- Field testing (evaluation).
- Equipment fabrication.
- User documents.
- Training courses.
- Visual aids.
- Specifications.
- Multi-State trial installations.
- Workshops, conferences.
- Implementation packages, brochures.
- Techshare reports.
- Information dissemination.
- Evaluation and followup.
- Marketing analysis, strategy.

The broad process of packaging and/or development generally involves five steps. The first is assembly of information, product, and resources. This may include a lot of preparation—developing, building, and gathering of assistance, support, and outside help.

Next, there is usually a test and evaluation or "shakedown" effort where the product, process, or device is used in a realistic environment. This can involve a brief, single action. At the other extreme, it can involve efforts by a number of States over a period of several years.

The third step is to change, improve, or finalize the item just before it is ready for the marketplace. This, again, can be minimal or it can involve major, additional research and development.

The next step is preparation of tools and the mechanisms for technology transfer. This includes packages, user documents, training materials, dissemination materials, and delivery systems.

The final step is initiation of the technology transfer plan. This is usually the initial dissemination effort and is handled primarily by the operating and field offices. It is essentially the point of change from development to technology transfer.

## Technology Transfer Activities

Now let's turn from "development" to "technology transfer." Technology transfer concerns the action or promotion stage of getting new technology into practice. It generally falls between development and adoption in the new technology process.

Technology transfer is actually an FHWA-wide activity involving all offices and most programs in the agency. There are four programs, however, that are almost exclusively involved with technology transfer:

- Development/implementation.
- Experimentation.
- Demonstration.
- Training.

Because this article is concerned primarily with research and development, the other three programs—experimentation, demonstration, and training—are not discussed in detail although they are all part of technology transfer. In fact, the latter three are major "delivery systems" or promotion programs.

### Technology transfer process

Referring again to the six steps in applying new technology, the technology transfer process basically concerns the last three—promotion, evaluation, and adoption.

### Promotion stage

The promotion stage can be complex and lengthy. It is the action stage where FHWA endorses a product and gives the product to its constituents. It can include formal announcement and dissemination, demonstration, training, workshops, experimental projects, and organized field activities.

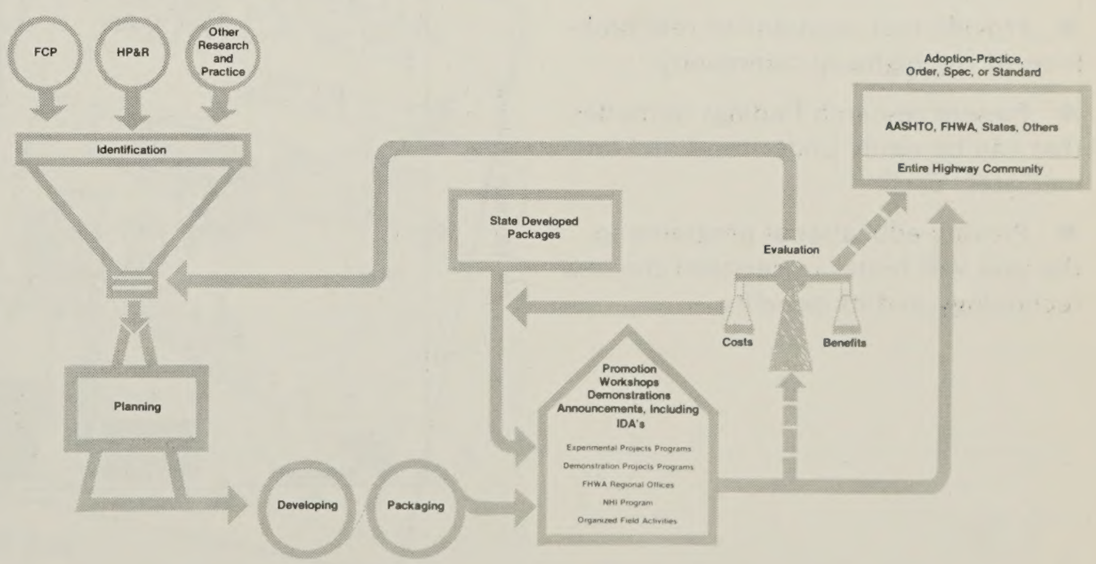
Promotion needs to be planned and carried through to insure maximum benefit to the greatest number of users or constituents. Reaching the customer effectively and achieving a multiplier effect are principal goals.

### Evaluation stage

Evaluation is the second major technology transfer function and concerns measurement and assessment of the results of the program. It includes measuring the technological results and benefits as well as the promotion effort, delivery effectiveness, and implementation strategy. Quantitative evaluation has been one of the most difficult weaknesses in the program to correct and is a major challenge to all participants. There have been a variety of efforts to improve this, but a satisfactory process has not yet been found.

Evaluation is conducted at various stages of the program such as identification, development, promotion, and adoption, because frequent intermediate decisions are made concerning continuation of the implementation effort.

*Figure 4.—The technology transfer process.*



### Adoption stage

Adoption is the final step in the process and represents the "bottom line." At this stage, action is taken to place the technology into standard practice in a community large enough to allow the technology to stand on its own.

## Technology Transfer as a Management Process

Technology transfer in FHWA, in addition to being a procedure that translates and promotes the results of research into practice, is also a management process. In order to carry this out, those responsible for technology transfer have the following:

- The support of top management.
- Adequate funding.
- An effective organization.
- Cooperation from all elements involved both at headquarters and in the field.

The importance of the management approach can be appreciated by considering the following FHWA-developed principles or guidelines under which the program operates:

- Create a constructive environment by obtaining cooperation and support of top management.
- Involve the operating offices in the research and development process.
- Provide real solutions to real problems of the highway community.
- Present research findings in modes that can be easily understood and immediately used.
- Provide educational programs so the user will better understand the new technology and its benefits.
- Provide a management framework that is flexible, avoids duplication, minimizes red tape, and responds to needs.
- Assess the progress and the results of the program through feedback from users.

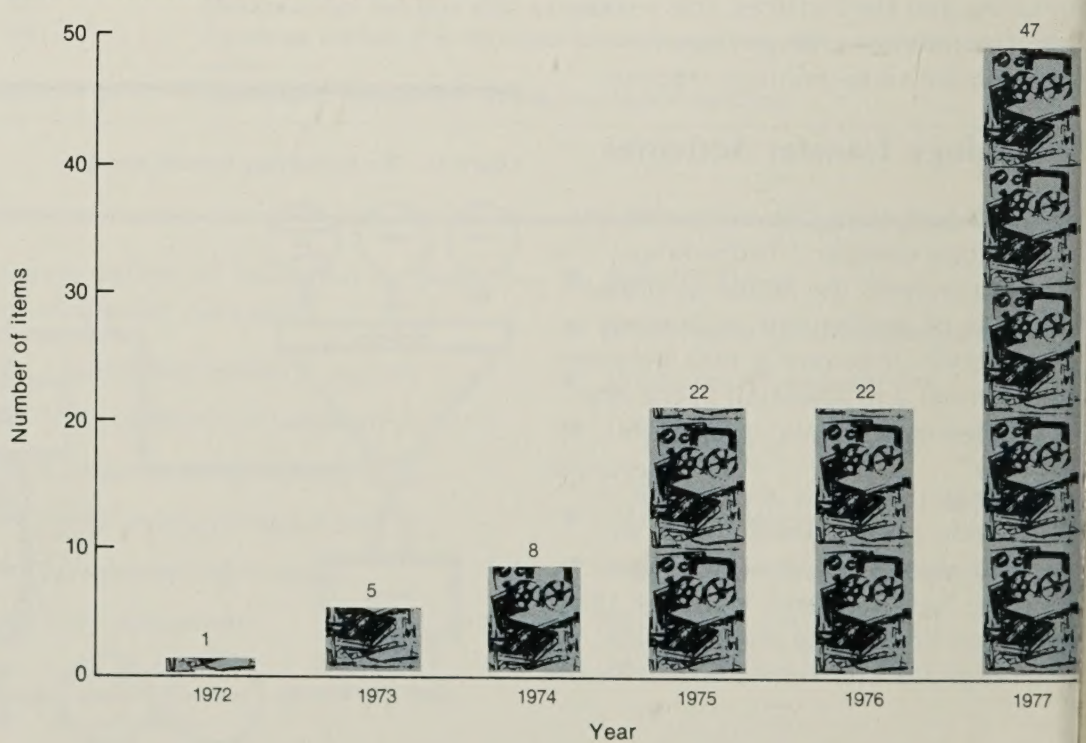
## Accomplishments

In the years since the reorganization of FHWA's Offices of R&D, many new highway items have been introduced via the process described in this article. Figure 5 shows the growth of this activity since 1972 as measured by the number of packages issued.

In the introductory part of this article we listed a number of important milestones. Today's innovations are accompanied by a package of user materials, such as those shown in figure 6 for Bicycle Safety Lanes. Some other recently introduced (1977) items are briefly described as illustrative of the kinds of improvements that are being put into practice today:

- A *Texas Quick-Load Method* to determine the load bearing capacity of piles and drilled shaft foundations that can be performed in 1 to 2 hours as compared to the more than 100 hours for the old standard method has been developed.
- A *Bridge Deck Drain Cleanout Device* that eliminates ponded water quickly and safely has been developed.
- A *Noise Barrier Design Handbook* that provides design information for noise abatement barriers and includes methods for predicting noise exposure, assessing noise impact, and describing other methods of noise control has been published.
- *A Summary of Highway Facilities Where Hazardous Materials are Restricted* identifies highways which restrict or prohibit transport of hazardous materials and describes the restrictions.

*Figure 5. — Implementation package output.*



● *Fly Ash—A Highway Construction Material* describes fly ash, a new highway construction material in abundant supply, which is used in soil stabilization, in aggregate-treated base course, embankments, structural backfill, and grouting mixtures.

● *Pile Driving Analysis*, and a manuscript for a tape-slide presentation, describe how complex problems encountered in pile driving, particularly to predict compressive and tensile strengths and soil resistance, can now be solved more easily with computer assistance. New computer programs for both diesel and air/steam hammers are available in these publications.

## Summary

This article has covered two major activities in FHWA—development and technology transfer. The two generally come in sequence between research (the beginning) and practice (the end). Although often overlapping, the two are treated separately to distinguish their roles and functions.

## A Brief Look Into the Future

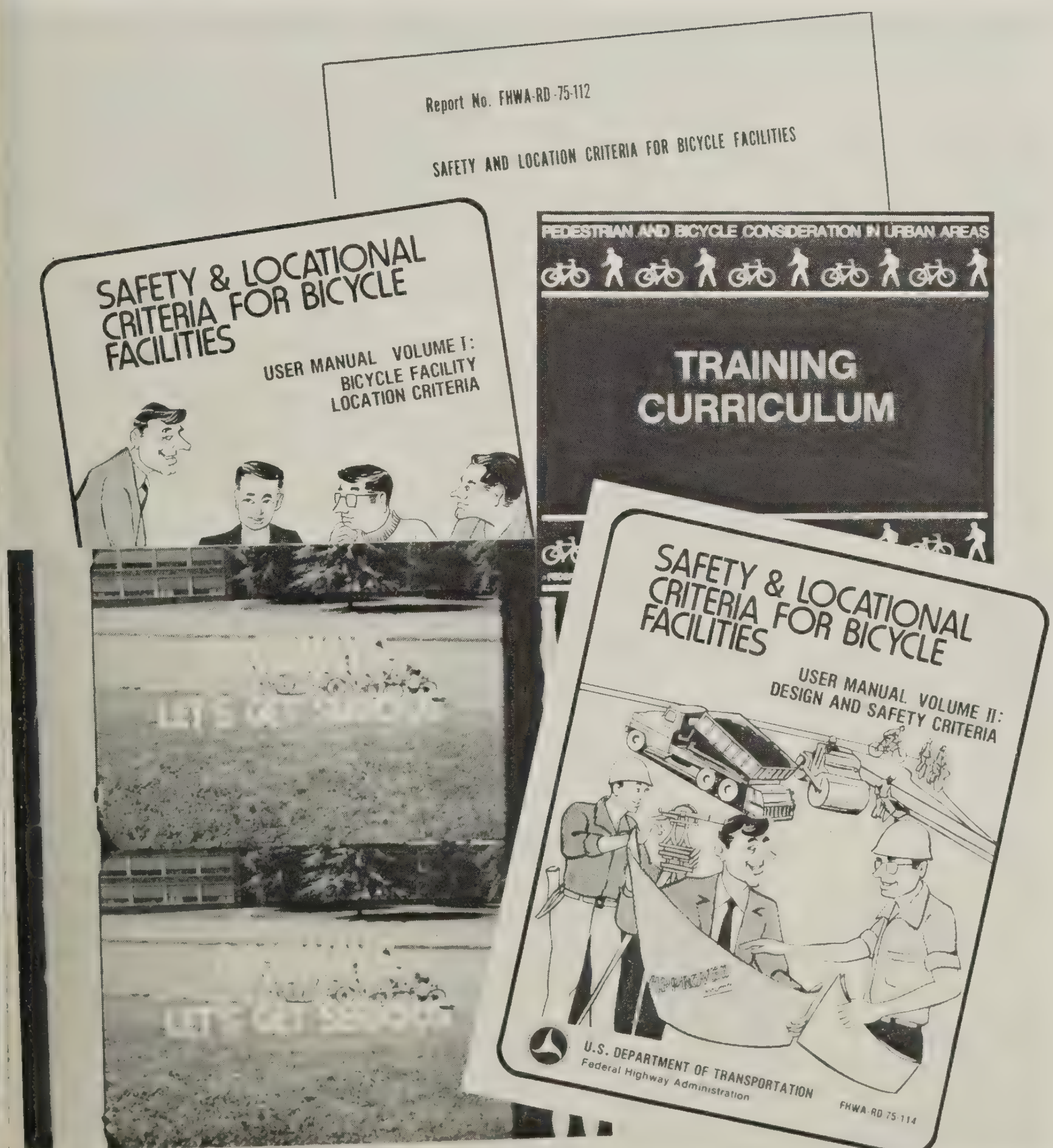
This article implies that technology transfer has solved the problems of getting worthwhile research projects accepted and used by the highway community—including elements both within and outside FHWA. This is not completely true. There are difficult problems that remain to be addressed and eventually resolved, including evaluating and measuring the effects and the accomplishments of these efforts in quantitative terms where possible.

Another important problem facing us is that of delivery. We have packaged, documented, and evaluated products for the highway community but we do not always have the right path to the priority targets. We are working on this right now.

We have a problem in providing service. We warrant and wish to service our products somewhat as automobile manufacturers do. We have not been able to provide that kind of support and so are actively working on ways to provide continuing service to our "customers."

These three issues—quantitative evaluation in followups, timely delivery of new products, and service of distributed products—are still with us.

*Figure 6.—Package of user materials.*



*Counterflow bus lanes can obtain greater efficiency from existing facilities. Research is in progress to find methods for safe and effective management.*

# New Directions for the Federally Coordinated Program of Highway Research and Development

**by Charles F. Scheffey**

## Introduction

The general case for the value of research in modern society hardly needs to be sold. Most people agree that it is necessary in order to keep American industry competitive in world markets, raise our standard of living, conquer disease, improve communications and the entertainment media, and keep our defenses strong. They are less willing to agree that tax money should be spent on research in fields such as transportation. In particular, there is a general assumption that because we now have virtually completed the Interstate Highway System, there is little justification for an ambitious program of highway research. Exactly the opposite is true; there is now a more urgent need for a vigorous program of highway research than at any time since the end of World War II. This is because the highway program itself is now directed toward goals which until now were frequently neglected.

## The Need for a Continuing Research Program

In general, the public and some political decisionmakers believe that the highway program is now approaching completion and there is little need for further research and development (R&D). In some cases, this attitude is due to the idea that the only responsibility of the Federal highway program is the Interstate Highway System. If this were true, we probably could relax, express satisfaction in a job well done, and quietly fade away; however, this is not realistic.

### Changing national priorities

The petroleum supply crisis has placed the full weight of the Federal Government behind a move to lighter and more efficient automobiles. This trend has produced a significant change in the composition of the motor vehicle fleet, and in many ways has made a highway system design for 1970 automobiles obsolete. One example is the recognition that our system of guardrails, bridge rails, and median barriers does not provide adequate protection for the new generation of light, small passenger vehicles (fig. 1).

The same energy crisis that is forcing us into smaller automobiles also calls for larger, heavier cargo vehicles. This is not a contradiction. In both cases, fuel economy demands a more favorable tare weight to payload ratio. Fo

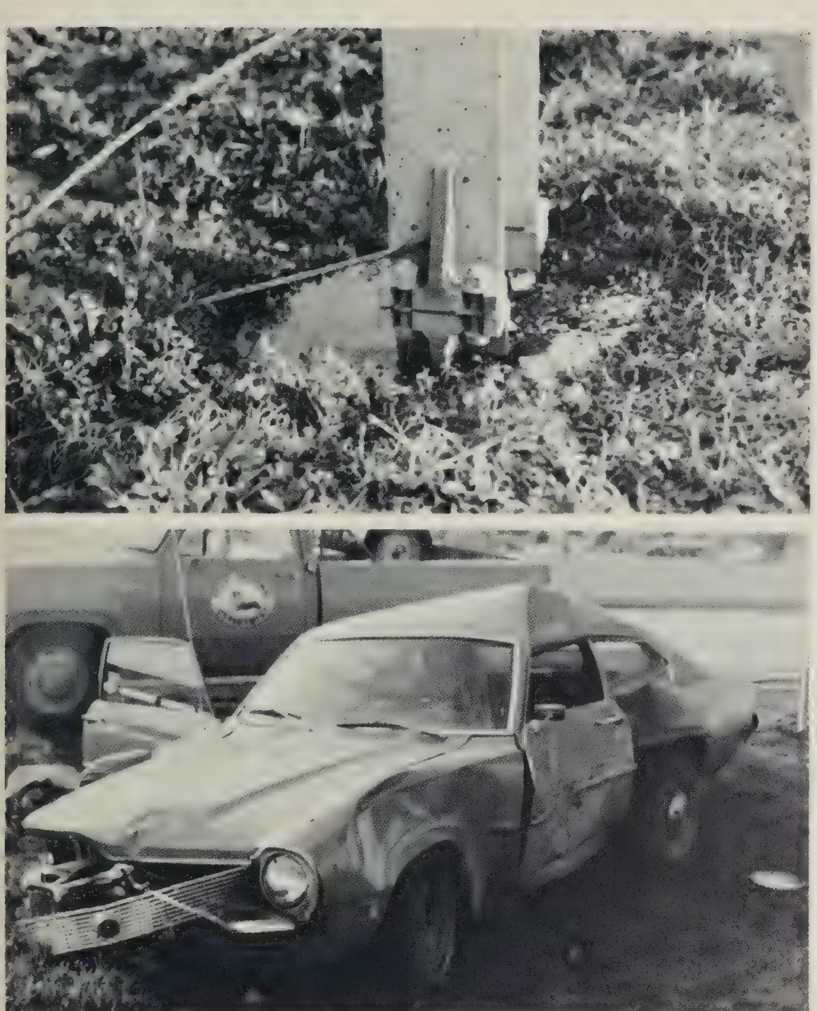


*Figure 1.—This base for a breakaway sign satisfies present requirements for conventional-sized automobiles, but when struck "side on" by a compact automobile severe damage resulted.*

passenger automobiles, this requires reduction of the tare weight as a complement to the efforts to increase payload by the encouragement of carpools. For cargo vehicles, immediate improvement can be obtained by increases in payload; but from both an energy and ton-mile (ton-km) cost standpoint, these benefits are limited by the design and condition of the existing highway network.

**Deterioration of the existing system**

Another reason further research is needed is the fact that the existing system is wearing out. A major program is already underway to repair, renovate, and restore the system. As the deteriorated state of our pavements and bridges becomes more obvious, the public demand to restore workable levels of service is accelerating. At the same time, the realization that we are not technologically fully prepared to handle this situation is becoming apparent. For example, since 1965 extensive efforts have been made to develop reliable methods to estimate the remaining life expectancy of bridges. These efforts have not produced a solution, but rather a paradox. It has been clearly demonstrated that the stresses produced in existing bridges are generally well below those anticipated in the design. In fact, the stresses are low enough that even with the greatly expanded level of vehicle traffic, the existing theories of fatigue damage would indicate that in most cases no fatigue fractures should be anticipated. Nevertheless, there are well-documented cases of fatigue failures in highway bridges; some of these failures are on the same structures on which the above-mentioned data on the frequency of various stress levels were collected.

In the past 2 to 3 years, some clues as to the reasons for this paradox have become apparent. However, none of these clues shows that the fatigue problem can be ignored. A parallel program has demonstrated that many of our bridge structures have an enormous reserve of capacity for passing individual heavy loads. One of the bridges tested to ultimate load in Tennessee recently carried 1,250,000 lb (567 Mg) before exhibiting the beginnings of a collapse mechanism—this on a structure designed for HS20 loading![1] As frustrating as these contradictions may be, they point to an attractive opportunity. They indicate that many of our existing structures, provided they are functionally adequate, can be provided with a new lease on life by a knowledgeable program of rehabilitation and repair. However, there is no cut-and-dried set of rules by which this can be done. Bridges are individualistic structures and a competent examination for possible critical details and fatigue damage will require a level of expertise exceeding that which was involved in the original design. Creation of such expertise will require a vigorous continuation of our present research activities to develop understanding of the problem, inspection instrumentation, and methods for analysis and interpretation of conditions discovered in such inspections.

The rehabilitation of pavements finds us in a similar position of running hard to catch up. It is true that rational methods for design of overlays that are more reliable than older empirical methods are now available. However, the investigations that have led to these design methods have also shown that the placement of such an overlay without some method to restore structural continuity in the existing pavement is probably not a good investment. Two or 3 in (51 or 76 mm) of asphaltic concrete overlay should not be

[1] Specifically an HS20-44 loading, which would imply a single vehicle of 72,000 lb (32.7 Mg) or a total of 288,000 lb (130.6 Mg) if two vehicles were placed in each lane of the 90-ft (27.4 m) span tested. "Comparison of Measured and Computed Ultimate Strength of Four Highway Bridges," by Burdet and Goodpasture, Highway Research Record No. 382, *Highway Research Board*, Washington, D.C., 1972.

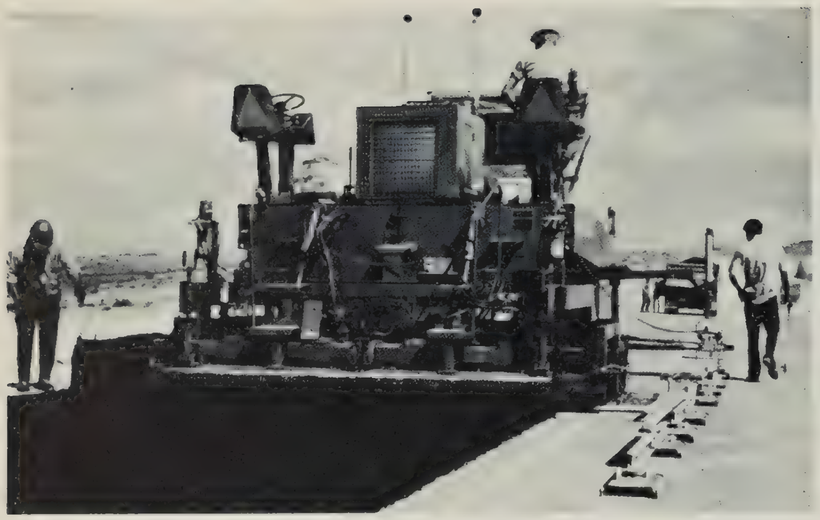


*Figure 2.—It looks like a new pavement, but will it give service in proportion to the investment? Should more be spent first on restoration of existing pavement structure?*

expected to do a job which 6 or 8 in (152 or 203 mm) failed to accomplish! New approaches to reprocessing, stabilization, or repair in place of the existing layers before resurfacing are essential to economical rehabilitation of the highway system (fig. 2).

There are also major policy problems involved. In both the bridge replacement and rehabilitation program and the pavement restoration activity, we are currently rebuilding a system to a load capacity which economic and technical studies have already shown to be suboptimal. The incremental investment to upgrade the system to obtain greater benefits is modest if it is done in conjunction with the bridge replacement and pavement rehabilitation program. A clear and detailed delineation of costs and benefits of such an improvement must be developed to provide policy guidance.

**Environmental, traffic congestion, and safety problems**

In addition to these physical aspects of our deteriorating highway system, there are other problems that have been with us for a long time, such as more reliable prediction of the environmental impacts of air pollution, noise, vibration, and runoff water contamination. Beyond mere prediction, better understanding of these problems may lead to an actual reduction of negative impacts. Certain positive environmental effects can be obtained in the design for new or modified highway facilities. Because many future highway projects will involve modification to existing systems, the importance of obtaining meaningful and representative public participation in highway planning and location has increased. Also, managing the existing highway network, especially in urban areas, in order to achieve maximum efficiency with respect to mobility, energy consumption, and reduction of air pollution is of continuing concern. We have only scratched the surface with respect to what can be done with modern technology in this problem area. Further advances will involve going far beyond the mere control of the traffic signals by a central computer. The next steps for greater efficiency will probably involve information feedback systems to help drivers control their movements to enhance system efficiency and reduce their own travel time. Future improvements may also make use of selective traffic controls that give priorities to high occupancy vehicles and separate cargo movements by route and time as much as possible (fig. 3).

The highway accident problem still consumes enormous resources every year and loss of life and disabling injuries caused by highway accidents rank as one of our major public health problems. The unsolved problems of highway safety would by themselves require a vigorous research program for many years to come. In particular, the new requirements imposed on the system by the shift to lighter, smaller automobiles must be clearly identified and options to satisfy them quickly developed.

*Figure 3.—Bypass lanes for carpools is just one of many techniques for encouragement of high occupancy vehicles.*

Finally, partial automation of highway vehicles and selected routes is an attractive possibility with enormous benefits in respect to energy conservation and safety (fig. 4). Progress in developing microprocessors has been so rapid that some knowledgeable people in the motor industry predict that by 1985 most new automobiles will contain an onboard microprocessor that will control many of the functions now provided by mechanical linkages and gadgetry. Once a basic microprocessor is available, additional features and capabilities can be provided at very small incremental cost. The possibility for a range of devices in the automobile to assist the driver to carry out his driving task in a safer and more effective manner is very real. The hardware which might be required in the highway system to exploit this capability will undoubtedly be expensive even if it is highly cost effective. Therefore, it would appear prudent to have research programs which would open a wide range of options and alternatives so the most effective system may be selected with full recognition of available capital and expected future benefits.

*Figure 4. — Test vehicle used in studies of guidance system for highway automation on the Ohio State University test track.*

## Keeping the Research Program Responsive

Any complete research program must perform at least four functions: It must solve the urgent and current operating problems, it must provide fundamental insight as to how the system operates and where there are opportunities for improvement, it must identify problems that are developing before they become critical, and it must open viable options for dealing with these problems.

First, the term research must be defined. For the purpose of this article, research includes the broad range of activities from scientific investigations of the basic technologies related to highways to the development of prototype devices for control of construction or traffic operations and the field trials of these devices to show where sufficient performance data exists to permit decisions for appropriate deployment of the device. It includes basic research, applied research, and development, but falls short of "implementation" and "demonstration" which are necessary but separate functions.

Responsiveness of the R&D program to the needs of the Federal Highway Administration (FHWA), the highway community, and the public involves at least five requirements:

- Develop cost-effective technical solutions to major current operation problems.
- Define characteristics of the existing system at an adequate level to provide policy guidelines, to provide factual basis for decisions among available or newly developed alternatives, and to identify emerging problems so development of solutions may begin before the problems become critical.
- Provide a technology base for new functions which are legislatively mandated or established by Department of Transportation policy.
- Compare current design and operating technology with the current research literature of both the highway community and related fields in order to identify elements of technical policy which with revision would exploit technology breakthroughs, thereby permitting more effective or lower cost operations.
- Conduct basic and applied research to open new options for the future.

Those benefiting from a research program may expect some useful technological innovations which provide workable and economical solutions to their problems. In addition, the benefits from the application and deployment of these solutions should demonstrate that the research program is paying its own way.

There are also some things which should not be expected of a research program. The first of these is "instant results." Research by its very nature is future-oriented. Although any well-established research organization must often come up with a quick solution for current operating problems, this is not and should not be its primary function. The bulk of the effort should center on identifying problems in the operating system which are still in the embryonic stage and producing solutions to these problems before they become critical. FHWA's present program in highway research is a mixture of orderly development or options for future action and activities to improve existing operational methods.

A second set of expectations which leads to disappointment is the thought that research studies can provide justification for existing policies. Because of the nature of the research community and because legislative requirements place research results in the public domain, it is possible that carefully conducted studies will show that existing policies are not justified.

Finally, realization of research benefits cannot be expected if the information and insights produced are not applied. The investment of resources in a research program requires parallel commitment by operational elements of the organization to give adequate attention to the results produced and a commitment by top management to deploy innovations and changes in the system where they are cost effective.

In an effort to make FHWA's research program responsive, we now annually engage in a number of formal solicitations in which representatives of operating elements in State highway agencies, city and county traffic departments, highway safety organizations, and the FHWA field offices are asked to identify problems for which research could provide beneficial insights and solutions. The major solicitations are those now managed by the Office of Highway Safety, the Offices of Engineering and Operations, and the National Cooperative Highway Research Program (NCHRP).

It must be stressed, however, that these are not the only channels of communication by which the Office of Research staff becomes aware of operating problems and research priorities. For many years, there have been effective informal channels of communication. First of all, specialists on our staff review every Highway Planning and Research Program (HP&R) research study initiated by a State highway agency. This is perhaps one of the most useful guides to what a State considers important because the initiation of such a study requires commitment of resources by the State agency. These same specialists review every problem statement coming from the States under the NCHRP program.

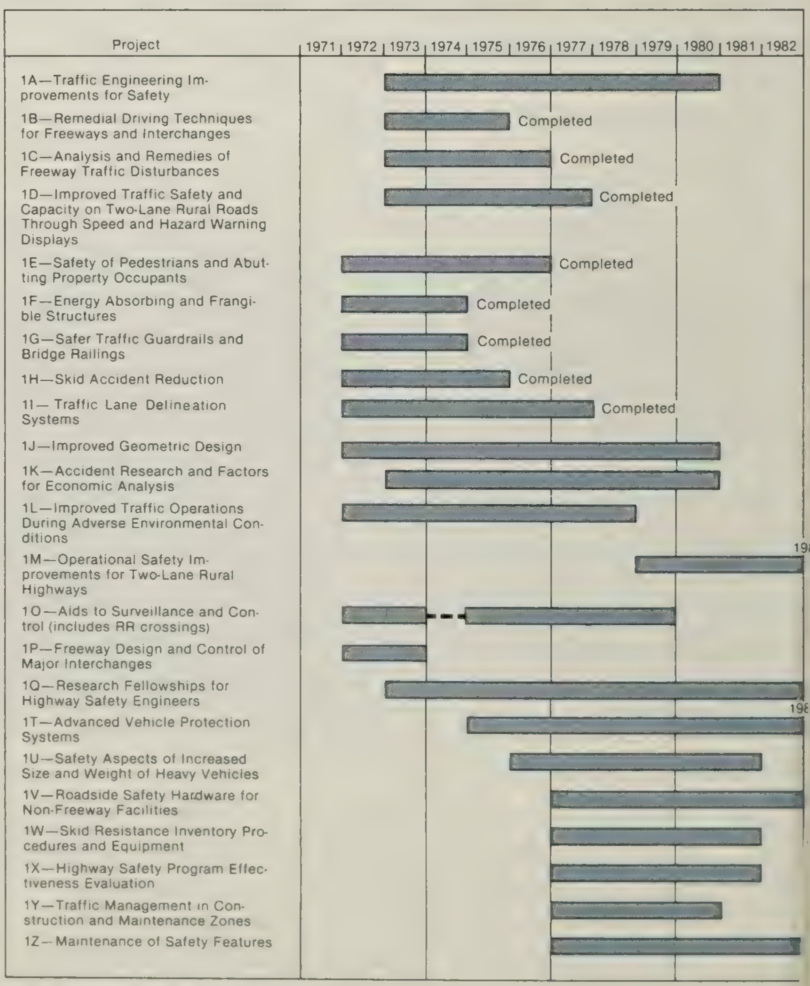
As a result of these contacts as well as membership in many national organizations related to highway technology, it is rare that the formal solicitations ever turn up problems or approaches to solutions that are totally unknown to our staff. The principal benefit of the formal solicitations is the guidance provided by the operating elements as to the relative importance of the various problems identified.

## Changing Directions in the Federally Coordinated Program of Highway Research and Development (FCP)

The impact of the new directions in the highway program and our efforts to improve responsiveness are detailed in figures 5 through 9. A number of new projects have been initiated in the FCP to concentrate research efforts on appropriate objectives. As planned from the initiation of the FCP in 1970, the older projects are being closed out, either because they have successfully reached their objectives or because further extension appeared to have marginal benefits.

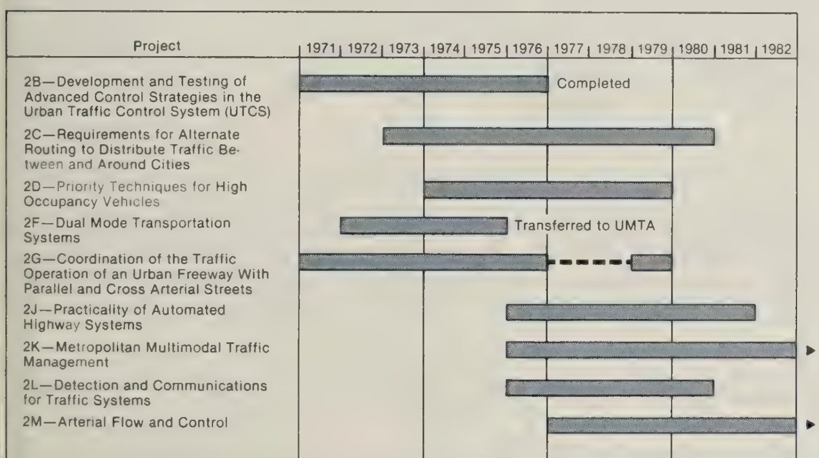
In the safety program of Category 1 (Improved Highway Design and Operation for Safety), six new projects have been initiated over the past 4 years. Project 1T, "Advanced Vehicle Protection Systems," is aggressively pursuing the development of the necessary modification of existing traffic barriers and other safety hardware to accommodate the new generation of passenger automobiles and to provide for

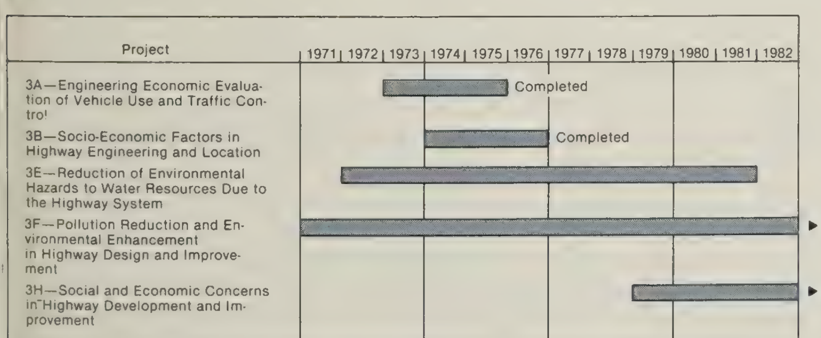
*Figure 5. — FCP Category 1: Improved Highway Design and Operation for Safety.*




Note The original objectives under Projects 1N 1M 1R and 1S were combined with other projects within the first few years of the program and these elements were dropped as separate projects. Designation 1M has now been applied to a new project initiated in FY 78 selective protection for heavy vehicles. Project 1U, "Safety Aspects of Increased Size and Weight of Heavy Vehicles," seeks to obtain well-documented facts on the relationship between traffic accidents involving trucks and their weight classification and to diagnose such accidents and examine the feasibility of countermeasures. The outputs of this project will provide policy guidance for the gathering crises developing over the size and weight issue due to the conflicts between energy conservation, highway maintenance and safety, and other projects in the program which address the technical aspects of bridge and pavement life expectancy.

*Figure 6.—FCP Category 2: Reduction of Traffic Congestion, and Improved Operational Efficiency.*




Note. Projects 3C and 3D were combined with other projects early in the program

*Figure 7.—FCP Category 3: Environmental Considerations in Highway Design, Location, Construction, and Operation.*

Project 1V, "Roadside Safety Hardware for Nonfreeway Facilities," addresses the critical problem of upgrading older highways and bridges in such a way as to provide concurrent improvements in safety hardware at reasonable cost. When the major project on reduction of skidding accidents was completed, there were still some impediments to effective implementation, resulting in the initiation of Project 1W, "Skid Resistance Inventory Procedures and Equipment." At the request of the Office of Highway Safety, Project 1X, "Highway Safety Program Effectiveness Evaluation," was initiated to develop objective methodology for evaluation and guidance of State highway safety programs. Also at the request of the Office of Highway Safety, Project 1Y, "Traffic Management in Construction and Maintenance Zones," was initiated to provide a major advance in our understanding of driver behavior in such zones and how it may be altered most effectively to provide safe work zones. An additional new project now in the final planning stages will attack the two-lane rural and low volume road safety problems.

In Category 2 (Reduction of Traffic Congestion and Improved Operational Efficiency), four new projects have been initiated. Project 2J, "Practicality of Automated Highway Systems," grew out of earlier HP&R and advanced technology developments. This activity was raised to project status when it became apparent that automated systems were not only technically feasible but also offered significant capacity and safety advantages. The current work stresses resolution of economic, institutional, and human factors problems. Upon completion of Project 2B, "Urban Traffic Control Systems," it was realized that there was a definite upper bound on traffic flow improvements which can be obtained by even the most sophisticated control of signals. Further improvement must involve information feedback to drivers, coordination with public transit, encouragement of high occupancy vehicles, and possible separation in space or time of cargo movements as addressed in Project 2K, "Metropolitan Multimodal Traffic Management." A parallel supporting project—Project 2L, "Detection and Communications for Traffic Systems"—will develop such things as wide area detection methods and methods to exploit effectively the growing number of CB radios in automobiles for both traffic management and safety. The specific problem of arterial highways will receive concentrated attention in Project 2M, "Arterial Flow and Control."

The major projects of Category 3 (Environmental Considerations in Highway Design, Location, Construction, and Operation) are receiving increased resources to address the physical problems of air and water pollution reduction, noise and vibration control, and ecosystem protection. A new effort to develop better approaches to obtaining relevant public participation in highway planning and location

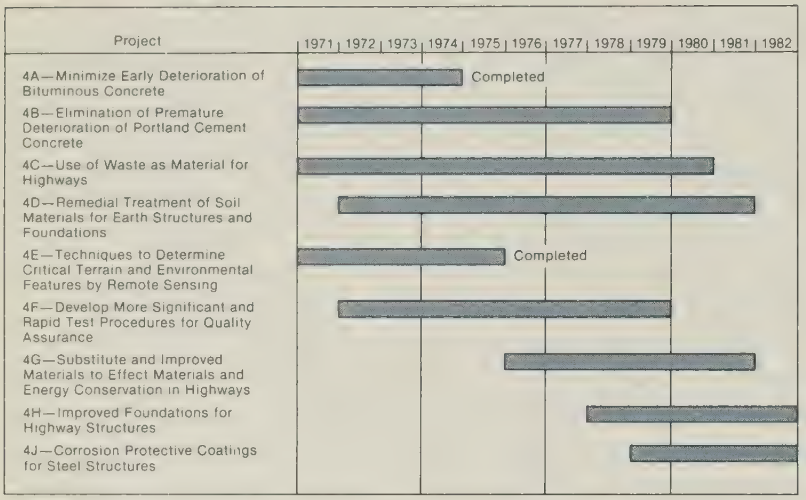
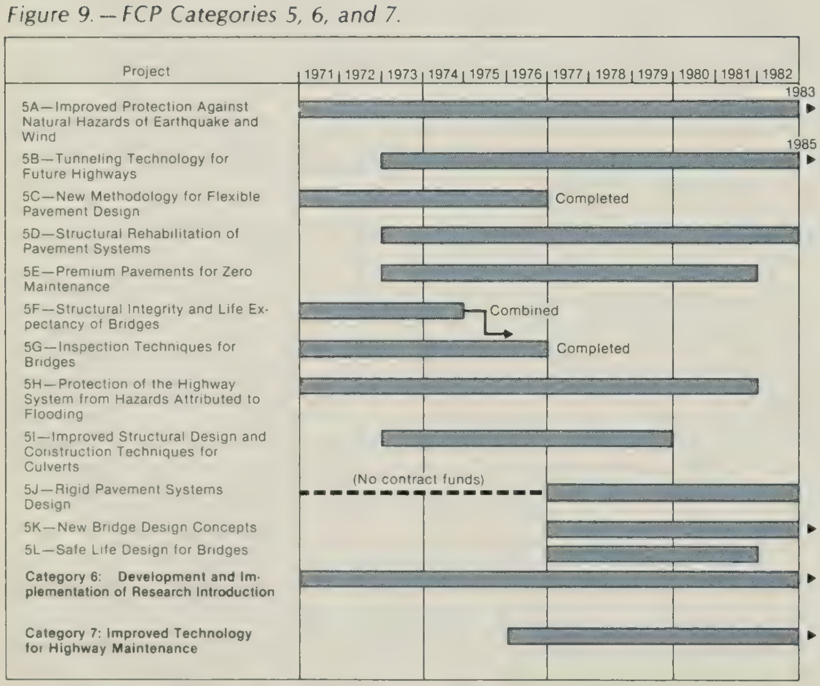



*Figure 8. — FCP Category 4: Improved Materials Utilization and Durability.*

*Figure 9. — FCP Categories 5, 6, and 7.*



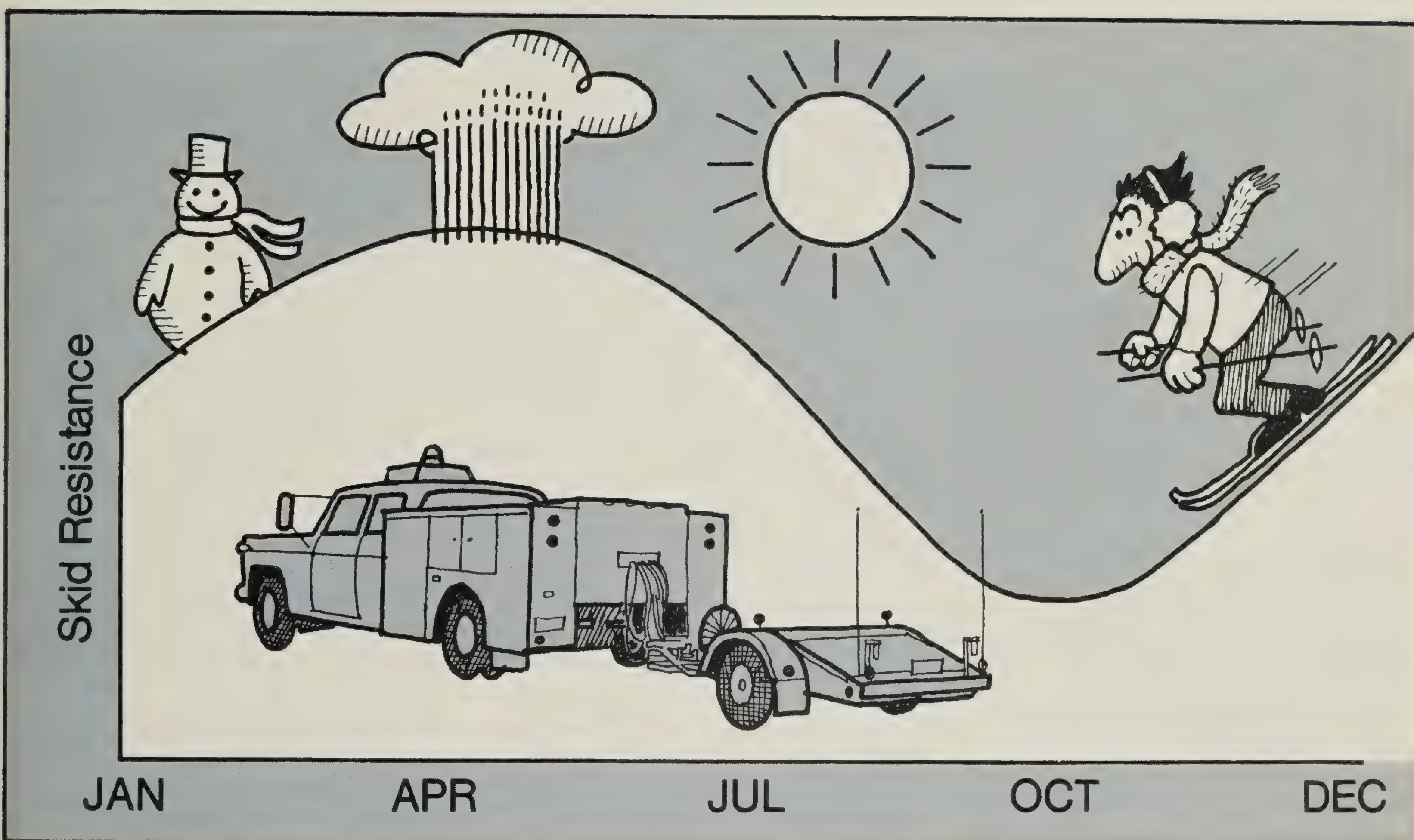

will be launched in FY 1979 as Project 3H, "Social and Economic Concerns in Highway Design and Improvement."

In the traditional research areas involving materials and structures, there is also a new look. In Category 4 (Improved Materials Utilization and Durability) there are three recently initiated projects. Project 4G, "Substitute and Improved Materials to Effect Materials and Energy Conservation in Highways," seeks to reduce dependence on petroleum derived materials for highway construction and repair. There are some exciting developments in the use of sulfur as an engineering material and in activities addressing the problem of shortages of sources of high quality aggregate. The substructure of bridges will get attention in Project 4H, "Improved Foundations for Highway Structures." There is also a new project in the final planning stages aimed at the problem of improved and environmentally acceptable coatings for steel highway structures, which will probably be designated Project 4I. In Category 5 (Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety), a national method for design of portland cement pavements will be sought in Project 5J, "Rigid Pavement Systems Design." The problem of bridges will be pursued in two new projects: Project 5K—"New Bridge Design Concepts"—which will include work on bridge repair and strengthening as well as advanced concepts of prefabrication, and Project 5L—"Safe Life Design for Bridges"—which emphasizes the fracture control problem.

The problems of highway maintenance will also get increased attention. However, because the urgent needs in this field appeared to involve mostly improved equipment and management methods, it will be managed by the Office of Development. A series of projects is being developed under Category 7 (Improved Technology for Highway Maintenance) for this purpose.

## Conclusion

Experience has shown that it takes 3 to 5 years from the time of commitment of the first significant resources to carry out a major research and development effort from conception to implementation and deployment. Adding the 2-year budget cycle to this, it is apparent that major new thrusts require advance planning and multiyear budgeting. The concern of the FHWA's Associate Administrator for Research and Development must therefore include not only responding to current operational problems, but also insuring that there will be ability and a knowledge base for capable response to requests of future operating leadership. It is his responsibility to recommend a program that provides an effective balance among current concerns, a factual basis for policy guidance, the exploitation of new technology, and a solid base for future options. A program such as this should insure that the necessary highway and transportation research will be accomplished to meet the continuing demands of our changing society.




# Seasonal Variations in Pavement Skid Resistance—Are These Real?

by Rudolph R. Hegmon

## Introduction and Definitions

An earlier article by Rice stated that "It has been recognized for some time that pavement surface characteristics undergo seasonal changes which affect the frictional properties." (*1*)[1] There are, however, those who doubt the reality of seasonal changes and who attribute any observed changes to the lack of precision in measuring skid resistance. Such doubts are understandable; measuring skid resistance can be difficult and frustrating. This article will examine whether the lack of precision in measurements can account for the variations of 20 or more SN (skid numbers) reported in Rice's article. (*1*)

First, precision and what precision can realistically be expected in skid testing should be defined. The following definition is given by the American Society for Testing and Materials (ASTM) Committee E-11 on Statistical Methods: "Precision of a measurement refers to the degree of mutual agreement between individual measurements . . ., while accuracy refers to the degree of agreement of such measurements with an accepted reference level . . ." (*2*)

The term precision is often used in a different sense, namely as the number of significant digits in a measurement or computation. (*3*) By this second definition, precision is a measure of "resolution," whereas by the first definition, it is a measure of "repeatability." The variance $s^2$ or standard deviation s, which is the square root of the variance, is the statistical measure of repeatability or the lack of it. Differences between repeat measurements that cannot be

[1] Italic numbers in parentheses identify references on page 62.

explained by identifiable causes are accepted as unavoidable errors; the standard deviation is a measure of this error.

## Errors in Skid Testing

In the measurement of skid resistance, the primary concern is with precision as a measure of repeatability. A single measurement never establishes the skid number of a given pavement. In the United States, skid resistance is measured almost exclusively in accordance with the ASTM Standard Method E-274-77, which recommends at least five measurements per test section. (*4*) Preferably, the number of necessary tests should be determined by the desired precision and the standard deviation of the skid resistance measurement system. National Cooperative Highway Research Program (NCHRP) Report 151 provides guidelines for determining the standard deviation of a skid tester and for determining the precision obtainable. (*5*) Using these guidelines, fewer than five measurements are sufficient in many cases, especially with skid resistance measurement systems which have small standard deviations. Most State highway departments have taken advantage of the services provided by the FHWA calibration centers and, as a consequence, now have a reliable estimate of the standard deviation of their systems. In many cases, the services provided at the centers have resulted in a reduction of the standard deviations and have helped to keep these in bounds.

The second definition of precision, resolution, is a concern in calibrating skid testers. Normally skid resistance is measured in whole numbers with no decimals. It is an accepted rule of thumb that the precision of a measuring system be about 10 times better than the required resolution. (*6*) Thus, skid testers should be calibarated to a precision of 0.1 SN. For example, with skid resistance about 40 SN, calibration to 0.1 SN requires a precision of 0.25 percent or better.

Skid testers are usually calibrated with the use of a force plate calibration system. This is a static calibration whereby the test wheel is placed on the force plate under its full test load. A known force is applied to the force plate in the same direction as the friction force acts on the test wheel during testing. The force registered by the tester instrumentation is compared to the known applied force. The tire deforms somewhat under the action of this force and allows the force plate to move as much as 1 in (25 mm). The force plate is supported on bearings to accommodate this motion, but friction in these bearings may become the primary source of error in the calibration and must therefore be reduced to assure reliable calibration. Figure 1 shows the calibration graphs for equipment supported by ball bearings and the improvement achieved by using an air bearing. (*7*) Using air bearings seems to be the only practical method for achieving acceptable calibration results, provided that the electronic components are of adequate quality.

In a study on error sources in skid resistance testing, calibration errors have been shown to be the largest contributor to the overall variability. (*5*) The other sources of error, in order of magnitude, are as follows: lateral position, chart evaluation, water nozzle and test tire, zero shift in the instrumentation, and temperature during testing. A brief discussion of each follows.

Newly paved surfaces have uniform skid resistance, but the polishing action of traffic, which generally moves in well-defined wheel tracks, results in lower skid resistance in these tracks. Skid resistance between tracks may be as much as 10 SN above the values in the tracks, as shown in figure 2. Obviously, in testing for skid resistance it is critical to measure in the wheel track; the higher readings may give a false sense of safety.

The standard test method (*4*) prescribes that the trace evaluation should begin after the transients (that is, the initial peaks in figure 3) have decayed, and extend over about 1 second of recorded data. However, even in this stable or steady state part of the measurement, manual evaluation of the traces may contribute to a significant error. The two sets of traces in figure 3 were taken with the same skid tester. The average error in evaluating the upper set was 1 SN and 2 SN for the lower set. Although it is clearly easier to evaluate a smoother signal, some pavement surfaces produce rough signals. Signal smoothing can be achieved through filtering, but filtering introduces a systematic error. The four traces in figure 4 are from the same two tests, which were recorded on magnetic tape. In playback onto a chart recorder, no filtering was used in the first case, and a different filter was used in each of the others. The average reading dropped as much as 14 percent.

These two sources of error, straying off the wheel track and chart evaluation, depend largely on the operator and evaluator. It is therefore important to have well-trained and motivated personnel. So far there is no practical method for guiding the skid tester in the wheel track, and we must rely on the operator's skill and reliability. The FHWA calibration centers have performed a valuable service in this respect by providing operator training as part of the equipment calibration.

Data evaluation can be automated, bu other sources of error too complex to be discussed within the scope of this

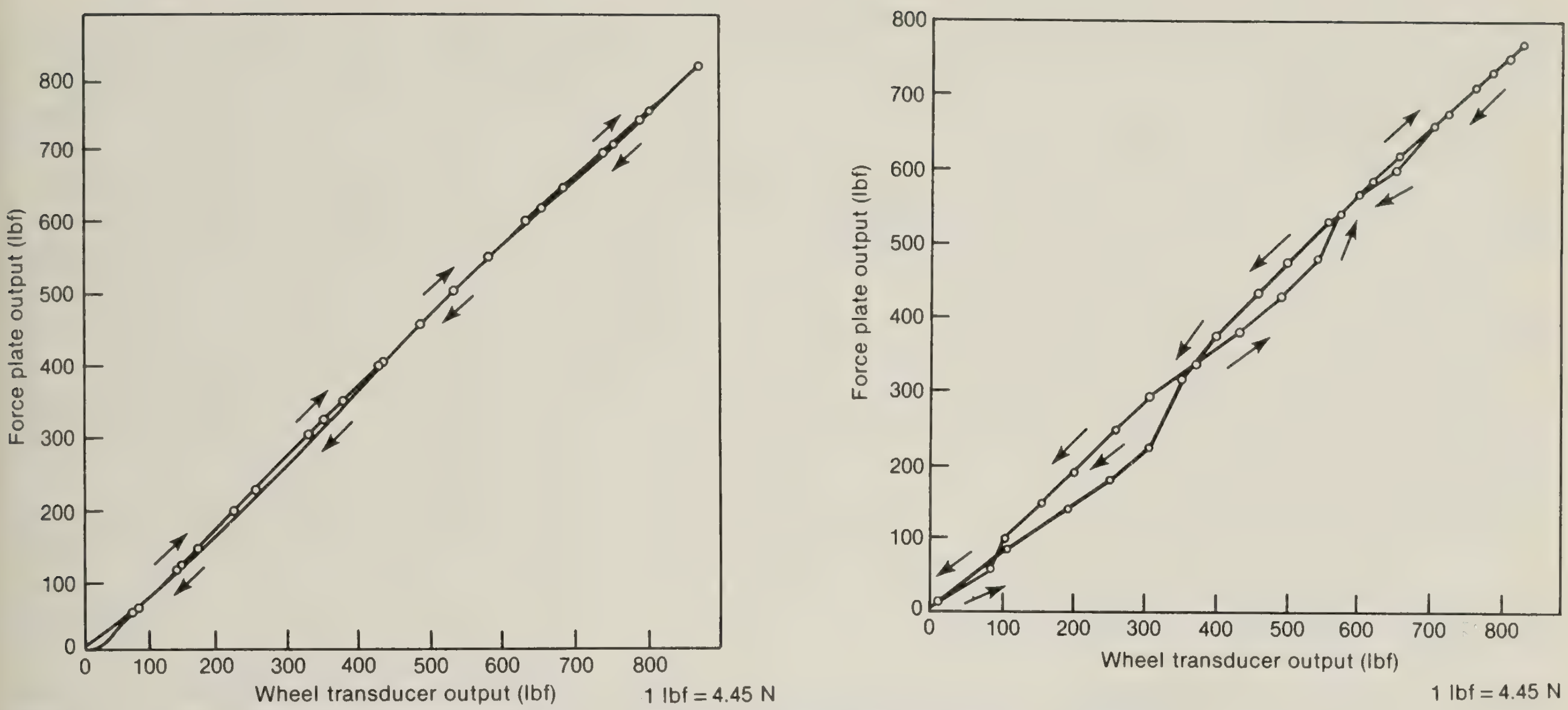



*Figure 1.—X-Y plots of wheel transducer calibration. Left—air bearing force plate. Right—ball bearing force plate. (7)*

article are thereby introduced. This is not to suggest that automated data evaluation should not be used, but the user should be aware that careful design and selection of the equipment is indispensible. Many users of skid test equipment now employ some type of automated data processing, which is valuable in handling the large amount of data in inventory testing.

In the referenced study (5) the combined effects of water nozzle and tires were determined. New data have since been reported which allow discussion of each factor separately. The water nozzle is used to wet the pavement in front of the skidding tire as uniformly as possible. The nominal water film thickness is 0.02 in (0.5 mm) (4), and slight deviations have little effect on the measurement. In a recent study, doubling the water film thickness reduced the mean skid resistance by 1.6 SN. (8) A thin water film adheres to the pavement surface, wets it completely, and reduces friction appreciably. Additional water is easily displaced by the tires except at high speeds when the available time becomes too short and hydroplaning may occur. In this case the amount of water on the pavement becomes an important factor. The actual water film thickness on the pavement cannot be measured unless the pavement is flooded. Thus, when measured film thickness is reported, the measurement is from the water surface downward to the top of the asperities. Under most rain conditions, pavements will not become flooded, although thicker water films may accumulate in rutted wheel tracks. (9)

The water film used in skid testing is intended to wet but not flood the pavement. On a flooded pavement hydroplaning may occur at the higher test speeds, obscuring the difference between a slippery and a nonslippery pavement surface, and resulting in steep skid resistance—speed gradients. For the measurement of pavement skid resistance, flooding must be avoided and the primary consideration must be to deposit the water film uniformly. A recent study found that three differently designed nozzles met the requirement for uniform water distribution and the differences in measured skid resistance were insignificant.[2] Several other nozzles that failed to uniformly distribute water were not included in the skid testing comparison.

[2] "Study of Skid Trailer Water Nozzles," by E. Buth. Unpublished report for Contract DOT-FH-11-7718, 1972.

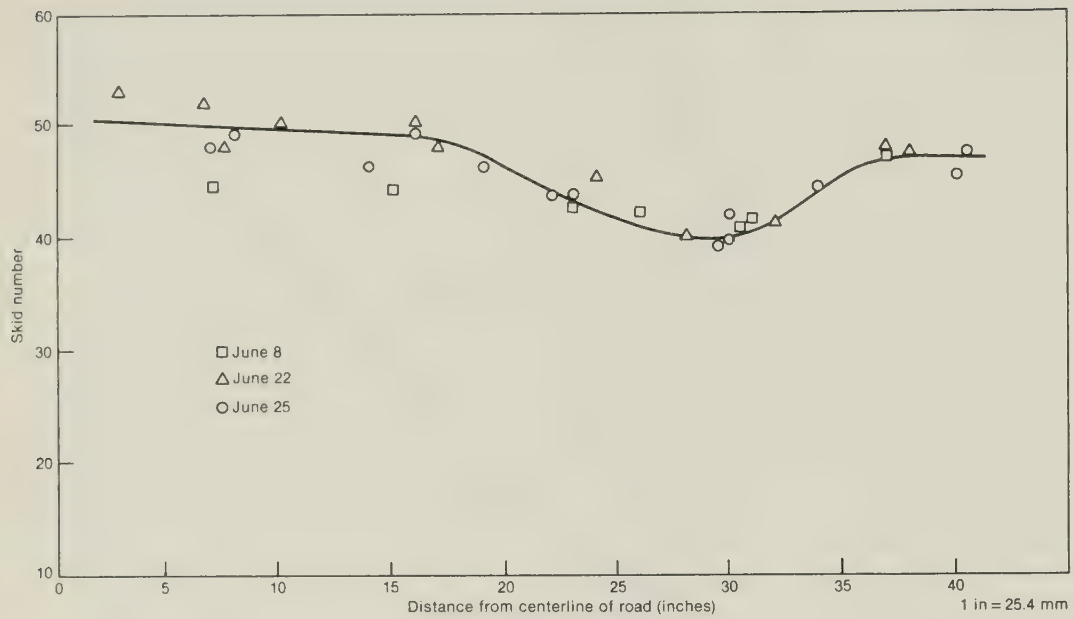



*Figure 2.—Variation of skid resistance across wheel track. (5)*

The skid test tire is standardized (*10*) and does not contribute significantly to the variability in skid testing (*8*), but tire wear (differences in groove depth) has a measurable effect. Assuming a linear relationship, the effect of tire wear from new to minimum groove depth may result in a drop of about 2 SN (*8*) at a medium level of skid resistance. This estimate is based on data obtained with tires in new and shaved-below-wear-line condition, corresponding to wear of about 0.2 in (5 mm). Laboratory results of a recent experimental investigation of the effect of tire wear on friction have essentially confirmed these findings. (*11*)

Good and reliable instrumentation is a must in skid resistance testing and is now readily available. The higher cost for quality instrumentation is easily recovered through reduced need of attention. Zero shift and drift are common instrumentation errors. Figure 5 shows zero shift, that is, the signal did not return to its initial position after the test. Often the cause of this zero shift is not known; it could be the instrumentation, the mechanical drag in the skid trailer, or both. Rezeroing, therefore, becomes a critical task. (*5*) The need for rezeroing is reduced if drift-free instrumentation is used.

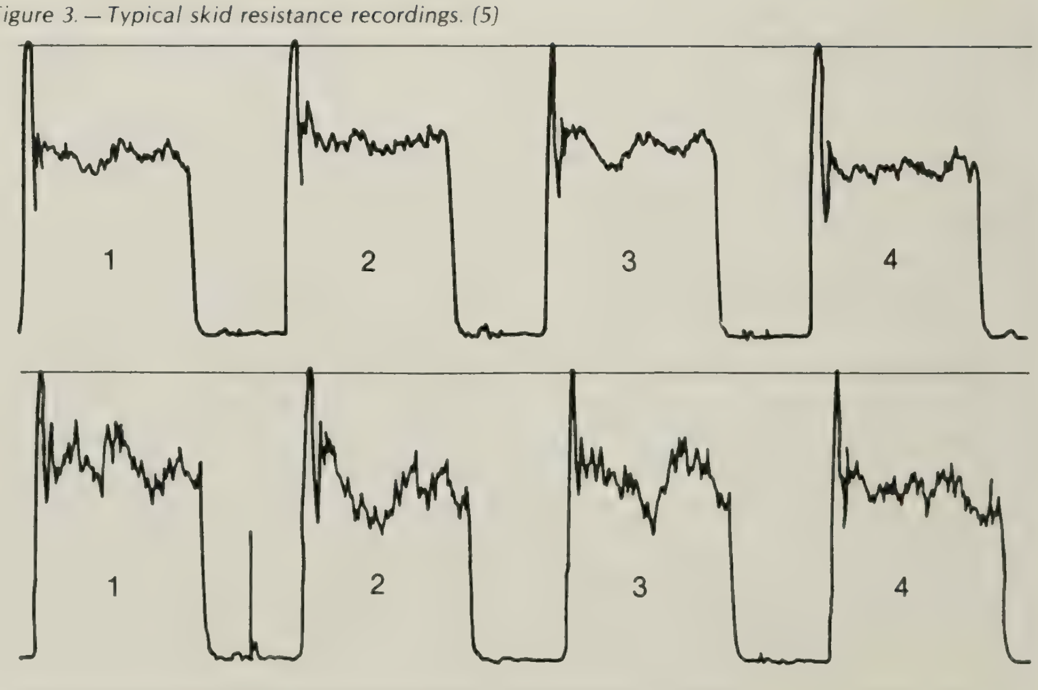
Temperature variations are responsible for some instrumentation drift; this can be reduced by air conditioning the towing vehicle. Temperature variations also affect skid resistance directly, primarily because of the dependence of tire properties on temperature. An average 2 percent decrease in skid resistance can be expected for a 10° F (5.6° C) temperature increase. (*8*)

## Confidence in Skid Testing

How can there be any confidence in skid resistance measurements with so many error sources? The answer is that, if the magnitude of the error can be estimated, confidence limits can be attached to the measurement. Fortunately, the total error of the measurement is not the sum of the individual errors. For example, if there are 5 errors of 3 percent each, the total expected error is not 15 percent, but less than 7 percent (the square root of $5 \times 3^2$). (*6*)

In addition to the measurement error, the total variation in skid testing includes a component which depends on the lack of uniformity of the pavement surface. This, however, is the surface which is being measured and on which

*Figure 3.—Typical skid resistance recordings. (5)*

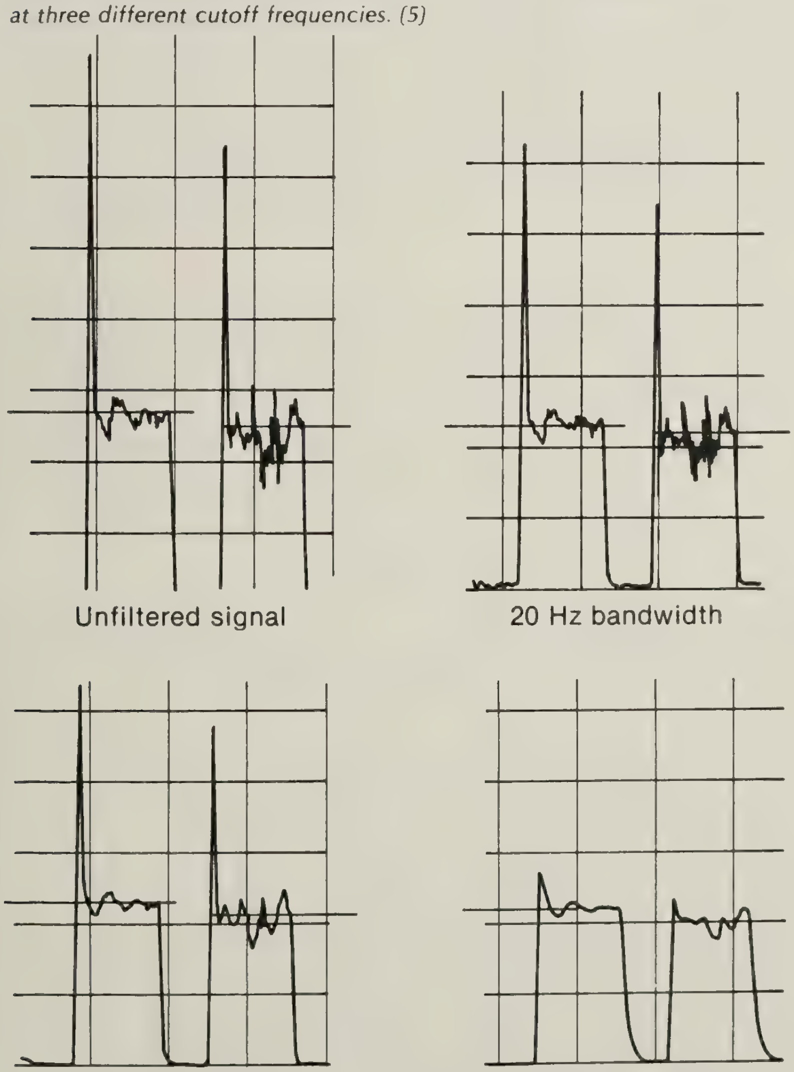


drivers operate their vehicles. Thus, longitudinal variation in skid resistance is not a measurement error, but is included in the total error because there is no simple way of separating its contribution. It is estimated that pavement nonuniformity may increase the standard deviation by a factor of 1.2 to 1.6. (5)

The average standard deviation of a good skid testing system, including the pavement contribution, should not exceed 2 SN. This limit is based on a review of recent results by many skid testers (table 1). An agency involved in skid testing is advised to keep a record of the standard deviations to determine the trend. A standard control chart is useful in observing long term trends. If the trend is an increase in the standard deviation, corrective action is indicated.

Because standard deviation is a statistical quantity, a brief discussion of statistics is appropriate. The variance is a measure of the spread of a distribution, and the standard deviation is its positive square root. "Within variance" is a measure of the spread of several repeat measurements from which a mean value is computed. "Between variance" is a measure of the spread of several such means. (*8*) Statistical theory also shows that the variance of means should be smaller than the variance of single observations by a factor equal to the number of observations.

*Figure 4.—Typical skid resistance record, unfiltered and filtered at three different cutoff frequencies. (5)*




Applied to skid testing, the "within variance" is a measure of the spread of about five repeat tests from which the mean skid number is computed. The "between variance" is a measure of the spread of such means. These could be measurements by several different testers taken at the same time or measurements by the same tester taken at different times. The expected reduction in the standard deviation of the means is generally not realized. This implies that these means do not reflect a random sample from a homogeneous population. The reason for this can only be speculated.

In the first case, the mean skid numbers determined simultaneously by several skid testers show a greater than expected spread. The reason may be slight operational differences among the skid testers. Some or all of the skid testers may have systematic errors. Single tester inaccuracy is reduced significantly as a result of calibration at the FHWA centers. However, from a statistical point of view, the inaccuracy of single testers may be treated as lack of precision for the group of testers.

The second case, that is measurements by the same tester at different times, is of interest in determining seasonal skid resistance variations. Mean skid

*Figure 5.—Skid resistance record showing zero shift.*

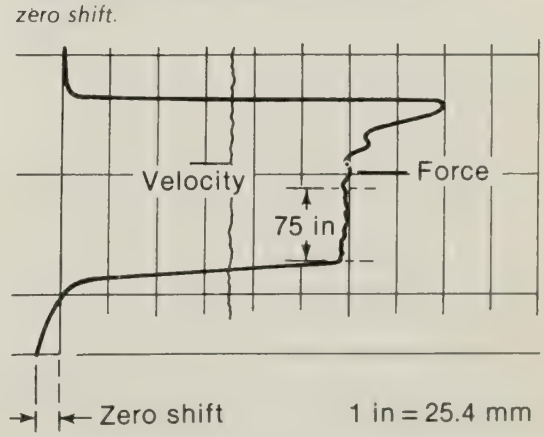


Table 1.—Standard deviations within repeat measurements in skid testing

| Number of skid testers | Range of standard deviations | Test conditions[1] |
|---|---|---|
| 11 | 1.13-1.84 (1.80-2.94) | Tester standard deviation from analysis of variance. To include pavement contribution, values have been multiplied by 1.6 (in parentheses). Five different pavements. (*5*) |
| 11 | 0.86-1.43 (1.38-2.28) | Same as above, but after recalibration. (*5*) |
| 6 | 0.86-2.98 | 40 mph (64 km/h) data, one pavement. (*5*) |
| 1 | 1.60-2.70 | Four pavements, two tire types. (*8*) |
| 2 | 0.89-2.04 | Four pavements. (*14*) |
| 2 | 1.17-3.72 | Same as above, but tests spaced 0.1 miles (0.16 km) apart. (*14*) |
| 2 | 1.48-2.41 | Six pavements, three speeds, ribbed and bald tires. (*15*) |
| 2 | 1.10-4.00 | Five pavements, three speeds. (*16*) |

[1] Repeat measurements refer to each single set of test conditions.

resistance, measured with the same skid tester at short intervals, shows a greater data spread than would be expected from statistical theory. Assuming that the operator skill and tester precision have not changed, the reason for the greater than expected data spread is probably traceable to the pavement surfaces. Skid resistance along a supposedly uniform test section may vary considerably, as shown in figure 6 (*12*), and unless the same location is tested every time, data spread will be significant. Also, the pavement surface (as well as the tire surface) may undergo subtle changes during testing and possibly as a result of repeated testing (fig. 7). Because of this, it is found in skid testing that "within" and "between" variances are of the same order of magnitude, notwithstanding the theoretical predictions.

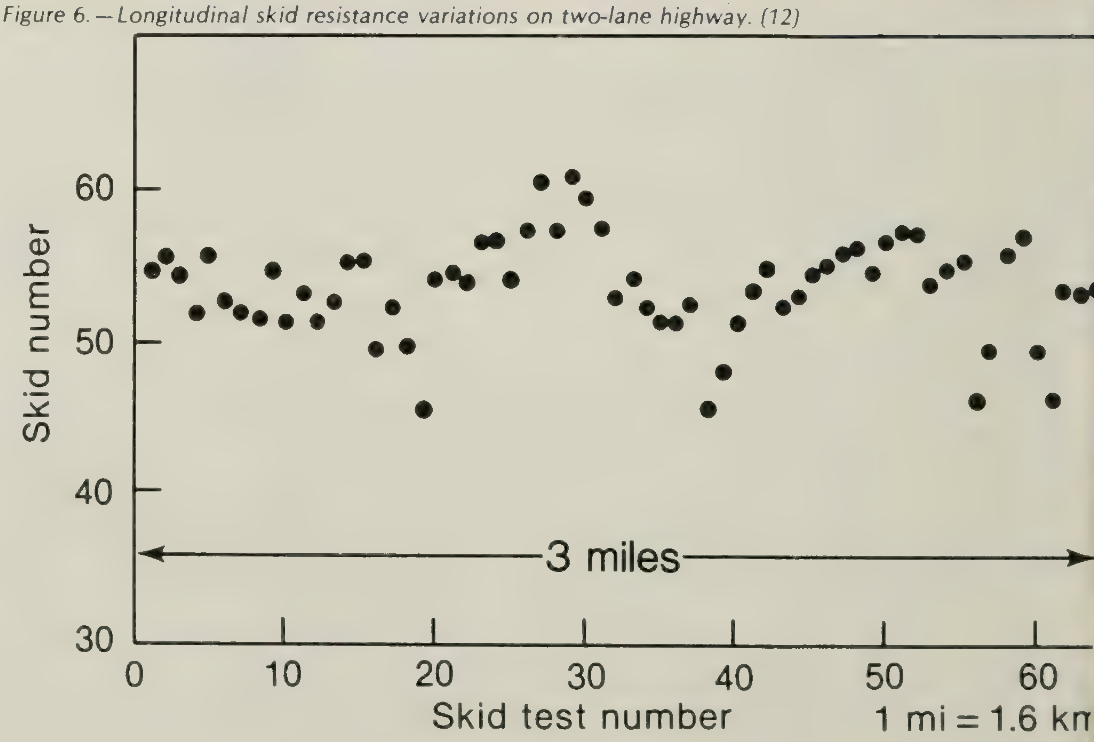
A comparison of the "within variance" and the "between variance" for a particular test program is given in table 2. There were eight replicate tests; thus, the expected "between variances" should be smaller by a factor of 8. The actual reduction is by a factor of about 1.5, which is not much of an improvement. Therefore, the same levels of standard deviations may be used for repeat tests and for means. This gives a conservative estimate and should therefore lead to increased confidence in the test results.

## Errors in Skid Testing Versus Seasonal Variations

Measurement of skid resistance, like any other measurement, has some inherent variability. Therefore, small differences between consecutive measurements are inevitable, even with precautions in testing. Using the standard deviation of 2 SN, one can predict the probability of large deviations from a mean value. It is assumed that mean skid resistance data, for any given pavement, are normally distributed. This assumption is based on the Central Limit Theorem. (*13*) Basically, the theorem states that even though single data points may not have a normal distribution, the distribution of means of sets of data points tends to be normal.

For a normal distribution, the limits of ±2.5 standard deviations include more than 98 percent of the population. In other words, mean skid resistance values, obtained with a system which has a standard deviation of 2 SN, should fall within ±5 SN in 98 of 100 tests. Variations of more than 10 SN are highly unlikely. As a practical ex-

*Figure 6.—Longitudinal skid resistance variations on two-lane highway. (12)*



ample, recent data from a current study on seasonal skid resistance variations show a difference of 12 SN between April and September 1977 (fig. 8).[3] These data, taken with the Pennsylvania Transportation Center skid tester, had a standard deviation of 1.43 SN at the time of the NCHRP correlation program. (5) That means that the minimum and maximum skid numbers are more than four standard deviations from the mean (0.5(44 + 32) = 38). The probability for this to happen by chance is about 0.006 percent. Assuming that the tester performance has deteriorated and its present standard deviation is 2 SN, the probability of chance variations of ±6 SN is still only 0.27 percent. An interesting observation in figure 8 is that short term variations can be of the same magnitude as seasonal variations.

Another consequence of the normal distribution of means is that the probability of the results being too high is the same as the probability of the results being too low. Therefore, the number of pavements having high skid resistance in spring and low skid resistance in fall should be the same as the number of pavements changing the other way. There is overwhelming evidence that most pavements exhibit lowest skid resistance in early fall, as can be seen for the two bituminous pavements in figure 8. This fact cannot be explained by pure chance.

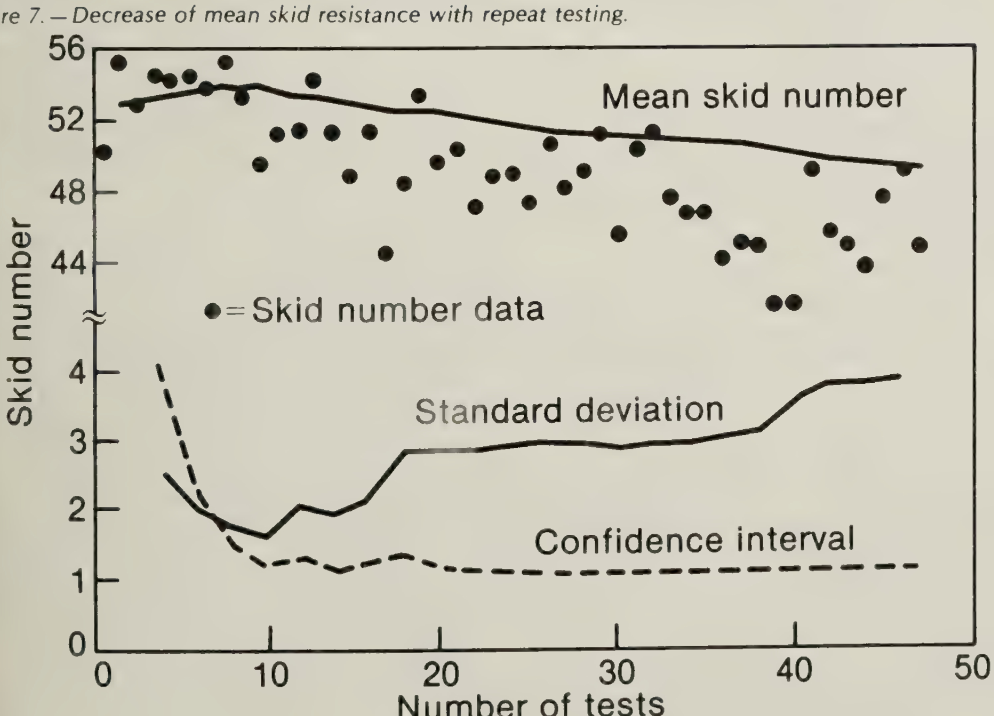
[3] "Seasonal Skid Resistance Variations," by Dr. J. J. Henry, principal investigator. Report being prepared from test data from Pennsylvania HP&R study 41H3 352.

**Table 2.—Comparison of "within" and "between" error variances**

| Tire and speed (mph) | Pavement 2 | Pavement 11 | Pavement 1 | Pavement 6 | Means | Pooled "within variance" standard deviation | Pooled "between variance" standard deviation |
|---|---|---|---|---|---|---|---|
| E 249: | | | | | | | |
| 20 | 5.80 | 4.21 | 5.19 | 12.60 | 6.94 | 4.46 | 3.38 |
| 40 | 1.99 | 2.00 | 4.35 | 5.15 | 3.37 | 2.11 | 1.84 |
| 60 | 1.54 | 1.40 | 5.80 | 3.54 | 3.07 | | |
| E 501: | | | | | | | |
| 20 | 6.35 | 5.09 | 5.23 | 11.71 | 7.09 | 4.80 | 2.97 |
| 40 | 2.52 | 1.92 | 5.07 | 5.95 | 3.87 | 2.19 | 1.72 |
| 60 | 1.54 | 1.67 | 6.45 | 4.12 | 3.45 | | |

1 mph = 1.6 km/h

*Figure 7.—Decrease of mean skid resistance with repeat testing.*




## Summary

Skid test data from various sources have confirmed that the variability in skid testing has a mean standard deviation of 2 SN or better. Using this estimate and assuming that pavement skid resistance, as measured by mean skid numbers, is normally distributed, the following conclusions have been drawn:

- Ninety-eight percent of the test results for any given pavement should be within ±5 SN (±2.5 standard deviations) of the mean skid number.
- Up to 2 percent of the test data may, by pure chance, fall outside of this 10 SN band.
- The likelihood that lack of precision may cause skid resistance variations larger than 10 SN is extremely small.
- Seasonal skid resistance changes of any magnitude cannot be explained by chance alone. If they could, variations would be manifested by increases for approximately 50 percent of the pavements and by decreases over the same period for the remaining pavements.

There can be no doubt that systematic, large changes in skid resistance are real and are related to changing conditions. Lack of precision in skid testing may obscure the results by making the

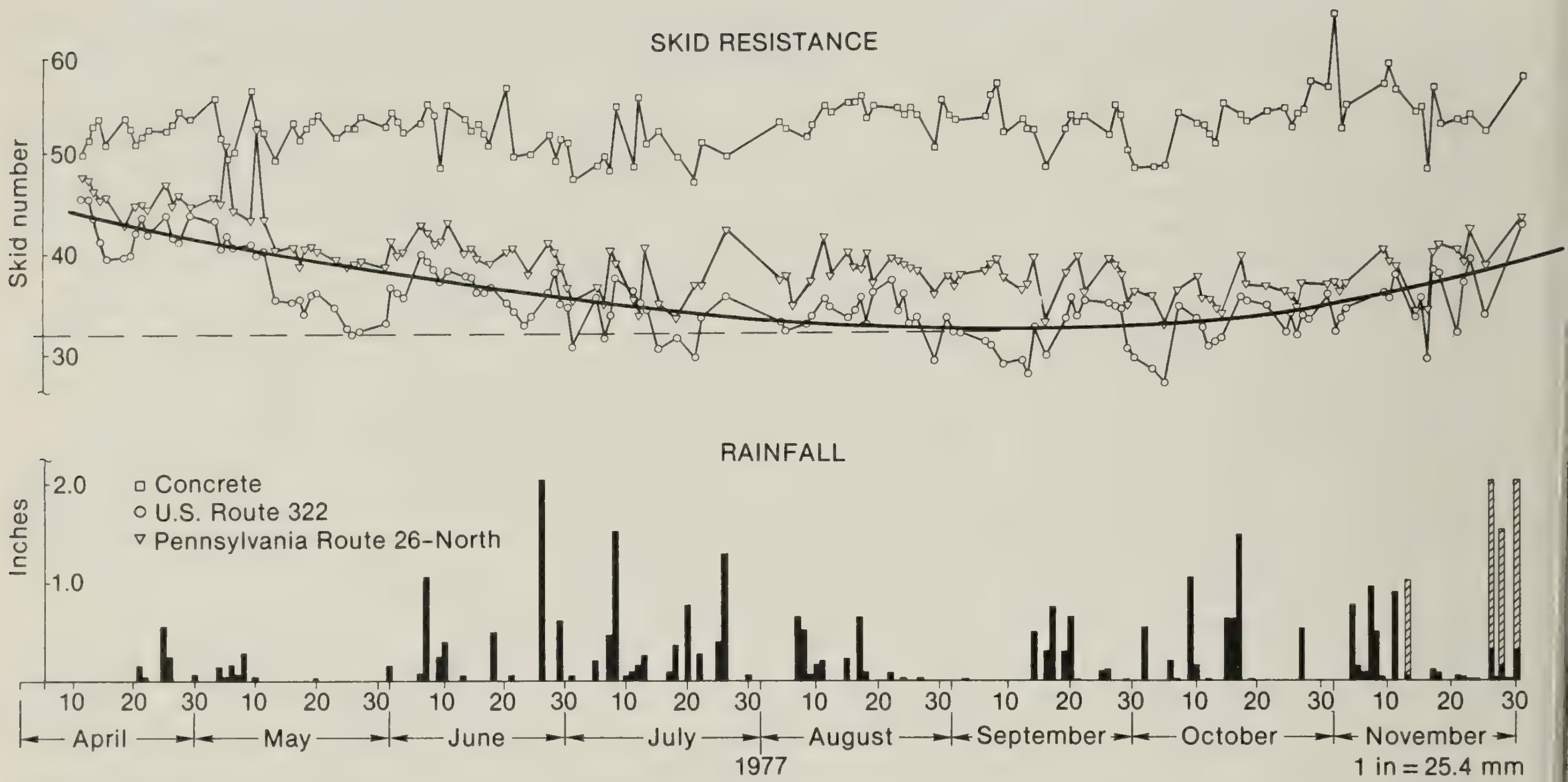



*Figure 8.—Skid resistance data for three pavements over an 8-month period.*

changes appear either larger or smaller than they really are. For this reason it is important to keep the skid test system in top condition. For monitoring system performance, a continuous record of the system variability is recommended. Increasing standard deviations are clear indicators of problems that need corrective action.

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# Ice Loads on Bridge Piers

by Frederick J. Watts and Walter Podolny, Jr.

## ntroduction

ce forms annually on rivers and lakes in a large part of the Jnited States (fig. 1). (*1*)[1] Ice pressure on structures must be :onsidered in the design of bridge crossings in streams, ivers, flood plains, lakes, or estuaries located in this region.

Vhen faced with the problem of designing a pier in a large iver having severe ice conditions, early engineers designed nassive piers; the dimensions were generous and were ›ased on the engineer's best judgment. This conservative rend has continued to this day.

n response to the need for reliable design information, the Iydraulics and Review Branches of the Bridge Division, Ofice of Engineering, Federal Highway Administration FHWA), conducted an in-house study of ice loads on piers.

*Figure 1.—The region north of the line has average temperatures of less than 32° F (0° C) during the coldest month of the year, 1 ft (0.305 m) or more of frost penetration in the ground during late winter, and 60 days or more of ice on navigable water. (1)*

Excerpts from the study report[2] are presented here. Physical properties of ice, variables that affect ice forces, measurements of ice pressures on bridge piers, and a proposed ice load specification for bridge piers are described.

Italic numbers in parentheses identify references on page 70.

2 "Ice Loads on Bridge Piers," Structural Engineering Series No. 1, Bridge Division, Office of Engineering, *Federal Highway Administration,* Washington, D.C., January 1976.

## Ice Forces on Piers

Both dynamic and static ice forces must be considered when designing piers for rivers, estuaries, or lakes in cold climates. Horizontal static forces can result from thermal expansion of thick ice sheets, from ice jams bearing directly on a pier or superstructure, and from ice pushes created by strong winds. Static uplift forces can occur where a pier is encased in an ice sheet and a change in stage occurs. Some examples of bridge damage caused by ice jams and pushes are shown in figures 2 and 3. (*2, 3*)

Dynamic forces occur when a moving ice sheet or ice flow impinges directly on a pier. Because of unsymmetrical formation of ice jams or because of river alinement, the ice flow can be directed toward the side of the pier, which creates a significant load on the pier in the direction of minimum pier strength. The pressure exerted by the ice on the pier will be quite different depending on the mode of ice failure and whether the loading is static or dynamic. *Ductile* failure of ice is associated with static loading. Although the ice cover may be relatively thick (ice jamming and pushes), the maximum effective pressures are low[3], 75 psi (0.517 MPa) or less. *Brittle* failure of ice is associated with dynamic loading. In this case the ice is generally thinner, but effective pressures are high, ranging from 100 to 400 psi (0.689 to 2.758 MPa).

The current American Association of State Highway and Transportation Officials specification (article 1.2.17) for evaluating the force of ice on highway bridge piers addresses only the dynamic load problem:

> All piers and other portions of structures which are subject to the force of flowing water, floating ice, or drift shall be designed to resist the maximum stresses induced thereby.
>
> The pressure of ice on piers shall be calculated at 400 pounds per square inch (2.758 MPa). The thickness of ice and height at which it applies shall be determined by investigation at the site of the structure. (*4*)

This specification does not consider static ice pressures—jams, ice pushes, thermal expansions, and uplift; it does not address the lateral load problem, that is, the line of action of the applied ice load; it does not consider the effect of sloping the leading edge of the pier (battering); and it specifies only one effective ice pressure (400 psi [2.8 MPa]).In actuality, ice pressure may vary significantly depending upon the type of ice, the temperature of the ice, and the ratio of ice thickness to pier width.

[3] Effective pressure is defined as the force exerted by the ice on the pier divided by the projected frontal area of the pier over which the force is applied

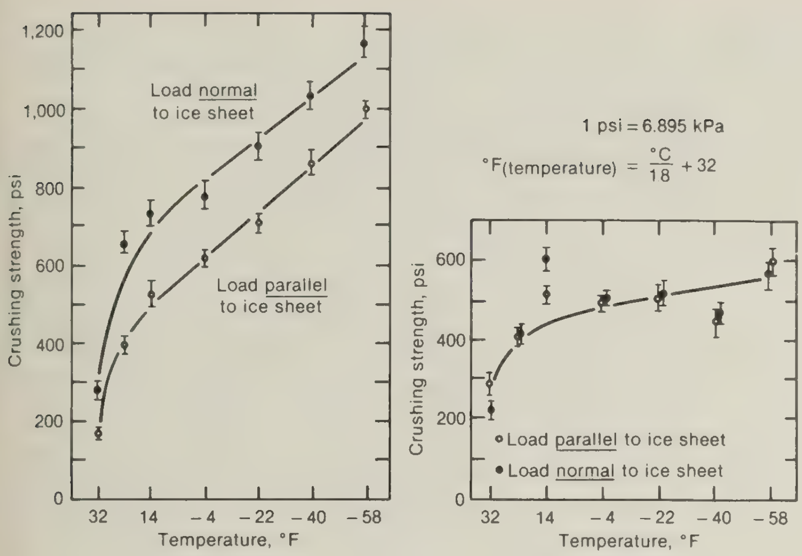
## Physical Properties of Ice

The strength of ice varies drastically with temperature, with the structure and density of the ice (the manner in which it forms), and with the quantities of impurities and bubbles of vapor entrapped in the ice. Laboratory crushing strengths of ice vary from 50 psi to 1,200 psi (0.345 to 8.274 MPa). High strengths are always associated with very dense ice that is well below the freezing temperature; low strengths are associated with ice at or near the melting point. Figure 4 shows an example of the wide variation in ice strength as a function of change in temperature, direction of applied load, and type of ice (clear lake ice versus snow ice). (5)

There are many problems associated with estimating the crushing strength of *river* ice at the time ice runs occur. The

*Figure 2.—Ice shoving on bridge at Logan, Mont., 1963. (2)*

*Figure 3.—St. John River Bridge, Allagash, Maine—superstructure has slid 3 ft (1 m) on pier number 4 from its original position. (3)*




a. Clear lake ice b. Snow ice

*Figure 4.—Crushing strength versus temperature of ice on Portage Lake, Mich. (5)*

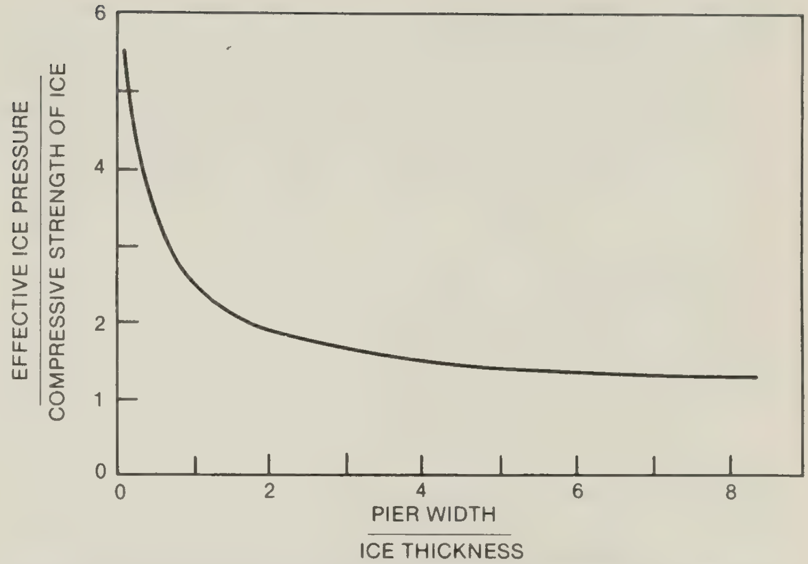



*Figure 5.—Relationship for modifying effective ice pressure as a function of the ratio of pier width to ice thickness.*

temperature of the ice at the water-ice interface in a river must be about 32° F (0° C) at all times. During the winter period when the ice cover is static, the temperature of the ice near the air-ice interface will be close to the air temperature. The air temperature varies significantly both daily and seasonally. Because the ice temperature varies between the top and bottom of the slab, the mechanical properties of the ice will also vary from top to bottom. In addition, the ice cover is generally built up of successive layers of columnar ice, snow ice, and agglomerates, thus further complicating the prediction of average ice strength.

The ice cover at the time of breakup is usually quite weak as a result of surface melt, fractures from the daily rise and fall of stage during spring runoff, and surface flooding of large areas of ice. When the ice starts to move, it is generally near 32° F (0° C)—the temperature of minimum crushing strength.

The highest ice strengths occur when a thick cover of columnar ice, chilled at a very low temperature for an extended period of time, is lifted by a change in river stage (release from an upstream reservoir or a large, rapid runoff event in the headwaters), and moves downstream essentially intact. Even under these conditions, the temperature of the ice at the water surface is 32° F (0° C). Because of the variation in the density of ice throughout the cover and the racking, fracturing, and flooding of the ice sheet caused by change in stage and irregularities of channel section and alinement, only a small quantity of ice could be significantly below 32° F (0° C). To date, the maximum impact ice pressures measured on piers is around 150 psi (1.034 MPa). (6) Thus, it is apparent that the factors mentioned above combine to reduce considerably the effective ice pressure from the theoretical crushing strength of cold ice tested under laboratory conditions.

The rate of loading and the effect of lateral support (triaxial effect) are also significant in testing a sample of ice. For the purpose of design, these effects can be considered by using the relationship shown in figure 5.[4] This figure illustrates how the effective ice pressure is reduced as the ratio of pier width (or pile diameter) to ice thickness increases.

## Formation of River Ice

River ice is formed in nature by two general processes, frazil ice evolution and the growth of shore ice.

*Frazil* ice is formed in large quantities when the surface layer of turbulent water becomes supercooled to 0.02° to 0.12° F below freezing (−0.01° to −0.07° C). The supercooled water is carried below the surface and frazil ice (small disk-shaped ice crystals) is formed. An example of the quantity of ice that can be formed by this process is the estimated 3 million $yd^3$ (2.29 $Mm^3$) of frazil ice produced per day in the 40 $mi^2$ (103.6 $km^2$) of open river surface along the Niagara River between Lake Erie and Lake Ontario. The conditions necessary for producing frazil ice are an open stretch of turbulent water, air temperature well below freezing, stream water near freezing temperature, and low levels of incoming radiant heat.

4 "Selected Aspects of Ice Forces on Piers and Piles," by C. R. Neill. Paper presented at the Atlantic Regional Hydrotechnical Conference, Fredericton, N.B., Canada, Nov. 4–5, 1975.

Frazil ice generally evolves through the following sequence of forms: disks, flows, slush, ice pans, and consolidation of ice pans into a solid ice cover. Frazil ice may also adhere to solid objects under water (such as rocks, weeds, and ice cover) and build up significant deposits. The frazil evolution process is dominant in wide, high velocity streams having rapids and pool reaches.

*Shore* ice forms in still water along the banks as a result of cold air and cold bank material. A clear solid ice sheet forms across the water surface from the bank toward the deepest part of the stream. This formation process is dominant in low-gradient, narrow streams where the bank area is in contact with a high proportion of the stream flow.

Because of the wide variation in meteorological and hydrological conditions throughout the season and from year to year, many possible combinations of ice can be formed: solid black columnar ice, solid black ice formed of congealed frazil slush, compacted slush and ice plates, dense snow ice, light snow ice, or fresh compacted snow.

## Ice Forces on Piers: The Effect of Pier Nose Shape

A thick sheet of ice impinging on a pier may come to rest, pivot about the pier, or fail by compression, shear, or flexure at the point of impact. The impact force of a sheet of ice coming to rest can be computed using the momentum formula:

$$\text{Force} = \frac{\text{(mass) (change in velocity)}}{\text{(increment of time during which the velocity change occurs)}}$$

The force computed by this formula can then be compared to the force estimated by an ice indentation formula. The *minimum* force computed would be the appropriate design force.

For a large, thick ice sheet impinging on a vertical pier nose, both experimental and field observations verify that ice failure can be by indentation that leaves a clean slot in the ice. At the contact point, a very complex plastic-elastic failure zone develops (fig. 6) (5), and tension cracks propagate into the ice sheet. The sheet may eventually split or rotate about the pier nose, or both, but initially a clean smooth slot is cut.

Following the Russian theory of Korzhavin (*7*), the effective ice pressure for an indentation type of failure can be expressed as follows:

$$P_e = C_1 C_2 C_3 C_c$$

Where,

$P_e$ = The effective ice pressure applied to the contact area of the pier.

$C_c$ = The compressive strength of an unconfined ice sample obtained from the ice sheet.

$C_1$ = An indentation coefficient ranging from 1 to 2.5. This coefficient accounts for the fact that the crushing strength of a small cube of ice confined in a thick, wide ice sheet will be much higher than the unconfined crushing strength of an isolated ice cube—that is, the triaxial stress effect.

$C_2$ = A contact coefficient ranging from 0.4 to 0.8 as a function of pier width and ice flow velocity. When ice is failing at a pier nose, incomplete contact between the pier and the ice occurs. Only the rigid high points of the unfractured ice are simultaneously loaded at any one time, in contrast to the uniform distribution of pressure on the end of a capped ice sample loaded to failure under laboratory conditions. For this reason, the apparent crushing strength of ice failing at a pier nose will always be less than the laboratory crushing strength of an ice sample.

$C_3$ = A shape coefficient determined from a series of laboratory indentation (penetration) tests on ice samples using indentures with various shaped tips. Combining the laboratory data with observed field failure data, Korzhavin prepared a table of $C_3$ values as a function of the internal angle of the pier nose. $C_3$ ranges from 1.0 for a blunt nose to 0.54 for a sharp-edged nose.

The force to be applied to the nose of a vertical pier is as follows:

$$F = P_e \, t \, w$$

Where,

$F$ = The horizontal force.

$t$ = The thickness of the ice sheet.

$w$ = The width of the pier.

$P_e$ = The effective ice pressure previously defined.

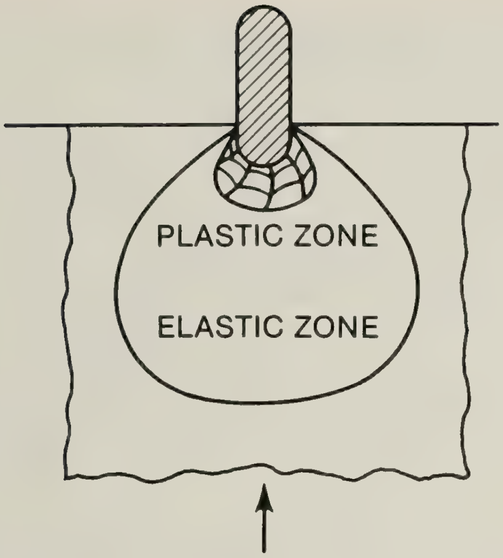


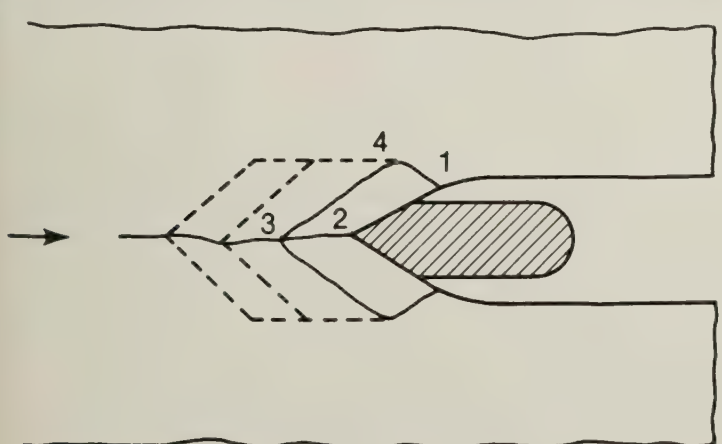

*Figure 6.—Stress zones. (5)*

## Ice Forces on a Pier: The Effect of a Sloping Leading Edge

When a moving ice sheet impinges on a *sloping* pier nose, the sheet tends to ride up the nose; when a sufficient area is supported above the water, the sheet tends to fail as a series of rectangular plates by a combination flexure and shear failure mode (fig. 7). (5) The attack velocity and the narrow dimension of the fractured ice plate are approximately constant; consequently, the ice fails in a regular manner. As a result, the structure is subjected to a cyclic loading, and resonance can be a problem for narrow sloping structural members.

Based on indirect field measurements, laboratory-developed relationships, and the data cited above, the Russians have developed a standard procedure for determining dynamic

*Figure 7.—Progressive bending failures of an ice sheet at an inclined edge of a pier. (5)*




loads on bridge piers. (*8*) The procedure requires the use of regional coefficients developed specifically for Russia. Because regional coefficients for North America are not available at this time, the design procedure cannot be used in this country until appropriate coefficients are developed.

## Measured Ice Forces on Piers (Direct)

The most comprehensive and reliable data available have been obtained from instrumented piers installed on two northward flowing rivers in central Alberta, Canada—the Athabasca River and the Pembria River. (*6, 9, 10*)[5] Piers with articulated noses (pinned at the bottom, supported longitudinally by a load cell at the top) were constructed in the Athabasca River at Hondo and in the Pembria River at Pembridge. At the Hondo site, the river is approximately 850 ft (259 m) wide, and the pier is 7.5 ft (2.3 m) wide. At the Pembridge site, the river is approximately 250 ft (76.2 m) wide, and the pier is 2.8 ft (0.85 m) wide. Ice thickness on both rivers ranges from 1.5 to 3 ft (0.45 to 0.91m), and heavy ice runs occur. The maximum rise in stage during the breakup period is 1.5 ft (0.45 m). Penetration velocities have ranged from 1 to 5 ft/sec (0.3 to 1.5 m/sec).

At the Hondo site, the articulated nose block has a semicircular cross section in plan view—nose piece 24 ft (7.3 m) high, 7 ft (2.1 m) wide, 3 ft (0.9 m) long. The leading edge is battered 23° from vertical (figs. 8 and 9). (*10*) The nose was constructed as an integral part of the pier, with a float well and access shaft within the pier for measuring stage and for servicing the load cell.

When ice movement occurs, the response of the load cell and the time are recorded on a strip chart at each site. Concurrently, the ice action in the vicinity of the pier nose and the dial of a clock synchronized with the strip chart are filmed. This permits comparison of the recorded force with particular events observed on the film. Ice thickness is estimated by measurements of in situ ice thickness prior to ice movement and by scaling the thickness of ice plates from film strips. Alternate dark and light horizontal bands of known dimension have been painted on the pier noses for scaling purposes.

Data collected from 1967 through 1972 have been analyzed and reported. (6)[6] The unit pressures on the projected area of the pier nose (ice thickness times pier width) were computed by using load cell forces and measured projected

5 "Selected Aspects of Ice Forces on Piers and Piles," by C. R. Neill. Paper presented at the Atlantic Regional Hydrotechnical Conference, Fredericton, N.B., Canada, Nov. 4–5, 1975.

6 Ibid.

areas. The maximum average unit pressure (averaged over 0.4 seconds) for a vertical pier nose (Pembridge site) subjected to loads from moving ice flow about 20 in (508 mm) thick has been about 130 psi (0.90 MPa). The highest instantaneous pressure has been about 300 psi (2.07 MPa): an instantaneous spike on the chart resulted from the impact of the ice flow on the slender vertical pier nose of small mass freely supported at each end.

However, when one considers a massive pier that is supported longitudinally by backfill around the pier and piling and by the reaction of the superstructure at the top, instantaneous loads are not significant. A certain time-force product is required to accelerate the massive restrained pier. Therefore, a force averaged over 0.3 or 0.4 seconds might be appropriate for design of massive piers. This aspect of the problem needs further study. Certainly, for the case of slender structures (individual piles, cables, tower legs), instantaneous peaks and resonance must be considered.

*Figure 8.—Load-measuring pier, Hondo Bridge. Painted stripes 3 ft (0.9 m) high enable ice level to be read from photographs. (10)*
*—courtesy, Alberta Department of Highways and Research Council of Alberta*

For the Hondo site, which has a battered pier 23° from vertical and 7 ft (0.21 m) wide, the maximum deduced unit pressure, averaged over 0.1 second from ice flows about 20 in (508 mm) thick, has been 81 psi (0.56 MPa). The maximum instantaneous peak stress has been about 162 psi (1.12 MPa). These stresses are much lower than those reported for the Pembridge site, although ice conditions were similar. The batter of the pier nose is assumed to account for most of the reduction. However, the larger ratio of pier width to ice thickness and the larger mass (inertia) of the articulated nose are also factors.

## Indirect Estimate of Ice Loads (Canada)

The collapse, or ultimate, strength of five piers that had satisfactorily withstood heavy flows of ice for 22 to 66 years was estimated and reported. (9) The maximum thickness of ice at each of the sites was also known. This information was used to deduce the maximum effective ice pressure that theoretically would cause collapse. The estimated maximum effective pressures ranged from 120 to 250 psi (0.83 to 1.72 MPa). None of the structures showed any signs of failure; therefore, it was concluded that the maximum effective ice pressures at the sites had been less than 120 to 250 psi (0.83 to 1.72 MPa).

The "Kinematic method" reported by Korzhavin consists of recording the velocity and direction of a moving ice sheet as it impinges on a pier. (*7*) The apparent force is determined by solving the momentum equation using the maximum deceleration rate of the ice sheet, the drag exerted on the bottom of the ice sheet by underflow, the slope component of the weight of the ice sheet, and the unbalanced hydrostatic forces on the upstream and downstream edge of the sheet. Numerous sites were analyzed using this procedure. The maximum unit pressure reported was 25 psi (0.17 MPa) for a blunt pier nose 25.3 ft (7.7 m) wide. The ice was badly deteriorated, and pier width to ice thickness ratios for all sites were large—conditions which lead to minimum effective ice pressures.

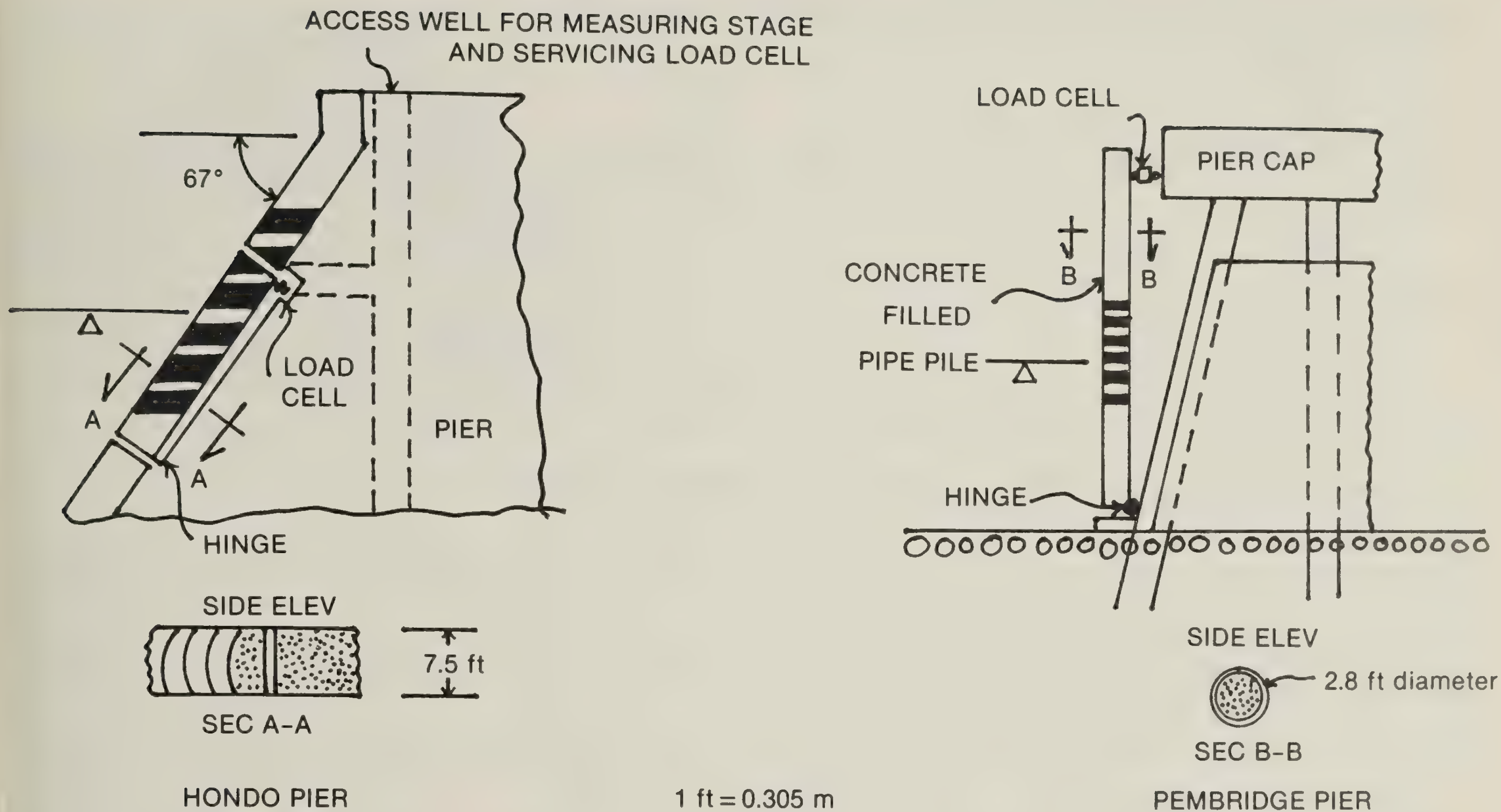



*Figure 9. — Pier details.*

## New Canadian Code for Estimating Ice Forces

After several years of study and a careful review of available information, the Canadian Committee of Highway Bridges has adopted a new code for estimating ice loads on highway bridges. (*11*) The code specifies that consideration shall be given to dynamic ice pressures due to moving ice sheets, to static pressures due to thermal expansion of ice and ice jams, and to static uplift or vertical loads resulting from adhering ice in waters of fluctuating level.

Horizontal forces resulting from the pressure of moving ice are to be calculated by the following formula:

$$F = C_n P_e t w$$

Where,

$F$ = Horizontal ice force on pier.

$C_n$ = Coefficient for nose inclination (table 1).

$P_e$ = Effective ice pressure.

$t$ = Thickness of ice in contact with pier.

$w$ = Width of pier or diameter of circular-shaft pier at the level of ice action.

The specified effective ice pressure ranges from 102 to 406 psi (0.7 to 2.8 MPa), depending on the type of ice and the ice temperature at the time of the ice run.

The effective ice pressures cited are for a width of pier to ice thickness ratio of 2. They are modified as necessary for variation in this ratio, as shown in figure 5.[7]

A force not less than 15 percent of the longitudinal force of ice must be applied transversely to the longitudinal axis of the pier. Where the longitudinal axis of the pier is not parallel to the principal direction of ice forces, the force on the pier shall be calculated by the formula and resolved into vector components; not less than 20 percent of the total force is to be applied transversely for this condition.

The Canadian specification thus covers all significant aspects of ice loads on piers, and it incorporates the latest ice research data.

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7 "Selected Aspects of Ice Forces on Piers and Piles," by C. R. Neill. Paper presented at the Atlantic Regional Hydrotechnical Conference, Fredericton, N.B., Canada, Nov. 4-5, 1975.

Table 1.—Coefficients for nose inclination

| Inclination of nose to vertical (degrees) | $C_n$ |
|---|---|
| 0 to 15 | 1.00 |
| 15 to 30 | 0.75 |
| 30 to 45 | 0.50 |

## Summary and Conclusions

Uncertainties associated with estimating the mechanical properties of ice preclude a rigorous analysis of the ice-pier interaction. Properties of ice differ drastically according to the direction of loading, the temperature of the ice, the quality of the ice, and the rate of loading.

The best that can be done with the information at hand is to design in accordance with the current Canadian specification. (*11*) The specification is based on observed behavior of piers constructed in rivers with large ice runs and on the most reliable ice-force measurements obtained to date. This code requires that both dynamic and static loads be considered, provides the engineer with a reasonable range of effective ice pressure, and considers significant variables such as the batter of the pier nose and the ratio of pier width to ice thickness.

Much remains to be accomplished in the study of ice forces on structures. Additional piers should be instrumented at both severe ice run sites and moderate ice run sites. The effect of nose inclination and the significance of the ratio of pier width to ice thickness should be studied further. In all likelihood, even the Canadian specification describes much too severe a load for some piers constructed in the United States. (*11*)

A standard procedure is needed for sampling and measuring mechanical properties of river ice, and a data collection network should be established. A reliable data bank would be invaluable both to designers and to researchers.

The development and verification of methodologies for assessing the potential for forming ice jams and estimating ice jam heights should be pursued. Significant preliminary work has been done, but much work remains. A broad-based effort is necessary to accomplish these objectives.

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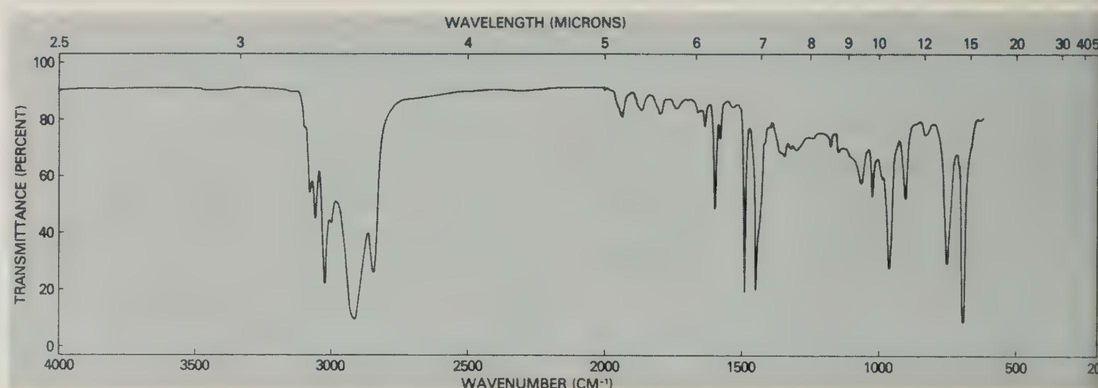
# Recent Research Reports You Should Know About

**The following are brief descriptions of selected reports recently published by the Office of Research, Federal Highway Administration, which includes the Structures and Applied Mechanics Division, Materials Division, Traffic Systems Division, and Environmental Design and Control Division. The reports are available from the address noted at the end of each description.**




### Styrene-Butadiene Latex Modifiers for Bridge Deck Overlay Concrete, Report No. FHWA-RD-78-35

**by FHWA Materials Division**

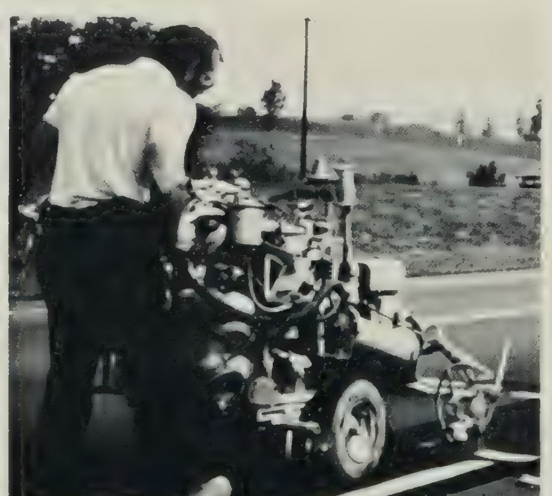
Latex modified concrete overlays are being used in bridge deck rehabilitation and also to protect new bridge decks from rapid deicer-borne chloride intrusion. Extensive research was done to evaluate four commercially available styrene-butadiene (S/B) latex modifiers for bridge deck overlay concrete and to develop chemical specifications for the material, a prequalification program to permit evaluation of other S/B latex modifiers which become available, and a certification program to insure that the user receives a prequalified product.

The chemical and physical properties of the latex emulsions studied are reported. An infrared spectroscopic fingerprint was developed for each manufacturer's latex.

The report is available from the Materials Division, HRS-20, Federal Highway Administration, Washington, D.C. 20590.

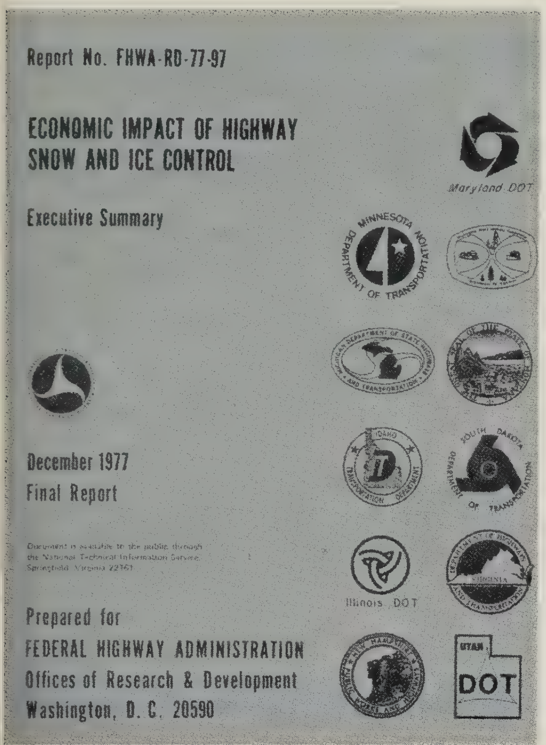
### Nontoxic Yellow Traffic Striping, Report No. FHWA-RD-78-1

**by FHWA Materials Division**



This report presents the results of an extensive laboratory and field test pro- gram to identify yellow organic pigments that are acceptable substitutes for lead chromate in yellow traffic paint. Thirty-six yellow traffic paints were prepared using lead chromate and alternative pigments as the yellow color source. A number of commercially available organic yellow pigments were found which performed as well as or better than lead chromat pigment in field tests of alkyd resin-based traffic paints on a heavily traveled highway. The report includes a review of the literature on the environ ment and toxic effects of lead chromate. Also presented are approximate cost data for the lead chromate pigment and the various organic yello pigments.

The report is available from the Materials Division, HRS-20, Federal Highway Administration, Washington, D.C. 20590.




### Economic Impact of Highway Snow and Ice Control, Final Report (Report No. FHWA-RD-77-95), User's Manual (Report No. FHWA-RD-77-96), and Executive Summary (Report No. FHWA-RD-77-97)

**by FHWA Environmental Design and Control Division**

The research described in these reports developed a rational method for determining the costs and benefits gained from highway snow and ice control. The areas covered in the study were maintenance, traffic and safety, environment, structure damage, and vehicle corrosion. Supporting research including accident rates, user delays, traffic volumes during winter storms, and the effect of reduced mobility on businesses is discussed.

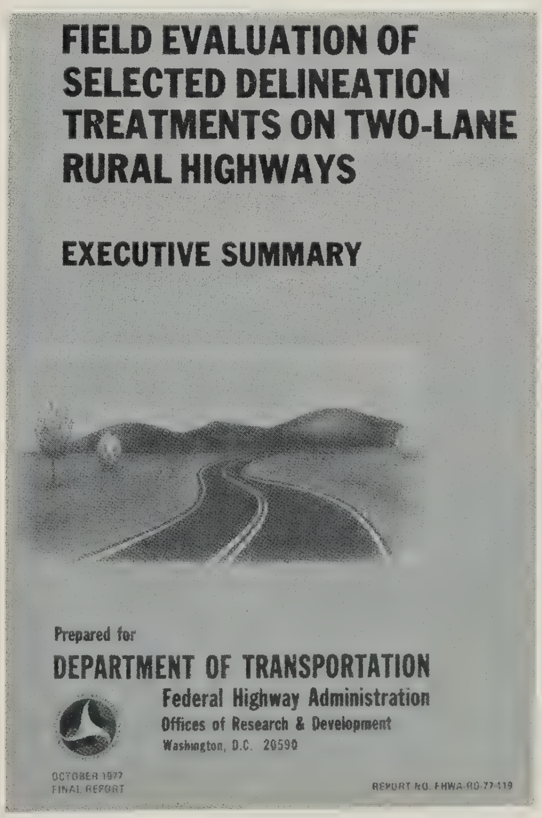
The economic model is documented in the final report. It should be of interest to those concerned with the economic, operational, and environmental aspects of winter maintenance. The user's manual is intended for those interested in the computerized economic model. The executive summary provides an overview, conclusions, recommendations, and suggestions for implementation of the study.

The reports are available from the Environmental Design and Control Division, HRS-42, Federal Highway Administration, Washington, D.C. 20590.

### Field Evaluation of Selected Delineation Treatments on Two-Lane Rural Highways, Final Report (Report No. FHWA-RD-77-118) and Executive Summary (Report No. FHWA-RD-77-119)

**by FHWA Environmental Design and Control Division**

These reports document a traffic engineering study that attempted to establish relationships between traffic performance and accident probability on two-lane rural highways, develop an experimental design for field testing the effectiveness of conventional and novel delineation treatments, evaluate the effect of selected delineation treatments on traffic performance and accident probability, and make recommendations for the design and use of delineation treatments.




In the first study phase regression analysis was used to correlate delineation-related accident potential to speed and lateral placement measures. In the second study phase additional accident and traffic performance data were collected to test the correlation models and to evaluate the safety effectiveness of 21 delineation systems.

The Executive Summary is included in the Final Report and is also available separately. The reports are available from the Environmental Design and Control Division, HRS-42, Federal Highway Administration, Washington, D.C. 20590.

### Motorists' Requirements for Active Grade Crossing Warning Devices, Report No. FHWA-RD-77-167

**by FHWA Traffic Systems Division**

Approximately 22 percent of the public grade crossings in the United States have active grade crossing warning devices and about 20 percent of the train-involved grade crossing accidents occur at these crossings. This report documents research undertaken to improve the visibility of existing grade crossing active devices.

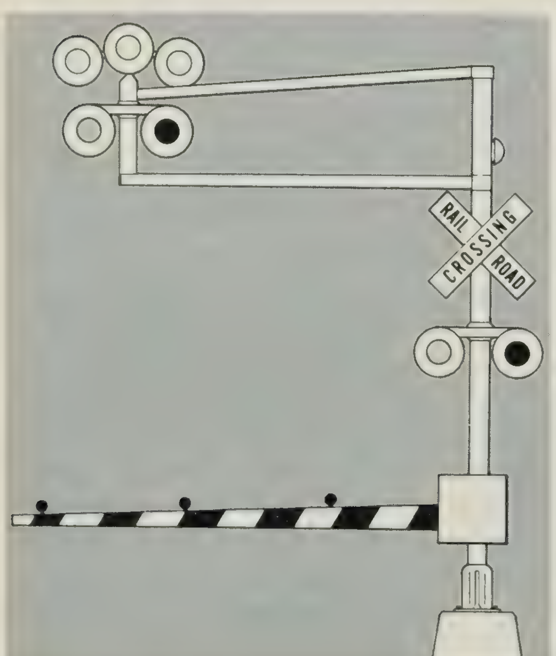
Modifications to active devices were laboratory tested under daylight, late afternoon fog, and night conditions. Field tests of the most promising modifications for both flashing lights and gates were conducted at two locations in California. These modifications included the addition of three white strobes over the flashing lights and the addition of red, white, and blue strobe lights on the gate arm.

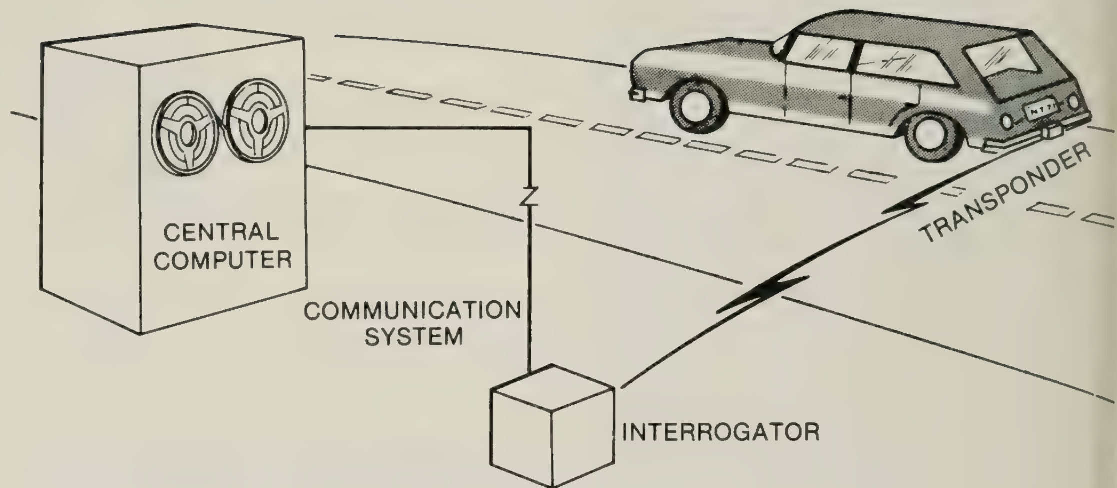
Results of the study are as follows: 12 in (305 mm) signal heads overcome background competition more effectively than increased luminance of 8 in

(203 mm) signal heads; the use of multiple white strobes to supplement the existing red flashers significantly improves the visibility of the signals; white strobes use about one-eighth the energy of red strobes; and the color red now used for the flashing lights was determined to be the most effective color for flashing incandescent lights.

The report contains an annotated bibliography divided into the following sections: conspicuity of signals and flashing lights, color of lights, restricted visibility studies, accident studies and railroad-highway accident predictors, technical innovations, driver behavior approaching a railroad crossing, and sound stimuli.

A limited number of copies of the report are available from the Traffic Systems Division, HRS-33, Federal Highway Administration, Washington, D.C. 20590.




**Assessment of the Application of Automatic Vehicle Identification Technology to Traffic Management (Report No. FHWA-RD-77-87), Appendix A (Report No. FHWA-RD-77-88), Appendix B (Report No. FHWA-RD-77-89), and Appendix C (Report No. FHWA-RD-77-90)**

**by FHWA Traffic Systems Division**

Automatic vehicle identification (AVI) is a concept in which the identities of vehicles passing a particular location are extracted by an automated surveillance system. The record of each passage is transmitted to a central computer for data storage and processing. Automatic vehicle monitoring (AVM) systems permit the communication of a limited amount of information about the operational status of each vehicle in addition to the vehicle identity. These studies report the feasibility of using AVI and AVM technology for purposes of traffic management.

Several traffic management strategies—congestion pricing, traffic restraint, truck restrictions, preferential lane usage, corridor control, and traffic signal control—for which AVI or AVM may be useful are examined in detail. For each application, the relative costs and effectiveness of AVI or AVM are compared to the best nonautomated method.

The conclusion is that no current or proposed application appears to warrant the cost of using AVI or AVM technology. However, if multiple traffic management applications are considered, the use of AVI may be justified in some cases provided that vehicles are equipped with AVI transponders for other purposes as well. These other purposes include uses on toll roads, parking garages, and for fleet monitoring.

The information is contained in four volumes. The first discusses AVI technology, identifies potential traffic management applications for AVI, and discusses uses for AVM technology. Appendix A documents a comprehensive review of AVI. Appendix B estimates production costs for key system components. Appendix C provides a parallel cost effectiveness analysis of the use of AVM for a particular traffic management application.

A limited number of copies of the report are available from the Traffic Systems Division, HRS-32, Federal Highway Administration, Washington, D.C. 20590.

**U.S. Demonstration Projects on 6-in Prestressed Pavements**

| | | Date Constructed | Length (ft) | Width (ft) |
|---|---|---|---|---|
| 1. | Milford, Del. | July 1971 | 300 | 14.5 |
| 2. | Dulles Airport | December 1971 | 3,200 | 24 |
| 3. | Kutztown, Pa. | September 1972 | 500 | 24 |
| 4. | Harrisburg, Pa. | November 1973 | 8,300 | 24 |
| 5. | Brookhaven, Miss. | Fall 1976 | 13,200 | 24 |
| | Also, 8-in CRCP, adjacent | | 13,200 | 24 |
| 6. | Tempe, Ariz. (Superstition Freeway) | July 1977 | 6,336 | 31.5 |

1 in = 25.4 mm
1 ft = 0.305 m

**Technological Review of Prestressed Pavements, Report No. FHWA-RD-77-8**

**by FHWA Structures and Applied Mechanics Division**

This report assesses engineering advances in prestressed concrete pavement construction since the first such pavement was built at the Paris Orly International Airport in 1946.

The report presents a history of the development of prestressed concrete pavement technology and outlines features of prestressed concrete pavements that have been built in various parts of the world. Prestressing methods used on different projects are described, as are joint details, particularly for those pavements built in the United States. Information is presented on pavement performance under traffic, results of load tests, prestress distribution and loss, length change, and strand friction. Methods used for designing prestressed concrete pavements are outlined and material properties of the concrete, prestressing steel, and subbase components are identified. A glossary of terms related to prestressed concrete pavements, and a comprehensive bibliography are included.

This report is available from the National Technical Information Service, 5285 Port Royal Rd., Springfield, Va. 22161 (Stock No. PB 278688).

**Review of the Design and Construction of Long-Span, Corrugated Metal, Buried Conduits, Report No. FHWA-RD-77-131**

**by FHWA Structures and Applied Mechanics Division**

This report presents the design and construction state of the art for long-span, corrugated metal, buried highway structures being used as new or replacement drainage culverts and as vehicle or pedestrian underpasses.

Such structures generally are assembled onsite by bolting together curved, corrugated metal, structural-plate members.

Over 600 of these structures are in place in North America. Shapes include horizontal and vertical ellipses and low and high profile arches. Spans up to 51 ft (15.5 m) have been successfully constructed and have performed satisfactorily. When spans exceed 15 to 25 ft (4.6 to 7.6 m) or radii of curvature exceed 8 to 12 ft (2.4 to 4.9 m), design criteria and construction procedures must be modified to insure satisfactory performance.

Design concepts, construction procedures, economic considerations, experimental investigations, failures, and analytical modeling requirements are described in detail. The report concludes with recommendations for future investigations of these structures directed toward further improvement in their design, construction, and inservice performance. Current American Association of State Highway and Transportation Officials specifications for such structures are included in an appendix.

This report is available from the National Technical Information Service, 5285 Port Royal Rd., Springfield, Va. 22161 (Stock No. PB 278696).

# Implementation/User Items "how-to-do-it"

**The following are brief descriptions of selected items which 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). Some items by others are included when they have a special interest to highway agencies.**

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

**Items available from the Implementation Division can be obtained by including a self-addressed mailing label with the request.**

### A User's Manual for a Management Control System for Street Maintenance, Implementation Package 77-20

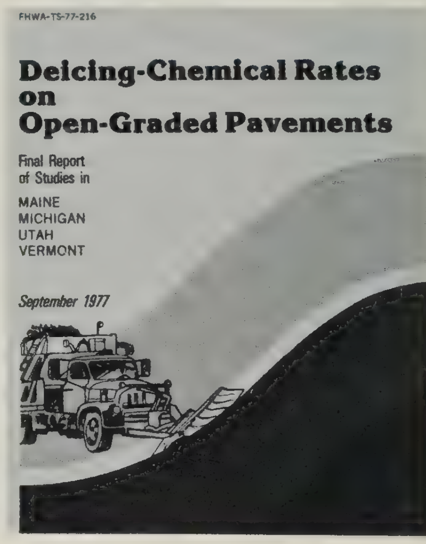
**by FHWA Implementation Division**


This manual presents procedures to follow for coordinating street maintenance activities. Maintenance work standards, a work program, a work calendar, scheduling procedures, work reports, and a management analysis of completed work are described in detail to present an approach for controlling street maintenance expenditures for small municipalities.

Although a specific system is presented, much flexibility in the procedures is provided. Any city or county can follow the basic system but deviate where necessary to meet individual requirements.

The introductory section of the manual outlines the formal system of street maintenance management. Section two provides detailed information on the elements of the management system. Section three explains the work control procedures and the methods for using the system data for improved management of the street maintenance department. Section four is a series of examples showing typical jobs, scheduling, control, and development of information feedback for measurement and analysis purposes. Section five contains important suggestions relating to implementation steps for the management control system. The appendixes consist of easy-to-use maintenance standards and tables of technical information that are needed in daily applications of the system.

The manual is available from the Implementation Division.




### Deicing Chemical Rates on Open-Graded Pavements, Report No. FHWA-TS-77-216

**by FHWA Implementation Division**

During the 1976-77 winter season, the Federal Highway Administration sponsored four studies to determine if more salt (sodium chloride) is needed to clear open-graded asphalt friction courses during winter storms than is needed to clear conventional pavements. This report summarizes the findings and describes the prevailing behavior of all open-graded pavement sections observed by the States conducting the studies—Maine, Michigan, Utah, and Vermont. An analysis of recorded data, photographs, and comments from the four States supports the view that more salt is not needed to clear open-graded pavements.

The report is available from the Implementation Division.


**Predicting Potential Strength of Portland Cement Concrete, Report No. FHWA-TS-78-212**

**by FHWA Implementation Division**

This report details a method by which concrete strength can be predicted by testing cylinders which are 24 to 48 hours old. An equation that estimates the strength of concrete at some later age, using the results of early age test values, can be derived by determining the relationship between maturity and strength at various ages. This method uses conventional curing with temperature monitoring. Sampling, preparation, curing, and testing of compressive strength specimens are in accordance with American Society for Testing Materials and American Association of State Highway and Transportation Officials methods. The advantage of this concept is that deficiencies are easy to correct because it is not necessary to wait 7 or 28 days to test cylinders. Also, the early strength determination is beneficial in using statistical methods of quality control.

The maturity concept described in the report will be one of the portland cement concrete (PCC) rapid tests included in a future implementation project for testing various methods of plastic PCC early strength determination.

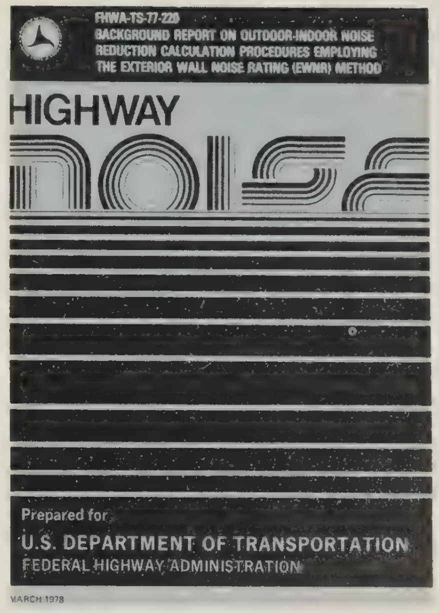
The report is available from the Implementation Division.

**Background Report on Outdoor-Indoor Noise Reduction Calculation Procedures Employing the Exterior Wall Noise Rating (EWNR) Method, Report No. FHWA-TS-77-220**

**by FHWA Implementation Division**

This report provides the basis for the table of exterior wall noise rating (EWNR) values and adjustment factors used to evaluate the composite noise reduction for various residential structural components in "Insulation of Buildings Against Highway Noise," (Report No. FHWA-TS-77-202). It reviews the basis of previous single number ratings emphasizing the sound transmission class (STC). STC was initially designed to account for the relative loudness of interior noises heard by neighbors in adjoining residences. The EWNR metric was developed so that the A-weighted indoor noise level, due to highway noise sources outdoors, could be roughly estimated directly from the value of EWNR and the A-weighted outdoor noise level. The basis for this is defined in terms of the basic theory for noise reduction from outdoors to indoors at one frequency. The result is then summed over all frequencies to give the overall effective noise reduction. The EWNR single number rating provides a valid method for predicting levels inside buildings due to outdoor transportation noise sources.

This report also briefly reviews the basis for the tables of EWNR values and tables of various EWNR adjustment factors used to evaluate the composite noise reduction of A-weighted




noise levels for a wide range of practical residential structural assemblies which may include walls, windows, doors, roofs, and ceilings.

The report is available from the Implementation Divison.

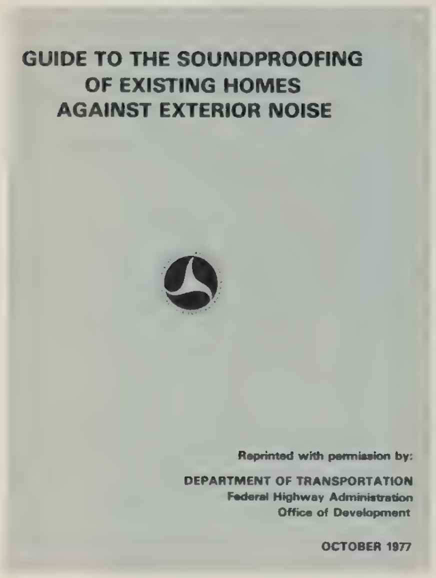
**Guide to the Soundproofing of Existing Homes Against Exterior Noise**

**by FHWA Implementation Division**

This guide presents the various successful methods used in a 1970 pilot project to increase the noise reduction capabilities of existing homes for the Los Angeles Department of Airports. Three categories of modification from minor to extensive are covered. The guide also provides a basic understanding of the elements of noise control and the systematic method of soundproofing homes.

This manual should be helpful to the designer in selecting and conceptualizing various methods of soundproofing existing homes. It would be useful with TechShare Report No. FHWA-TS-77-202, "Insulation of-Buildings Against Highway Noise," and TechShare Report No. FHWA-TS-77-220 (see above).

In the pilot project the homes chosen were in the immediate vicinity of the




airport; those homes close to the airport were designed for a higher noise reduction than those farther away.

The guide contains a brief description of the fundamentals of noise control including the transmission and absorption of sound, recommendations on a systematic approach to the soundproofing of homes, and a description of the best soundproofing methods used in the pilot project.

The guide is available from the Implementation Division.

### Drilled Shaft Manual, Volumes I and II, Implementation Package 77-21

**by FHWA Implementation Division**

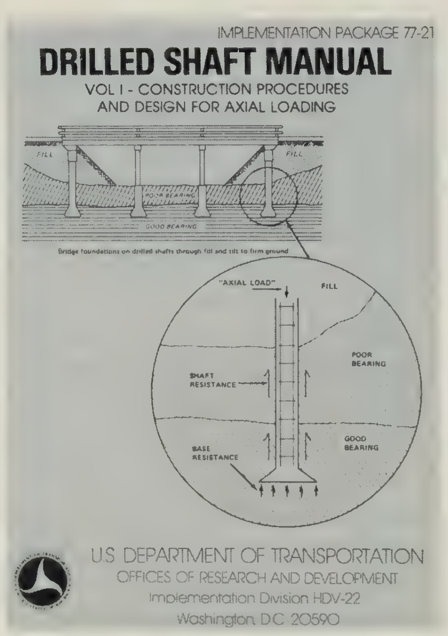
During the past decade, many studies have been made on drilled shaft foundations. Much of the research has been concerned with the testing of full-sized instrumented drilled shafts. Most of these instrumented shafts have been subjected to axial loads, but lateral-load tests have also been performed. This two-volume manual contains rational procedures and practical guidelines for the design and construction of drilled shaft foundations. The results of extensive full-scale load tests on instrumented shafts have been incorporated in the design and construction guidelines.

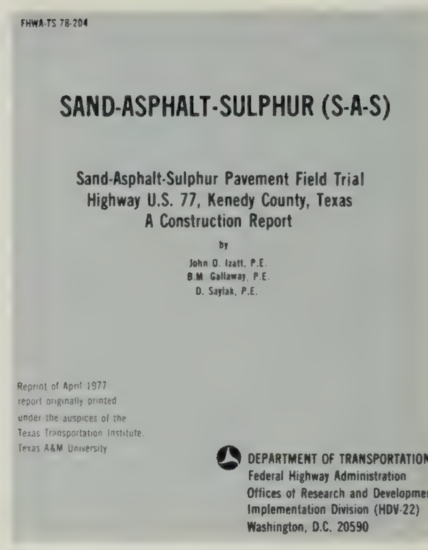
Volume I, **Construction Procedures and Design for Axial Loading,** is concerned with construction methods, inspection, preparation of specifications, design of drilled shafts under axial loading, and cost estimation.

Volume II, **Structural Analysis and Design for Lateral Loading,** presents alternate methods for computing the response of the shaft to lateral loading and presents the structural design of the shaft for axial and lateral loading.

Practical application of the information in these manuals should result in increased use of drilled shafts in situations where savings in cost, construction time, and environmental disruptions can now be predicted with increased confidence.

The manual is available from the Implementation Division.



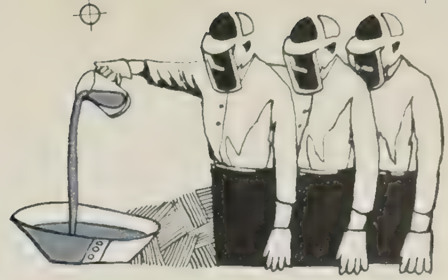

### Sulphur Extended Asphalt (SEA), Lufkin Field Trials (Report No. FHWA-TS-78-203), Sand-Asphalt-Sulphur (S-A-S), Kenedy County, Tex. (Report No. FHWA-TS-78-204), and Paving With Sulphur (movie)

**by FHWA Implementation Division**

Although still in the developmental stage, the use of sulphur in pavements is expected to become increasingly popular. The movie, "Paving With Sulphur," portrays two types of pavements in which sulphur is used: (1) Sulphur Extended Asphalt (SEA) pavements in which elemental sulphur is used as a partial replacement of the asphalt binder; and (2) Sand-Asphalt-Sulphur (S-A-S) pavements in which elemental sulphur, by primarily acting as a structuring agent between aggregates, allows the use of poorer quality aggregates in pavement construction. The procedures used to design and construct SEA and S-A-S pavements for field trials in Texas are described in these reports.

The reports are available from the National Technical Information Service, 5285 Port Royal Rd., Springfield, Va. 22161 (Stock Nos. PB 279093 and PB 279199). The movie is available from FHWA regional offices (see inside bac cover).

# New Research in Progress



The following items identify new research studies that have been reported by FHWA's Offices of Research and Development. Space limitation precludes publishing a complete list. 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)—Performing State Highway Department; National Cooperative Highway Research Program (NCHRP)—Program Director, National Cooperative Highway Research Program, Transportation Research Board, 2101 Constitution Avenue, NW., Washington, D.C. 20418.

## FCP Category 1—Improved Highway Design and Operation for Safety

### FCP Project 1I: Traffic Lane Delineation Systems for Adequate Visibility and Durability

**Title: Temporary Pavement Marking Systems. (FCP No. 51I3103)**
**Objective:** Explore the feasibility of innovative traffic marking paint systems that may be strippable or otherwise removable in a controlled manner so as to provide effective traffic delineation for a minimum period of 2 weeks.
**Performing Organization:** Georgia Institute of Technology, Atlanta, Ga. 30332
**Expected Completion Date:** June 1979
**Estimated Cost:** $70,000 (NCHRP)

**Title: Effect of Raised Markers on Traffic Performance. (FCP No. 41I3203)**
**Objective:** Determine the effects of snowplowable raised pavement markers on traffic safety and efficiency and driver visibility at exit gores and hazardous curves at night and in the rain.
**Performing Organization:** New Jersey Department of Transportation, Trenton, N.J. 08625
**Expected Completion Date:** April 1980
**Estimated Cost:** $104,000 (HP&R)

### FCP Project 1V: Roadside Safety Hardware for Nonfreeway Facilities

**Title: Vehicular Impact Tests of Breakaway Wood Post and Timber Pole Sign Supports. (FCP No. 41V3134)**
**Objective:** Conduct impact test per FHWA Notice 5040.20 on the largest size breakaway wood posts and timber poles regularly used by Caltrans for two-post signs.
**Performing Organization:** California Department of Transportation, Sacramento, Calif. 95805
**Expected Completion Date:** January 1980
**Estimated Cost:** $118,000 (HP&R)

### FCP Project 1Y: Traffic Management in Construction and Maintenance Zones

**Title: Construction Zone Safety and Delineation. (FCP No. 41Y1694)**
**Objective:** Determine the nature and causes of traffic problems on State-maintained highways during construction and maintenance operations where longer term lane closures and diversions are required. Determine extent of problems that can be addressed by improving delineation. Install and evaluate improved delineation, marking, and/or lighting devices.
**Performing Organization:** New Jersey Department of Transportation, Trenton, N.J. 08625
**Expected Completion Date:** December 1981
**Estimated Cost:** $96,000 (HP&R)

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

### FCP Project 2M: Arterial Flow and Control

**Title: Application of Existing Strategies to Arterial Signal Control. (FCP No. 32M2043)**
**Objective:** Develop and test arterial traffic signal control systems.
**Performing Organization:** A. M. Voorhees and Associates, McLean, Va. 22101
**Expected Completion Date:** April 1980
**Estimated Cost:** $230,000 (FHWA Administrative Contract)

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

### FCP Project 3F: Pollution Reduction and Environmental Enhancement

**Title: Highway Traffic Noise Computer Program Development. (FCP No. 43F4642)**
**Objective:** Develop computer program combining a noise model and terrain model.
**Performing Organization:** Washington State Highway Commission, Olympia, Wash. 98507
**Expected Completion Date:** October 1979
**Estimated Cost:** $118,000 (HP&R)

**Title: Insulation of Buildings to Attenuate Noise. (FCP No. 33F4922)**
**Objective:** Determine the feasibility of insulating private residences to mitigate traffic noise. The basis of the procedure is FHWA's insulation manual.

**Performing Organization:** California Department of Transportation, Sacramento, Calif. 95805
**Expected Completion Date:** December 1981
**Estimated Cost:** $263,000 (FHWA Administrative Contract)

**Title: Evaluation of Noise Barriers. (FCP No. 33F4962)**
**Objective:** Determine inplace attenuation of noise barriers; assess cost effectiveness, evaluate community acceptance or barriers, and develop design guidelines.
**Performing Organization:** California Department of Transportation, Sacramento, Calif. 95805
**Expected Completion Date:** December 1981
**Estimated Cost:** $170,000 (FHWA Administrative Contract)

## FCP Category 4—Improved Materials Utilization and Durability

### FCP Project 4B: Eliminate Premature Deterioration of Portland Cement Concrete

**Title: Low Porosity, High Strength Concrete for Bridge Decks. (FCP No. 44B1702)**
**Objective:** Determine the potential suitability of low porosity cement concrete for use in long lasting bridge decks. Low porosity cement is ordinary portland cement clinker ground finer than normal, to which no gypsum or anhydrite is added; rather, set control and rheological characteristics are regulated by addition of a special sulfonated lignin retarder and an alkali carbonate or bicarbonate.
**Performing Organization:** Purdue University, West Lafayette, Ind. 46200
**Funding Agency:** Indiana State Highway Commission
**Expected Completion Date:** June 1981
**Estimated Cost:** $80,000 (HP&R)

### FCP Project 4C: Use of Waste as Material for Highways

**Title: Rubber Type and Optimum Particle Size for Asphalt Rubber Systems. (FCP No. 44C1152)**
**Objective:** Determine the optimum rubber particle size and range of rubber concentrations for acceptable visco-elastic properties, the effect of asphalt source on optimum particle size, and the effects of rubber type and processing on the properties of selected asphalt rubber mixtures.
**Performing Organization:** Engineers Testing Laboratory, Phoenix, Ariz. 85036
**Funding Agency:** Arizona Department of Transportation
**Expected Completion Date:** June 1979
**Estimated Cost:** $95,000 (HP&R)

**Title: Pavement Recycling, Phase I, Energy, Environmental, and Material Considerations. (FCP No. 44C4014)**
**Objective:** Develop mix-design criteria for the use of recycled materials in maintenance and construction of pavements, ascertain energy and cost data for manufacture and placement of portland cement and asphalt concrete materials, and develop a design of a roadway structure which incorporates recycled pavement components.
**Performing Organization:** Connecticut Department of Transportation, Hartford, Conn. 06115
**Expected Completion Date:** March 1979
**Estimated Cost:** $98,000 (HP&R)

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

### FCP Project 5B: Tunneling Technology for Future Highways

**Title: Improved Design and Control of Grouting in Soils. (FCP No. 35B1102)**
**Objective:** Develop improved design concepts and criteria and improved construction control measures to assure satisfactory grout treatment of soils through improvement of concepts for grout distribution, sensing of distribution, and evaluation of treated soils.
**Performing Organization:** Hayward Baker Company, Odenton, Md. 21113
**Expected Completion Date:** December 1979
**Estimated Cost:** $240,000 (FHWA Administrative Contract)

### FCP Project 5C: New Methodology for Flexible Pavement Design

**Title: Implementation of a Pavement Design System. (FCP No. 45C3392)**
**Objective:** Develop and implement a pavement design system for Ohio. This mechanistic system will be based on previously developed computer programs and methodologies. The procedures of prediction of pavement performance and evaluation of this performance for maintenance required will be integrated to provide a pavement optimization strategy.
**Performing Organization:** Ohio State University, Columbus, Ohio 43215
**Funding Agency:** Ohio Department of Transportation
**Expected Completion Date:** April 1980
**Estimated Cost:** $88,000 (HP&R)

### FCP Project 5D: Structural Rehabilitation of Pavement Systems

**Title: Development of a Network Optimization System. (FCP No. 45D1274)**
**Objective:** Develop procedures for determining pavement improvement and maintenance actions that will achieve maximum benefit to the road users.
**Performing Organization:** Woodward-Clyde Consultants, Phoenix, Ariz. 8500
**Funding Agency:** Arizona Department of Transportation
**Expected Completion Date:** May 1979
**Estimated Cost:** $110,000 (HP&R)

**Title: Relating Pavement Distress to Serviceability and Performance. (FCP No. 35D1282)**
**Objective:** Develop a meaningful relationship between the occurrence of

*U.S. Government Printing Office: 1978—720-425

pavement distress to serviceability and performance and develop a model for these relationships that can be used in a predictive pavement design and management system.
**Performing Organization:** Austin Research, Austin, Tex. 78746
**Expected Completion Date:** January 1980
**Estimated Cost:** $140,000 (FHWA Administrative Contract)

**FCP Project 5H: Protection of the Highway System from Hazards Attributed to Flooding**

**Title: Methods for Assessment of Stream-Related Hazards to Highways. (FCP No. 35H1012)**
**Objective:** Develop assessment approaches which consider geomorphology and land use.
**Performing Organization:** Colorado State University, Fort Collins, Colo. 80523
**Expected Completion Date:** July 1979
**Estimated Cost:** $103,000 (FHWA Administrative Contract)

**Title: Development of a Revised Procedure for Estimating Design Floods From Ungaged Watersheds. (FCP No. 45H3652)**
**Objective:** Revise the Pennsylvania flood estimate procedures developed in 1971 to include all flood data up to 1977; compute flood frequency statistics according to WRC Bulletins 17 and 17A; and estimate effects of reservoir urbanization, glaciated soils, limestone, and wooded areas.
**Performing Organization:** Pennsylvania State University, University Park, Pa. 16802
**Funding Agency:** Pennsylvania Department of Transportation
**Expected Completion Date:** March 1980
**Estimated Cost:** $122,000 (HP&R)

**FCP Project 5J: Rigid Pavement Systems Design**

**Title: Development of a System for Nationwide Evaluation of Portland Cement Concrete Pavements. (FCP No. 55J1374)**
**Objective:** Develop a practical system for continuous evaluation of the performance of PCC pavement and demonstrate the system for jointed PCC pavements representing a range of serviceability, climate, and regions of the country.
**Performing Organization:** University of Illinois, Urbana, Ill. 61801
**Expected Completion Date:** January 1980
**Estimated Cost:** $125,000 (NCHRP)

**FCP Project 5L: Safe Life Design for Bridges**

**Title: Bridges on Secondary Highways and Local Roads, Rehabilitation and Replacement. (FCP No. 55L3042)**
**Objective:** Develop procedures for repairing or replacing bridges on secondary highways and local roads. Develop a rational cost-effective methodology for selection between alternative remedies in a given situation.
**Performing Organization:** University of Virginia, Charlottesville, Va. 22903
**Expected Completion Date:** November 1980
**Estimated Cost:** $120,000 (NCHRP)

## FCP Category 0—Other New Studies

**Title: Development and Analysis of Terrestrial and Aerial Photogrammetry for Structure Monitoring. (FCP No. 40M1593)**
**Objective:** Establish a photogrammetric method by which any structure can be monitored and use statistical analysis for evaluation. Reduce targeting. Establish a method whereby shapes of structures can be graphically recorded.
**Performing Organization:** University of Washington, Seattle, Wash. 98504
**Funding Agency:** Washington State Highway Commission
**Expected Completion Date:** June 1979
**Estimated Cost:** $79,000 (HP&R)

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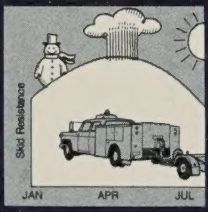
## Getting Research Into Practice

## New Directions for the Federally Coordinated Program of Research and Development




## Seasonal Variations in Pavement Skid Resistance—Are These Real?

## Ice Loads on Bridge Piers

public roads
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