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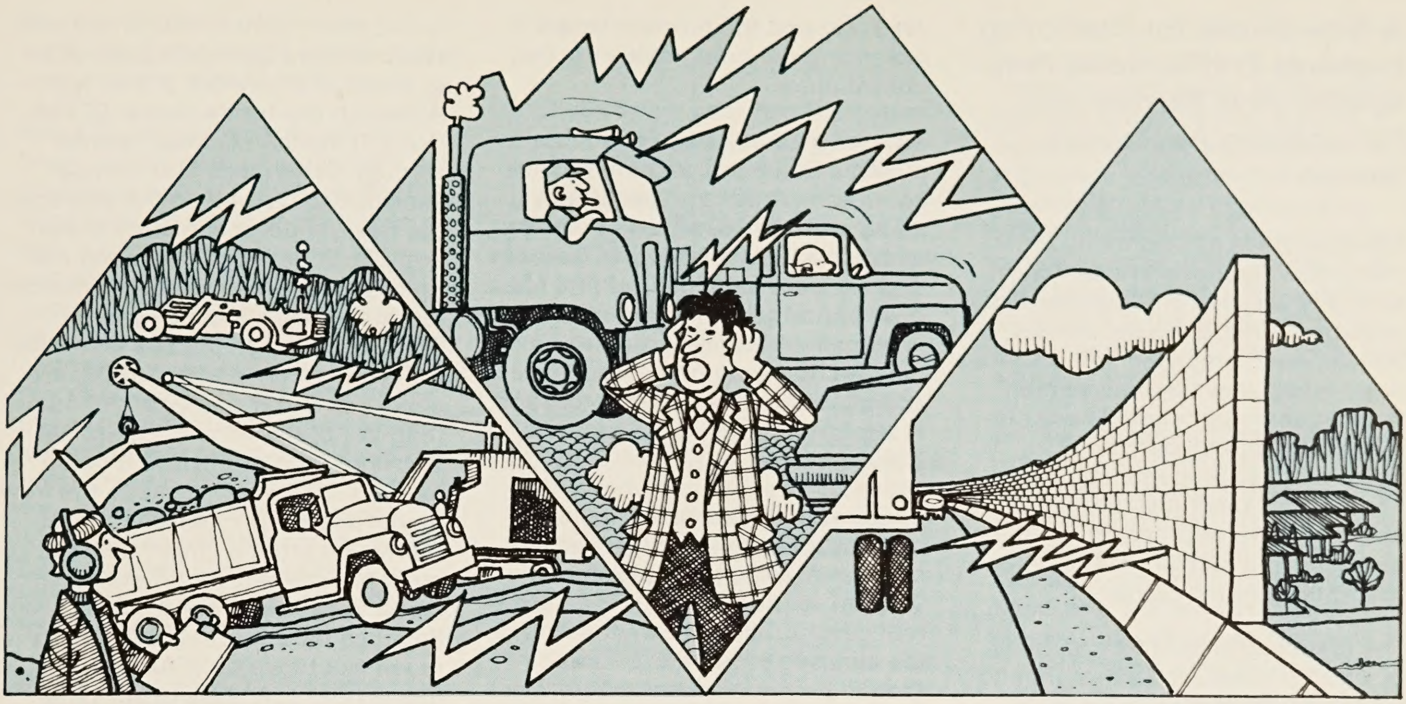


Prediction Modeling for the Assessment and Abatement of Highway Traffic and Construction Noise

by
Fred M. Romano

Environmental assessments of highway related noise are based on analytic prediction models. Because the application of current noise models is limited to freely flowing traffic and simple site characteristics, FHWA is developing refined noise models that will have application to a greater variety of highway noise assessments that must be performed. Noise models have been designed to assess noise propagation over asymmetric barriers and nonuniform ground cover, noise generated by stop-and-go traffic in urban settings, and construction noise impacts.

Computer versions, capable of predicting the energy-averaged equivalent sound level, L_{EQ}, have been prepared for each model and are undergoing test and evaluation.

Introduction

The Federal Highway Administration (FHWA) is committed to providing accurate traffic noise prediction models so traffic noise impacts may be anticipated and, when necessary, appropriate steps taken to minimize such impacts. Current traffic noise prediction models are accurate only in the average sense, and generally their application is limited to freely flowing traffic. Consequently, discrepancies between predicted and measured noise levels at particular sites may be unacceptably large, especially if noise barriers are present.

Examinations of current modeling practices have revealed three areas of noise assessment for which discrepancies may be removed and limitations overcome:

- Propagation of traffic noise over barriers and nonuniform absorptive terrain.
- Propagation of stop-and-go traffic noise in urban settings.
- Prediction of highway construction noise.

To remove deficiencies in these areas, three new and more accurate prediction models have been developed. Computer versions of these models are undergoing test and evaluation by FHWA. The first model predicts the propagation of noise from freely flowing traffic over nonuniform terrain. The second model is an analytic procedure developed to predict the generation and propagation of stop-and-go traffic in an urban setting. The third prediction model is concerned with the analysis and abatement of highway construction noise.

A New Model for Predicting Highway Traffic Noise Propagation over Barriers and Nonuniform Absorptive Terrain

Because noise assessments for freely flowing traffic are statistical, accuracy is based on time-averaged measurements. Even so, the deviation between predicted and actual noise levels may be unacceptably large at particular sites. These discrepancies can, in part, be attributed to noise propagation over nonuniform absorptive ground planes and noise propagation in the presence of a barrier resting on an absorptive ground plane.

The improved predictive capability of a traffic noise model designed to overcome these shortcomings is being evaluated. This new analytic model differs from the current FHWA noise prediction model, STAMINA 2.0 (*1, 2*)[1] [2], because it treats noise propagation over asymmetric barriers and nonuniform terrain.

Although both the new model and STAMINA 2.0 predict the equivalent sound level by treating freely flowing traffic as point sources traversing finite length roadways, the new model includes an algorithm that accounts for the coherence between direct and ground-reflected propagation, that is, the coherence of noise from a single vehicle reaching a listener by two or more sound paths (direct transmission and ground reflections). This improvement enables the user to assess the propagation effects of frequency weighted source spectra over terrain of varied ground impedance and, thus, consider the dependency of receiver noise levels on the absorptive features of multiple ground covers between the highway and the receiver when assessing the total noise contribution.

To treat ground reflections properly, suitable input information must be provided on both the topography and the ground cover characteristics of the roadside terrain. Because real sites are seldom level and often have varied terrain cover, guidelines have been prepared for the user on these matters. Based on survey information, uneven ground is approximated by contiguous plane surfaces.

Concurrent with model development, a new method of terrain characterization has been developed so the user with special terrain cover problems can determine the acoustic properties of that ground cover. Even though physical measurements of soil samples demonstrate a wide variability in soil flow resistivity, when the characteristics of roadside terrain are derived from site specific soil flow resistance measurements the resulting predictions agree well with noise measurements. Alternatively a user will be able to select from sets of terrain characteristics built into the model. However, further guidelines must be developed for this purpose.

The new model also deals with noise barrier heights that have step changes or continuous slopes and with barriers not necessarily parallel to all roadways. The model determines the point-to-point excess attenuation in the presence of a barrier by using the Edge + Images barrier attenuation model developed under the National Cooperative Highway Research Program. (*3*) At each third octave center frequency, the model adds the direct pressure component diffracted over the barrier and those components undergoing one specular reflection on either or both sides of the barrier.

Noise predictions have been compared with scale model experiments and full-scale tests based on normal traffic flow. Predictions agreed well with experimental measurements. It is important to note that these predictions have generally been close to those of STAMINA 2.0 as well. Although the fundamental STAMINA 2.0 model has been refined through experience and may be expected to do well on the average, the new model is sensitive to several site dependent and measurement procedure dependent parameters that STAMINA 2.0 ignores. Thus, the predicted noise levels for full-scale freely flowing traffic are generally closer to measured data than the predictions of STAMINA 2.0, both with and without noise barriers. However, because the new model deals with roadside topography and ground cover, the user must provide relevant input on topography and ground cover. Because input formats are set up much like those of STAMINA 2.0, this is relatively easy to do. When the new mathematical model is iterated through all the roadway segments, with all vehicle types, and in consideration of traffic and roadside parameters, it provides a prediction of the equivalent sound level, L_{EQ}, at all receivers. These iterations are performed for any fixed configuration of roadways, receivers, barriers, traffic mix and density (per roadway), and ground characterization.

Program input

Where possible, the format for input information that the program user must provide is much like that required for STAMINA 2.0. There are eight data blocks containing information as follows:

1—Program initialization parameters.

2—Roadway parameters.

3—Barrier parameters.

4—Pavement width.

5—Receiver parameters.

6—User specified group impedance.

7—Ground topography.

8—Roadway-roadway segment-receiver combinations.

Block 1 entries define the receiver height adjustments, the number of frequency bands to be calculated, and the source height adjustments

[1] Italic numbers in parentheses identify references on page 91.

[2] "Prediction of Highway Traffic Noise Propagation Over Barriers and Absorptive Terrain: Computer Model Development and Validation," by J. M. Lawther, O. McDaniel, et al. Final report submitted to Federal Highway Administration under Contract No. DOT-FH-11-9515. Not yet published.

for four vehicle types—cars, medium trucks, heavy trucks, and a user defined vehicle (optional).

Block 2, the roadway parameter block, includes the number of roadways and, for each roadway, its identification number, its traffic flow and vehicle speed for each vehicle type, and a series of XYZ-coordinate positions indicating the beginning points of the centerlines of straight line sections comprising the roadway (and an end point for the section farthest downstream). If any section is upgrade in the direction of traffic flow, the user may also request a grade-correction computation for heavy truck noise. In this and all other blocks, provision is made to accept alphanumeric title information.

Block 3, the barrier parameter block requires the identification numbers and the location of all barriers. (Barriers are defined as all sizable ground features and manmade objects that obstruct the view of any part of a roadway from any designated receiver.) It is important to note that whenever a section of roadway is elevated, the shoulder may screen one or more receivers from automobile sources and possibly from higher sources. In such cases, the shoulder edge should be considered a barrier. Similarly, the upper edges of cuts that screen automobiles in depressed roadway sections should be included as barriers. In general, gently rolling terrain with breaks in the line of sight to automobile tires of 0.5 m (1.5 ft) or less may be considered as introducing no barrier.

Because the acoustic model incorporates specular reflections that depend on the local ground impedance, it is necessary to define regions with uniform impedance properties. The highway pavement is one such region. Thus entries are required for each roadway section to define the pavement width along the section and to define the placement of the section (lane) within it. Block 4 contains this data.

Block 5 defines the user's choice of receiver locations. The user has the option to read out all roadway sections that individually contribute levels within 5 dB of a user specified criterion.

In Block 6, the user has the option of entering his or her own values for the complex impedance of a ground cover type that may be specific to his or her locale. To use this option, the user must enter one pair of real numbers, corresponding to the real and reactive part of the complex ground impedance, for each of 24 center frequencies corresponding to the $1/3$-octave bands spanning the 50 to 10,000 Hz range. Block 6 may be omitted if the user is satisfied that each terrain cover type at the site in question is like one of the five terrain cover characteristics built into the program.

In Block 7 the user enters data that define the ground topography and surface cover characterizations for the entire site. This is done by defining regions of uniform ground impedance as adjacent polygons in a Cartesian coordinate system. In Block 8 this overall description is broken down so that when the program is working on any one receiver and roadway section combination, it has to refer only to those topographical features and ground covers that pertain to that combination.

With the input information supplied to the eight data blocks, the program can complete the computation and call for the printout of all output results. A central result is the value of L_{EQ} at each receiver for the user-stipulated input conditions.

Stop-and-Go Traffic Noise Prediction

In stop-and-go traffic, vehicles constantly move through acceleration, cruise, deceleration, and stationary modes. In these situations, the simplified time-energy averaged equivalent sound level model cannot be based on a uniform speed assumption. Also, if the roadway is in a complex urban environment, the propagation adjustment for excess attenuation due to ground cover is not appropriate.

Limited efforts have been made to predict noise levels from stop-and-go traffic near urban intersections because all significant source-receiver propagation mechanisms must be accounted for if noise assessment is to be accurate. (*4, 5*) A procedure to predict the sound level time history of urban stop-and-go traffic calls for application of propagation equations with (1) a data base of vehicle noise emissions as a function of operating mode, and (2) an urban traffic flow simulation model.

During the development of a comprehensive urban traffic noise prediction procedure, a time dependent noise propagation model has been developed to account for direct radiation, single and multiple reflections, and diffusion of acoustic energy. Individual vehicle types are modeled as moving point sources whose emissions levels are a function of velocity and acceleration. Noise propagation around street corners is accounted for in order to assess the impact at an arbitrary receiver location due to the noise contribution from all traffic passing through an intersection. Based on noise histories generated at receiver positions, the equivalent sound level is also computed.

The intersection noise model is formulated so all vehicles on all approaches and in the intersection proper can contribute to the noise level on each approach.

The principal features of the model are as follows:

1. Each vehicle is characterized by a noise level that is a function of the vehicle type, operational mode (cruise, idle, acceleration, deceleration), and speed. The emission level data base contains over 100 observations on each of over 3,000 vehicles undergoing changes in speed and acceleration. This data lends a high degree of significance to time-averaged noise statistics such as L_{EQ}.

2. Any approach may have continuous walls or barriers (for example, buildings) on either side, on both sides, or on neither side.

3. The wall/barrier height, the

reflection coefficient, and the scattering coefficient may be specified for each approach separately.

4. The spacing and lateral distance of the receptor locations can be specified for each approach separately.

The model is restricted to the intersection of two streets at right angles, and to continuous or averaged building fronts where buildings are present. Traffic flow data used in the urban traffic noise prediction procedure are acquired through a modified version of the Network Flow Simulation Model (NETSIM). (*6*) The modified program generates traffic flow data as a function of time for a single intersection.

Contributions to receiver noise levels

Any vehicle passing through the intersection area can contribute to the noise at an arbitrary receptor location by one or more of the following mechanisms, in order of importance:

- Direct radiation.
- Simple reflection from one or more surfaces.
- Multiple reflection.
- Diffusion or scattering.

These are shown in figure 1 (a-d).

Consider the case of two intersecting streets, each having building walls on both sides. For direct radiation, the building corner provides a direct cutoff and the receiver can only receive sound radiated from the shaded zone shown in figure 2a. If there are no buildings, the receiver has an unlimited view as the vehicle travels the entire street (fig. 2b). Figures 3a and 3b show the paths by which a source can contribute to a receiver via a first reflection when buildings are present.

Figure 4 illustrates the four distinct first reflections for sources across the intersection from the receiver. Figure 5 illustrates one section of multiple reflections accounted for by the method of images.

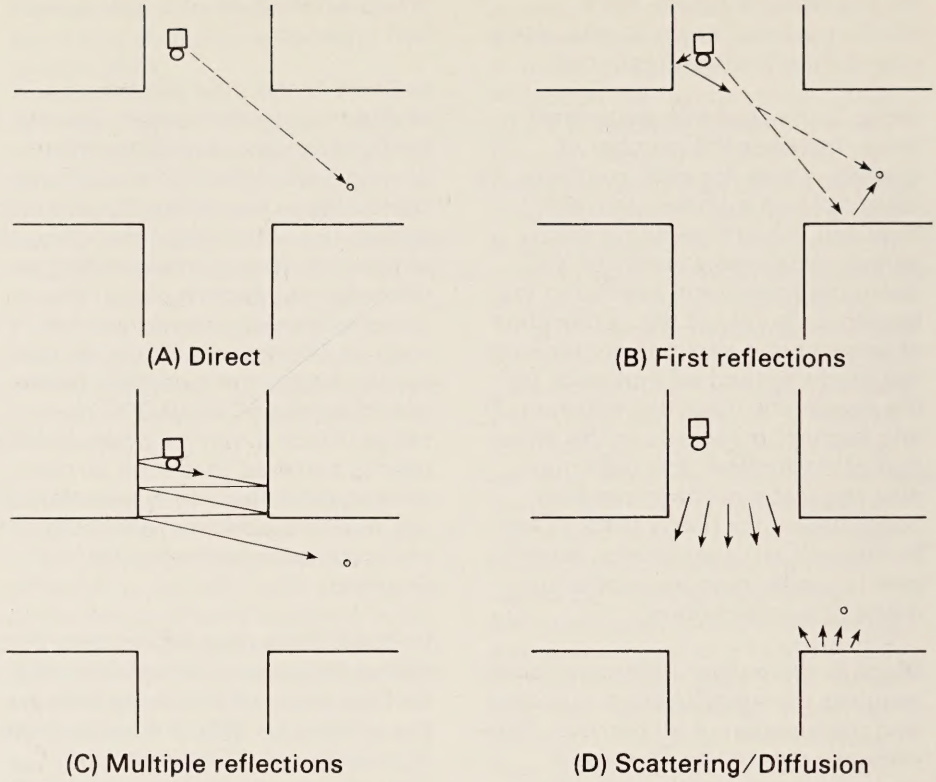


Figure 1.—Four mechanisms by which a vehicle approaching an intersection can radiate sound into a cross street.

Generally the diffusely radiated sound in the presence of a cross street is described as a power flux modified by the reflection coefficients of buildings of arbitrary height. The power flow in each street direction is described by two second-order differential equations, solvable in terms of a Green's function, and added to give the total flux in the street and the flux issuing into the intersection. The diffuse power entering the intersection is apportioned to enter the other streets based on relative cross sectional areas of those streets.

The analytical formulation of the propagation model has been organized so that the ray path contributions to pressures and wall intensities on the receiver streets make use of exact source and receiver geometrics for direct paths and singly reflected paths (including the effect of geometry on ray blockage). The contributions of higher order reflection paths are approximated by placing the source and receiver lateral positions on the centerline of the street. All formulations include the effect of the building wall configuration on each street (2 walls, 1 wall on right, 1 wall on left, no walls) and of the combination of wall types involved in each source-receiver street pair.

Formulations have been created to match each possible pair of source-receiver street types. The number of alternative choices is large. However, based on relationships between the coordinates of alternative geometric configurations, analyses for such configurations may be generated by a simple transformation of coordinate configurations (such as those which are mirror images of each other, or which exhibit reciprocity relationships).

The computerized urban traffic noise prediction model for stop-and-go traffic is composed of a vehicle noise emission level data base, a traffic flow model based on NETSIM, and an urban noise propagation model. The model predicts the sound level at 1-second intervals for arbitrary positions and elevations at up to 40 positions. L_{EQ} and L_{10} may be had for up to 10 positions on each of 4 streets.

Prediction and Analysis of Highway Construction Noise

A program to provide assistance to State highway agencies for the prediction and abatement of highway construction noise has resulted in the development and validation of a highway construction noise prediction model.[3] A computerized version of the mathematical model will predict construction site noise levels in detail. Simpler methods based on either a programable hand-held calculator or manual use of charts and graphs are also available. During the planning and design stages of a highway project, these prediction methodologies may be used to assess anticipated construction noise impacts. The computer version of the model also serves as a design tool for evaluating noise abatement strategies based on equipment noise control, selective placement of equipment to modify noise propagation paths, rescheduling of construction tasks, and adoption of alternative construction processes.

[3]"Highway Construction Noise—Environmental Assessment and Abatement," by W. Bowlby and L. Cohn. Final report submitted to Federal Highway Administration under Contract No. DTFH61-81-C-00082. Not yet published.

The construction noise model is used to predict 8-hour equivalent sound levels, $L_{EQ}(8h)$, at receiver locations near a highway construction site, from a variety of equipment and operations. The prediction model is designed for users with minimal background in acoustics and provides acoustic emission data for a large variety of construction equipment. However, the model also has options that permit the entry of user-supplied data bases and, therefore, is also useful to acoustic specialists. Although acoustics expertise is not required to operate this program, some knowledge of highway construction procedures and equipment is needed.

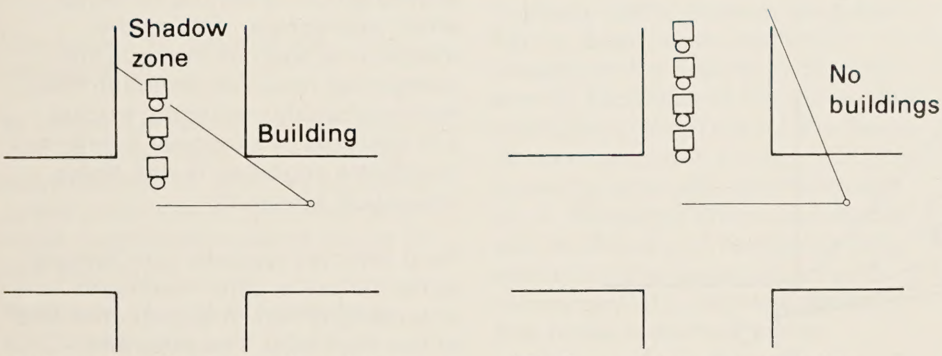


Figure 2.—Effect of a corner building in blocking direct sound radiated from a cross street.

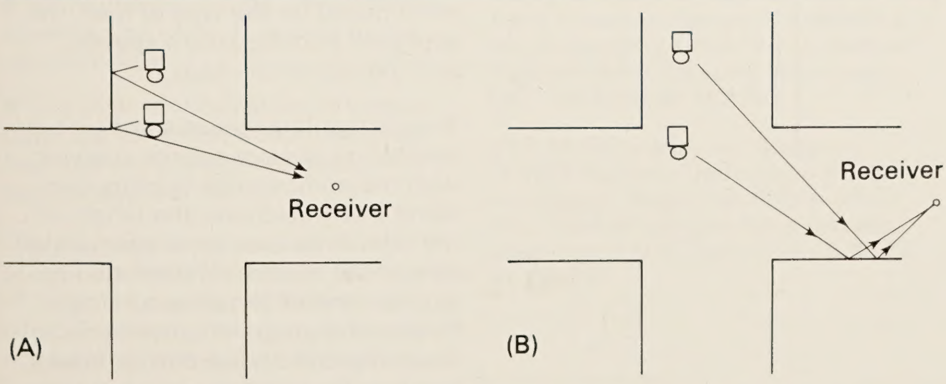


Figure 3.—Paths of a single reflection by which a vehicle radiates sound to a cross street receiver.

The computer model is an interactive program, where the user responds to data requests from the computer. It may be run from a video display or printing terminal. The program consists of two parts: HINPUT, which requests the input data from the user and performs initial acoustical and geometric calculations; and HICNOM, which performs the bulk of the acoustical calculations. HINPUT prepares a file containing the input data and initial calculations. This file is the input file to HICNOM, which prepares a report of the results.

Someone unfamiliar with computer programing or acoustics can use the program quite easily, but it also has a variety of options for the more experienced user regarding the types and operations of construction equipment.

Program capabilities

The computer version of the highway construction noise prediction model calculates an 8-hour equivalent sound level, $L_{EQ}(8h)$, at up to 10 receiver locations for construction activities representing various point, line, and area noise sources.

A useful and simplified approach was taken to predict L_{EQ} for engine-powered equipment because equipment noise levels are generally available as maximum levels, L_{MAX}. An "acoustic usage factor" was developed to relate L_{MAX} to the energy-average emission level required for calculation of L_{EQ}. This is statistically based on measured differences between L_{MAX} and L_{EQ} during the duty cycle of particular equipment.

Construction equipment has been classified into point, line, and area noise sources as follows:

- Point sources include compressors, jackhammers, and other stationary equipment.
- Line sources include scrapers, motor graders, and other equipment moving back and forth over the same path.
- Area sources include a bulldozer spreading dirt over a fill section of a project. Other examples are graders, compactors, and backhoes.

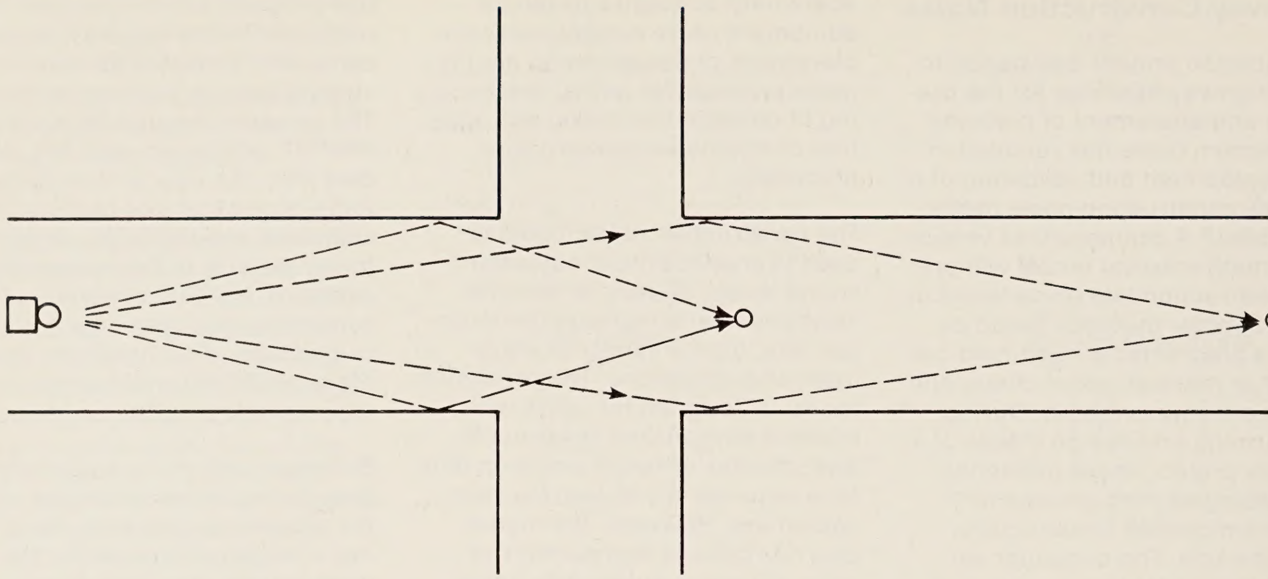
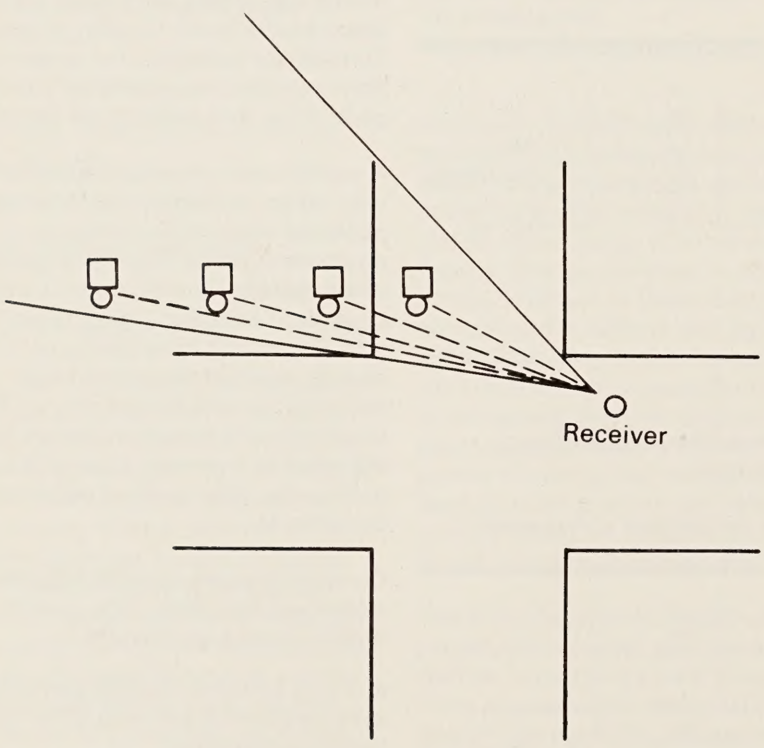


Figure 4.—Four paths of a single reflection by which a vehicle radiates sound to receivers across an intersection.

Figure 5.—Multiple reflections accounted for by the method of images.



Acoustically, the program analyzes point sources using an energy-averaged emission level and spherical wave propagation factored by an excess ground attenuation factor when appropriate. The model divides line sources into two subcategories: haul and nonhaul. Haul line sources (for example, trucks) are analyzed in a manner similar to the FHWA Highway Traffic Noise Prediction Model. (*2*)

Haul vehicles typically turn around either before or after loading or unloading to return to the other end of the haul road. The program includes routines to generate a series of straightline segments that approximate different types of turnaround loops. The model also computes average speeds on each segment based on the type of load, the approach and departure speeds, and the size of the loop.

The nonhaul line source analysis is analogous to point source analysis, with the point source contribution being integrated over the length of the line. Area sources are simulated as a series of parallel nonhaul line sources and analyzed accordingly. Finally, the program contains routines to predict noise barrier insertion loss for point sources and line source approximations.

The program is designed to handle a maximum of 10 point sources, 6 line sources, 5 area sources, and 3 noise barriers.

Also included is a built-in data base for over 50 types and models of construction equipment. However, this data base may be expanded to include nearly 300 emission levels. Users may also specify their own emission level data for construction equipment.

Certain types of equipment in the program have production rates, that is, they are constrained in their operation by their capacity (a dump truck) or by how long it takes them to perform one cycle of operation (a loader filling trucks). If two such pieces are working together on an actual construction site, their activities will be coordinated; for example, the number of trucks on a haul road in a specified period of time depends on the ability of the loader to fill them. The program is set up to compute this working relationship based on the production capability of each piece of equipment.

The following features are noteworthy:

- When 2 pieces of mobile equipment are operating together, the activity levels of one may be keyed to the duty cycle of the other so the noise contribution will be based on one duty cycle.
- Excess ground attenuation is specified by the user for each receiver location.
- Haul road turnaround loops and acceleration/deceleration profiles are automatically generated.
- A diagnostic output identifies the contribution of each source to the overall noise.
- For easy identification of output data, the user may supply descriptive names for each receiver, source, and barrier.

The highway construction noise prediction model has been validated at a limited number of construction sites. Generally the predictions are accurate to within 3 dBA. Further evaluation of the accuracy will be performed as the prediction tool is applied to construction sites.

Summary

This article has presented three noise prediction models. Together these procedures provide the methodology for performing all highway related noise assessments with greater accuracy and flexibility than has previously been available. These improvements are dependent on more detailed input data than previous prediction tools. Consequently the user of the computer based models faces a greater time commitment for the gathering and coding of site specific input data.

Acknowledgments

The following persons are recognized for their technical contributions leading to development of the noise prediction models discussed in this article: Professors J. M. Lawther, O. McDaniel, and S. I. Hayek of the Pennsylvania State University for the development of a highway traffic noise propagation-barrier attenuation prediction procedure; Professors S. Slutsky and W. McShane of the Polytechnic Institute of New York for the formulation of an urban noise prediction model for stop-and-go traffic; and Dr. K. Plotkin of Wyle Laboratories and W. Bowlby of Vanderbilt University for the development and refinement of a highway construction noise prediction model.

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(*1*) F. F. Rudder, Jr., et al., "Users Manual: FHWA Level 2 Highway Traffic Noise Prediction Model, STAMINA 1.0," Report No. FHWA-RD-78-138, *Federal Highway Administration,* Washington, D.C., 1978. PB 80 162340.

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(*4*) H. G. Davies, "Multiple-Reflection Diffuse-Scattering Model for Noise Propagation in Streets," *Journal of the Acoustical Society of America,* 64(2), August 1978.

(*5*) D. Gilbert, L. Moore, and S. Simpson, "Noise from Urban Traffic Under Interrupted Flow Conditions," Supplementary Report 620, *Transport and Road Research Laboratory,* Crowthorne, England, 1980.

(*6*) "NETSIM User's Guide," Report No. FHWA-IP-80-3, *Federal Highway Administration,* Washington, D.C., January 1980.

[4]Reports with PB numbers are available from the National Technical Information Service, 5285 Port Royal Rd., Springfield, Va. 22161.

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Reliability of Locked-Wheel Skid Resistance Tester Confirmed

by
Rudolph R. Hegmon

Introduction

Highways play a major role in the economy of industrialized nations by facilitating high speed transportation of passengers and goods. To safeguard the initial investment, it is essential to provide for continuing maintenance and periodic upgrading. Periodic evaluation of pavement skid resistance is one of the requirements of pavement management. This article examines the problems in pavement friction measurement and the results of a Federal Highway Administration (FHWA) staff study[1] on the reliability of the locked-wheel skid resistance tester.

The ability to safely maneuver a vehicle in traffic, without skidding, depends on the interactions between the vehicle's tires and the pavement. The forces in braking and steering maneuvers are reacted by friction forces in the tire-pavement contact areas. As a first approximation the required coefficient of friction is equal to the deceleration in braking (a/g) or the acceleration in cornering (V^2/rg).[2,3]

Accelerations in normal driving rarely exceed 0.2 g's, but in emergency maneuvers, levels of 0.4 g or greater are frequently reached; as the g level rises, pavement skid resistance becomes more important for maneuvering a vehicle safely. It is no coincidence that accident rates have been shown to increase when pavement skid resistance drops below 40 SN.[4] (*1*)[5] However, there are many pavements with skid resistance as low as 20 SN that have below average accident rates. (*2*) This shows that pavements do not fit into safe or unsafe categories by the simple requirement for minimum skid numbers published in the National Cooperative Highway Research Program (NCHRP) Report 37 (*3*), and endorsed in Highway Safety Manual 12. (*4*) Other factors also come into play, such as amount of traffic, roadway geometry, and the need for emergency maneuvers.

However, although skid accident probability cannot be predicted solely from a skid number (*5*), skid resistance testing provides a measure of pavement friction, which is one of the indices of pavement performance. (*6*)

Tire-Pavement Friction Measurement Methods

Emergency braking

Several years ago, emergency braking was used to measure pavement friction. (*7*) In this method, the driver applies full brakes at a predetermined speed to lock the wheels. The distance it takes for the vehicle to

[1]The staff study "Friction in Cornering and Braking, Steady State and Transient" was conducted under the Federally Coordinated Program of Highway Research and Development (FCP) Project 1H, "Skid Accident Reduction."

[2]a = deceleration.
g = gravity acceleration.

[3]V = speed.
r = radius of curvature.

[4]The skid number, SN, is defined as 100 times the coefficient of friction as measured by the standard test method.

[5]Italic numbers in parentheses identify the references on page 101.

come to a full stop is measured and the coefficient of friction computed from the dissipated energy.

This test method, with a skidding distance of 30 m (100 ft) and more, is inherently unsafe. To make it safer, variations on this method were developed. For instance, directional stability can be maintained if one front wheel and the opposite rear wheel are locked while the others continue to rotate. (*8*) In another variation, the deceleration between predetermined initial and final speeds is measured, and the car does not need to come to a full stop. (*9*)

But even with these improvements, there are problems in friction testing with a braking vehicle. The tests cannot be performed on highways without impeding traffic. Also, because skid resistance on wet pavements is always lower than on dry ones, testing is done on wet pavements and this requires some means for uniformly wetting the surface. Experience has also shown that the dynamics of the automobile affect the test results. That is, different automobiles, or the same automobile with different loads, should not be expected to perform alike. For all these reasons skid resistance testing with a braking automobile has been discontinued, except for special studies.

Locked-wheel skid resistance tester

Friction test equipment was needed that would provide the information previously obtained in vehicle braking tests. The locked-wheel skid resistance tester became the generally accepted test method in the United States. It is used at regular driving speeds without interfering with traffic, it carries its own water supply and wetting system, and its operating cost is low, even though the initial cost is relatively high. The tester was designed to use a full-size automobile tire, with load, inflation pressure, and construction representative of tires in use. The only difference between the standard test tire and regular passenger car tires is in the tread design. The test tires have plain, circumferential ribs.

Friction measured with the test tire is of the same order of magnitude as would be measured by a regular production tire (fig. 1), and measured stopping distances are highly correlated with skid numbers (fig. 2). (*10, 11*)

Over the years, skid resistance testers have improved and most testers in use today meet the standard specifications developed by the American Society for Testing and Materials (ASTM). (*12*) Also, calibration methods have been developed that help maintain tester accuracy. (*13*) An NCHRP study demonstrated how tester precision can be improved, and accurate data obtained through calibration techniques. (*14*) This study also showed that most skid testing errors were a result of inadequate procedures in tester operation and data analysis. Skid resistance tester Calibration and Correlation Centers established by FHWA brought further improvements in tester performance. (*15*) In addition to calibrating the testers and subsystems, these centers provided informal operator training, a forum for exchange of experience, and assistance in tester maintenance.

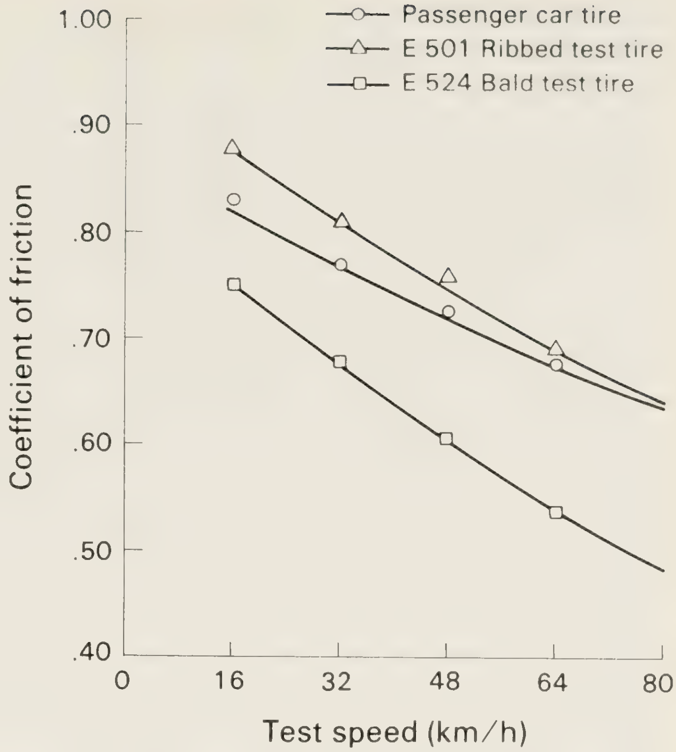


Figure 1.—Coefficient of friction versus speed for three tires. (10)

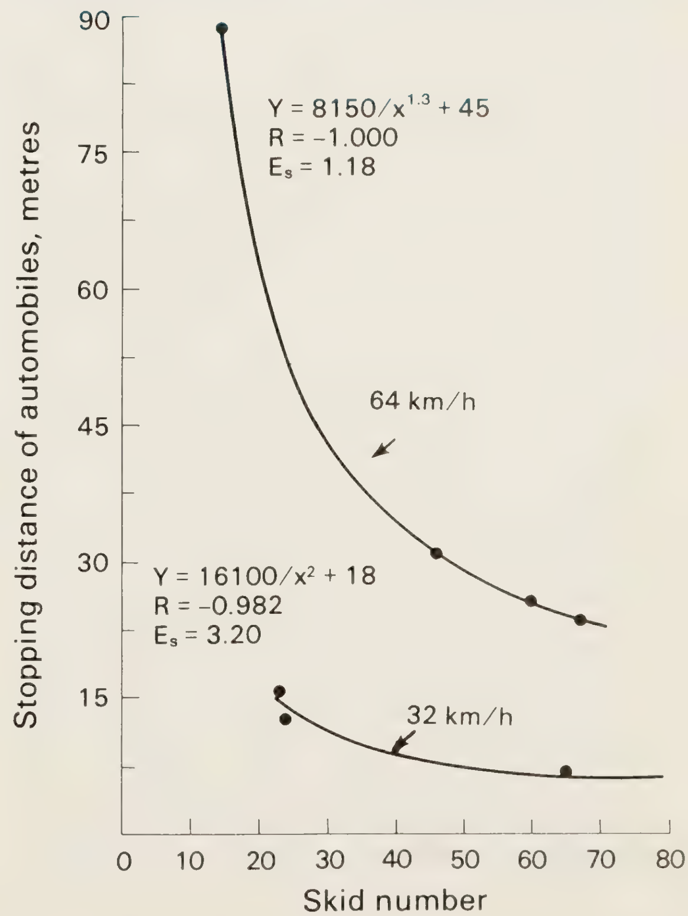


Figure 2.—Stopping distances of automobiles versus skid numbers for 32 and 64 km/h (20 and 40 mph) test speeds. (11)

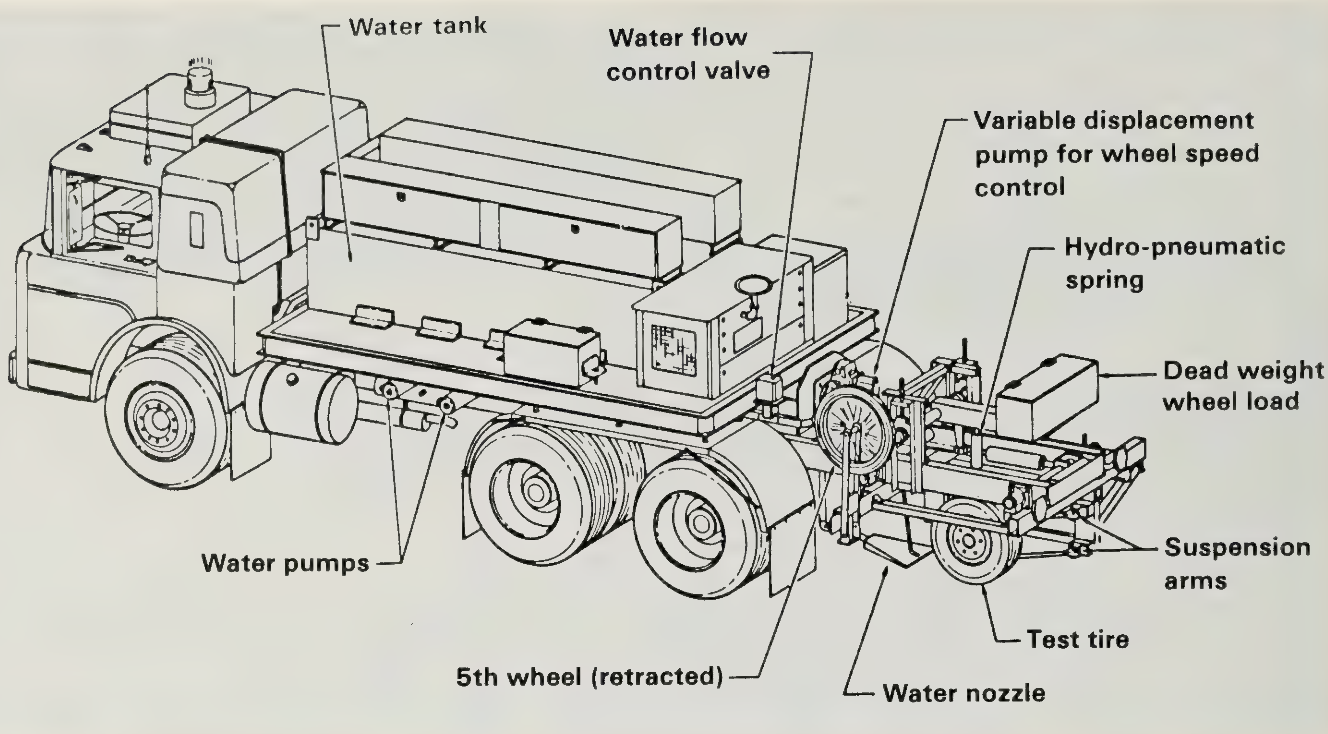


Figure 3.—Mobile Tire Traction Dynamometer (MTTD). (19)

Study Objectives

Although the improvements and increased accuracy of skid resistance testers have led to a high level of confidence in skid resistance measurement, some questions have been raised concerning the locked-wheel method:

- Is a measurement made with a locked wheel, sliding at constant speed, representative of the interaction between tires and pavements during all types of vehicle maneuvers? (*16*) Tires on vehicles undergo more complex interactions during braking, cornering, and avoidance maneuvers than straight-ahead skidding.
- What other methods of measurement, beside the locked-wheel method, are or could be used?
- Are such other methods equivalent, that is, do they rank pavement surfaces in the same order?

The objective of the staff study was to determine if different test modes rank pavements similarly, and if pavement friction measurements in any one test mode are valid for all the different vehicle maneuvers. To answer these questions, a few different test modes were considered to be absolutely necessary. In addition to the standard locked-wheel tests, these included testing at longitudinal slip values that give the peak friction force and testing with a yawed wheel to determine maximum side friction force. Similar tests would also have to be made under transient conditions, which resemble driving conditions better than steady state testing does.

Test Program

Testing equipment

Equipment for running the tests described above was not available in-house. An effort was begun to design the needed equipment, but was halted because similar equipment—the Mobile Tire Traction Dynamometer (MTTD)—was being built by the Safety Research Laboratory (SRL) of the National Highway Traffic Safety Administration (NHTSA).

The MTTD design is similar to the mobile tire tester constructed by the Cornell Aeronautical Laboratory for the Air Force (*17*), and a similar unit operated by the Highway Safety Research Institute of the University of Michigan (*18*), but includes some improvements. The MTTD has the capability to test in many of the modes under consideration. An overall view of the completed MTTD is shown in figure 3, and a complete description can be found in reference 19.

The MTTD was to be used for comparing and evaluating a number of different test modes, one being the standard locked-wheel test. The MTTD is a much more complex machine than a standard skid resistance tester; it has different dynamic response, and the test wheel is an integral part of the test vehicle. It was, therefore, of interest to determine how well locked-wheel tests with two such different testers would compare. Tests were run on four surfaces at the National Aeronautics and Space Administration's (NASA) Wallops Island (smooth and coarse concrete, smooth and coarse asphalt) at 32, 64, and 96 km/h (20, 40, and 60 mph). The overall correlation between these 12 tests, each with 6 replicates, was 0.988. A typical result is shown in the graph of figure 4.

Having determined that MTTD locked-wheel tests are equivalent to standard trailer tests, it was agreed to use the MTTD in the planned research. An interagency agreement for a coordinated test program was signed with NHTSA.

Some additions to the MTTD were necessary for the FHWA test program. As designed the MTTD has a single test wheel that can be operated in the braking mode, the yaw mode, and a combination of these. To put the wheel in a yaw position a hydraulic cylinder turns it at some angle from the straight forward position, similar to the steering action in an automobile. The wheel is also connected to a hydraulic motor by a drive shaft. Changing the motor's speed causes the wheel to slip relative to its free rolling speed. The locked-wheel condition is provided by mechanically blocking the wheel. Thus the braking operation of the MTTD is quite different from the braking process in an automobile. When brakes are applied in an automobile the rate of slowdown depends not only on the brake application, but also on the tire-pavement interaction. This is not true when braking with the hydraulic motor. Therefore, a second braking mode was provided by adding an automotive disk brake as an alternate system. An electronic brake control system was also included, because such controls became available at the time as optional equipment on cars and trucks.

Test modes

In planning the test program it was clear that several different test modes were necessary. Indirect test methods were ruled out because of the limited understanding of tire-pavement interactions. (*20*) Test modes to be considered should duplicate, to some degree, the behavior of a vehicle's tires during various normal and emergency maneuvers. This requirement limited the choice to testers with automotive tires and measuring at regular travel speeds. The 15 different test modes that were identified are listed and briefly discussed below.[6]

Mode 1: Fast braking to wheel lock (about 0.5 sec) at 0° yaw angle. (This mode is used as a reference test to supply the standard ASTM skid number. The 100 percent condition is held for 1.5 seconds, the test speed is 64 km/h (40 mph), and wetting is at a rate of 0.6 L/min/mm (4.0 gal/min/in) of wetted width.)

Mode 2: Slow braking to wheel lock (about 5.0 sec) at 0° yaw angle.

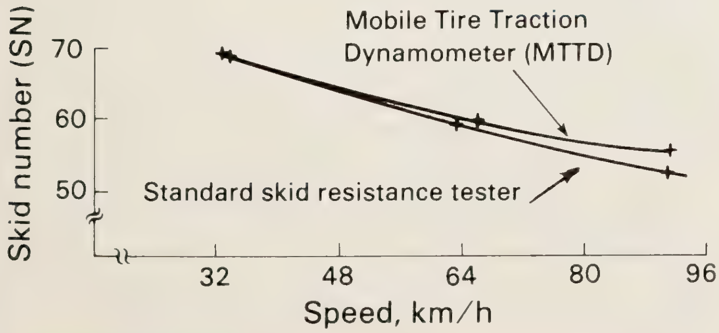
Mode 3: Steady state braking slip at 0° yaw angle to identify peak braking coefficient. Slip incremented in steps of 5 percent, between 0 to 45 percent.

Mode 4: Fixed yaw angle and fast braking to wheel lock (about 0.5 sec) at 8° yaw angle.

Mode 5: Fixed yaw angle and slow braking to wheel lock (about 5.0 sec) at 8° yaw angle.

[6]Modes 1 through 6 must use the hydraulic motor to retard the test wheel. Modes 10 through 15 must use the disk brake. Modes 7, 8, and 9 may be done with either system, however, with the hydraulic motor system the drive shaft must be removed.

Figure 4.—Skid number versus speed.



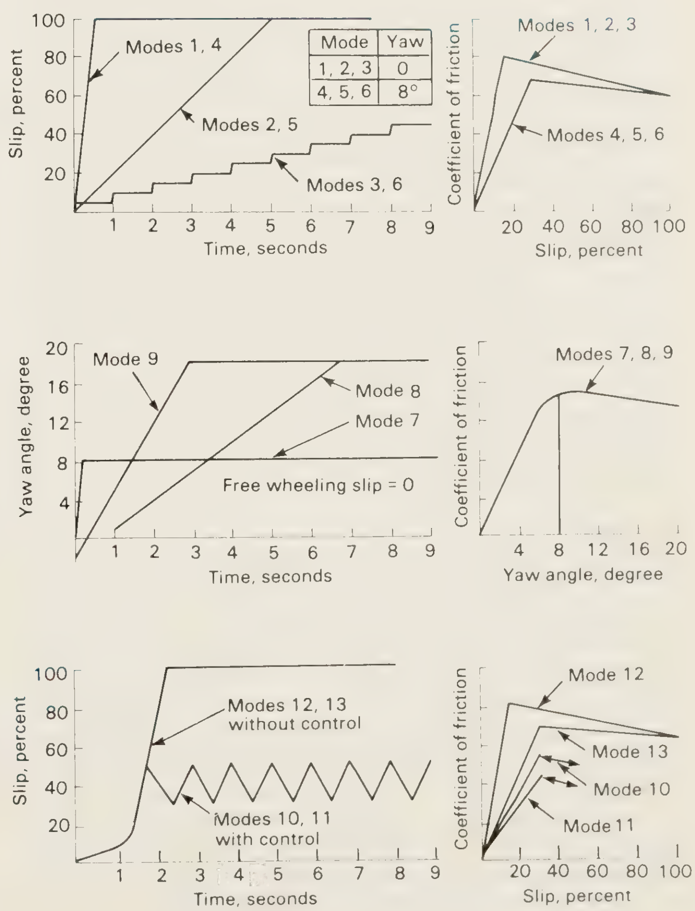


Figure 5.—Test mode schematics.

Mode 6: Steady state braking slip at 8° yaw angle to identify peak braking coefficient. Slip incremented in steps of 5 percent, between 0 and 45 percent.

Mode 7: Free rolling (0 percent braking slip) at constant yaw angle of 8°.

Mode 8: Free rolling and slow sweep of yaw angle (3° per sec) between -2° and +18°.

Mode 9: Free rolling and fast sweep of yaw angle (10° per sec) between -2° and +18°.

Mode 10: Transient slip with disk brake and brake control (0° yaw angle).

Mode 11: Transient slip with disk brake and brake control (8° yaw angle).

Mode 12: Transient slip to wheel lock with disk brake but without brake control (0° yaw angle). (This mode is the standard ASTM skid resistance test when all conditions [speed, wheel load, wetting] conform to ASTM Method E 274. [*12*])

Mode 13: Transient slip to wheel lock with disk brake but without brake control (8° yaw angle).

Mode 14: Transient slip with disk brake and brake control, slow sweep of yaw angle (3° per sec) between -2° and +18°.

Mode 15: Transient slip to wheel lock with disk brake but without brake control, slow sweep of yaw angle (3° per sec) between -2° and +18°.

Application of the test modes (except Modes 14 and 15) is shown in figure 5. In Modes 1 through 6 the hydraulic motor increases the slip at a selected rate (upper graphs). In Mode 7 the yaw angle is held constant, while in Modes 8 and 9 the yaw angle increases at a constant rate (center graphs). In Modes 10 and 11 the brake control system prevents the wheel from going into 100 percent slip; in Modes 12 and 13 the brake control is deactivated and wheel slip increases fast beyond about 15 percent slip (bottom graphs). Schematics of the corresponding friction curves are also shown. An actual recording of the wheel speed and friction force variations during brake control application is shown in figure 6.

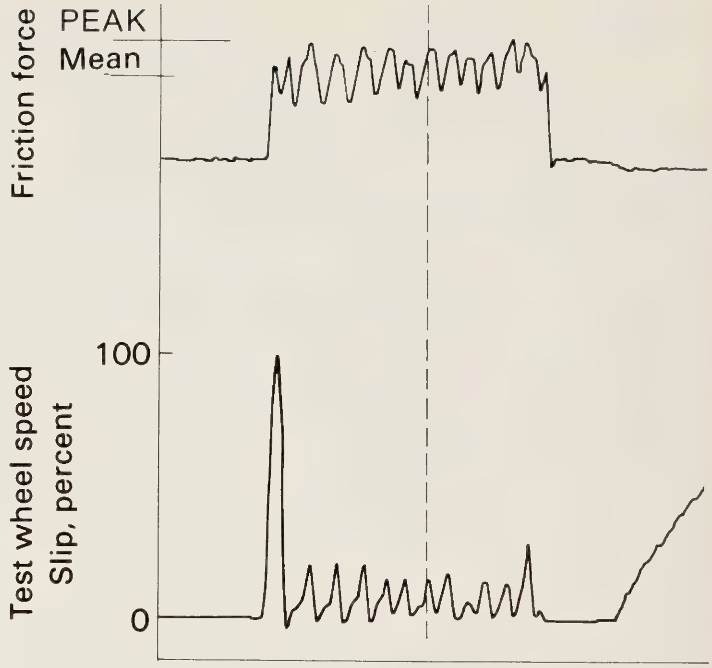


Figure 6.—Record of wheel slip and corresponding friction force with brake control system operating.

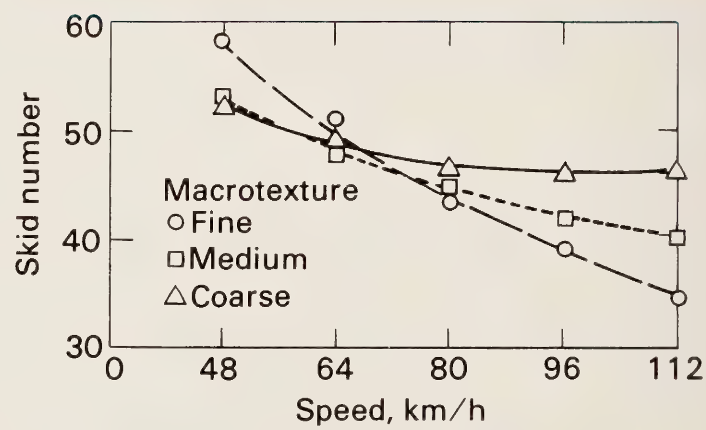


Figure 7.—Speed gradients for three groups of pavements. (23)

Other considerations

Measured at the standard test conditions, skid resistance on wet pavements generally ranges from 20 to 60 SN, depending on the pavement surfaces. Seasonal and short term variations of skid resistance may cause changes by as much as 30 SN. (*1*) Effects of exposure to changing weather conditions are strongest on limestone aggregates. (*21*) Such short term changes can affect the outcome of correlation programs.

Many different production tires as well as the standard ASTM test tire (*22*) were included in this cooperative test program with the Safety Research Laboratory. (This article treats only ASTM tire data.) Combined test sequences were agreed upon to reduce the need for frequent mode changes, some of which are quite time consuming. Temperatures and weather conditions changed during the several days it took to complete such test sequences. To compensate for the short term changes of the test surfaces, frequent control tests were run and used to correct the test data. However, these corrections did not produce the expected results and were discontinued. To avoid similar problems during the remainder of the test program, testing with the ASTM tire was separated from the other tire tests so a complete sequence could be finished in 1 day. It was learned from this experience that correlation programs on pavement friction measurements should be conducted in the shortest possible time.

Another major factor in skid resistance testing is the test speed. Generally, skid resistance decreases as speed increases. The rate of decrease is a function of macrotexture, and thus varies from pavement to pavement (fig. 7). (*23*) To develop a valid correlation between different test modes (or different testers), the test program must be run on a number of different pavements and at several different speeds.

Test Pavements and Sequences

Because a good range of different pavement surfaces was not available in one location, the testing was done in four different areas.

The first tests were run on two surfaces at the Army's Aberdeen Proving Grounds in Maryland: A bituminous concrete runway, and a 1.6 km (1 mile) loop of bituminous concrete with a Jennite coating, which reduced the skid resistance to about 20 SN.

The runway was barely used by aircraft and therefore had a uniform surface with a high skid resistance of 65 SN. The shakedown tests for the MTTD were run on this surface. After correcting some minor malfunctions, the first test sequence, Modes 1 through 9, was conducted. The disk brake system, needed for the other modes, had not yet been installed.

A second test sequence on the same surfaces was run about 2 years later. The skid resistance on the runway had dropped from 65 to 52 SN. Based on the interim results, only four modes (9, 10, 12, and 13) were tested.

Three test sequences were run over 6 months at the Ohio Transportation Research Center (TRC), a newly opened facility that has a large, bituminous concrete area designed for vehicle dynamics testing, and a long, portland cement concrete pad for skid resistance testing. The concrete pad consists of six parallel lanes with texture increasing from smooth to coarse, and coarse textured, bituminous concrete shoulders.

Because of the almost new condition, skid resistance was high on all surfaces. Three surfaces were selected: One lane on the skid path (TRC-1), one of the shoulders (TRC-2), and the vehicle dynamics test area (TRC-3). The skid resistance ranged from 52 to 65 SN. The three test sequences included regular production tires so it was impossible to run all modes at one time. Modes 7, 8, 9, 10, and 12 were run in April; Modes 3 and 6 in August; and Modes 1, 2, 4, and 5 in October. The skid resistance of the vehicle dynamics test surface dropped from 65 to 62 to 57 over the 6 months. During the long breaks between test sequences, partial data analyses were made.

Additional tests in Modes 9, 10, 12, and 13 were run on the four surfaces at NASA's Wallops Island (smooth and coarse portland cement concrete, and smooth and coarse bituminous concrete) and on two surfaces used by the Pennsylvania Transportation Institute (a new, unopened stretch of Interstate with a grooved portland cement surface, and a fine textured, sand-filled epoxy surface).

Test Results

Preliminary findings

Although initially 15 test modes were identified, some of these were expected to be impractical, while others might be redundant (no significant differences found between the results of some of the modes). One of the first tasks in the test program was to reduce the number of modes to a more manageable size by weeding out the impractical and redundant modes. After a few trial runs Modes 14 and 15 were dropped. Both of these modes simulate braking in a turn, a condition which often leads to spinout. To achieve acceptable repeatability in these tests, the brakes need to be applied after a given level of sideforce has been reached. This was impossible to control. The tests were run with a fixed time lag between steering input and brake application, but the sideforce developed during this time interval varied too much and the two modes could not produce repeatable data.

Mode 11 was also dropped. Both Modes 10 and 11 used the automatic brake control, which prevents wheel lock-up. The brake pressure is cycled about a slip value at which the coefficient of friction is highest. In practice the mean friction value at 0° yaw angle was lower with brake control than without (76 versus 94). This result was not unexpected. Like any feedback control system, brake control activation lags the feedback signal. Brake pressure and wheel slip cycle about the optimum (fig. 5) and the mean friction values are therefore lower. The value of antiskid systems is not in reducing stopping distances, but in preventing loss of control because of skidding wheels. The corresponding peak value for braking at 8° yaw angle without brake control was 73. Also the standard deviations in Mode 10 were much higher than in any other mode (table 1). This high standard deviation means that for a given number of replicate tests the confidence interval is larger, or for a desired precision a larger number of replicate tests must be run. For example, a skid resistance measurement with a standard deviation of 2 SN at five replicates as recommended in the standard test method (*12*) will result in a confidence interval of 2.5 SN. (*14*) If the standard deviation is about 6 SN (as in Mode 10), the corresponding confidence interval would be 7.5 SN. Conversely, to achieve the same precision of 2.5 SN about 20 replicate tests would have to be run instead of 5. Thus, it became clear early in the program that testing with brake control was not a good choice because of poor repeatability. Mode 10, however, was retained to accumulate more data for a better evaluation of the merits of this test mode.

A complete series of tests was run on the three surfaces at the Ohio Transportation Research Center. No significant differences were found when the results of the various modes were compared. Table 2 lists the range of mean values for Modes 1, 2, 3, and 12 (braking at 0° yaw angle) and Modes 4, 5, and 6 (braking at 8° yaw angle). The differences in test results between the different modes were random within each group.

Therefore, the narrow ranges of the mean friction coefficients prove that no significant differences exist within each of these groups of test modes.

Similarly the test results in the three cornering modes (7, 8, and 9) were very close (fig. 8). The peak coefficients are about the same, but before the peak is reached there is a significant difference between the fast and slow yaw rates. Any differences before the peak friction do not measure the friction potential of the pavement. Such differences are caused primarily by tire characteristics. Only the peak values are of interest for measuring the maximum side friction coefficient of pavements. Thus, for pavement friction testing the three cornering modes are equivalent.

Because of these findings, further testing was limited to four modes—9, 10, 12, and 13. All of these could be run with the automotive brake system, so use of the hydraulic motor for the braking tests was discontinued. This simplified the test program and saved a great deal of time and effort. The remainder of the test program could be completed in a relatively short time, eliminating the need to account for pavement changes during testing. Table 3 shows the final test series and the equivalent, discontinued modes.

Before discussing the final test series, some observations from the preliminary tests should be made (tables 1 and 2). The peak friction values are much lower at 8° yaw angle than in straight-ahead braking. This, of course, is not unexpected. The same effect occurs when braking in a turn, that is, the available braking force is reduced. This reduction can be explained by a pavement-tire friction model called the friction ellipse (fig. 9). It shows that the total available friction is limited. As the demand for longitudinal (in the wheel plane) friction increases, the available cornering friction decreases. Figure 10 is a record of the braking and sideforce friction as wheel slip is increased. On the other hand, with the locked wheel, the coefficient of friction at 8° is not much lower than at 0° yaw angle. Typical test data are shown in table 4. In this example the friction coefficient reaches a peak of 0.643 at 40 percent slip and decreases to 0.526 for the locked-wheel condition. The sideforce coefficient, with a constant yaw angle of nominally 8°, decreases from a high of 0.732 to 0.228 at 40 percent slip and to 0.053 for the locked-wheel condition. Thus, at the peak friction coefficient the sideforce coefficient is about one-third the peak value; with the locked wheel, it is about one-tenth the locked-wheel coefficient.

In addition, table 2 shows that the effect of speed is much greater in locked-wheel sliding. The gradient, defined as the change of the coefficient of friction divided by the corresponding change in speed, is about twice as large in the locked-wheel mode as in the peak friction mode.

These results show that there are no significant differences in the ranking of pavement friction when tested in any of the modes in this test program. This conclusion must be qualified; the same test tire must be used in all modes. Selection of a particular test mode should therefore be based on other criteria.

Table 1.—Mean standard deviations in twelve test modes

Mode	For coefficient of friction at peak[1]			For coefficient of friction with locked wheel[2]		
	30 mph	40 mph	50 mph	30 mph	40 mph	50 mph
Braking at 0° yaw angle						
1	—	4.6	3.8	—	2.7	2.7
2	—	4.2	3.7	—	2.1	2.9
3	—	2.2	3.6	—	—	—
10	5.2	6.3	6.4	—	—	—
12	3.3	3.5	3.5	1.9	2.5	2.5
Means (without Mode 10)	3.3	3.6	3.6	1.9	2.4	2.7
Braking at 8° yaw angle						
4	—	2.5	4.8	—	2.3	2.8
5	—	3.4	3.3	—	3.2	1.6
6	—	1.8	2.8	—	—	—
13	2.6	2.2	2.4	1.8	2.6	2.4
Means	2.6	2.5	3.3	1.8	2.7	2.3
Cornering[3]						
7	—	2.2	2.9	—	—	—
8	—	4.2	3.2	—	—	—
9	2.9	4.4	3.2	—	—	—
Means	2.9	3.6	3.1			

1 mph = 1.6 km/h
[1]Mean standard deviation for all peak braking modes = 3.1.
[2]Mean standard deviation for all locked-wheel modes = 2.3.
[3]Mean standard deviation for all cornering modes = 3.2.

Table 2.—Range of mean friction coefficients on three pavements

Mode	At peak			With locked wheel		
	40 mph	50 mph	Gradient	40 mph	50 mph	Gradient
Braking at 0° yaw angle: 1, 2, 3, 12	92—99	89—96	.30	54—59	46—54	.65
Braking at 8° yaw angle: 4, 5, 6	68—74	65—70	.35	53—54	43—50	.70
Cornering: 7, 8, 9	82—95	77—91	0.4			

1 mph = 1.6 km/h

Correlation Between the Principal Test Modes

In the final phase of the test program a balanced set of data was collected on eight test sites and at three speeds. The data included peak friction values in cornering (Mode 9), peak friction values with the brake control system (Mode 10), and both peak and locked-wheel friction values in straight-ahead braking (Mode 12) and braking with an 8° yaw angle (Mode 13). These six friction values were analyzed in simple, one-to-one correlations. Table 5 lists the correlation coefficients.

The locked-wheel friction measurements in Modes 12 and 13 are highly correlated (0.96). The correlation between the peak friction coefficients is only slightly lower (0.93), although the 8° yaw angle reduces the peak friction coefficient by about 25 percent (table 2). All other correlations are lower, but still satisfactory. Correlation coefficients of better than 0.8 were computed for the peak friction coefficients of Mode 10 (with brake control) with each of the peak friction coefficients in Modes 12 and 13. Correlations between peak friction coefficients and locked-wheel coefficients ranged from 0.56 to 0.78. These are still significant correlations. Finally, the sideforce coefficient is highly correlated with both locked-wheel coefficients (0.86 and 0.88) and with the peak friction coefficient at 8° yaw in Mode 13 (0.86). The correlations with the peak friction coefficient in straight-ahead braking are lower (0.61 in Mode 10, 0.76 in Mode 12).

Table 3.—Disposition of test modes

Mode in final test program	Equivalent modes
9	7, 8
10	—
12	1, 2, 3
13	4, 5, 6

Table 4.—Relation between longitudinal and sideforce coefficients in Test Mode 4 (fast braking at fixed yaw angle)

Percent slip	Yaw angle degree	Friction coefficient	Sideforce coefficient
0.0	8.1	0.000	0.732
5.0	7.6	0.303	0.657
10.0	7.8	0.470	0.557
30.0	8.1	0.630	0.298
35.0	8.0	0.638	0.253
40.0	8.1	0.643	0.228
45.0	8.2	0.640	0.207
50.0	8.2	0.635	0.176
95.0	7.9	0.530	0.064
100.0	8.0	0.526	0.053

Summary and Conclusions

Interpretation of research findings

Analysis of the test results has not produced any evidence that different modes of friction testing will result in a different ranking of pavement surfaces. The less-than-perfect correlations between test modes do not reflect differences in ranking, but are caused by random errors in the measurements. It is very difficult to achieve good repeatability in friction testing, even under well-controlled laboratory conditions. Friction testing on highways is much more difficult to control and the best one can hope for is to hold the measurements within a 10 percent error. NCHRP Report 151 has identified the various error sources in locked-wheel friction testing. (*14*) It can be assumed that the same error sources are present in all pavement friction test modes to a greater or lesser degree. These errors combine and partially cancel each other, resulting in an overall error that cannot be further reduced.

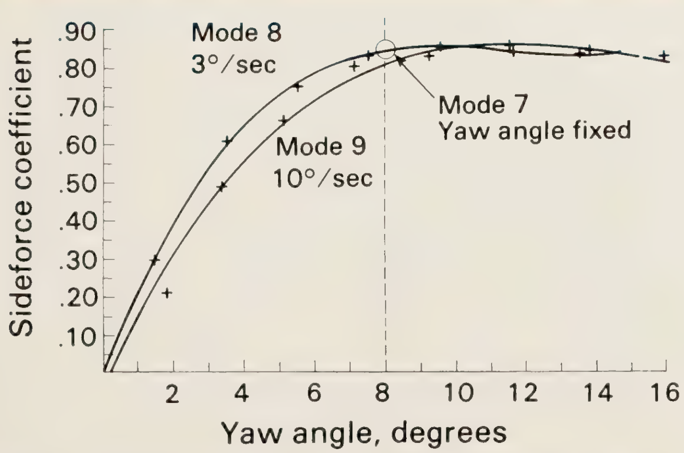
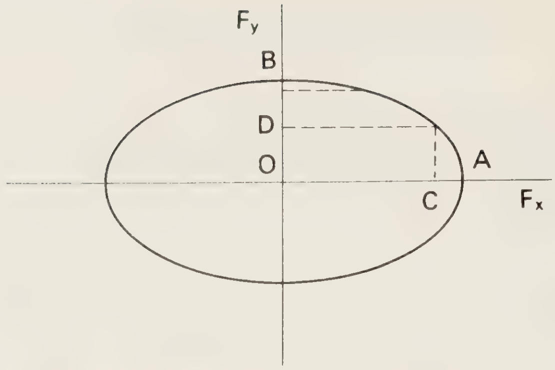


Figure 8.—Sideforce coefficient versus yaw angle for E 501 test tire, fast and slow yaw rates.

The standard deviation is a commonly used measure of random errors or the lack of repeatability in a series of tests under presumably identical conditions. Table 1 shows that locked-wheel tests had an overall standard deviation of 2.3, versus over 3.0 for the peak friction and side friction modes. This is not surprising because the test condition in the locked-wheel mode is uniquely defined. The other two modes attempt to determine the maximum friction in braking and cornering. These maximums do not always develop at the same values of wheel slip or slip angle. Thus, testers operating at a fixed wheel slip or slip angle do not always measure maximum friction. A sweep through the wheel slip or slip angle should, in theory, be able to find the maximum. In practice, however, identifying the maximum in the instant it occurs is so difficult that the additional complexity of a sweep mechanism is not justified. Undoubtedly, these uncertainties in measuring the peak values are the primary reasons for the larger standard deviations.

One of the reasons for undertaking this study was the question "Is a measurement made with a locked wheel,



OA Peak friction force F_x at 0° yaw angle
OB Peak side friction force F_y at zero slip
For combined slip and yaw angle
peak friction force reduced to OC
peak side friction force reduced to OD

Figure 9.—Concept of interaction between longitudinal friction F_x and side friction F_y for tire-pavement traction forces.

Table 5.—Pairwise correlation coefficients

	SFC 9[1]	PFC 10[2]	PFC 12	LWC 12[3]	PFC 13	LWC 13
SFC 9	1.0	0.61	0.76	0.86	0.86	0.88
PFC 10		1.00	0.86	0.56	0.82	0.61
PFC 12			1.00	0.64	0.93	0.70
LWC 12				1.00	0.73	0.96
PFC 13					1.00	0.78
LWC 13						1.00

[1]SFC is the sideforce coefficient in Mode 9.
[2]PFC is the peak friction coefficient in the indicated mode.
[3]LWC is the corresponding locked-wheel coefficient.

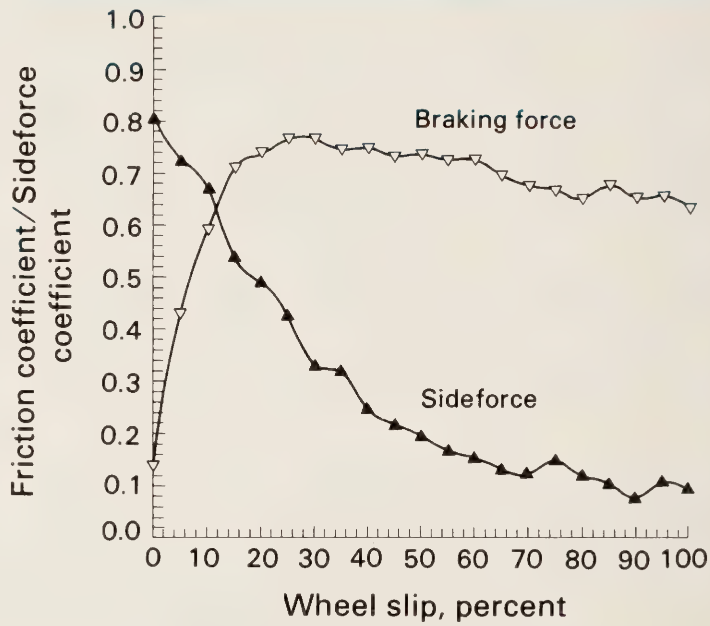


Figure 10.—Decrease of sideforce coefficient, as wheel slip increases.

sliding at constant speed, representative of the interactions between tires and pavements during all types of vehicle maneuvers?" The mechanism of these interactions is obviously different. However, based on the test results it can be concluded that the friction rating of pavements by the locked-wheel method is valid for all maneuvers. In other words, a pavement found to be slippery by a locked-wheel friction test will be slippery for all maneuvers. This study did not, and was not designed to, define at what level of skid resistance a pavement becomes hazardous. This level depends on many factors, but does not depend on the mode of measurement.

Even though the ranking does not depend on the mode of testing, the friction scales do. Table 2 shows peak and sideforce coefficients about 70 percent greater than the locked-wheel coefficients. This means that pavements with a marginal skid number of about 30 SN would be measured at about 50 on the peak friction and side friction scales. Such pavements, by the simple relationship between the coefficient of friction and acceleration, should be safe, because accelerations of 0.5 g are hardly ever experienced by drivers. The problem is that these peak values are available only over a very small range of the slip (or slip angle) range. Beyond these values the available friction decreases. Drivers cannot maintain the brake or steering inputs to take advantage of the maximum available friction. In theory, this is what brake control systems should do. But because of the need to cycle the brake (fig. 5), the effective coefficient of friction is about the same as in locked-wheel sliding.

Discussion and recommendations

As long as there is a need for pavement friction testing, the locked-wheel test method should continue to be used. Such testers have been used for more than 10 years and replacements may be needed in the near future. There seems to be no reason to switch to another test method, but consideration could be given to further improving and possibly simplifying the skid resistance tester. The basic mode of operation, however, should be retained.

Two operational arguments have often been made against using a locked-wheel mode. One addresses the excessive, and often nonuniform, wear on the tire. It is true that this is a disadvantage of locked-wheel testing, but wear could be reduced by reducing the normal load on the tire. Currently the load is specified as the tire design load. It is known, however, that the coefficient of friction does not change much with load changes. Therefore, it may be timely to consider a 10- or 15-percent reduction in wheel load. Such a reduction would also reduce the power requirement for the tow vehicle.

The second point of argument is the inability to conduct continuous tests with a locked wheel because of the high wear rate. The wheel is normally locked for about 30 m (100 ft), a sufficiently long sample for any purpose. Even if it were needed, continuous testing would deplete the water supply very quickly. Thus, in practical terms, the need to sample short pavement sections is not really a disadvantage.

There is no evidence that a systematic evaluation of friction testing modes had been made when the first locked-wheel skid testers were constructed. The almost universal adoption of this test mode in the United States may have been fortuitous, but it also turns out to have been a fortunate decision.

Acknowledgments

The author would like to acknowledge the following persons for their contributions to the test program described in this article: Messrs. Arthur Neill, Pat Boyd, and John Hinch of NHTSA's Safety Research Laboratories, who conducted the test program and preliminary data analysis; and Miss Linda G. Faigen, a co-op student, who did most of the statistical analysis.

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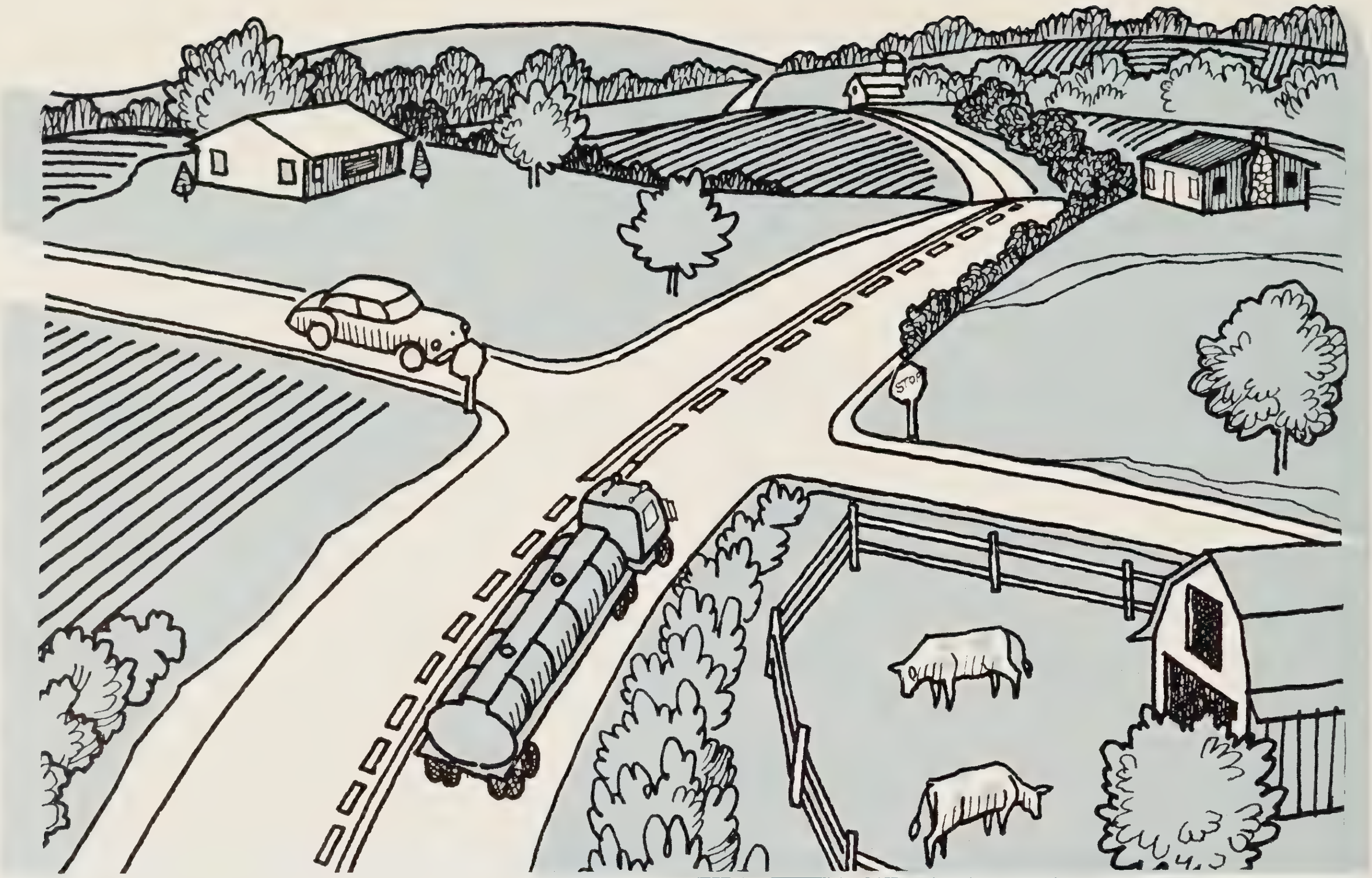

Intersection Control and Accident Experience in Rural Michigan

by
Harry S. Lum and Martin R. Parker, Jr.

Introduction

The basic purpose for Stop sign control of an intersection is to provide orderly and safe movement of traffic through the intersection. Stop signs provide orderly movement by assigning the right-of-way and safe movement by warning motorists of a hazardous situation. In most cases, low-volume intersections are Stop controlled[1] rather than uncontrolled or Yield controlled. It is estimated that 95 percent of nonsignalized low-volume intersections in Texas are Stop controlled. (*1*)[2] Data extracted from an ongoing Federal Highway Administration (FHWA) contract "Geometric Treatments for Reducing Passing Accidents at Rural Intersections on Two-Lane Highways" showed that 96 percent of 885 randomly sampled nonsignalized intersections were Stop controlled. It is hard to believe that such a high percentage of low-volume intersections are unduly hazardous or that most motorists approaching such intersections do not know who has the right-of-way. Regardless of the type of control, the driver on the minor road must not enter the intersection when a vehicle on the major road is close enough such that entry by the driver on the minor road would "constitute an immediate hazard." (*2*)

A study has been conducted in selected counties of Texas, New York, and Florida to investigate the

[1]This article does not consider multiway Stop-controlled intersections, only intersections having Stop control on one of the intersecting roadways.
[2]Italic numbers in parentheses identify references on page 105.

use and need for Stop control at low-volume intersections. (*3*) The findings of the study were as follows: (1) Stop signs do not reduce accident experience at low-volume intersections, and (2) Stop signs are being used even where there is adequate sight distance. However, the sample size in this study was rather small—only 140 intersections.

This article reports on a similar, but more extensive, study conducted in rural Michigan. In the Michigan study almost 900 intersections were examined based on type of control and related accident experience.

Principal Variables

The principal variables considered in the Michigan study were sight distance, volume, and speed. Both sight distance and volume at Stop-controlled and uncontrolled intersections were directly examined. Approach speed, while not specifically examined for its effect on accident frequency, was accounted for in the development of the sight distance criteria. Moreover, because the study was limited to two-lane rural roads, the approach speed on the major road did not vary much from one intersection to another.

Sight distance

All traffic engineers agree that sight distance is a critical criterion for the use of Stop control. They disagree, however, as to what the distance should be. The following sight distance criteria were used in the Michigan study analysis:

a. Restricted—less than the stopping sight distance.[3]

b. Marginal—stopping sight distance plus an additional distance up to 61 m (200 ft).

c. Unrestricted—stopping sight distance plus an additional 61 m (200 ft) or more.

These criteria are based on the formula presented in the Transportation and Traffic Engineering Handbook. (*4*) Table 1 presents the distribution of examined intersections by control mode and sight distance criteria. The basic hypothesis (null) was to determine if Stop-controlled and uncontrolled intersections are independently distributed over the different sight distance criteria. In testing this hypothesis, the minimum discrimination information statistic (m.d.i.s.) analogous to the chi-square test statistic was used. (*5*) The test indicated that Stop-controlled and uncontrolled intersections are proportionally distributed over the three sight distance criteria. Thus, the data do not support the supposition that Stop signs are used at intersections where sight distance is poor; Stop signs are being used even where sight distance is unrestricted.

Table 1.—Distribution of rural intersections in Michigan by control mode and sight distance criteria

Control mode	Sight distance criteria: Restricted	Marginal	Unrestricted	Total
Stop controlled	401	112	339	852
Uncontrolled	10	7	16	33
Total	411	119	355	885

Volume

The Michigan data were also examined relative to volume. For this data base, all minor roadways had traffic volumes less than 500 vehicles per day (vpd).

The major volumes for all uncontrolled intersections were less than 1,000 vpd. The volume analysis in table 2 is for Stop-controlled and uncontrolled intersections with major and minor volumes not to exceed 1,000 and 500 vpd, respectively. The results show, using m.d.i.s., that there is no significant difference in accident frequencies for Stop-controlled and uncontrolled intersections for the two minor volume categories. In table 2, the data for three-leg and four-leg intersections are grouped together. Table 3 separates the data for three-leg and four-leg uncontrolled intersections to determine if any significant difference in accident frequency was observed. Because of the small cell sizes for the four-leg intersections, an extension of the Fisher-Yates exact statistical method (*6*) was used to evaluate the probability of obtaining the displayed distribution. The probability of obtaining the observed number of intersections with the given accident frequencies was 0.52, which is

[3]Stopping sight distance is the sum of two distances: (1) the distance a vehicle travels after the driver sights an object and before braking, and (2) the distance the vehicle travels after braking. (*4*)

Table 2.—Distribution of intersections with accidents (1978-1980) by control mode and minor roadway volumes (major roadway volume is limited to 1,000 vpd)

Control mode	Minor volume 0-225	226-500	Total	Percent
Uncontrolled:				
Number with accidents	10	7	17	63
Number without accidents	6	4	10	37
Total	16	11	27	100
Stop controlled:				
Number with accidents	80	30	110	67
Number without accidents	33	20	53	33
Total	113	50	163	100

Table 3.—Distribution of uncontrolled intersections by frequency of accidents and number of approaches

Number of approaches	Frequency of accidents 0	1	2+	Total
Three-leg	10	12	7	29
Four-leg	1	3	0	4
Total	11	15	7	33

far from being significant at the 5 percent level. Thus, the observed data showed no significant relationship between accidents and number of approaches for uncontrolled intersections.

Accident Experience

The assertion is sometimes made that Stop signs are effective as traffic control devices because fewer accidents occur when they are used. To test this assertion, it would be desirable to conduct a controlled experiment and observe the frequency of accidents for both Stop-controlled and uncontrolled intersections under similar traffic and road characteristics. The experiment would have two phases:

1. Observe the accident frequency at uncontrolled intersections for a specified length of time. Change the intersections to Stop controlled and observe the accident frequency for an equal time period.

2. Reverse the procedure—observe Stop-controlled intersections first, then change to uncontrolled.

Although it is ideal, this approach would be very difficult to implement. First, greater use of Stop signs is not encouraged, and second, it is extremely difficult, legally and politically, to remove Stop signs once they are installed. Also, because of the low frequency of accidents at rural intersections, a large number of intersections would have to be observed for such an experiment to be statistically valid.

Although the Michigan study did not use the ideal approach described above, the resulting data can provide some insight into the relative safety of Stop-controlled and uncontrolled intersections and the assertion that fewer accidents occur when Stop signs are used can be assessed. Examination of table 4 shows that there is no statistical difference at the 5-percent significance level in the distribution of accident frequency between the three-leg and four-leg approaches for Stop-controlled intersections, nor is there any difference between the Stop-controlled and uncontrolled intersections. Because available data were limited for uncontrolled intersections with volumes greater than 1,000 vpd, extension of the analysis of table 4 was not possible.

It should not be concluded from table 4 that uncontrolled intersections are as safe as Stop-controlled intersections and Stop signs can be removed. Table 4 only shows that Stop signs alone do not guarantee fewer intersection accidents. The decision to use Stop signs should be based upon sound engineering practice, such as that presented in the Manual on Uniform Traffic Control Devices. (*7*) It states, as one condition, that Stop signs may be warranted where there is a combination of high speed, restricted view, and serious accident record.

Table 4.—Distribution of intersections by frequency of accidents and control mode (major volume limited to 1,000 vpd, minor road volume limited to 500 vpd), 1978-1980 inclusive

Control mode	Frequency of accidents 0	1	2	3	Total
Stop:					
Three-leg	32	46	9	4	91
Four-leg	21	28	14	3	66
Uncontrolled	10	12	4	1	27
Total	63	86	27	8	184

Summary and Discussion

In the Michigan study sample of almost 900 low-volume nonsignalized intersections, 96 percent were Stop controlled. Other findings from the Michigan study are as follows:

a. Stop signs are being used where there is adequate sight distance.

b. There is no relationship between the number of approaches on the minor roadway and accident experience for major volume under 1,000 vpd.

c. Accident experience at Stop-controlled intersections is neither better nor worse than at uncontrolled intersections under 1,000 vpd.

The findings of the Michigan study substantiated those of the study conducted in Texas, New York, and Florida. (*3*) The results of both studies suggest that the extensive use of Stop control at rural intersections may not be necessary. For many situations where some form of control is needed, Yield control may be a better alternative.

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Observations of Full-Scale Pile Group Performance

by
Michael W. O'Neill and Andrew G. Heydinger

Introduction

A great deal of information is available on experiments involving full-scale pile group behavior. The bibliography on page 111 lists documents that describe the results of some 75 full-scale load tests and observations of vertically loaded pile groups in prototype structures in clay and sand. These tests and observations were analyzed to see if behavioral trends could be identified.

Before generalized behavior patterns can be derived from reported full-scale test data, the parameters that control such behavior must be identified. The parameters of most interest are efficiency and settlement ratio. Efficiency is defined as capacity of pile group/N times capacity of an isolated control pile, where N = number of piles in the group. Settlement ratio has several definitions, which have subtle differences. The definition used here is the ratio of settlement of the pile group to the settlement of an isolated control pile when the load on the group divided by the number of piles in the group is one-half the failure load of the control pile.

Evaluation of Failure

The capacity of an isolated control pile and pile group capacity, or "failure load," must be evaluated to assess efficiency and settlement ratio. Scores of methods exist for such evaluation. Figure 1 shows the four methods used by the authors in their analysis of the literature listed in the bibliography. With these methods, certain loads on the gross load-settlement curve (or envelope to a cyclic load-settlement curve) are evaluated as failure loads. If the control pile or pile group actually plunges into the ground under applied loading (fig. 1, lower diagram), all of the methods yield the same value and failure is clearly and consistently defined. When failure does not occur by plunging (as is the case with most single piles in granular soils and for many groups), the various methods yield different results.

In the terminal linearity method, point of failure is defined as the point on the load-settlement curve where the curve assumes a final linear shape. (*1*)[1] A different point of failure can be calculated by using a modification of the rational "offset" method proposed by Davisson (*2, 3*):

[1]Italic numbers in parentheses identify references on page 111.

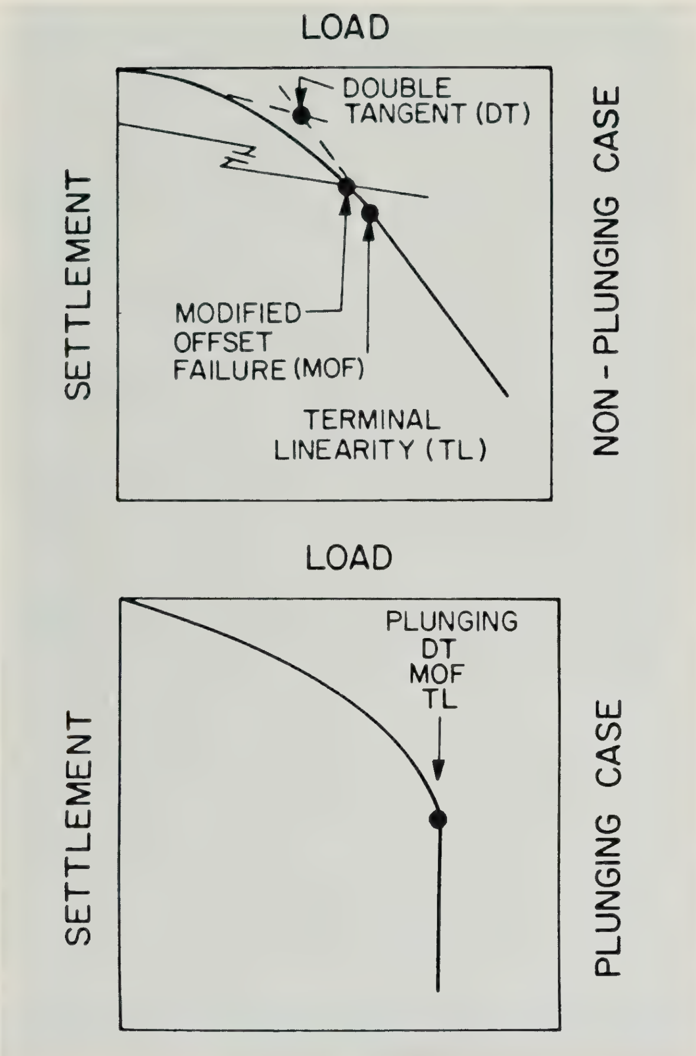


Figure 1.—Assessment of failure in piles or pile groups from gross load-settlement curve.

$$S_{fc} = \frac{0.6L}{AE} Q_{fc} + 4 + \frac{B}{120} \text{ (mm)}$$

$$S_{fg} = \frac{0.6L}{AE} \frac{Q_{fg}}{N} + 4 + \frac{NB}{120} \text{ (mm)}$$

Where,

S_{fc} = Settlement at failure for control (single) pile
S_{fg} = Settlement at failure for pile group
Q_{fc} = Failure load for control pile (point on load-settlement curve corresponding to S_{fc})
L = Pile length
AE = Axial stiffness of a pile
B = Tip diameter of single pile
N = Number of piles in group

The factor 0.6 was added to the original equation to apply uniquely to friction piles and friction pile groups. Whenever the piles are predominately end bearing (a fact usually derived from a review of boring logs), that factor should be increased to 1.0.

Also shown in figure 1 is the double tangent method, in which the failure load is defined as the load at the point where extensions of the initial and final linear portions of the curves intersect.

Another rational method of defining failure is shown in figure 2. (*4*) In this method, failure load is defined as the load that causes an increase in creep settlement. The method requires a nonstandard test in which load is applied in equal increments and in equal time intervals.

A problem unique to interpreting failure loads in pile groups arises when the load is not applied at the exact center of reaction from the piles and the soil is strain softening to the extent that individual piles within the group can plunge. Whenever these two factors exist, the pile cap will rotate under load and failure will progress from pile to pile. As a result, the group failure load appears to be less than the sum of the failure loads of the individual piles, because the load-settlement curve for the center of the pile cap plunges before every pile in the group plunges. Figure 3 shows that this effect was clearly observed in a group of prismatic steel piles tested in stiff fissured clay (*5*) but was much less pronounced in a group of tapered timber piles in medium to dense sand. (*6*) The principal consequence of this effect is that group efficiency becomes a function of the degree of concentricity of load in strain-softening soils, both in test and prototype foundations. Because of this, group failure in uninstrumented test groups in strain-softening soils may be better inter-

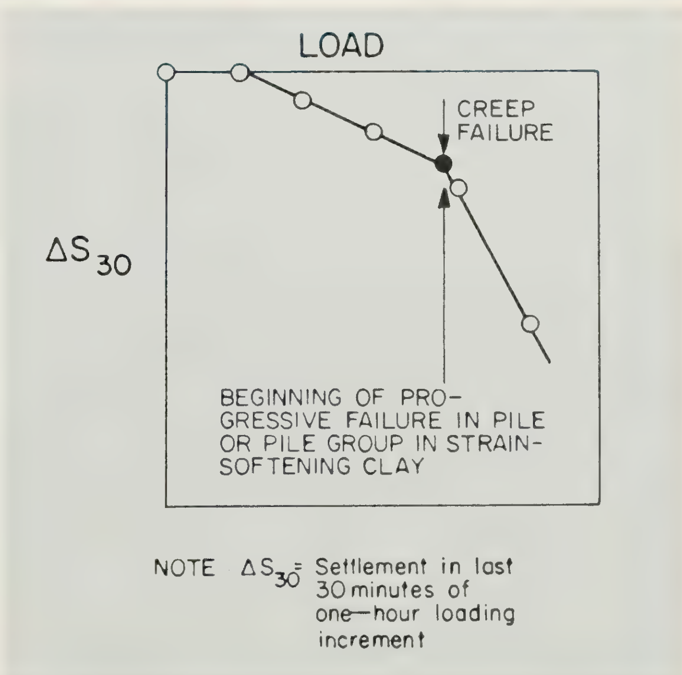
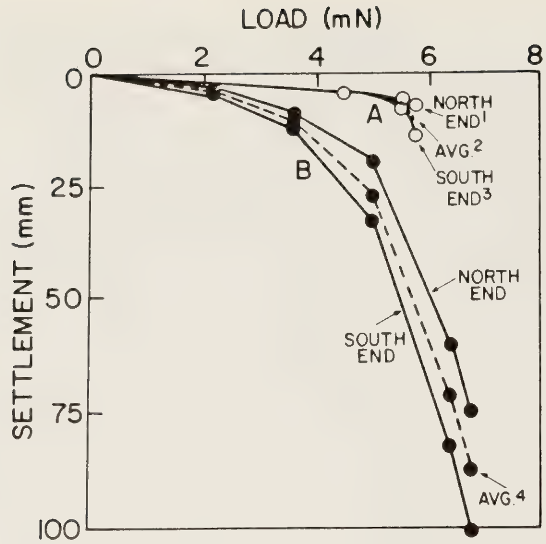


Figure 2.—Assessment of failure in piles or pile groups based on onset of high creep rate.



A. HOUSTON SITE : VERY STIFF CLAY, PRISMATIC STEEL PILES, STRAIN SOFTENING SOILS (O'Neill, Hawkins, and Mahar, 1980) (5)

B. ALTON SITE : MED. TO DENSE SAND, TAPERED TIMBER PILES, STRAIN HARDENING SOILS (Woodward-Clyde Consultants, 1979) (6)

1. Did not plunge. 2. Plunged.
3. Avg. curve has shape characteristic of plunging.
4. Avg. curve has shape characteristic of extreme end curves.

Figure 3.—Problems associated with load-settlement curves in pile groups which rotate under load.

preted by defining failure as the onset of high creep rate (fig. 2).

Using one of the methods shown in figure 1, the authors have computed failure loads for each set of control pile and pile group tests reported in documents listed in the bibliography. Where plunging was reported, the plunging load was used as the failure load; where plunging did not occur, but where a terminally linear portion of the load-settlement curve existed, the terminal linearity method was used; where neither of the above conditions existed, the modified offset method was used. Occasionally, where complete data were not provided, the interpreted failure load given in the document was accepted.

Study Parameters

Presumably, if enough factors are taken into account, a consistent picture of efficiency, settlement ratio, and other effects could be obtained from the mass of test data. In addition to the failure loads, a number of variables must be included in correlating the test results. For short term behavior of driven piles and pile groups these include the following:

- Geometric details of the piles.
- Order and rate of pile installation in the group.
- Type of hammer and cushioning materials used.
- Type of installation aids used (jetting, preaugering, etc.).
- Hydraulic diffusivity characteristics of the soil.
- Compression and density characteristics of the soil.
- In situ stresses and piezometric conditions of the soil.
- Strength and sensitivity characteristics of the soil.
- Stress-strain characteristics of the soil, extending to several group widths below the pile tips.
- Existence of cap-soil contact and, if contact exists, the integrity of that contact.
- Time lapse between driving and testing.
- Details of the reaction system (especially if reaction anchors are used).
- Geometric details of the load (point of load application relative to center of pile reaction).
- The manner of loading employed (cyclic, monotonic, constant-rate-of-penetration, etc.).

Unfortunately, most of the documents cited in the bibliography do not contain sufficient data for meaningful correlations. However, the authors have tried to correlate efficiency and settlement ratio to parameters that are consistently cited—soil type (clay or sand), cap condition for group (in contact with soil or suspended above soil), pile spacing (s), pile penetration (p), pile diameter (d_m), and group width (B_{av}).

Results

The results of correlating efficiency and settlement ratio with the above parameters (in dimensionless form) are shown in figures 4 and 5. Because so few variables were included, only general trend lines can be drawn from the data. The general trends that emerge are as follows:

- Efficiencies are enhanced in clays when caps are in contact with the soil (although very large settlements are required to develop full group capacity in such cases) but are less affected by caps in sands.
- In sands, a slight trend toward higher efficiency appears when p/s increases if the cap is suspended, but the opposite effect seems to exist if the cap is in contact.
- Settlement ratios for groups of piles in both clay and sand tend to increase when p/s is increased, but no dependence of settlement ratio on cap contact can be observed.

Further studies of full-scale pile group behavior are badly needed. However, if such studies are to be useful additions to the body of knowledge on this subject, the governing parameters enumerated earlier must be carefully evaluated and reported. In particular, the effects of cyclic and long term loading, which are not considered in this article, may be studied economically by instrumentation and careful observation of inservice pile groups. It is expected that the results of such research will indicate that existing methods for evaluating group efficiency, settlement characteristics, and distribution of loads to piles are too conservative.

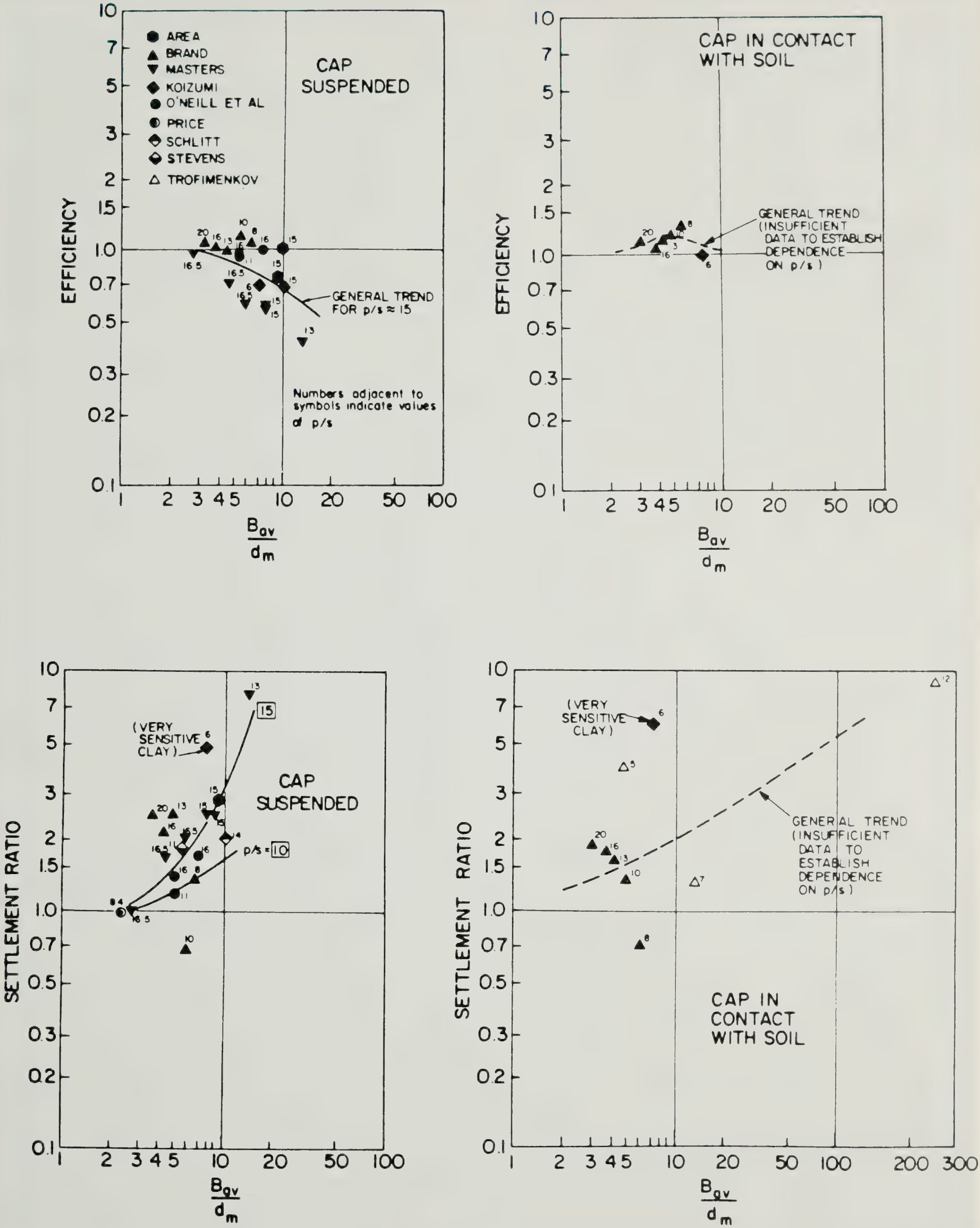


Figure 4.—Behavior of full-scale pile groups in clay.

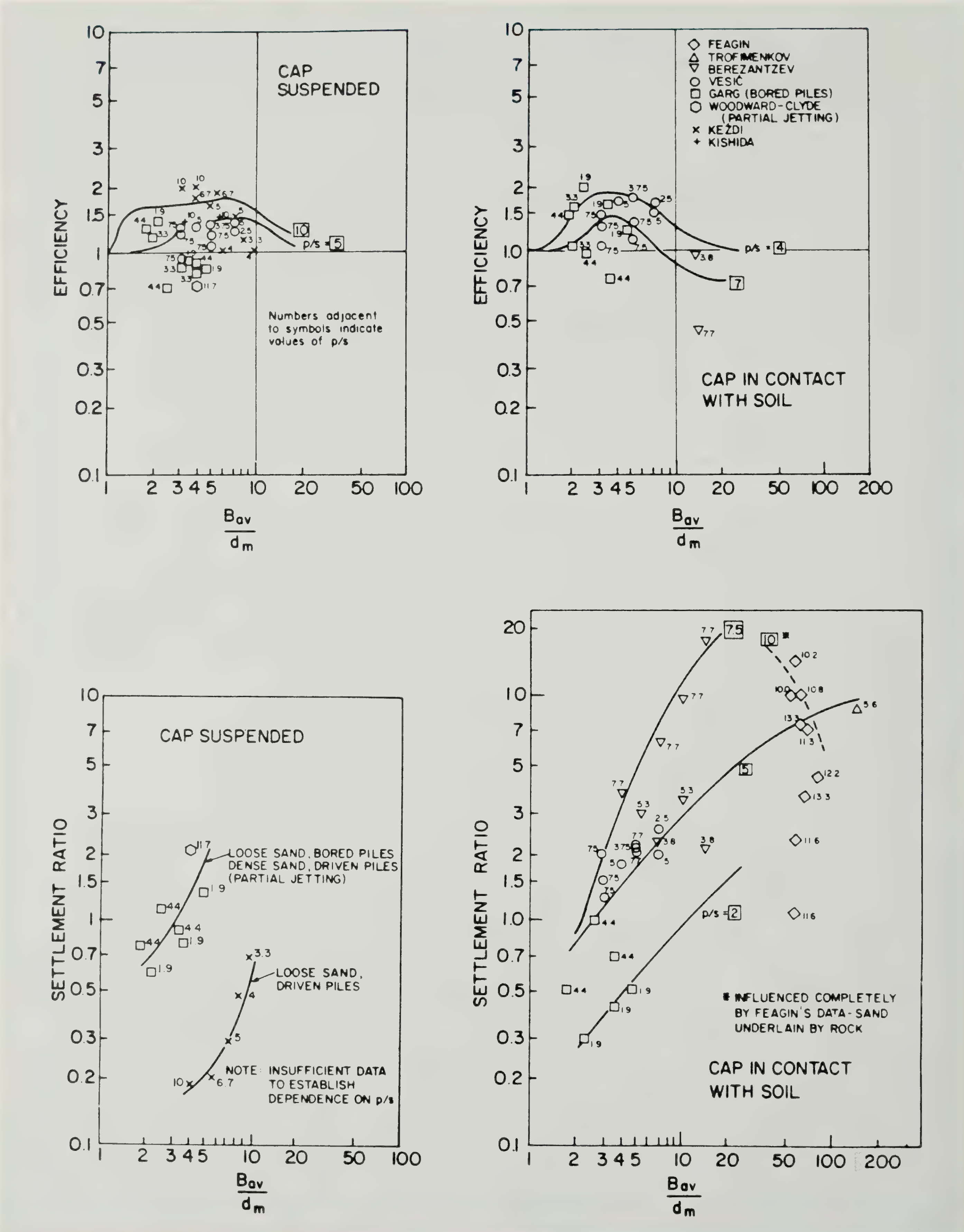


Figure 5.—Behavior of full-scale pile groups in sand.

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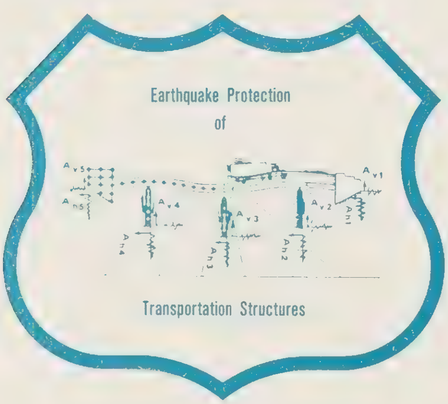
[2]Reports with PB numbers are available from the National Technical Information Service, 5285 Port Royal Rd., Springfield, Va. 22161.

Recent Research Reports You Should Know About

The following are brief descriptions of selected reports recently published by the Federal Highway Administration, Office of Engineering and Highway Operations Research and Development (R&D) and Office of Safety and Traffic Operations R&D. The reports are available from the address noted at the end of each description.

Guidelines for Strong-Motion Instrumentation of Highway Bridges, Report No. FHWA/RD-82/016



by FHWA Office of Engineering and Highway Operations R&D, Structures Division

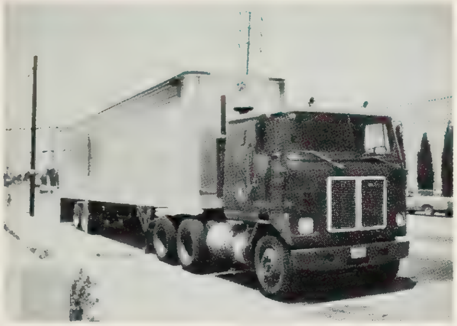
Catastrophic failure of some modern highway bridges during strong earthquakes has demonstrated how little is known about the dynamic behavior of bridges under seismic loading. As a result, State and Federal Government agencies have initiated programs to instrument selected bridges and obtain information that will lead to improving bridge performance in strong-motion earthquakes—those of sufficient magnitude to damage structures in the vicinity.

Strong-motion instrumentation permanently installed on bridges to sense and record ground or structural motion caused by a relatively large earthquake registers seismic motions as light traces on films, lines on a strip chart record, or analog or digital signals on magnetic tape. In all cases the motion is recorded as a function of time. The recorded motion is that of a fixed point on the bridge moving along a single axis. The motion is translated to an electrical or mechanical signal that is proportional to displacement, velocity, or (most often) acceleration, within some acceptable error.

This report presents guidelines for installing strong-motion instrumentation on highway bridges; includes discussions of strong-motion instrumentation characteristics and records, the objectives of instrumentation programs and criteria for selecting a bridge for strong-motion instrumentation, theoretical aspects of the linear dynamic behavior of bridges, technical aspects of the failure of highway bridges during the 1971 San Fernando, Calif., earthquake, recommended procedures for instrument placement on and adjacent to bridge structures, instrumentation types, installation techniques, and maintenance requirements; and presents a complete description of an inservice strong-motion instrumentation scheme installed on a continuous two-span bridge near El Centro, Calif. At present, eight highway overpass bridges and three long span bridges have been instrumented in the United States in accordance with the principles presented. These initial installations will provide dynamic response data, insight into improved future bridge strong-motion instrumentation plans, and significant information on instrument performance and reliability.

This report is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 82 177452).

Significant Factors in Truck Ride Quality, Vol. I—Summary Report, Vol. II—Comprehensive Report, Vol. III—Data Compendium, Report Nos. FHWA/RD-81/138-140



by FHWA Office of Engineering and Highway Operations R&D, Structures Division

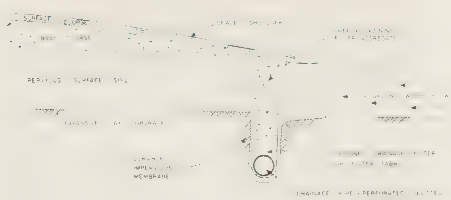
These reports document the results of a study to identify factors that significantly contribute to the differences in ride quality among various models and configurations of commercial long-haul trucks over a range of highway operating conditions. Full-scale field studies were conducted to measure dynamic motions and environmental variables in truck cabs and to record the drivers' subjective evaluations of ride comfort and the drivers' body motions as observed by a researcher riding in the passenger seat. Measurements were made in a baseline test vehicle operated under controlled test conditions and in 10 commercial long-haul trucks operated in typical over-the-road service on five categories of highway pavement. The baseline truck was a 3-S2, cab-over-engine tractor with a loaded, closed van, semitrailer. The route selected for the commercial vehicle inservice studies included 31 different pavement surface sections that were categorized as follows: smooth asphalt, smooth nearly new concrete, good concrete with some cracks and patches, faulted concrete with periodically displaced joints, and patched asphalt.

The data acquisition system included sensors for measuring cab air temperature and sound level and six accelerometers in the cab for determining vertical and front-to-back seat and floor motions. Each data channel was scanned 100 times per second; 10-second data samples were recorded intermittently at preselected road locations. Each record included a run identification, instrument calibrations, vehicle speed indication, and voice-logged location and subjective ratings. Vehicle characteristics compared included weight distribution, seat type, chassis suspension, and geometrical dimensions.

Data were gathered over a range of speeds to find the "worst" ride quality conditions. In the baseline vehicle cab a predominant 3.6 Hz motion frequency was observed to peak at 64 km/h (40 mph). The collected data were used to present various ride quality statistical spectra. The subjective ride quality ratings correlated fairly well with accelerations measured on the floor and seat in the truck cab. The dominant factors found to influence ride quality were pavement condition, wheel asymmetry, truck configuration and loading variation, and, to a lesser degree, cruising speed. No one type of vehicle provided a clearly superior ride.

These reports are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock Nos. PB 82 126954, PB 82 126962, and PB 82 126970).

Improving Subdrainage and Shoulders of Existing Pavements, Report No. FHWA/RD-81/078



by FHWA Office of Engineering and Highway Operations R&D, Pavement Division

This report describes methods for the design of subsurface drainage of pavements built on expansive soils and in areas of deep frost action. It also includes the results of channeling and pumping studies, a discussion of the effectiveness of curb and gutter drainage systems, and descriptions of equipment and procedures for maintaining and cleaning subsurface drainpipes. A general design philosophy is presented that emphasizes the importance of predicting and controlling moisture content when designing pavement subsurface drainage systems.

Limited copies of the report are available from the Pavement Division, HNR-20, Federal Highway Administration, Washington, D.C. 20590. The report also is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 82 225426).

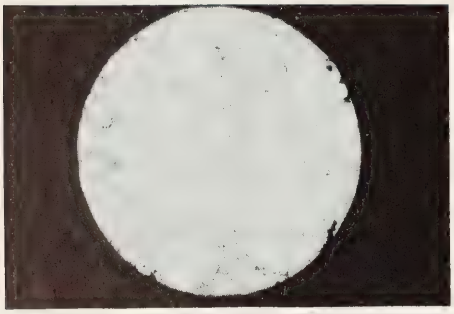
A Pavement Moisture Accelerated Distress Identification System, Vols. 1 and 2, Report Nos. FHWA/RD-81/079-080

by FHWA Office of Engineering and Highway Operations R&D, Pavement Division

These reports present the development and application of an analysis method for examining existing pavements for moisture accelerated distress. The logical step-by-step procedure can be used to evaluate the present condition of the pavement, determine what portion of the present distress, if any, can be related to moisture, and determine the factors involved. The procedure also indicates the potential for moisture accelerated distress to continue developing, and provides information on maintenance strategies best suited to halting or reducing the rate of moisture accelerated distress.

Limited copies of the reports are available from the Pavement Division, HNR-20, Federal Highway Administration, Washington, D.C. 20590. The reports also are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock Nos. PB 82 181728 and PB 82 181736).

Mixing Efficiency of Recycled Asphalt Paving Mixtures, Report No. FHWA/RD-81/174



by FHWA Office of Engineering and Highway Operations R&D, Pavement Division

This report covers an extensive evaluation of techniques for measuring the degree of mixing during the recycling of old asphalt pavements. The practice of using small amounts of rejuvenating or recycling agents is coupled with the problem of quality control. No suitable method exists for detecting how well the recycling agent (or, in some cases, virgin asphalt) mixes with the aged pavement materials. Usual quality control tests, such as extracting and measuring the binder content and properties, are not appropriate because these tests mask the presence of recycling agents and extent of mixing.

The project described in this report was to develop a test method that could be conducted in the field with a minimum of equipment and training. Among the more traditional tests, the resilient modulus (M_R) was found to be most suitable for physical testing of the recycled mixtures. This method could determine the relative quantity of recycling agent used because it is sensitive to small changes. However, as a quick test for measuring the efficiency of mixing, this method showed little promise.

Dye chemistry was found to be best among the less traditional methods used by civil engineers. After investigating many variables, the dye print technique was optimized. A small amount of dye chemical is incorporated into the recycling agent and thereby combined in the complete mixture as it passes through the asphalt mixing plant. By placing a sawed face of a resulting asphalt concrete briquet against a chemically treated piece of fabric, a dye print showing spots where the dye chemical (and hence, recycling agent) is located in the mixture then can be developed. Differences of various mixing patterns are readily observed. The resulting dye prints can be evaluated visually or by using densitometer scanning and statistical analysis techniques.

The report is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 82 257155).

System for Inventorying Road Surface Topography (SIRST), Report No. FHWA/RD-82/062

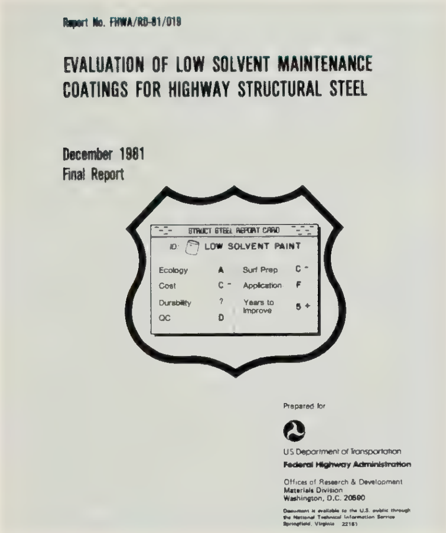
by FHWA Office of Engineering and Highway Operations R&D, Pavement Division

An experimental trailer-mounted instrumentation system that surveys and records data on the roadway topography while being towed at normal highway speeds has been developed and tested. The system uses noncontacting electro-optical sensors to measure the relative height of the roadway surface along 12 selected paths spaced across a normal traffic lane. To compensate for trailer bounce, the vertical acceleration is measured and double integrated. Data on the cross slope and longitudinal slope of the surface and the direction of travel are obtained from a gyro-type inertial reference unit mounted on the instrumentation trailer. At 0.3 or 0.6 m (1- or 2-ft) intervals along the roadway (depending on the speed), a solid-state data acquisition system samples the outputs from each height sensor, the double integrated accelerometer signal, and the roll and pitch signals from the inertial reference system. These data are digitized and recorded on a digital cassette-type magnetic tape recorder. The data can be processed to provide the longitudinal profiles, cross slopes and ruts, or topographic maps. The vertical resolution is 0.5 mm (0.02 in); slope measurement accuracy is 0.5 degree.

Further evaluation is needed to establish performance under dynamic conditions and the correlation of the data on roadway surface topography with that of other measurement techniques.

Limited copies of the report are available from the Pavement Division, HNR-20, Federal Highway Administration, Washington, D.C. 20590. The report is also available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 83 104018).

Evaluation of Low-Solvent Maintenance Coatings for Highway Structural Steel, Report No. FHWA/RD-81/019


Report No. FHWA/RD-81/019

EVALUATION OF LOW SOLVENT MAINTENANCE COATINGS FOR HIGHWAY STRUCTURAL STEEL

December 1981
Final Report

Prepared for

U.S. Department of Transportation
Federal Highway Administration

Offices of Research & Development
Materials Division
Washington, D.C. 20590

Document is available to the U.S. public through the National Technical Information Service Springfield, Virginia 22161

by FHWA Office of Engineering and Highway Operations R&D, Materials Technology and Chemistry Division

With increased restrictions on lead- and chromate-containing primers and the amount of organic solvents allowed in maintenance coatings, there is a great need to develop and evaluate suitable alternatives. The coatings industry has concentrated its major research efforts to meet these requirements.

This report summarizes the state of the art regarding regulations, new technology, impact upon structural steel painting practices, and recommendations. The most promising technologies include water-borne solutions and latices as well as reformulations with chlorinated solvents for mild and moderate environments, and with water-thinned zinc-rich paints and water-borne and high-solid epoxies for more severe environments.

Although new technology is rapidly emerging, there is still no viable, safe, and practical low-solvent alternative now available for use on structural steel in most environments. It was concluded that at least 2 years are required before low-solvent coatings can be proven for use in mild environments, 5 years for moderate environments, and longer for severe, heavy-duty exposures. Procurement of low-solvent bridge paints and painting will require adoption of performance criteria, coordinated highway coatings evaluations, and recognition of the concept of zones of defense. Higher costs may be expected in more complicated paints, alternate surface preparation, more difficult application, closer inspection, and probably shorter painting cycles.

Limited copies of the report are available from the Materials Technology and Chemistry Division, HNR-40, Federal Highway Administration, Washington, D.C. 20590.

Recycling Agents for Recycled Bituminous Binders, Report No. FHWA/RD-82/010

by FHWA Office of Engineering and Highway Operations R&D, Materials Technology and Chemistry Division

This report describes a comprehensive evaluation of recycling agents and aged asphalt binders. Salvaged asphalt treated pavement materials were obtained, analyzed, and combined with recycling agents. Laboratory tests were performed on the field aged mixtures, field aged asphalts, recycling agents, aged asphalt-recycled agent blends, and recycled mixtures. Results from these tests suggest that recycling agents can restore aged asphalts to desired consistency levels and can be used to produce recycled mixtures with acceptable properties. However, the type of recycling agent and the nature of the aged asphalts will determine the temperature susceptibility of the blended binder.

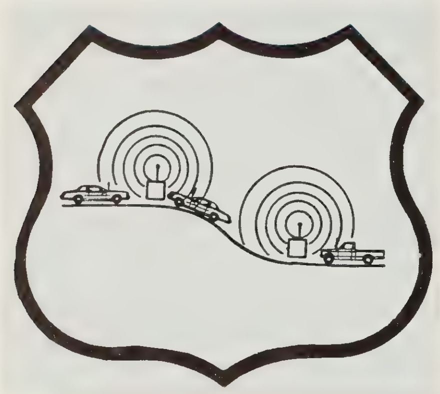
Potential problems exist with aged asphalt-recycling agent compatibility. Tests and criteria need to be developed to more accurately recognize such problems. In the interim, a laboratory oven aging test conducted on the aged asphalt-recycling agent blend is suggested for use.

Recycled mixture properties can be adjusted by controlling the amount of recycling agent added. The properties of recycled mixtures are dependent upon the method and temperature of sample preparation. The blending of the recycling agent with the aged asphalt is both time and temperature dependent.

Pavement performance has been predicted for recycling agents and a method for the design of recycled mixtures is contained in the report.

The report is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 82 197856). Limited copies of an Executive Summary, Report No. FHWA/RD-82/122, are available from the Materials Technology and Chemistry Division, HNR-40, Federal Highway Administration, Washington, D.C. 20590.

Feasibility and Concept Selection of a Safety Hazard Advance Warning System (SHAWS), Report No. FHWA/RD-81/123

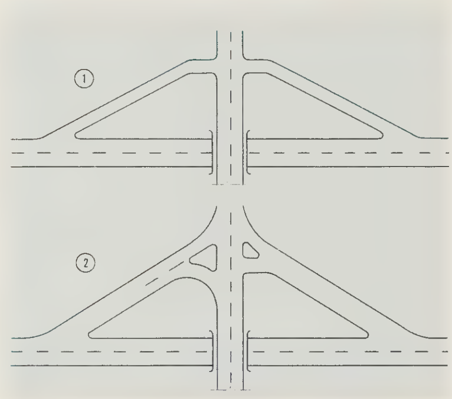


by FHWA Office of Safety and Traffic Operations R&D, Systems Technology Division

This report documents a study to investigate the feasibility of providing a **S**afety **H**azard **A**dvance **W**arning **S**ystem (SHAWS) using low powered radio transmitters to warn motorists of potential hazards such as hidden intersections and moving maintenance operations. The system would transmit warnings to approaching vehicles by a simple audio and/or visual display. The system could be deployed on rural and urban secondary roads where hills, curves, vegetation, and other physical features hinder a driver's view of traffic and roadway hazards.

Limited copies of the report are available from the Systems Technology Division, HSR-10, Federal Highway Administration, Washington, D.C. 20590.

Procedures and Guidelines for Rehabilitation of Existing Freeway-Arterial Highway Interchanges, Vols. I-IV, Report Nos. FHWA/RD-81/103-106



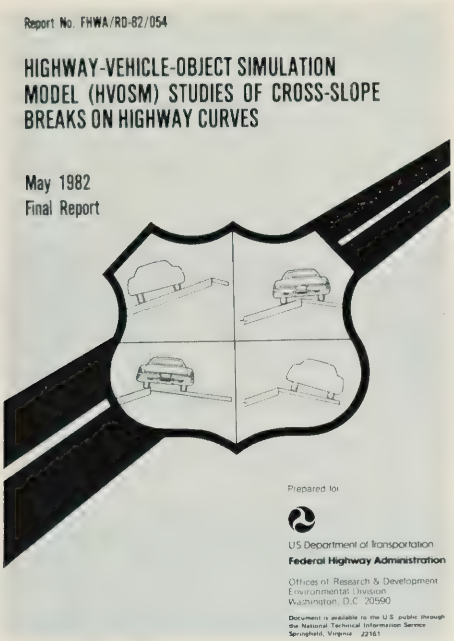
by FHWA Office of Safety and Traffic Operations R&D, Safety and Design Division

During the past 40 years, the United States has constructed an extensive system of multilane, limited-access freeways. Freeway-arterial interchanges have been constructed at intervals to provide access from the conventional highway system to the freeway system. "Interchange rehabilitation" is defined as any construction or maintenance project intended to improve traffic operations or safety at an interchange through geometric design modifications.

These reports describe recommended interchange rehabilitation project design procedures including identification of interchanges with traffic operational or safety problems, identification of specific deficiencies through engineering studies, identification of improvement alternatives, quantification of the effects of improvement alternatives, evaluation and selection of the best alternatives, and implementation and evaluation of the improvement project.

Volume I, Executive Summary, gives a brief overview of the project objectives and results. Volume II, Design Procedures for Rehabilitation of Freeway-Arterial Interchanges, presents the procedures and guidelines recommended for use in interchange rehabilitation projects, and Volume III, Evaluation of Interchange Rehabilitation Projects, presents evaluations of 40 such projects recently constructed by highway agencies. Volume IV is the final research report.

Limited copies of the reports are available from the Safety and Design Division, HSR-20, Federal Highway Administration, Washington, D.C. 20590 .



Highway-Vehicle Object Simulation Model (HVOSM) Studies of Cross Slope Breaks on Highway Curves, Report No. FHWA/RD-82/054

by FHWA Office of Safety and Traffic Operations R&D, Safety and Design Division

The research described in this report was conducted to investigate the operational effects of cross slope breaks on highway curves. These breaks are created by the superelevation of the traveled way and the adverse shoulder slope. HVOSM simulation studies were performed on a variety of break designs to test the effects of curvature, speed, and vehicle path on vehicle operations.

The study findings revealed the importance of shoulder slope and width in designing the shoulder to accommodate vehicular recoveries on the outside of curves. Recommendations regarding design of cross slope breaks, including treatments for special situations such as narrow shoulders, high superelevation, and rehabilitation of projects, were derived from the research findings.

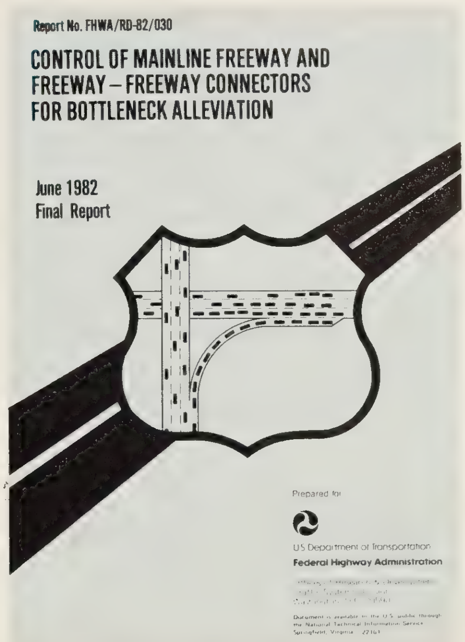
Limited copies of the report are available from the Safety and Design Division, HSR-20, Federal Highway Administration, Washington, D.C. 20590.

Control of Mainline Freeway and Freeway-Freeway Connectors for Bottleneck Alleviation, Report No. FHWA/RD-82/030

by FHWA Office of Safety and Traffic Operations R&D, Urban Traffic Management Division

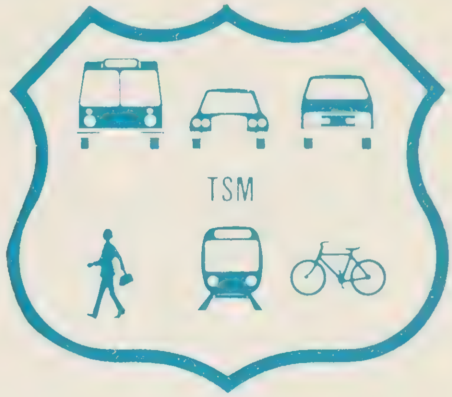
This is the final report on a study that examined the feasibility of metering freeway connectors and mainline sections to improve traffic flow at bottlenecks downstream of the metering locations. The report presents guidelines that will enable operating agencies to determine the appropriateness of such control.

The principal finding in the study was that connector metering should be used only when ramp metering is not feasible or is insufficient to maintain uncongested traffic flow through a bottleneck location.



Limited copies of the report are available from the Urban Traffic Management Division, HSR-40, Federal Highway Administration, Washington, D.C. 20590.

Measures of Effectiveness for TSM Strategies, Report No. FHWA/RD-81/177



by FHWA Office of Safety and Traffic Operations R&D, Urban Traffic Management Division

This report is the second and final report resulting from the study "Measures of Effectiveness for Multimodal Urban Traffic Management." The objectives of the study were to develop a comprehensive set of goals and objectives for transportation system management (TSM) strategies, to derive measures of effectiveness for determining the degree to which each objective was achieved, to develop a classification scheme for TSM strategies, and to identify and present data collection and analysis methods for the evaluation of TSM strategies.

This volume documents the research results and describes the study methodology. An earlier report, FHWA/RD-79/113, presented a summary of the study as a guide for practicing engineers and planners involved in developing and evaluating urban area TSM plans.

Limited copies of the reports are available from the Urban Traffic Management Division, HSR-40, Federal Highway Administration, Washington, D.C. 20590.

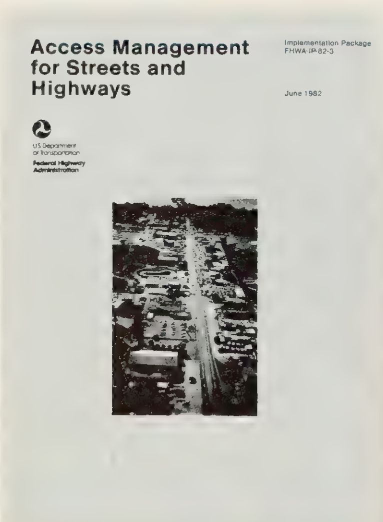
Implementation/User Items "how-to-do-it"

The following are brief descriptions of selected items that have been recently completed by State and Federal highway units in cooperation with the Office of Implementation, 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 Implementation (HRT-1)
Washington, D.C. 20590

Items from the Office of Implementation can be obtained by including a self-addressed mailing label with the request.

Access Management for Streets and Highways, Report No. FHWA-IP-82-3



by Office of Implementation

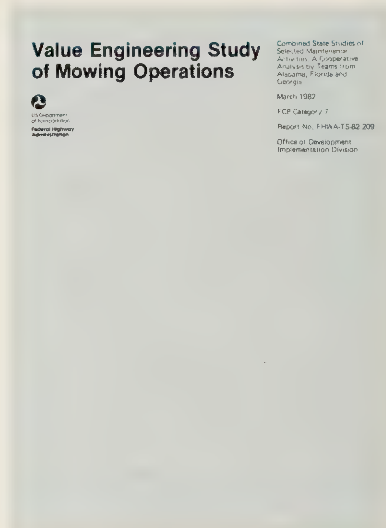
Access management is an effective technique for reducing traffic conflicts involving driveways and intersections. Most highway agencies have a comprehensive access management policy, but the effectiveness of current practices varies widely. This report was developed to further promote and encourage effective access management techniques, and provides design details and traffic operation methods for reducing the frequency and severity of traffic accidents at driveways. The report also provides guidance for establishing a comprehensive access management program and a review of the current access policies in Wisconsin, Pennsylvania, and Colorado.

This report may be purchased for $7.50 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock No. 050-001-00248-5).

Value Engineering Study of Mowing Operations, Report No. FHWA-TS-82-209

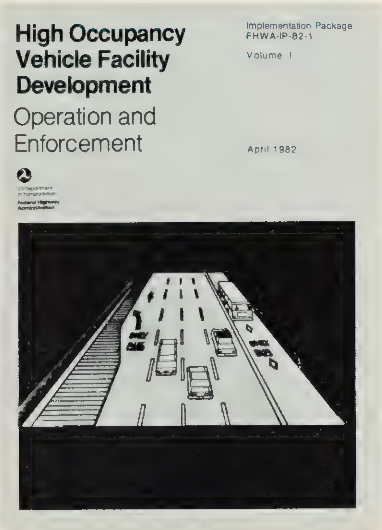
by Office of Implementation

This report is the 11th in a series on Optimizing Maintenance Activities and summarizes the results of a cooperative Value Engineering Study of Mowing Operations. The study was conducted by teams of maintenance and operations engineers from Alabama, Florida, and Georgia who applied value engineering techniques to both chemical and mechanical mowing operations.



The report includes specific recommendations on equipment combinations, use of herbicides, and establishing and enforcing a standard mowing height policy. By implementing these recommendations, the three participating States expect an estimated annual savings of $600,000.

Limited copies of the report are available from the Office of Implementation. The report is also available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 82 263872).



High Occupancy Vehicle Facility Development, Operation and Enforcement, Vols. I and II, Report No. FHWA-IP-82-1

by Office of Implementation

Priority treatment for high occupancy vehicle (HOV) projects was a direct result of energy shortages and escalating fuel prices. Numerous projects on HOV's have been implemented and evaluated. This report presents summaries of HOV project implementation experience and provides guidance on the planning, design, operation, and enforcement of HOV facilities.

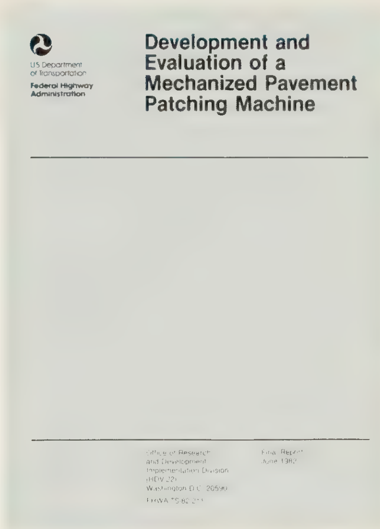
Volume I describes the need for HOV projects and depicts various HOV treatments. Volume II is an appendix that contains complementary materials for use with the HOV Treatment Selection Procedure detailed in Volume I.

The reports are available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. Volume I may be purchased for $8 (Stock No. 050-001-00247-1) and Volume II may be purchased for $5.50 (Stock No. 050-001-00249-3).

Development and Evaluation of a Mechanized Pavement Patching Machine, Report No. FHWA-TS-82-211

by Office of Implementation

This report presents the results of an evaluation of state-of-the-art pavement patching equipment. The evaluation was based on literature reviews and interviews with State highway department personnel.



The Perma-Patch Machine was found to meet the requirements for a fully mechanized pothole patcher.

The report also includes the results of field evaluations of the Perma-Patch Machine, which is a prototype device. Although the prototype equipment experienced some mechanical difficulties, the patch durability was very good and there were no failures in the patches placed during the study.

Limited copies of the report are available from the Office of Implementation. The report is also available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 82 262437).

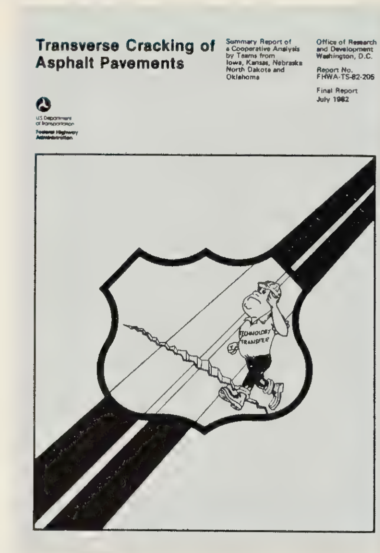
Polymer Concrete Patching Manual, Report No. FHWA-IP-82-10

by Office of Implementation

This report describes procedures for using polymer concrete as a rapid patching material to repair deteriorated concrete. The report will be of interest to engineers in need of a long-lasting, rapid-curing concrete patching material.

The unique properties of the polymer concrete patching material include rapid curing at ambient temperature, high strength, good adhesion to concrete surfaces, long term durability to freeze-thaw cycles, low permeability to water and deicing salts, and good chemical resistance. Because of these properties, this material is especially suitable for use at sites where traffic conditions restrict closing for repair work.

Limited copies of the report are available from the Office of Implementation.



Transverse Cracking of Asphalt Pavement, Report No. FHWA-TS-82-205

by Office of Implementation

Through the years, there have been much research and many reports on elimination and reduction of transverse cracking of asphalt pavements. Most of the studies indicated that transverse cracking can be reduced through mix design procedures and asphalt grade and quality controls, but followup reports on the success of these procedures are not available.

At the September 1981 pavement management study meeting in Omaha, Nebr., representatives from Iowa, Kansas, and Nebraska recognized the need for an indepth engineering study of thermal cracking of bituminous pavement and agreed to participate in such a study. Oklahoma and North Dakota also took part in the study.

The study analyzed all functions relating to thermal cracking to determine how different uses of preventive materials, mix design measures, maintenance repairs, and design of bituminous pavements and overlays contributed to the problem and determined what improvements could be made in these procedures to reduce thermal cracking. This report presents the study approach, results, and recommendations. It should be of interest to pavement designers and maintenance engineers concerned with asphalt pavement performance.

Limited copies of the report are available from the Office of Implementation.

New Research in Progress

The following items identify new research studies that have been reported by FHWA's Offices of Research, Development, and Technology. 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 or Transportation 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 1N: Safety of Bicyclists, Moped Operators, and Pedestrians

Title: Methods of Increasing Pedestrian Safety at Right Turn on Red Intersections. (FCP No. 31N1052)
Objective: Identify and field test engineering approaches to increase pedestrian safety at right turn on red intersections. Examine guidelines for the prohibition of right turn on red.
Performing Organization: Goodell Grivas, Inc., Southfield, Mich. 48075
Expected Completion Date: September 1984
Estimated Cost: $161,856 (FHWA Administrative Contract)

FCP Project 1P: Visual Guidance for Night Driving

Title: Reflective Characteristics of Roadway Pavements During Wet Weather. (FCP No. 31P2012)
Objective: Determine the directional reflective characteristics of common pavements during wet weather and develop a design procedure that will facilitate the consideration of wet weather in the design of roadway lighting systems.
Performing Organization: Ketron, Inc., Wayne, Pa. 19087
Expected Completion Date: August 1984
Estimated Cost: $226,287 (FHWA Administrative Contract)

FCP Project 1S: Compatibility of Highway and Vehicle Standards with Driver Characteristics

Title: Vehicle Characteristics Affecting Highway Design. (FCP No. 31S1062)
Objective: Identify the highway geometric design and traffic control criteria that are affected by vehicle characteristics. Determine the relationship of these vehicle characteristics to geometric design and traffic operations criteria. Develop trends and distributions of the vehicle characteristics that affect current criteria. Determine the sensitivity of these criteria to changes in vehicle characteristics.
Performing Organization: Wagner-McGee Associates, Inc., Alexandria, Va. 22304
Expected Completion Date: March 1984
Estimated Cost: $135,500 (FHWA Administrative Contract)

Title: Side Friction for Superelevation on Horizontal Curves. (FCP No. 31S2042)
Objective: Perform analytical evaluation of the forces on each wheel of a vehicle. Using this information, evaluate criteria for superelevation using several specific conditions, such as front-wheel drive, wet pavement, etc. Perform field tests to validate the analytical assessment.
Performing Organization: HSRI, University of Michigan, Lansing, Mich. 48109
Expected Completion Date: June 1985
Estimated Cost: $150,000 (FHWA Administrative Contract)

FCP Project 1U: Safety Aspects of Increased Size and Weight of Heavy Vehicles

Title: Truck Stopping Sight Distance Requirements. (FCP No. 31U2072)
Objective: Determine the stopping sight distance requirements of the existing truck population and how well the stopping sight distances provided by American Association of State Highway and Transportation Officials design standards meet these requirements.
Performing Organization: Automated Sciences Group, Inc., Silver Spring, Md. 20910
Expected Completion Date: August 1983
Estimated Cost: $100,000 (FHWA Administrative Contract)

FCP Project 1X: Highway Safety Program Effectiveness Evaluation

Title: Exposure Measures for Evaluating Highway Safety. (FCP No. 31X1052)
Objective: Develop appropriate exposure measures for various highway geometric and traffic conditions. Identify data collection techniques for each exposure method including sampling, cost, and reliability.
Performing Organization: University of North Carolina, Chapel Hill, N.C. 27514
Expected Completion Date: September 1983
Estimated Cost: $167,250 (FHWA Administrative Contract)

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

Title: Development of a Low-Cost, Low-Maintenance Channelizing Device. (FCP No. 31Y1154)
Objective: Develop a set of functional requirements for channelizing devices that would be used to separate traffic in a two-lane, two-way operation (TLTWO).
Performing Organization: Russel M. Lewis, Annandale, Va. 22003
Expected Completion Date: September 1983
Estimated Cost: $53,640 (FHWA Administrative Contract)

FCP Category 2—Reduce Congestion and Improve Energy Efficiency

FCP Project 2L: Detection and Communications for Traffic Systems

Title: Evaluation of Inductive Loop Configurations. (FCP No. 42L1072)
Objective: Document the operational characteristics and reliability of performance of inductive loop configurations which are currently used in Florida or other States for the detection of all types of vehicles on the highway.
Performing Organization: Florida Department of Transportation, Gainesville, Fla. 32602
Expected Completion Date: January 1984
Estimated Cost: $66,000 (HP&R)

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

FCP Project 3E: Reduction of Environmental Hazards to Water Resources Due to the Highway System

Title: Management Practices for Mitigation of Highway Stormwater Runoff. (FCP No. 33E3302)
Objective: Synthesize and evaluate current stormwater and non-point source runoff management practices. Identify practical, effective, implementable mitigation measures to reduce or eliminate the impact from highway stormwater runoff. Develop guidelines for implementation of highway stormwater runoff mitigation measures and management practices.
Performing Organization: Versar, Inc., Springfield, Va. 22151
Expected Completion Date: February 1984
Estimated Cost: $148,479 (FHWA Administrative Contract)

FCP Category 4—Improved Materials Utilization and Durability

FCP Project 4K: Cost-Effective Rigid Concrete Construction and Rehabilitation in Adverse Environments

Title: Long Term Evaluation of Bridge Decks. (FCP No. 44K2344)
Objective: Observe bridge decks to determine performance characteristics of decks built with conventional portland cement concrete

and uncoated steel reinforcements in a chloride-intensive environment. Perform visual observations, chain drags, chloride contents, and half-cell potentials.
Performing Organization: New York State Department of Transportation, Albany, N.Y. 12232
Expected Completion Date: December 1992
Estimated Cost: $147,800 (HP&R)

Title: Installation of Cathodic Protection System. (FCP No. 34K3003)
Objective: Select an appropriate bridge and select, design, install, monitor, and evaluate a state-of-the-art cathodic protection system.
Performing Organization: Pennsylvania Department of Transportation, Harrisburg, Pa. 17120
Expected Completion Date: May 1986
Estimated Cost: $60,000 (FHWA Administrative Contract)

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

FCP Project 5A: Improved Protection Against Natural Hazards of Earthquake and Wind

Title: Seismic Design Guidance. (FCP No. 35A1902)
Objective: Develop general guidance for the earthquake design of transportation structures. Based on post observed damage, develop a seismic zone map of the United States depicting the regions where ground motion can adversely affect transportation structure response.
Performing Organization: Computech Engineering Services, Berkeley, Calif. 94705
Expected Completion Date: September 1983
Estimated Cost: $25,225 (FHWA Administrative Contract)

Title: Large-Scale Quasi-Dynamic Bridge Column Testing. (FCP No. 35A2618)
Objective: Conduct tests of full-scale and reduced-scale reinforced concrete bridge columns, designed by recently developed seismic design guidelines, to determine (1) effects of scaling factor on the interpretation of results obtained from small scale testing, (2) column performance and ductility, and (3) performance of repaired columns.
Performing Organization: National Science Foundation, Washington, D.C. 20550
Expected Completion Date: May 1985
Estimated Cost: $40,000 (FHWA Administrative Contract)

FCP Project 5K: New Bridge Design Concepts

Title: Techniques for Measuring Existing Long Term Stresses in Prestressed Concrete Bridges. (FCP No. 35K3162)
Objective: Develop techniques for measuring long term (existing) stresses in prestressed concrete bridges by (1) a state-of-the-art survey, (2) analytical studies, (3) laboratory studies, and (4) field studies. Develop a manual of operations for using the techniques.
Performing Organization: Construction Technology Laboratory, Skokie, Ill. 60077
Expected Completion Date: June 1985
Estimated Cost: $318,100 (FHWA Administrative Contract)

FCP Category 6—Improved Technology for Highway Construction

FCP Project 6E: Rigid Pavement Systems Design

Title: Design to Prevent Pumping in Rigid Pavement. (FCP No. 36E2043)
Objective: Develop improved rigid pavement support in terms of erosion resistance to withstand excess water pressure, permeability, and/or limiting deflection. Establish trade-off criteria among subbase support, slab thickness, load transfer, reduced water infiltration, and subsurface drainage as design tool to prevent pumping. Develop procedures for incorporating a consideration of pumping into the overall design of rigid pavements.
Performing Organization: Purdue Research Foundation, West Lafayette, Ind. 47907
Expected Completion Date: August 1984
Estimated Cost: $75,000 (FHWA Administrative Contract)

FCP Project 6G: Performance Related Quality Assurance Specification for Highway Construction

Title: Cost Effectiveness of Current Sampling and Testing Programs for Paving Construction and Materials. (FCP No. 36G3014)
Objective: Provide State agencies with means of priorities among quality control tests and for optimizing sampling frequencies for each test. Establish cost effectiveness of tests for bituminous binders and mixtures, hydraulic

cements and concretes, and soils and soil aggregates. Base cost effectiveness assessment on available data relating test results to performance (pavement serviceability) and on other factors such as the initial cost and quantity of the product, cost of the testing, failure rates and variabilities typically encountered with the material, and criticality of performance.
Performing Organization: Brent Rauhut Engineering, Inc., Austin, Tex. 78758
Expected Completion Date: May 1984
Estimated Cost: $110,000 (FHWA Administrative Contract)

FCP Category 7—Improved Technology for Maintenance

FCP Project 7A: Physical Maintenance

Title: Rapid Repair of Wet Asphalt. (FCP No. 47A1284)

Objective: Identify and field test materials and work methods which will yield a long lasting, economical, wet weather patch for asphalt concrete pavements.
Performing Organization: University of Texas, Austin, Tex. 78712
Funding Agency: Texas State Department of Highways and Public Transportation
Expected Completion Date: July 1985
Estimated Cost: $100,000 (HP&R)

Title: Pavement Marking Removal. (FCP No. 47A4164)

Objective: Investigate pavement marking removal methods for effectiveness and efficiency. Document methods used, contract conditions, and results achieved. Introduce variations in procedures when it appears improved results may be achieved.
Performing Organization: New York State Department of Transportation, Albany, N.Y. 12232
Expected Completion Date: January 1985
Estimated Cost: $90,000 (HP&R)

FCP Category 0—Other New Studies

Title: The Expanded Montana Asphalt Quality Study Using High Pressure Liquid Chromatography (HPLC). (FCP No. 40M3752)

Objective: Determine the validity of the correlation of molecular size distribution of asphalts (determined by an HPLC technique) with pavement performance of normal and recycled asphaltic pavements. Develop guidelines and implement the use of the HPLC method in asphalt pavements.
Performing Organization: Montana State University, Bozeman, Mont. 59717
Funding Agency: Montana Department of Highways
Expected Completion Date: April 1984
Estimated Cost: $272,511 (HP&R)

Dr. Edward T. Harrigan (left) and Mr. Howard J. Lentz (right) with Mr. Edwin M. Wood, Associate Administrator, Offices of Research, Development, and Technology.

Edward T. Harrigan and Howard J. Lentz Receive Awards

Dr. Edward T. Harrigan and Mr. Howard J. Lentz were the recipients of the 1982 award in the annual outstanding paper competition held among the employees of the Federal Highway Administration (FHWA) Offices of Research, Development, and Technology. This award covers the documentation of any technical accomplishment, which may be a publication, technical paper, report, or package; an innovative engineering concept; an instrumentation system; test procedure; new specification; mathematical model; or unique computer program. Each eligible candidate is judged on excellence, creativity, and contribution to the highway community, general public, and FHWA.

Messrs. Harrigan and Lentz received their awards for their research paper, "Laboratory Evaluation of Sulphlex-233, Binder Properties and Mix Design."

Edward T. Harrigan is a research chemist in the Materials Technology and Chemistry Division, Office of Engineering and Highway Operations Research and Development (R&D). Before joining FHWA in 1974, he was a weapons test project officer for the Air Force Systems Command. He is currently technical manager for contract studies in several areas of materials research, including delineation, alternative binder materials, and deicing chemicals.

H. J. (Bud) Lentz is a supervisory materials engineering technician in the Pavement Division of the Office of Engineering and Highway Operations R&D. He supervises the bituminous mixtures research laboratory. Before joining FHWA in 1969, he supervised Amoco's paving and roofing asphalt research and technical service laboratory in Baltimore, Md.

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Expanded Research Facility

The expanded research facility at the Fairbank Highway Research Station in McLean, Va., is nearing completion. The new facility will provide additional laboratory, office, and support space, centralizing the Offices of Research, Development, and Technology, which are presently located in both Washington, D.C., and McLean. Dedication ceremonies for the new facility will be held in the spring.

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