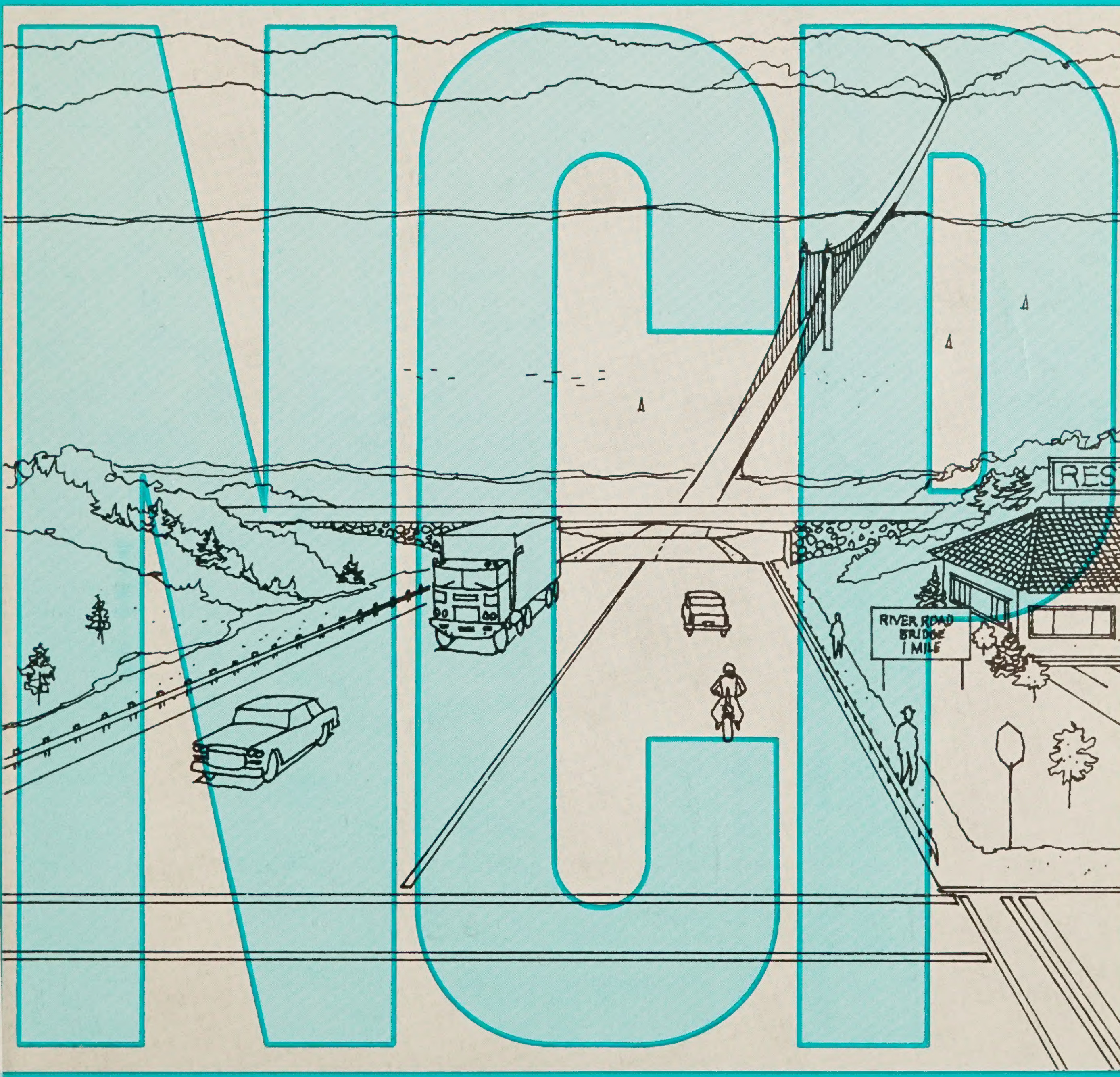
June 1987
Vol. 51, No. 1

Public Roads

U.S. Department of Transportation

Federal Highway Administration

A Journal of Highway Research and Development



Public Roads

A Journal of Highway Research and Development

June 1987
Vol. 51, No. 1

COVER: The Nationally Coordinated Program (NCP) of Highway Research, Development, and Technology, initiated in October 1986, is an improved management framework that links all levels of highway research, development, and technology transfer.

U.S. Department of Transportation
Elizabeth Hanford Dole, *Secretary*

Federal Highway Administration
R.A. Barnhart, *Administrator*

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

Public Roads is published quarterly by the Offices of Research, Development, and Technology
David K. Phillips, *Associate Administrator*

IN THIS ISSUE

Articles

Departments

Address changes (send both old and new) and requests for removal for the free mailing list should be directed to:
Public Roads Magazine, HRD-10
Federal Highway Administration
6300 Georgetown Pike
McLean, VA 22101-2296

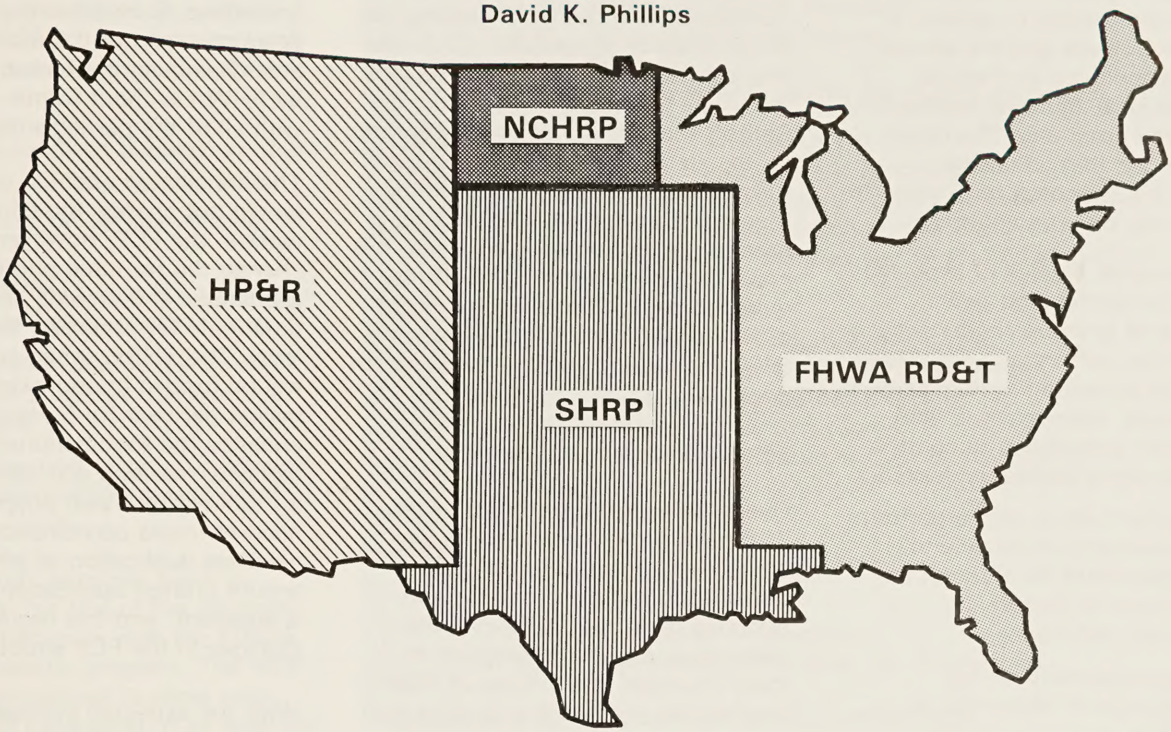
At present, there are no vacancies on the *FREE* mailing list.

Public Roads, A Journal of Highway Research and Development, (ISSN 0033-3735) is sold by the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402, for $12 year ($3 additional for foreign mailing) or $3.25 per single copy (81 cents additional for foreign mailing). Subscriptions are available for 1-year periods. Free distribution is limited to public officials actually engaged in planning and constructing highways and to instructors of highway engineering. At present, there are no vacancies on the free mailing list.

The Secretary of Transportation has determined that the publication of this periodical is necessary in the transaction of the public business required by law of this Department.

The Nationally Coordinated Program (NCP) of Highway Research, Development, and Technology

by
David K. Phillips



Introduction and Background

The concept of a partnership between the Federal Government and the State highway agencies has existed since the beginning of the highway program in 1893 when the primary concern was the development and use of new technology. The U.S. Office of Road Inquiry, established in that year as a result of the appropriations act for the U.S. Department of Agriculture, included in its charter ". . . to make investigations in regard to the best method of roadmaking . . . and to . . . assist in disseminating information on this subject . . ." (*1*)[1] This concept has carried over to the present research, development, and technology transfer (RD&T[2]) program.

The Federal Highway Administration (FHWA), States, and local highway agencies share the responsibility for selecting and developing the best possible technology for planning, designing, constructing, operating, and maintaining the highway system. This requires a vigorous program of research, development, and technology application to bring all available resources and the best talent into the process. A systematic framework also is necessary to ensure maximum cooperation and minimum duplication of effort.

FCP

The management framework established in 1971 to coordinate and manage Federal and State activities was the Federally Coordinated Program (FCP) of Highway Research, Development, and Technology. The structure of the FCP provided a logical framework for classifying the major program areas and distinguishing the sub-elements of these areas, for assigning budget resources and responsibilities, for determining objectives, and for communicating the program to FHWA field offices and States. The FCP consisted of broad categories containing selected projects that concentrated available resources on obtaining timely solutions to urgent national highway problems.

For fiscal year 1984, the FCP was revised to simplify the structure and make it more responsive to FHWA and State priorities. The revision of the FCP also reflected the 1982 reorganization of FHWA's Offices of Research, Development, and Technology (RD&T) and the transition of the U.S. highway program from major Interstate highway construction to restoration and reconstruction of the existing system.

---

[1]Italic numbers in parentheses identify references on page 4.

SHRP

During fiscal years 1983 and 1984, FHWA funded a study by the Transportation Research Board (TRB) to examine carefully the overall strategy in the highway research programs. In 1984, TRB issued a report that concluded that highway research was grossly under-funded in relation to the research needs and the annual capital expenditures by Federal, State, and local agencies involved in the highway programs. The report recommended that additional resources be dedicated for 5 years to the following six program areas:

1. Fundamental studies of asphaltic materials to identify and define chemical and physical characteristics related to the performance of these materials in pavement systems and to develop tests, specifications, and construction procedures to control the performance standards desired.

2. A long-term study of the performance of pavements in service to increase pavement life through improved pavement design and rehabilitation techniques.

3. An intensive study of the technology and management of highway maintenance activities.

4. An extension of existing research on methods to rehabilitate existing chloride-contaminated concrete bridge components that were built before the use of protective systems.

5. Fundamental studies of methods to improve the strength and durability of concrete structures.

6. Improved methods for the chemical and mechanical control of snow and ice in winter highway operations. (*2*)

This Strategic Highway Research Program (SHRP) has been proposed for funding in fiscal year 1987, subject to congressional authorization. In preparing for this major new program, it became necessary for the Offices of RD&T to activate a new management plan that would coordinate the SHRP and ensure the "continuity and health of existing national research programs." (*2*) It was important that the SHRP not replace the existing national programs. Rather, the SHRP was to concentrate on the six program areas; previously funded highway research programs then could shift their emphasis to other high-priority research areas. It is important to note that the SHRP requires some additional commitment of Highway Planning and Research (HP&R) funds to achieve the program goals.

The Need for a Change

Over the years the elements of the FCP have evolved as research was completed successfully (or abandoned) and as new problems and priorities have arisen. Despite the responsiveness of the program to these changes, the Offices of RD&T reached the point where a major revision was needed.

The FCP often was perceived, by States and others, as the Federal *Contract* Program. Many did not remember that the FCP specifically included the four major programs of highway research and development that involve funding from the Highway Trust Fund and was designed to carefully and effectively coordinate these programs. The four programs must be carefully and effectively coordinated, considering the diversity of administration among them: the HP&R program, conducted primarily by the individual States; the FHWA contract program and the FHWA staff research program, conducted through the Offices of RD&T; and the National Cooperative Highway Research Program (NCHRP), recommended by the Select Committee on Research of the American Association of State Highway and Transportation Officials (AASHTO).

In addition, in the early years of the FCP, annual national conferences with broad participation by States, contractors, university representatives, and others provided recommendations for research priorities. These conferences were discontinued several years ago because of reduced travel funds and meeting attendance limitations. Consequently, in recent years selection of the FCP priority areas has been performed primarily by FHWA without formal discussions with all of the participants.

The anticipated addition of the SHRP would not change the contents of the work in the FCP; however, it would change the resource priorities and allocations and provide an accelerated timeframe for attacking these problems. The SHRP, when authorized, will be funded at approximately $30 million per year for 5 years, which will enhance the total national program of highway research and development to a $130-million-a-year program. The need for close coordination to avoid needless duplication of effort and to ensure prompt application of results is apparent, and this requires some changes in the FCP structure.

With the expected increase in motor carrier research, it is worthwhile to have an entire technical category that identifies and clearly defines the planned activities in this area. An additional technical area not covered by the FCP is planning and policy research. The FHWA contract research program in this area typically exceeds $1 million annually, making this program area a worthy candidate for its own technical category. We also needed a framework for describing work that falls outside of the FCP so that expenditures and technical accomplishments could be reported on the full range of FHWA and federally aided research activities.

Responding to all of these concerns, we have replaced the FCP with a new, broader based program—the Nationally Coordinated Program (NCP).

The Nationally Coordinated Program (NCP) of Highway Research, Development, and Technology—An Improved Management Framework

The NCP replaced the FCP October 1, 1986. This new program is an active and positive link to all levels of highway research, development, and technology transfer to ensure the following:

- Minimize needless duplication of effort.
- Focus attention on key problem areas.
- Permit SHRP to take full advantage of current as well as past research.
- Organize all related research and development activities that address central issues.
- Provide for joint efforts for prompt implementation of the results of all programs.

The "Federal" term has been removed from the title of the program to reduce confusion with the FHWA contract research program. The NCP is broadly structured to allow coordination and cataloging of all federally supported work within program areas. FHWA will not establish priorities for work in the NCP, but will designate a small number of emphasis areas where we will be focusing our contract and staff efforts. In addition, the program can be used as a framework for interaction among other groups (such as the AASHTO Select Committee on Research and NCHRP), to recommend national priorities for HP&R work, and to designate lead agencies, States, or groups of States in selected research areas.

NCP Categories and Program Areas

The NCP is composed of nine categories (see fig. 1). Each category is composed of program areas containing several projects. Projects are further subdivided into studies and, in some cases, tasks and studies if the project is very complex. Such a

NCP Categories and Programs

Category A—Highway Safety

Program A.1: Traffic Control for Safety
A.2: Improved Driver Visibility of Roadway Environment
A.3: Highway Safety Analysis
A.4: Special Highway Users
A.5: Design
A.9: Technology Transfer for Highway Safety

Category B—Traffic Operations

Program B.1: Traffic Management Systems
B.2: Traffic Analysis and Operational Design Aids
B.3: Motorist-Highway System Interactions
B.9: Technology Transfer for Traffic Operations

Category C—Pavements

Program C.1: Evaluation of Rigid Pavements
C.2: Evaluation of Flexible Pavements
C.3: Field and Laboratory Testing
C.4: Management Strategies
C.9: Technology Transfer for Pavements

Category D—Structures

Program D.1: Design
D.2: Management
D.3: Hydraulics
D.4: Corrosion Protection
D.9: Technology Transfer for Structures

Category E—Materials and Operations

Program E.1: Asphalt and Asphalt Mixtures
E.2: Cement and Concrete
E.3: Geotechnology
E.4: Paints and Coatings for Highways
E.5: Maintenance Effectiveness
E.6: Snow and Ice Control
E.7: Environmental Design
E.8: Construction Control and Management
E.9: Technology Transfer for Materials and Operations

Category F—Planning and Policy

Program areas under development.

Category G—Motor Carrier Transportation

Program areas under development.

Category H—R&D Management and Coordination

Program H.1: Transportation Research Board
H.2: International Road Federation
H.3: General Support Service
H.4: Specific Support Service
H.5: Advanced Concepts
H.6: Small Business Innovative Research Program
H.7: Other

Category I—Other NHI/RTAP

Program areas under development.

Figure 1.—NCP categories and program areas.

breakdown, arranged so that the SHRP technical research areas correspond directly to specific NCP program areas, will allow the NCP to meet its objectives.

Program Area 9 in the technical categories of the NCP describes all FHWA T² work related to the category. In addition to the Implementation Program, this includes National Highway Institute (NHI) training courses and Rural Technical Assistance Program (RTAP) projects, as well as Demonstration Projects and Special Experimental Projects. Program Area 9 also describes plans for FHWA T² Program Emphasis Areas being developed for multiyear, multioffice application as recommended by the FHWA T² Executive Committee, a group with oversight of FHWA's T² activities.

Three additional categories, F—Planning and Policy, G—Motor Carrier Transportation, and I—Other NHI/RTAP, organize the research, development, and technology transfer in these areas and simplify the program planning, management, coordination, priority setting, and budgeting activities.

HTIMS

The Highway Technology Information Management System (HTIMS), the Offices of RD&T's comprehensive information system, currently is being expanded and reprogrammed to reflect the NCP. HTIMS eventually will include not only all research but technology transfer activities as well. We also plan to include in the expanded system demonstration projects and the State activities of the Special Experimental Projects program, both monitored by the Office of Highway Operations.

Looking Forward

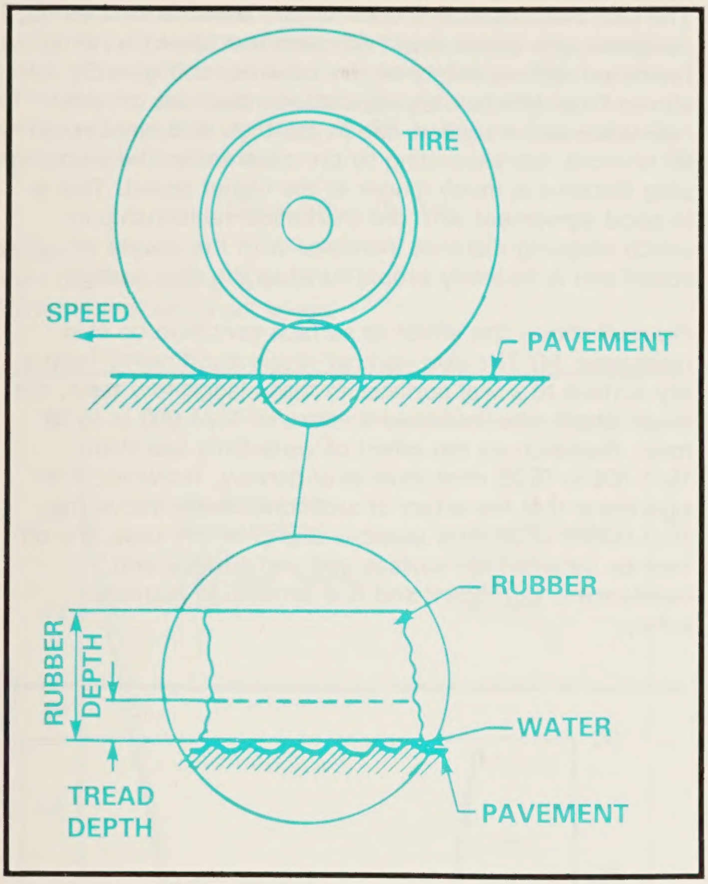
We feel that the newly implemented NCP systematically organizes the various national programs into a very effective single document program. This will allow all of us to coordinate our individual roles and act in unison in setting our national priorities, which will ensure effective coordination of State and Federal activities in solving significant highway-related problems.

REFERENCES

(*1*) "America's Highways 1776-1976," *U.S. Department of Transportation, Federal Highway Administration,* Washington, DC, 1977, p. 44.

(*2*) "America's Highways, Accelerating the Search for Innovation," Special Report 202, *Transportation Research Board,* Washington, DC, 1984.

David K. Phillips is Associate Administrator for Research, Development, and Technology, Federal Highway Administration. Before assuming his present position, Mr. Phillips served as Director of FHWA's Office of Engineering. He has held various positions in FHWA in the Office of Traffic Operations and the Connecticut, Puerto Rico, and New York division offices. Mr. Phillips is a graduate of the FHWA Highway Engineer Training Program.



Tire-Pavement Interaction[1]

by
Rudolph R. Hegmon

Introduction

The forces required to maintain a vehicle on the selected course at the desired speed are provided by the frictional coupling between the pavement and the tires. This tire-pavement friction is needed for traction and braking as well as directional stability. The magnitude of tire-pavement friction depends on a number of variables and is difficult to predict.

Under certain driving conditions, the friction demand may exceed the available friction, resulting in skidding, loss of vehicle control, and possibly an accident. A high coefficient of friction is needed to prevent skidding. "Skid resistance" describes the frictional resistance of a pavement and is measured in accordance with American Society for Testing and Materials Test Method E274—Skid Resistance of Paved Surfaces Using a Full-Scale Tire. (*1*)[2] The test is conducted at a constant 40 mi/h (64 km/h) speed on a wet pavement. A special test tire is used, and the wheel is locked for about 100 ft (30 m). The average coefficient of friction is multiplied by 100 and reported as a skid number (SN). Skid numbers vary widely, and pavements with low skid numbers are potentially hazardous.

This article presents an overview of the interactions between vehicle tires and the pavement, with the emphasis on highway safety. Factors affecting tire-pavement friction under wet conditions are discussed as well as means for improving the friction coupling. Although this article mainly addresses passenger cars, the principles discussed also apply to heavy trucks, except that most problems are amplified for trucks.

The Mechanism of Tire-Pavement Friction

Vehicle tires are part of a dynamic system, and their interaction with the pavement cannot be viewed in isolation. Tires transmit forces from the vehicle to the pavement, and the pavement must be able to withstand these forces. The vertical forces carry the total load, while the horizontal forces provide traction, braking, and directional stability. These horizontal forces, of primary interest for highway safety, depend on the coefficient of friction between the tires and the road surface.

[1]A paper with this same title was originally presented on February 24, 1987, at the annual meeting of the Society of Automotive Engineers in Detroit, Michigan.

[2]Italic numbers in parentheses identify references on page 11.

The strength of the friction coupling between tires and pavement depends on the properties of the tires, the vehicle suspension, and the pavement. On clean, dry pavements, friction is adequate for all but the most severe driving maneuvers. But friction is reduced drastically when the pavement is wet, covered with snow or ice, or contaminated. Also, much more friction is needed when accelerating (speeding up or braking), changing direction, or climbing a grade. For example, braking requires increased friction force in the direction of travel. Changing direction (in cornering or lane changing) requires an increased friction force perpendicular to the direction of travel—a side force. Braking during cornering complicates the matter further.

Friction demand and supply

For safe highways, the available friction or friction supply must exceed the friction demand. Available friction is the maximum frictional force that can be transmitted under the existing conditions. Friction demand is the frictional force needed to perform the intended maneuver, for example, braking, cornering, or a combination of these.

On dry and ice-covered pavements, the available friction is independent of speed and is high enough for most driving conditions on dry pavements. But available friction on wet surfaces can vary by a factor of 2 to 3. Figure 1 shows the basic relationship between available friction on wet pavements and friction demand. (*2*) Friction demand increases with increasing speed while available friction decreases on wet pavements. Thus, speed is a major variable in highway safety on wet pavements.

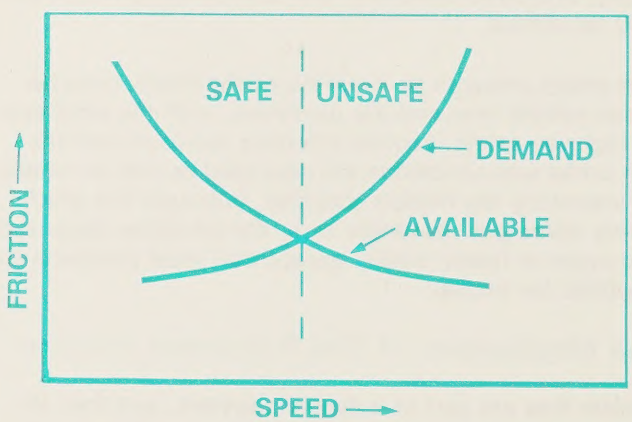


Figure 1.—Friction demand and available friction on wet pavements. (2)

The fact that available friction on dry pavements does not decrease with speed does not mean that speed is not a factor in highway safety on dry pavements. Figure 2 shows how vehicle stopping distance depends on skid resistance and on speed. (*3*) At the high skid numbers of 60 or more, corresponding to dry pavements, the stopping distance is much longer at the higher speed. This is in good agreement with the theoretical relationship in which stopping distance increases with the square of speed and is inversely proportional to the skid number.

Figure 3 shows the effect of surface condition on skid resistance. (*4*) The skid number drops significantly from a dry surface to a wet surface. In these laboratory tests, the water depth was increased in steps of 10/1,000 in (0.25 mm). Research on the effect of waterfilms less than 10/1,000 in (0.25 mm) thick is underway. However, it is significant that the effect of additional water above the 10/1,000-in (0.25-mm) depth is slight. In any case, the difference between dry surface and wet surface skid resistance is significant and is a concern in highway safety.

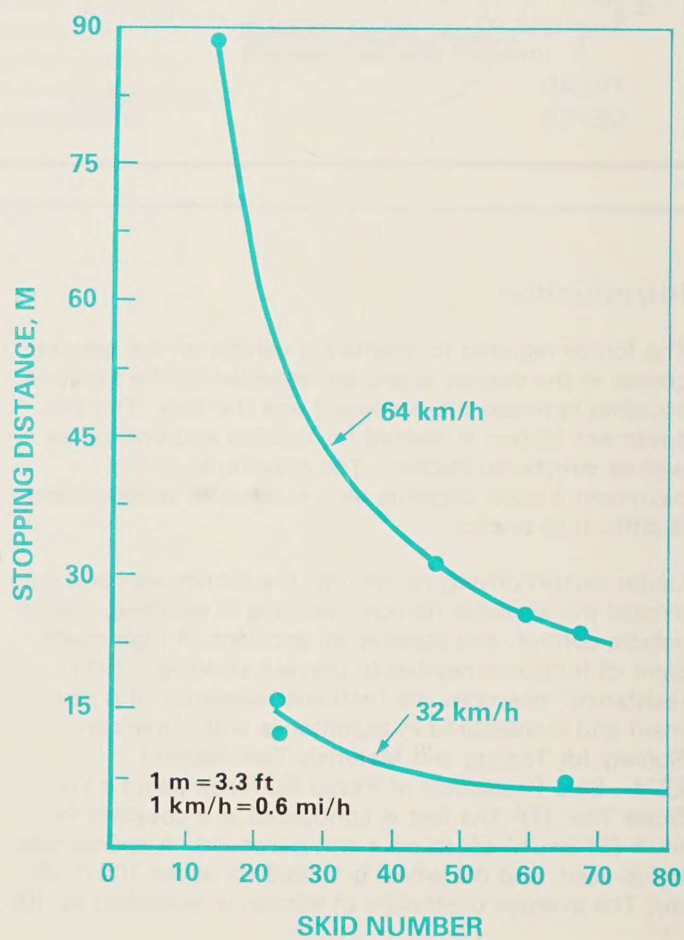


Figure 2.—Stopping distance of cars. (3)

Figure 4 also shows the difference in skid resistance between dry and wet surfaces. (*5*) Pavements covered with loose gravel or ice provide even less friction. The variable of interest in this figure is tire slip, defined as the difference between free-rolling speed and the rotational speed of the braked tire:

$$Slip = (Vo - Vb)/Vo$$

Where,
Vo = the free-rolling speed,
Vb = the braked wheel speed.

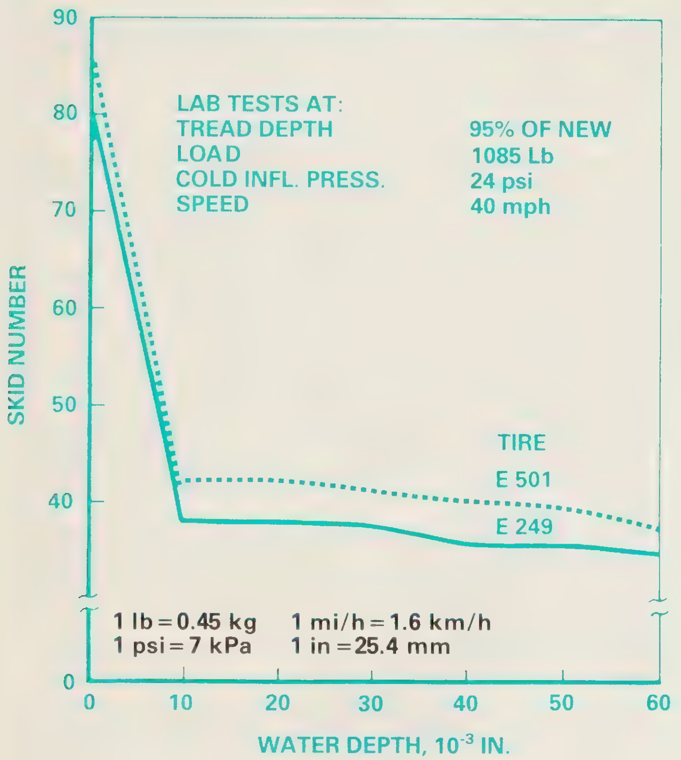


Figure 3.—Effect of wetness on skid resistance. (4)

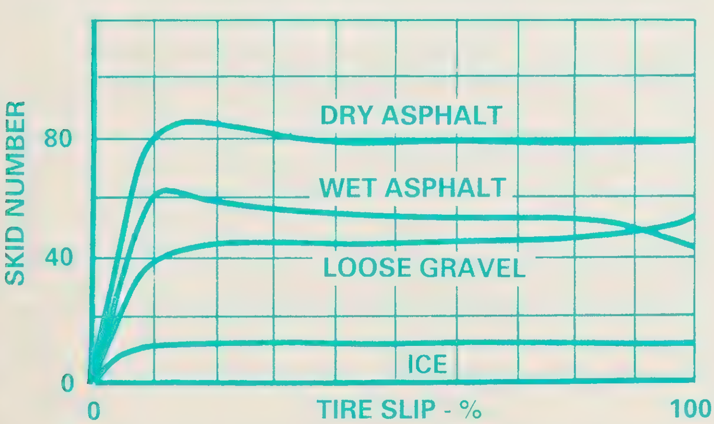


Figure 4.—Skid resistance under different surface conditions. (5)

Friction decreases above a certain value of slip. The significance for a driver is that in emergency braking, the wheels will lock when slip goes beyond the 10- to 20-percent range in which peak friction is usually reached. The locked-wheel coefficient is about 30 percent lower than the peak coefficient in the case shown in figure 4. Furthermore, a locked wheel has no directional stability. Even experienced drivers cannot prevent lockup in emergency situations. This is what antilock systems are designed to do.

The principle of an antilock system can be explained using figure 5. (*5*) As the slip increases beyond the peak coefficient and reaches point C, the antilock system reduces the brake pressure and the wheel gains some speed. At point D below the peak coefficient, the brake pressure is increased again. This cycling of the brake pressure is repeated until the vehicle is almost at rest. Such antilock systems are standard equipment on all airliners and are an option on some automobiles and trucks. Some automobiles use load-proportioning valves that adjust the brake relative to suspension deflection. Lightly loaded wheels tend to lock up first; reducing the brake pressure will reduce the probability of wheel lockup. Preventing wheel lockup should be one of the major objectives of automobile manufacturers, because a vehicle with locked wheels cannot be controlled and also has a greater risk of hydroplaning.

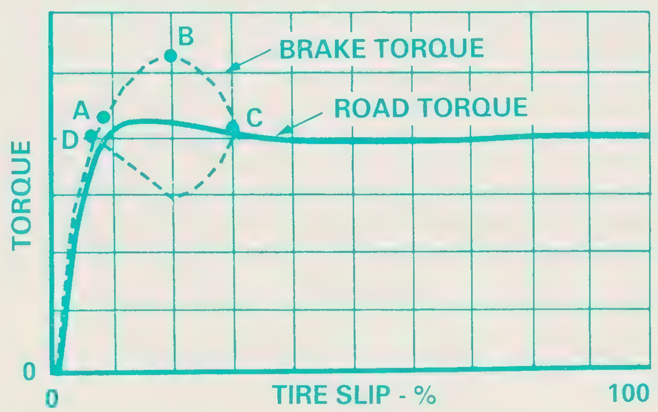


Figure 5.—Principle of an antilock brake system. (5)

The variation of friction force with tire slip was shown in figure 4, and figure 6 shows a similar curve with the side force curve superimposed. (*3*) When a vehicle is steered to change direction, inertia tends to keep the vehicle moving on a straight path. To keep the vehicle on the intended curved path, the tires must develop a side force. However, the combined side and braking forces cannot exceed the available friction. Applying the brake in a turn reduces the available side force significantly, even without locking the brakes. In the case shown in figure 6, the side force is reduced by more than 30 percent at 15-percent tire slip. Thus, if the speed is too high for a given curve, it is safer to slow down ahead of the curve.

Tire and pavement characteristics for wet weather safety

Skid resistance also depends strongly on the kind of tire and pavement. Some types of rubber provide more friction than others but unfortunately may not wear as well. So the tire designer must compromise between the contrasting requirements of good friction and good wear performance.

Figure 7 shows skid resistance as a function of speed and surface condition. (*6*) As previously mentioned, available friction is independent of speed on dry and ice-covered pavements but can vary on wet surfaces. The different shadings for the wet condition in figure 7 represent the distribution of friction levels on different pavements. The rate of skid resistance decrease with speed is different for different pavements.

These large differences in wet pavement skid resistance can be attributed partly to pavement texture. Pavement surfaces are not smooth and can be divided into three scales—roughness, macrotexture, and microtexture. Roughness is the largest scale and primarily affects ride comfort. Macrotexture and microtexture, however, are essential for adequate skid resistance on wet pavements. The basic structure of texture is shown in figure 8. (*7*)

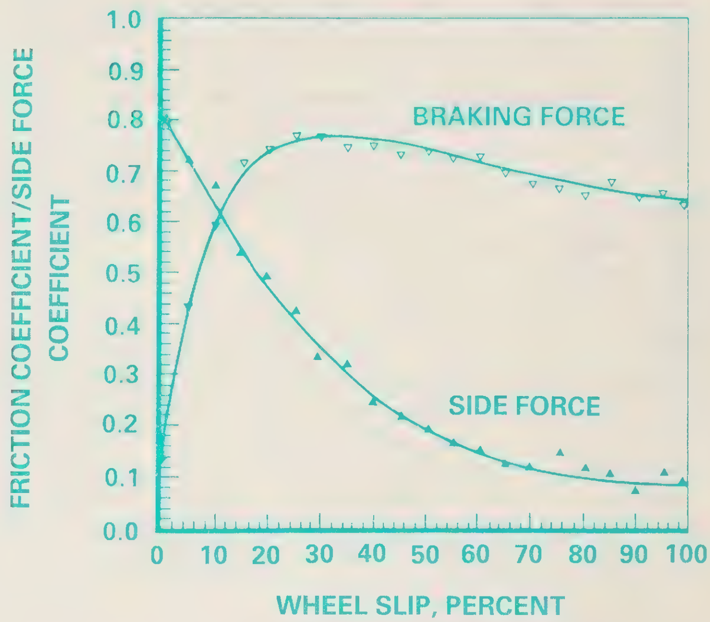


Figure 6.—Reduction in available side force with braked wheels. (3)

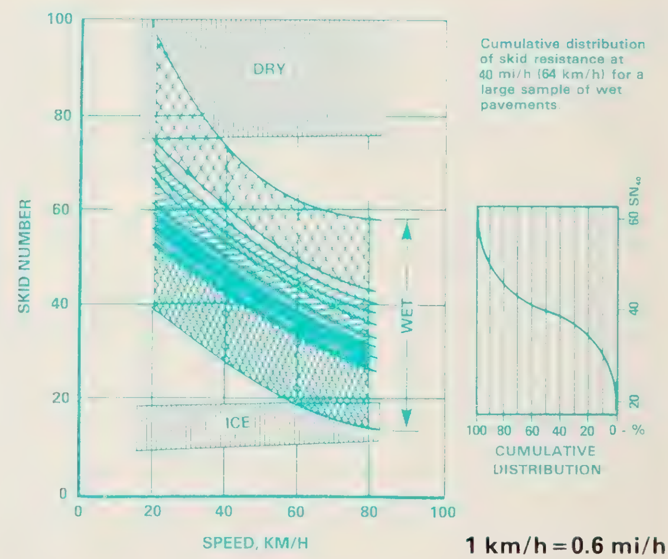


Figure 7.—Range of skid resistance on dry, wet, and icy surfaces. (6)

Pneumatic tires deform under load into a flat contact area with the pavement. On wet pavements, water trapped in this contact area must be expelled because the water reduces the available friction. The greater the vehicle speed is, the less time there is available for expelling the water, and this is the main reason for the decrease of friction with speed on wet pavements. Large, open flow channels provided by the tire tread and by the pavement macrotexture allow better and faster drainage and therefore reduce the speed dependence of skid resistance. Figure 9 shows the decrease in skid resistance as the tire tread wears, with a steep drop with bald tires. (*8*) Clearly, a minimum tread depth is essential on wet pavements.

Although macrotexture provides drainage channels, a thin waterfilm remains in the contact area. Harsh microtexture penetrates this film to establish quasi-dry contact points. Thus, both good macrotexture and microtexture are essential for good skid resistance under wet conditions. If water remains trapped in the contact area between the tire and pavement, hydroplaning may result. Dynamic hydroplaning, similar to waterskiing, is complete separation of the tire from the pavement by a continuous film of water. This is very rare and may occur at very high speeds such as the touchdown speed of an airplane. Underinflated tires are prone to hydroplaning because the low pressure may not be sufficient to expel the water. Overinflated tires have reduced contact areas and fewer quasi-dry contact points. This may lead to viscous hydroplaning, a transition phase between dynamic hydroplaning and wet friction.

Seasonal changes in skid resistance are typical and are very pronounced on asphalt pavement. Skid resistance usually reaches a minimum in late summer and recovers somewhat in the fall and during the winter. In addition, there are large short-term changes coinciding with rainy periods. The rain seems to chemically react with the aggregate to restore the microtexture. Thus, it is impossible to judge a pavement's skid resistance from a single measurement.

New pavement surfaces are designed for good macrotexture. Coarse macrotexture depends on the paving mixture and the surface finishing process. Harsh microtexture is obtained by selecting suitable aggregate (the stones and sand in the pavement surface). Aggregates providing good microtexture are relatively scarce, and highway departments sometimes must transport the surface aggregate great distances at increased cost. Fortunately, not all pavements need to be built to the same standard. For example, low-speed roads and urban streets do not require the same high-quality aggregate as high-speed roads do. Regardless of original construction standards, skid resistance will decrease with time. Pavement wear reduces macrotexture, while polishing by traffic reduces microtexture harshness necessary for penetrating thin waterfilms.

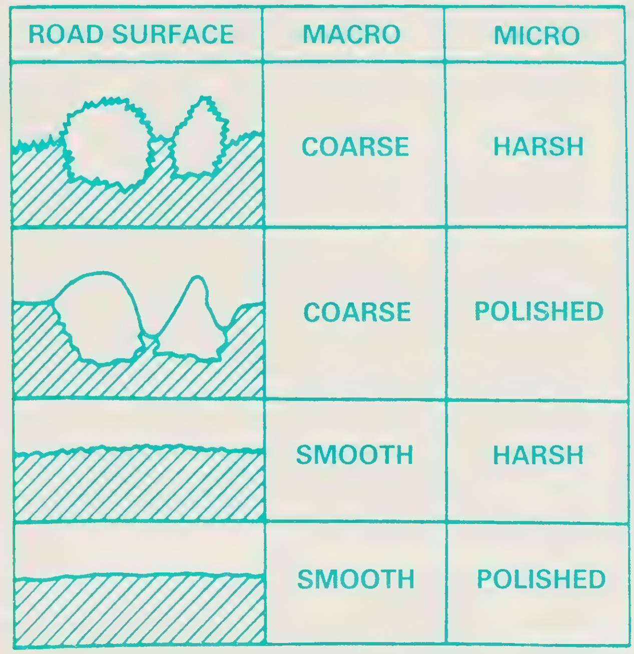


Figure 8.—Macrotexture and microtexture of pavement surfaces. (7)

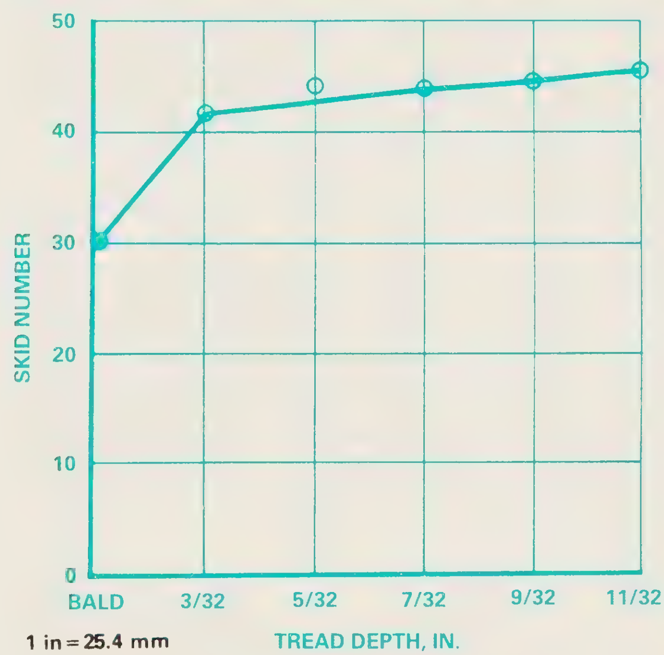


Figure 9.—Effect of tire-tread wear on skid resistance. (8)

In addition to providing skid resistance, macrotexture also reduces splash and spray and nighttime glare on wet pavements. Figure 10 shows the same site before and after resurfacing. (*9*) The coarse macrotexture has eliminated the glare completely. Thus, highway safety is enhanced on coarse-textured pavements in several ways.

Safety Problems for Trucks

The safety problems on wet pavements are amplified for trucks. Figure 11 shows that truck tires as a group develop less friction than passenger car tires under the same conditions. (*10*) One reason for this difference is that different rubber compounds are used in the tread of the truck tires for better wear under heavy loads. As discussed earlier, some friction potential must be sacrificed for good wear resistance. Also, truck tires are operated under higher loads and at higher inflation pressures than are passenger car tires. Both of these factors reduce the available friction.

The effect of dynamics also must be considered. Tire load does not remain constant; the load shifts among the tires of a passenger car during braking, cornering, and when traversing a rough road. Dual tires on trucks rarely share the load equally. Although the total load remains the same, the overall effect is to reduce the combined friction potential of the tires. Figure 12 shows how the coefficient of friction decreases with the frequency of wheel bounce. (*11*) Truck tires bounce at higher frequencies because of the higher inflation pressure and the stiffer truck suspension. Thus, the effect of rough roads on tire friction is worse for trucks than for passenger cars.

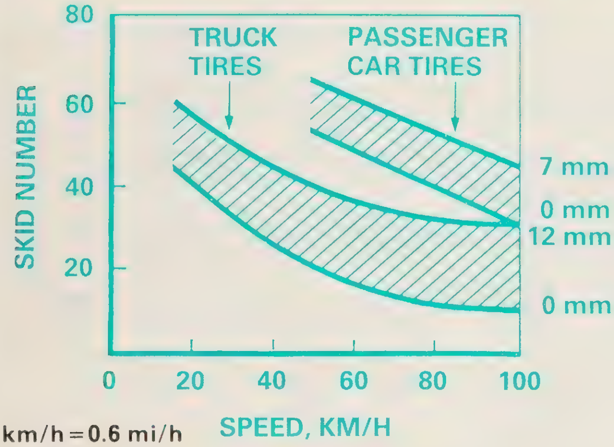
A Federal Highway Administration study is being conducted to investigate the frictional performance of truck tires under different pavement conditions and to determine the effective friction as affected by truck dynamics. Even under ideal conditions, it is difficult to achieve a uniform distribution of brake force to all wheels. The high center of gravity of most trucks leads to relatively large load shifts in braking and in cornering. The automotive industry has done an excellent job in improving the safety performance of passenger cars. The challenge now is to design trucks to the same level of safety.

Figure 10.—Glare on wet pavement before (top) and after (bottom) restoring coarse macrotexture. (9)

Summary

For safe driving, the friction demand must not exceed the maximum available friction. Available friction on wet pavement decreases rapidly with increasing speed. Good tire treads and coarse macrotexture allow better drainage and thus reduce the effect of speed. However, drainage does not remove all the water; harsh microtexture is needed to penetrate the remaining waterfilm.

Truck tire and suspension characteristics reduce available friction further. The greater the number of wheels, the more difficult it is to maintain proper brake balance. Also, the load on truck tires varies by a factor of 5 or more from an empty truck to one fully loaded. This makes it harder to optimize brake adjustments. Truck suspensions are designed to carry the full load and hardly deflect in an empty truck. This leads to extreme bouncing, which in turn reduces the available friction.



1 km/h = 0.6 mi/h
1 mm = 0.04 in

Figure 11.—Skid resistance of truck and passenger car tires, new-to-bald condition. (10)

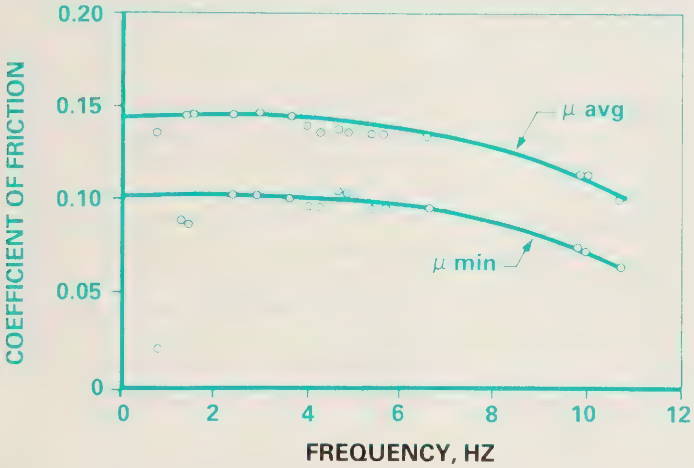


Figure 12.—Effect of road roughness on tire friction at about 3 percent slip. (11)

For all vehicles the friction potential of the total number of tires is less than the sum of the friction potential of the individual tires. This discrepancy can be minimized in the following ways:

- Highway departments can contribute by providing relatively smooth pavements with adequate skid resistance.
- Automobile manufacturers can contribute by designing tuned suspensions, that is, tire, spring, and shock absorber combinations to reduce wheel bounce.
- Lowering the center of gravity of trucks would be a major contribution toward greater highway safety.
- Antilock systems are available and would contribute to highway safety.
- Drivers can contribute by not making vehicle modifications that affect vehicle dynamics.

REFERENCES

(*1*) "1986 Annual Book of ASTM Standards: Section 4, Construction, Volume 04.03—Road and Paving Materials; Traveled Surface Characteristics," *American Society for Testing and Materials*, Philadelphia, PA, 1986.

(*2*) Joel M. Zuieback, "Methodology for Establishing Frictional Requirements," Transportation Research Record 623, *Transportation Research Board*, Washington, DC, 1976, pp. 51-61.

(*3*) Rudolph R. Hegmon, "Reliability of Locked-Wheel Skid Resistance Tester Confirmed," *Public Roads,* December 1982, pp. 92-101.

(*4*) R.R. Hegmon, S. Weiner, and L.J. Runt, "Pavement Friction Test Tire Correlation," Report No. FHWA-RD-75-88, *Federal Highway Administration*, Washington, DC, 1975, p. 57.

(*5*) Robert A. Grimm and Richard J. Bremer, "Wheel Lock Control State of the Art," Transportation Research Record 621, *Transportation Research Board,* Washington, DC, 1976, pp. 83-89.

(*6*) F. Gauss, "Vehicle Design and Skid Resistance," Transportation Research Record 621, *Transportation Research Board*, Washington, DC, 1976, pp. 19-27.

(*7*) Leonard H.M. Schloesser, "Tires and Road Surfaces," Transportation Research Record 624, *Transportation Research Board*, Washington, DC, 1976, pp. 15-26.

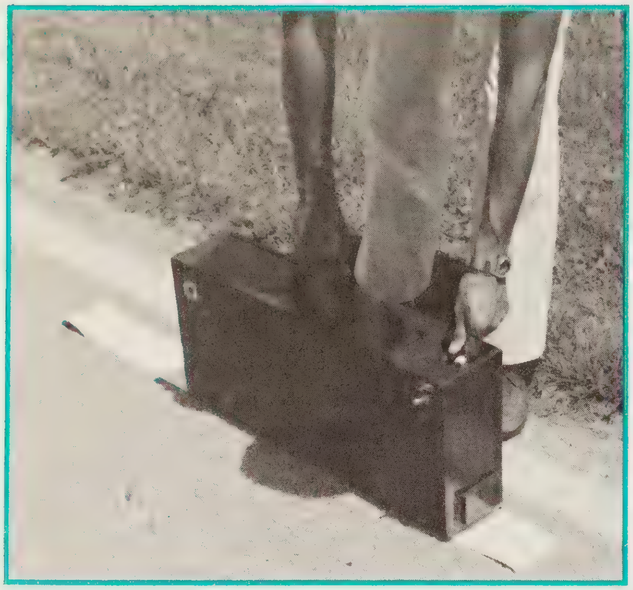
(*8*) David C. Mahone, "An Evaluation of the Effects of Tread Depth, Pavement Texture, and Water Film Thickness on Skid Number-Speed Gradients," Report No. VHTRC75-R40, *Virginia Highway and Transportation Research Council,* Charlottesville, VA, 1975, p. 85.

(*9*) W.Y.M. Van Bommel and J.B. deBoer, "Road Lighting," Philips Technical Library, Antwerp, Belgium, 1980, p. 16.

(*10*) Albert Dijks, "Influence of Tread Depth on Wet Skid Resistance of Tires," Transportation Research Record 621, *Transportation Research Board,* Washington, DC, 1976, pp. 136-147.

(*11*) Jerome S. Cap and J.C. Wambold, "Traction Loss of a Suspended Tire on a Sinusoidal Road," Transportation Research Record 1000, *Transportation Research Board,* Washington, DC, 1984, pp. 33-38.

Rudolph R. Hegmon is a mechanical engineer in the Pavements Division, Office of Engineering and Highway Operations Research and Development, FHWA. He has worked for FHWA in the areas of traffic safety and truck ride quality since 1973. Dr. Hegmon currently is working on the development of instrumentation for the measurement of pavement surface characteristics and vehicle dynamics. His research responsibilities include pavement-vehicle interactions and their effect on traffic safety, dynamic axle loads, and ride quality.



Correlation Study—Subjective Versus Instrumental Evaluation of Pavement Marking Retroreflection

by
Charles W. Niessner

Introduction

The use of portable retroreflectometers to measure the retroreflection of pavement markings has been increasing in recent years. Adequate means of measuring retroreflection of pavement marking materials have been available for many years; however, it has always been necessary to take samples of the materials from the field and test them in a laboratory to obtain a quantitative measure of retroreflection. Field evaluations of pavement marking retroreflection generally have been subjective. The procedure outlined under American Society for Testing and Materials Practice D-713 is used frequently. (*1*)[1] A rating panel of 3 to 10 people usually view the markings at night and rate each material's retroreflection on a scale of 1 to 10. As with most subjective ratings, many variables can affect the observer's rating. Paint stripes are particularly difficult to rate because differences among most paints and bead types are almost indiscernible. In these cases, it is invaluable to have an instrument that can quantitatively detect and measure the small differences among various samples. (*2*)

A number of States and private agencies have tried to build portable retroreflectometers to eliminate the subjectivity from evaluations, but without a standard for comparison, it is difficult to determine the success or failure of an instrument. In the late 1970's, three commercial retroreflectometers—the Ecolux, the Erickson, and the Optroniks—were introduced into the market. The Michigan Department of Transportation designed an in-house retroreflectometer that a number of highway agencies have either copied or slightly modified.

The two basic types of retroreflectometers are high-angle, or "coarse" geometry, and low-angle, or "fine" geometry. The primary difference between the two types is the entrance angle. For the low-angle instruments, this angle is approximately 86.5 degrees, and for the high-angle instruments it is 75 degrees. There are a few medium-angle retroreflectometers in which the entrance angle falls between the entrance angles of the high- and low-angle retroreflectometers.

With the increased use of both commercial and in-house retroreflectometers, it was desirable to determine the level of correlation among the various instruments. This article summarizes the field measurement procedures and data analysis of a correlation study of both high- and low-angle retroreflectometers available at the time of the study as well as subjective evaluations of pavement marking retroreflection.

Test Site

The test site was a two-lane, unlit rural highway near West Milford, New Jersey. The roadway was divided into seven test sections, each of which included a double yellow centerline and an 8-in (203-mm) wide white edgeline. In all of the test sections, each line of the centerline had a different bead system, and the edgeline was divided into two 4-in (102-mm) widths, each with a different bead system. Thus, each test section had four lines composed of different materials

[1] Italic numbers in parentheses identify references on page 15.

Data Collection

Subjective measurements

Subjective evaluations of the test lines were made at night using low-beam headlights of automobiles. Each line was rated three times on three separate drives through the test sections. The lines were rated on a scale from 1 to 10, with 10 as the brightest. All 18 raters who participated in the subjective evaluations were licensed drivers and employees of State highway agencies or private industries involved with pavement marking applications or products.

Instrument measurements

Fourteen different retroreflectometers were used to take measurements in this study (table 1). Five measurements were made by each retroreflectometer on each line in the seven test sections. The locations for the measurements had been marked previously to ensure that all readings were made at the same place.

Before the test began, however, each instrument was calibrated by taking five measurements at five different locations on a test panel. As in the actual test, each location had been marked previously, so all instruments made the measurements at the same location. This calibration procedure was repeated after all of the test sections had been measured to determine if the instruments "drifted" with extended use.

Line	Range	Mean	Standard deviation
White	0.187 to 0.964	0.710	0.166
Yellow	−0.38 to 0.944	0.528	0.225

Figure 1.—Correlation coefficients—rater versus rater.

Table 1.—Retroreflectometers used for measurements

Low-angle	Retroreflectometers Medium-angle	High-angle
Ecolux	Ohio Department of Transportation—Old	New York Department of Transportation
Potter's Experimental	Ohio Department of Transportation—New	Pennsylvania Department of Transportation 1
Zehntner 1		Pennsylvania Department of Transportation 2
Zehntner 2		Pennsylvania Department of Transportation 3
Optroniks		Virginia Department of Highways and Transportation
Erickson		Hercules

Data Analysis

Subjective method

The correlation coefficients comparing one rater with another rater are shown in figure 1. A correlation coefficient of 1.0 indicates perfect correlation. Negative coefficients indicate that the ratings were completely opposite, that is, one rater gave a line a very high rating while another rater gave a line a very low rating. As would be expected, the ranges of the correlation coefficients comparing the 18 raters with one another are quite broad. For example, for the white lines, the correlation coefficient for two of the raters was 0.964 whereas the correlation coefficient for two other raters was 0.187. Also, the range and standard deviation of the correlation coefficients are larger for the yellow lines than for the white lines, possibly because the differences among yellow lines are less discernible, making subjective evaluations more difficult and subject to variation.

Retroreflectometer calibration measurements

The calibration measurements taken before and after the actual test section measurements are shown in table 2. One of the Zehntner instruments had a 37-percent variation, so the data from this retroreflectometer were not used in developing the correlation coefficients. The variations between the before-and-after readings ranged from 1 to 14 percent, with the low-angle instruments varying between 8 and 14 percent and the high-angle instruments varying between 1 and 6 percent. All but two of the instruments were reading higher after the test sections were measured than before they were measured.

Retroreflectometer versus retroreflectometer

The correlation coefficients comparing one retroreflectometer with another are shown in figure 2. These ranges and standard deviations are much smaller than those for the subjective evaluations. As with the subjective evaluations, the range and standard deviation are larger for the yellow lines than for the white lines.

Table 3 shows the ranges of correlation coefficients comparing high-angle, medium-angle, and low-angle retroreflectometers with one another. For example, high-angle machine A may have a correlation coefficient of 0.995 with high-angle machine B and 0.947 with high-angle machine C; its correlation coefficient with low-angle machine G may be 0.823. The ranges for the high-angle versus high-angle instruments are approximately the same for the yellow lines and white lines (0.048 versus 0.042). For the yellow lines, the ranges for the high-angle versus the low-angle instruments (0.129) and the low-angle versus low-angle instruments (0.153) are about 3 times the range for the high-angle versus high-angle instruments (0.048). Again, all of the ranges for the yellow lines are larger than the comparable ranges for the white lines.

Line	Range	Mean	Standard deviation
White	0.881 to 0.996	0.958	0.026
Yellow	0.813 to 0.995	0.931	0.048

Figure 2.—Correlation coefficients—retroreflectometer versus retroreflectometer.

Table 2.—Calibration measurements

Instrument	Before (B) or after (A)	Readings 1	2	3	4	5	Average	Percent change
Ecolux[1]	B	142	139	151	150	123	141	+8
	A	153	152	162	155	140	152	
Potter's Experimental	B	375	395	380	385	352	377	−14
	A	320	340	355	320	296	326	
Zehntner 1[1]	B	368	352	379	384	292	355	+14
	A	414	421	407	450	326	404	
Zehntner 2[1]	B	286	286	292	282	265	282	+37
	A	307	409	400	418	375	382	
Optroniks[1]	B	379	380	357	328	313	351	+14
	A	392	422	434	405	349	400	
Erickson[1]	B	352	364	372	372	310	354	+11
	A	401	467	403	360	341	394	
Ohio DOT—Old	B	30	30	30	30	29	30	+10
	A	34	32	34	35	30	33	
Ohio DOT—New	B	36	36	36	36	36	36	+8
	A	39	37	41	42	37	39	
New York DOT	B	339	355	373	370	352	358	+6
	A	368	405	389	377	353	378	
PennDOT 1	B	173	178	182	188	162	177	+1
	A	168	203	164	168	186	178	
PennDOT 2	B	167	173	186	176	162	173	+5
	A	180	183	188	188	166	181	
PennDOT 3	B	172	188	184	197	171	182	+2
	A	174	198	191	197	167	185	
Virginia DH&T	B	392	370	420	427	379	398	+4
	A	367	408	450	457	378	412	
Hercules	B	195	198	208	209	195	201	−1
	A	187	210	203	212	189	200	

[1]Readings are in millicandela per square metre. (Readings for the other instruments are dimensionless.)

1 m = 3.3 ft

Instrumental versus subjective evaluations

An analysis of the instrumental data versus the subjective ratings yielded the correlation coefficients shown in figure 3. The ranges and standard deviations are large, particularly for the yellow lines.

Tables 4 and 5 rank the test lines according to the instrument retroreflection values and the subjective ratings of retroreflection. The rankings for the white lines, particularly the brighter ones, are almost identical for the two methods. For the yellow lines, the rankings are much more diverse.

Findings and Conclusions

- Generally there is good correlation among high-angle retroreflectometers for measurements on both white and yellow lines and among low-angle retroreflectometers for measurements on white lines. The correlation between low-angle and high-angle retroreflectometers is not as strong. Good correlation among high-angle instruments is to be expected because they all were made from the same blueprint and should be equal in performance. The other instruments, however, were made "from scratch," using different components and ideas.
- Correlation among subjective ratings is not very strong, suggesting that the use of observers to rate retroreflection may not be the best method, particularly when differences among paints and bead types are difficult to discern visually.
- The ranges and standard deviations of the correlation coefficients for the retroreflectometers are much smaller than those for the subjective ratings.
- In all of the comparisons, the ranges of the correlation coefficients are larger for the yellow lines than for the white lines.
- According to the retroreflectometer measurements in this study, the 10 least retroreflective white lines vary in retroreflection from 41.7 to 101.3, while the 10 least retroreflective yellow lines vary in retroreflection from 42.9 to 49.9. It is much easier to rank lines having a wide variation in retroreflection, such as with white lines. Yellow lines, which have less variation in retroreflection, are harder to rate visually.
- Over several hours of continuous use, all instruments drifted in their readings, some more than others. Care should be exercised in using retroreflectometers to determine the degree of drift and make the necessary corrections.
- It appears that if a large number (16 to 20) of raters are used for the subjective evaluation, the final ranking of the lines will be similar to the retroreflectometer ranking, particularly for brighter white lines. However, the subjective evaluation in this study was a one-time event. Normally in evaluating pavement marking, the subjective ratings would be repeated periodically over the duration of the study. From a practical and economic standpoint, it is not feasible to take a large group of raters out at night five or six times during a study to evaluate pavement markings.

Retroreflectometers offer a substantial improvement over subjective evaluations in conducting pavement marking studies. The retroreflectometer measurements can be made by one person in the daylight during normal work hours, whereas subjective evaluations are made at night

Table 3.—Comparison of ranges of correlation coefficients[1]

Retro-reflectometer	Yellow centerlines High-angle	Yellow centerlines Medium-angle	Yellow centerlines Low-angle	White edgelines High-angle	White edgelines Medium-angle	White edgelines Low-angle
High-angle	0.947 to 0.995 (0.048)			0.951 to 0.993 (0.042)		
Medium-angle	0.930 to 0.989 (0.059)	0.990 (N/A)		0.955 to 0.986 (0.031)	0.996 (N/A)	
Low-angle	0.823 to 0.952 (0.129)	0.854 to 0.957 (0.103)	0.813 to 0.966 (0.153)	0.881 to 0.977 (0.096)	0.946 to 0.993 (0.047)	0.936 to 0.983 (0.047)

[1]Numbers in parentheses are the differences between the high and low correlation coefficients.

Line	Range	Mean	Standard deviation
White	0.377 to 0.948	0.737	0.121
Yellow	−0.159 to 0.761	0.391	0.194

Figure 3.—Correlation coefficients—instrumental versus subjective evaluations.

Table 4.—Subjective versus instrumental ranking of white edgeline retroreflection

Test line number	Instrument ranking	Retroreflection value[1]	Subjective ranking	Average subjective rating
6L	1	164.5	1	7.7
7L	2	137.5	2	7.6
3L	3	136.8	3	7.5
6R	4	108.6	7	6.4
4L	5	101.3	5	6.6
5L	6	98.2	4	7.4
7R	7	86.5	6	6.6
5R	8	84.2	8	6.3
3R	9	71.1	14	4.2
1R	10	62.3	9	5.6
4R	11	53.5	11	5.0
1L	12	50.7	12	4.8
2R	13	47.1	10	5.5
2L	14	41.7	13	4.4

[1]Percentage of standard on Ecolux retroreflectometer.

Table 5.—Subjective versus instrumental ranking of yellow centerline retroreflection

Test line number	Instrument ranking	Retroreflection value[1]	Subjective ranking	Average subjective rating
4L	1	103.1	4	7.1
6L	2	74.3	2	7.4
5L	3	73.5	1	7.5
5R	4	52.4	7	6.7
7R	5	49.9	3	7.3
6R	6	49.4	5	7.0
7L	7	48.2	14	5.3
2L	8	47.6	9	6.3
3L	9	45.7	6	6.8
4R	10	45.3	10	6.2
3R	11	44.5	8	6.7
2R	12	43.9	12	5.7
1R	13	43.3	11	6.2
1L	14	42.9	13	5.3

[1]Percentage of standard on Ecolux retroreflectometer.

with a number of raters. Despite some drifting problems, which can be minimized, using retroreflectometers can reduce study costs and allow a safer (daytime versus nighttime) data collection operation.

Acknowledgment

The author wishes to acknowledge Potter's Industries, Inc., of New Jersey for conducting the data analysis in this study.

REFERENCES

(*1*) ASTM Practice D-713-81 "Conducting Road Service Tests on Traffic Paints," *American Society for Testing and Materials,* Philadelphia, PA, November 1981.

(*2*) Kenneth R. Agent and Jerry G. Pigman, "Development of a Portable Retroreflectometer," Report No. UKTRP-83-9, *Kentucky Transportation Research Program, University of Kentucky,* April 1983.

Charles W. Niessner is a supervisory highway engineer in the Engineering and Highway Operations Implementation Division, Office of Implementation, FHWA. His responsibilities include overall supervision of the pavements, maintenance, and delineation implementation programs.

Recent Research Reports You Should Know About

The following are brief descriptions of selected reports recently published by the Federal Highway Administration, Offices of Research, Development, and Technology (RD&T). The Office of Engineering and Highway Operations Research and Development (R&D) includes the Structures Division, Pavements Division, and Materials Division. The Office of Safety and Traffic Operations R&D includes the Traffic Systems Division, Safety Design Division, and Traffic Safety Research Division. The reports are available from the source noted at the end of each description.

Requests for items available from the RD&T Report Center should be addressed to:

Federal Highway Administration
RD&T Report Center, HRD-11
6300 Georgetown Pike
McLean, Virginia 22101-2296
Telephone: (703) 285-2144

Bridge Waterways Analysis Model: Research Report, Report No. FHWA/RD-86/108

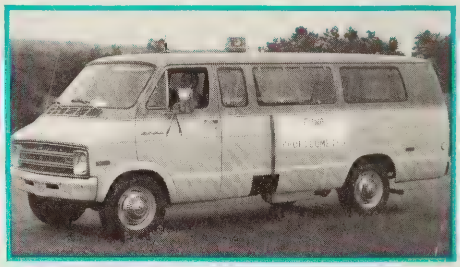
by Structures Division

Designers of flood plain encroachments often are required to make repetitive water-surface profile computations for alternative structures and for a wide range of floods, including floods that will overtop the road. The object of the study discussed in this report was to develop an improved water-surface profile computation program based on a model that would be compatible with conventional step-backwater analyses, would be easy to use, would have improved computations for flow through bridge openings, would handle combined road overflow and bridge-opening flow, would handle multiple waterway openings in a logical manner, and would have the capability to selectively output summary tables to enhance later analyses.

WSPRO, a digital model for water-surface profile computation, was developed to meet these needs. This report describes WSPRO's capabilities and data requirements and the theory and computational techniques incorporated into the model. The report compares results from WSPRO with results from two existing models for five field verification sites and discusses the applicability of WSPRO when designing bridges using risk analysis concepts.

Limited copies of the report are available from the RD&T Report Center.

The Ann Arbor Road Profilometer Meeting, Report No. FHWA/RD-86/100



by Pavements Division

At the Road Profilometer Meeting held in Ann Arbor, Michigan, in September 1984, 11 agencies used their profiling equipment to measure road roughness on 27 test sites. Overall, 13 independent measurements were made, including static rod and level measurements on 10 of the test sites. Analyses of the profiles obtained in the experiment were used to determine and compare some of the performance characteristics of profilometers in use today.

The profiles recorded in these 13 measurements were processed to yield quarter-car roughness, root-mean-square vertical acceleration (RMSVA) roughness, power spectral density functions, and waveband indices. Plots of filtered profiles also were compared. These results were used to determine the performance limits of the profilometers in terms of operating speed, surface type, and roughness level.

Most of the profilometers measured valid profiles over a full range of pavement roughnesses, with varying degrees of accuracy that depended on the particular profilometer and the analysis used. Some of the profiles were not valid, indicating that better data-checking methods need to be adopted.

Limited copies of the report are available from the RD&T Report Center.

Introduction of Lime Into Asphalt Concrete Mixtures, Report No. FHWA/RD-86/071

by Pavements Division

The objectives of the study discussed in this report were to recommend procedures for introducing hydrated lime into asphalt concrete mixtures, to recommend procedures for adjusting lime-treated mixture designs so that lime functions as an effective antistripping additive, and to evaluate the effectiveness of the recommended procedures using full-scale test sections.

To evaluate lime introduction systems, 15 test sections were built on 5 projects in 4 States. Mixtures and cores representing each lime system were tested to determine susceptibility to moisture damage. Current lime introduction practices were studied, but superior procedures could not be identified.

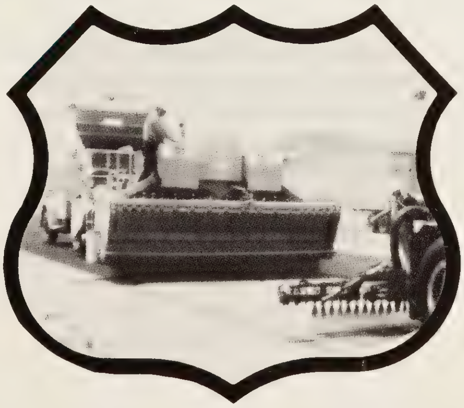
Neither mixtures nor cores at approximately age 1 day and age 6 months revealed conclusive differences among lime systems. Although differences among lime systems were too small to be conclusive, on each project the wet system (adding lime slurry or dry lime to damp mineral aggregate) was more resistant to moisture damage than was the dry system (adding dry lime to either dry mineral aggregate or asphalt cement). It was concluded that the test sections were not old enough for moisture damage to develop, and it was recommended that evaluation of test sections be extended to age 5 years.

Limited copies of the report are available from the RD&T Report Center.

Investigation of Materials and Structural Properties of Asphalt-Rubber Paving Mixtures, Report No. FHWA/RD-86/027

by Pavements Division

This report describes a study that investigated the use of ground tire rubber in asphalt pavement construction. Asphalt-rubber mixtures, in which the binder consists of 18 to 26 percent ground tire rubber blended with asphalt cement at high temperatures, were investigated as were other mixtures in which rubber is considered an elastic aggregate. Seal coats and interlayers used to prevent cracking also were evaluated.



The negative performance of some interlayer installations seemed to be related to the inappropriate use of materials rather than the fundamental material properties of these blends. Improved performance should be possible if use is limited to specific modes of pavement distress. The adverse performance of many asphalt-rubber seal coats studied can be related directly to a high incidence of flushing distress caused by excessive binder. A design procedure that should reduce flushing incidence is presented for asphalt-rubber seal coats. Also, guidelines are included for preparing construction specifications for seal coats and interlayers.

Limited copies of the report are available from the RD&T Report Center.

Corrosion of Highway and Bridge Structural Metals by CMA, Report No. FHWA/RD-86/064

by Materials Division

Corrosion of bridge structural metals by deicing chemicals that contain chloride has become a major economic problem in the United States. The Federal Highway Administration has proposed the use of calcium magnesium acetate (CMA) as a replacement deicer for sodium chloride and calcium chloride. This report describes a study of the effects of reagent-grade CMA and commercial-grade CMA on metals used in bridge construction.

Weight-loss tests after immersion, electrochemical tests, and ponding tests using CMA and salt solutions were conducted using weathered and unweathered galvanized steels, A-36 steels, cast iron, metal alloys, stressed and painted metals, and reinforcing steel in concrete.

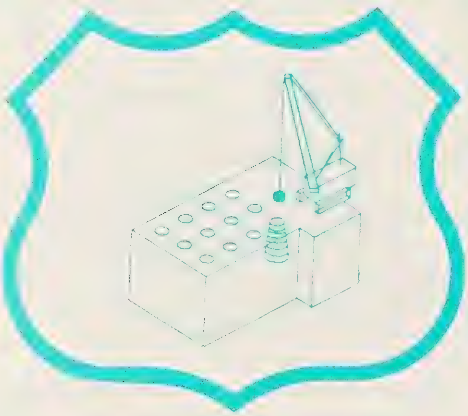
The results of these electrochemical and exposure studies indicate CMA generally is much less corrosive to the exposed metals than is sodium chloride.

Limited copies of the report are available from the RD&T Report Center.

Dynamic Compaction for Highway Construction, Volume I: Design and Construction Guidelines, Report No. FHWA/RD-86/133

by Materials Division

Dynamic compaction has been found to produce densification in certain natural and fill deposits to depths varying from 10 to 35 ft (3.0 to 10.7 m) below grade and has an application for highway construction. This report contains state-of-the-art information on dynamic compaction assembled from published articles, actual job records, interviews with engineers and contractors, and data obtained from three project sites.



Guidelines are presented for determining the suitability of deposits for dynamic compaction, estimating the depth and degree of densification, planning the spacing between drop points, estimating the required unit applied energy, monitoring the improvement, and predicting offsite ground vibrations. Nontechnical aspects of dynamic compaction also are discussed, including equipment requirements, typical costs, and methods for negotiating a contract including specification guidelines.

Limited copies of the report are available from the RD&T Report Center.

Economic Assessment of Potential Solutions for Improving Motorist Route Following, Report No. FHWA/RD-86/029

by Traffic Systems Division

This report summarizes the results of a study to establish the amount and cost of wasted travel caused by inefficient highway navigation for noncommercial vehicles in the United States. Excess travel caused by deliberate waste and excess time caused by failures in real-time route selection were not addressed.

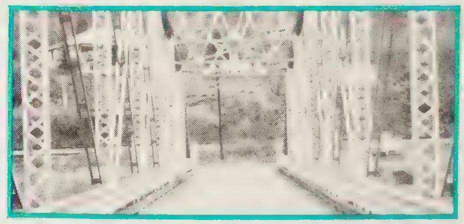
It was estimated that each year recoverable navigational waste amounts to 6.4 percent of all distance traveled by noncommercial vehicles, and the **annual** cost to individuals and society for this additional travel was estimated to be $45.7 billion considering only vehicle operating costs ($10 billion), accident potential ($4.4 billion), and the value of time ($31.3 billion). Suggested remedial measures to improve motorist route-following include improving driver skills and knowledge; providing route planning information; developing a highway information system; and developing trip planning, navigation, and guidance systems.

Limited copies of the report are available from the RD&T Report Center.

Retrofit Railings for Narrow Through Truss and Other Obsolete Bridge Structures, Report No. FHWA/RD-82/099

by Safety Design Division

Through truss structures present a unique danger because the superstructure of the bridge is exposed to impacts from errant vehicles. Complete collapse of truss structures has resulted from heavy vehicle impacts as well as automobile impacts. Effective railings for through truss structures must keep vehicles from contacting the critical truss members by limiting system deflection. In addition, heavy vehicles must be prevented from rolling over a barrier and contacting a truss member.



This report describes two bridge railing retrofit systems that were designed and developed. The high performance system is designed to contain and limit vehicle roll of 20,000-lb (9.1-Mg) buses impacting at 55 mi/h (89 km/h) at a 15-degree angle. The low service retrofit system contains and redirects 4,500-lb (2.0-Mg) automobiles impacting at 60 mi/h (97 km/h) at a 15-degree angle without endangering the truss members behind the retrofit system.

Crash tests with vehicles ranging from the bus to an 1,800-lb (0.8-Mg) minicompact vehicle were used in the development and evaluation of these retrofit systems. Design drawings of the bridge rails, bridge attachment detail, and approach rail are included in the report.

Limited copies of the report are available from the RD&T Report Center.

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

The following are brief descriptions of selected items that have been completed recently by State and Federal highway units in cooperation with the Office of Implementation, Offices of Research, Development, and Technology (RD&T), Federal Highway Administration. Some items by others are included when the items are of special interest to highway agencies.

Requests for items available from the RD&T Report Center should be addressed to:

Federal Highway Administration
RD&T Report Center, HRD-11
6300 Georgetown Pike
McLean, Virginia 22101-2296
Telephone: (703) 285-2144

Manual on Countermeasures for Sign Vandalism, Report No. FHWA-IP-86-7

by Office of Implementation

Sign vandalism in the United States costs taxpayers $50 million to $2 billion annually in maintenance costs and has been reported as a contributing cause in a number of serious traffic accidents. In addition, vandalism-related accidents may expose the highway agency or municipality to tort liability costs.

This manual describes the scope and magnitude of the sign vandalism problem and the associated impacts on system maintenance and repair costs, highway safety, and governmental liability. It describes available sign vandalism countermeasures and their effectiveness and guides State and local personnel in planning, implementing, and evaluating antivandalism programs.

Limited copies of the manual are available from the RD&T Report Center.

Manual on Real-Time Motorist Information Displays, Report No. FHWA-IP-86-16

by Office of Implementation

This manual provides practical guidelines for the development, design, and operation of real-time driver displays for freeway corridor traffic management. The manual discusses the recommended content of messages to be displayed in various traffic situations, where the messages should be placed in relation to the situations they are explaining, and the manner in which messages are to be displayed—format, coding, style, length, load, redundancy, and number of repetitions.

The manual is especially useful in designing displays for traffic management of freeway incidences or severe congestion. Many of the recommendations and principles also may be useful for traffic management during freeway maintenance or construction.

Limited copies of the manual are available from the RD&T Report Center.

Highways and Wetlands: Compensating Wetland Losses, Report No. FHWA-IP-86-22

by Office of Implementation

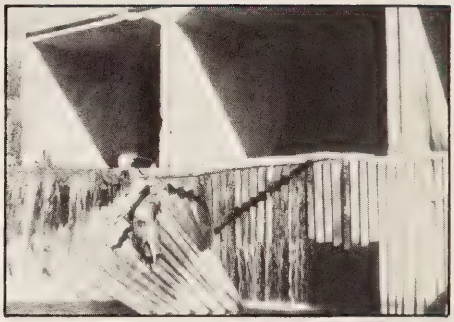
Wetlands are important functional components of the natural environment and are protected under Federal and State laws. When wetlands cannot be avoided by highway projects, measures to mitigate the adverse impacts must be considered. This report is a practical guide for creating and restoring wetland habitat. It provides cost-effective concepts, methods, and general specifications for compensating wetland losses.

The report provides a general discussion of the concepts and considerations involved in compensating unavoidable wetland losses. The topics addressed include wetland replacement, restoration, and enhancement as well as factors that may limit success. The report also provides information for the conceptual design of wetland systems and procedures for wetland establishment.

The site-specific nature of wetland compensation measures precludes detailed instructions and specifications for wetland establishment and enhancement, so judgment must be used in applying the report recommendations.

Limited copies of the report are available from the Environmental Analysis Division (HEV-20), Federal Highway Administration, 400 Seventh Street SW., Washington, DC 20590.

Culvert Inspection Manual: Supplement to the Bridge Inspector's Training Manual, Report No. FHWA-IP-86-2



by Office of Implementation

This manual provides practical guidelines and procedures for inspecting the various types of box, pipe, and long-span culverts. Inspection procedures are outlined and illustrated in detail. Sample documentation forms are provided for recording each inspection. This manual is a supplement to the **Bridge Inspector's Training Manual** and was prepared in accordance with its procedures and rating systems.

The manual may be purchased for $10 from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402 (Stock No. 050-001-00300-7).

Inspection of Fracture Critical Bridge Members: Supplement to the Bridge Inspector's Training Manual, Report No. FHWA-IP-86-26

by Office of Implementation

This manual provides practical procedures for the inspection and rating of various types of bridges with fracture critical members. The importance of inspecting these members is explained, and information is provided on planning, inspecting, and documenting the inspection of fracture critical bridge members. The manual is a supplement to the **Bridge Inspector's Training Manual** and was prepared in accordance with its procedures and rating systems.

The manual may be purchased for $11 from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402 (Stock No. 050-001-00302-3).

Guide to Management of Roadside Trees, Report No. FHWA-IP-86-17

by Office of Implementation

This guide, prepared for local and State authorities responsible for maintaining roads, documents the results of field testing of a step-by-step approach to roadside tree management. Information is included on how to identify and treat both existing and potential locations with a high risk of vehicle/tree accidents. Guidance is provided for implementing roadside tree removal and for addressing environmental and safety issues, alternative treatments, mitigation, and maintenance practices.

Limited copies of the guide are available from the RD&T Report Center.

Railroad-Highway Grade Crossing Handbook—Second Edition, Report No. FHWA-TS-86-215

by Office of Implementation

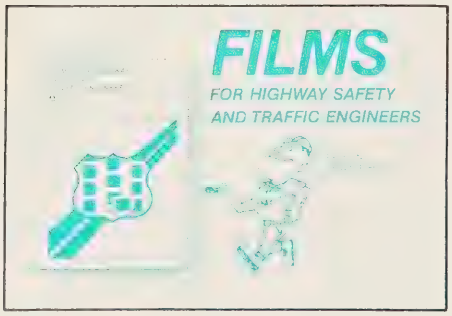
This handbook, an update of the 1978 report of the same title (Report No. FHWA-TS-78-214), aids personnel in determining the element of risk present at a given rail-highway grade crossing. Track condition, presence of pedestrians, and motor vehicle traffic are analyzed for their effect on safety. Several formulas are presented that quantify the degree of risk for each crossing and identify locations most in need of improvement. At-grade improvements such as active warning devices, passive warning devices, sight distance improvements, operational improvements, and crossing surface improvements are compared. Procedures, models, and computer programs are described that can help personnel choose the most cost-efficient improvement for each crossing.

Limited copies of the handbook are available from the RD&T Report Center.

Films for Highway Safety and Traffic Engineers, Report No. FHWA-IP-86-25

by Office of Implementation

This report provides abstracts of films of potential interest to highway safety and traffic engineers. Each abstract includes the film's content, format, length, production year, and target audience, as well as availability and ordering information. A subject index of key words is provided for all of the films, which are listed in alphabetical order.



The abstracted films come from both public and private sources. Some are very technical; others are suitable for general audiences. For example, several are aimed at teaching traffic skills to children, others are targeted for driver-education students, and still others stress the importance of using seatbelts or the dangers of drinking and driving.

Limited copies of the report are available from the RD&T Report Center.

Bicycle-Compatible Highways, Slide Presentation FHWA-TS-87-210

by Office of Implementation

This 20-minute slide presentation explores how limited modification of lane widths, surface textures, signs and markings, intersection treatments, and traffic controls can facilitate safe use of roadways by both motorists and bicyclists without interfering with motor vehicle travel. Topics of discussion in this slide show include lane markings, intersections, narrow bridges, pavement width, shoulders, traffic mix, types of pavements, factors limiting sight distance, and obstacles to bicyclists including railroad crossings, drainage grates, stream flow grates, parking lanes, and manhole covers.

The slide show, based on a New Jersey Department of Transportation report entitled "Bicycle-Compatible Roadways—Planning and Design Guidelines," offers a wide range of suggestions to highway engineers who must provide a safe environment for a mix of vehicles while making limited modifications of existing streets and highways.

Copies of the slide presentation are available on loan from the RD&T Report Center.

Revisions to the Manual on Uniform Traffic Control Devices, Slide Presentation FHWA-IP-86-27

by Office of Implementation

This 30-minute slide presentation is designed to identify and highlight Revisions 2, 3, and 4 to the 1978 edition of the Manual on Uniform Traffic Control Devices (MUTCD). The MUTCD sets forth the national standards for the design and application of all traffic control devices on public streets and highways.

The slide presentation will be of interest to State and local engineers involved with traffic control devices, including signs, signals, and pavement markings.

Copies of the slide presentation are available on loan from the RD&T Report Center.

New Research in Progress

The following new research studies reported by FHWA's Offices of Research, Development, and Technology are sponsored in whole or in part with Federal highway funds. Beginning with this issue, the studies cited in this department reflect the conversion of studies from the Federally Coordinated Program (FCP) of Highway Research, Development, and Technology to the Nationally Coordinated Program (NCP) of Highway Research, Development, and Technology. (See the article entitled "The Nationally Coordinated Program (NCP) of Highway Research, Development, and Technology" on page 1.)

For further details on a particular study, please note the kind of study at the end of each description and contact the following: Staff and administrative contract research—*Public Roads* magazine; Highway Planning and Research (HP&R)—performing State highway or transportation department; National Cooperative Highway Research Program (NCHRP)—Program Director, National Cooperative Highway Research Program, Transportation Research Board, 2101 Constitution Avenue, NW., Washington, DC 20418.

NCP Category A—Highway Safety

NCP Program A1: Traffic Control for Safety

Title: Traffic Control Design Elements for Accommodating Drivers With Diminished Capability. (NCP No. 3A1A0012)

Objective: Determine if the aged driver is being adequately accommodated by current traffic control design criteria. Identify the population of elderly drivers and determine how their visual and information processing decrements affect their driving performance and perception of highway signs. Consider the range of drivers and driver attributes affected by the aging process including visual acuity, dark adaption, glare sensitivity, color vision, and reaction time. Address the full range of driving situations and fixed and variable message signing and other traffic control devices. Include day and night situations.
Performing Organization: Ketron, Inc., Philadelphia, PA 19087
Expected Completion Date: February 1989
Estimated Cost: $285,000 (FHWA Administrative Contract)

Title: Motorist Compliance With Standard Traffic Control Devices. (NCP No. 3A1C0022)

Objective: Examine evidence from completed research and collect and analyze additional data to determine the nature and magnitude of noncompliance with various traffic control devices. Assess whether certain practices are effective in reducing noncompliance. Evaluate the effects of noncompliance on safety and traffic operations. Develop, test, and evaluate countermeasures.
Performing Organization: Center for Applied Research, Great Falls, VA 22066
Expected Completion Date: March 1989
Estimated Cost: $295,000 (FHWA Administrative Contract)

Title: Evaluation of Steady Burning Lights for Traffic Control in Highway Work Zones. (NCP No. 4A1E0082)

Objective: Evaluate the effects of steady-burn lights on delineation of the traveled way in construction and maintenance zones. Limit the study to an examination of steady-burn lights on tangent sections of rural freeways. Evaluate devices during both dry and wet weather conditions.
Performing Organization: University of Cincinnati, Cincinnati, OH 45221
Funding Agency: Ohio Department of Transportation
Expected Completion Date: May 1988
Estimated Cost: $64,620 (HP&R)

NCP Program A2: Improved Driver Visibility of Roadway Environment

Title: Minimum Visibility Requirements for Traffic Control Devices. (NCP No. 3A2A1022)
Objective: Determine minimum driver requirements for visibility of traffic control devices to assure safe operation. Develop and field test minimum retroreflectivity performance criteria to satisfy driver requirements at night.
Performing Organization: Ketron, Inc., Malvern, PA 19355
Expected Completion Date: March 1989
Estimated Cost: $458,740 (FHWA Administrative Contract)

NCP Program A3: Highway Safety Analysis

Title: Present Practices of Highway Transportation of Hazardous Materials. (NCP No. 3A3C3042)
Objective: Review existing data sources and trends and synthesize present knowledge and practices of local, State, and Federal agencies in the planning and operational management of transporting hazardous materials over highways. Include sources such as the Office of Motor Carriers' files, National Accident Sampling System data, the Office of Hazardous Materials Transportation's hazardous material incident reports, the Biotech truck accident study, the Federal Railroad Administration's rail accident-incident reporting system, and available information on exposure. Summarize information on frequency and severity of highway accidents and incidents, cargo type involved, and possible problem sites such as railroad crossings, ramps, high-density areas, and long downgrades.

Performing Organization: Midwest Research Institute, Kansas City, MO 64110
Expected Completion Date: August 1988
Estimated Cost: $173,350 (FHWA Administrative Contract)

NCP Program A5: Design

Title: Test and Evaluation of Guardrail Terminals Buried in Backslopes. (NCP No. 3A5D1052)
Objective: Review the standard plans and the accident experience of several States currently using W-beam guardrails buried in backslopes. Recommend designs for this type of end treatment. Conduct crash tests of at least one terminal and evaluate the results using the performance standards in National Cooperative Highway Research Program Report 230.
Performing Organization: Ensco, Inc., Springfield, VA 22151
Expected Completion Date: December 1987
Estimated Cost: $85,640 (FHWA Administrative Contract)

Title: Asphalt Mix Characteristics Affecting Friction Numbers. (NCP No. 4A5G0152)
Objective: Examine the relationships between Alabama asphalt mixes and pavement friction properties through the use of the Alabama data bank on friction properties and samples taken from pavements throughout the State.
Performing Organization: University of Alabama, University, AL 35486
Funding Agency: Alabama Highway Department
Expected Completion Date: December 1987
Estimated Cost: $81,900 (HP&R)

NCP Category B—Traffic Operations

NCP Program B1: Traffic Management Systems

Title: Holographic Signs. (NCP No. 2B1B0012)
Objective: Develop several new signs using holographic technology, and conduct limited laboratory and field evaluations.
Performing Organization: Federal Highway Administration, McLean, VA 22101
Expected Completion Date: November 1987
Estimated Cost: $60,000 (FHWA Staff Study)

NCP Program B2: Traffic Analysis and Operational Design Aids

Title: Application of Artificial Intelligence to Urban Congestion Problems. (NCP No. 3B2B1033)
Objective: Assess the feasibility and recommend an approach for developing a computer-based methodology for reducing highway corridor congestion using artificial intelligence concepts.
Performing Organization: KLD Associates, Inc., Huntington Station, NY 11746
Expected Completion Date: November 1989
Estimated Cost: $279,630 (FHWA Administrative Contract)

Title: Urban Interchange Performance. (NCP No. 4B2C1092)
Objective: Compare the performance of the existing diamond interchange at I-25 and Garden of the Gods Road in Colorado Springs, Colorado, with the performance of the urban interchange that will replace it in 1987. Compare capacity, safety, level of service, maintenance, and cost.
Performing Organization: University of Colorado at Denver, Denver, CO 80202
Funding Agency: Colorado Department of Highways
Expected Completion Date: November 1989
Estimated Cost: $30,350 (HP&R)

NCP Category C—Pavements

NCP Program C2: Evaluation of Flexible Pavements

Title: Development of a Flexible Pavement Overlay Design Procedure Utilizing Nondestructive Testing Data. (NCP No. 4C2C1072)
Objective: Develop a nondestructive testing mechanistic-based overlay design procedure. Determine how pavement deflections vary by season, temperature, region, and soil type. Develop structural algorithms for Arkansas conditions. Develop pavement performance transfer functions using Arkansas experience. Incorporate results in a routine design process.

☆U.S. Government Printing Office: 1987—181-780/60003

Performing Organization: University of Arkansas, Little Rock, AR 72204
Funding Agency: Arkansas State Highway and Transportation Department
Expected Completion Date: November 1989
Estimated Cost: $107,450 (HP&R)

NCP Program C4: Management Strategies

Title: Effect of Different Tire Sizes and Pressures on Performance. (NCP No. 3C4A1032)

Objective: Design and construct a dynamic load test system for the Turner-Fairbank Highway Research Center in McLean, Virginia. Relate dynamic loads to road profile, tire pressure, and truck spring type.
Performing Organization: Engineering, Inc., Hampton, VA 23666
Expected Completion Date: February 1989
Estimated Cost: $685,000 (FHWA Administrative Contract)

NCP Category D—Structures

NCP Program D1: Design

Title: Evaluation of Corrugated Metal Pipe Arches. (NCP No. 4D1D1072)

Objective: Conduct visual inspections and statistical analyses on corrugated metal pipe structures with spans between 10 and 17 ft (3 and 5 m). Calculate the correlation between various failure modes and factors such as age, depth of cover, metal gauge, rise, and span dimensions. Select a limited number of structures for dimensional analysis with the Multispan program. From this group, select a smaller number for subsurface investigations. From this evaluation, modify the SOILEVAL subroutine of the Multispan computer program.

Performing Organization: Bowser-Morner Associates, Inc., Dayton, OH 45401
Funding Agency: Ohio Department of Transportation
Expected Completion Date: June 1988
Estimated Cost: $189,000 (HP&R)

NCP Program D2: Management

Title: Nondestructive Inspection and Monitoring of Structural Cables and Strands for Stayed and Suspension Highway Bridges. (NCP No. 3D2A1022)

Objective: Design, assemble, and test a nondestructive system for inspecting and monitoring anomalies in structural cables and strands of in-service suspension highway bridges.
Performing Organization: Texas Research Institute, Austin, TX 78733
Expected Completion Date: August 1988
Estimated Cost: $299,100 (FHWA Administrative Contract)

Title: Development of an Acoustic Emission Monitoring System for Highway Bridges. (NCP No. 3D2D1032)

Objective: Develop, construct, and test an acoustic emission monitoring system for bridge monitoring of specific details that have known or suspected anomalies, such as active cracking of bridge members. Make the system totally digital, compatible with point contact transducer (PCT) sensors, and readily adaptable to various bridge configurations. Incorporate pattern recognition, source classification, and the ability to discriminate relevant from irrelevant events.
Performing Organization: Chamberlin Manufacturing Corporation, Niles, IL 60648
Expected Completion Date: August 1988
Estimated Cost: $262,170 (FHWA Administrative Contract)

NCP Program D3: Hydraulics

Title: Performance Evaluation of Coastal Gabion Installations. (NCP No. 4D3D1942)

Objective: Monitor and evaluate the performance of two installations of large stone riprap over a thinner gabion mattress. Study physical deformation, settlement, wire corrosion, stone disintegration, and relative movement by means of physical testing of the wire and photographic documentation.
Performing Organization: California Department of Transportation, Sacramento, CA 95805
Expected Completion Date: August 1993
Estimated Cost: $55,000 (HP&R)

NCP Program D4: Corrosion Protection

Title: Evaluation of Wearing Surface on Bridges. (NCP No. 4D4C0272)

Objective: Evaluate the performance of various type bridge wearing surfaces in providing durable and smooth riding surfaces and protecting the reinforcing steel. Study the relative costs of the various protective systems, including maintenance costs.
Performing Organization: Maine Department of Transportation, Augusta, ME 04333
Expected Completion Date: September 1988
Estimated Cost: $24,090 (HP&R)

NCP Category E—Materials and Operations

NCP Program E8: Construction Control and Management

Title: Investigation of Nuclear Asphalt Content Gauge. (NCP No. 4E8A6062)

Objective: Evaluate the accuracy of the nuclear asphalt content gauge compared with centrifuge and reflux extractors. Examine methods for establishing moisture content in asphalt concrete mixes, and establish suitable locations for taking aggregate samples for gradation tests, assuming extracted aggregate will no longer be available.
Performing Organization: Louisiana Transportation Research Center, Baton Rouge, LA 70804
Funding Agency: Louisiana Department of Transportation and Development
Expected Completion Date: December 1987
Estimated Cost: $52,750 (HP&R)

U.S. Department
of Transportation
Federal Highway Administration

400 Seventh St., S.W.
Washington, D.C. 20590

Official Business
Penalty for Private Use $300

Postage and Fees Paid
Federal Highway
Administration
DOT 512

U.S. MAIL

SECOND CLASS
USPS 410-210

in this issue

The Nationally Coordinated Program (NCP) of Highway Research, Development, and Technology

Tire-Pavement Interaction

Correlation Study—Subjective Versus Instrumental Evaluation of Pavement Marking Retroreflection

Public Roads

A Journal of Highway Research and Development