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Audible Pedestrian Signals

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COVER: Audible pedestrian signals emit buzzing, beeping, or chirping cues to help visually impaired persons cross streets.

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Guidelines For Audible Pedestrian Signals

by Morris B. Oliver

Introduction

Audible pedestrian signals emit buzzing, whistling, beeping, or chirping cues to help visually impaired—that is, persons who are color blind, have low vision, or are legally blind—in crossing streets. Although these signals have been available for at least 40 years (Portland, Oregon, installed one in 1948), their use in this country has not been widespread until recently. (*1*)[1] Today, over 100 U.S. cities have installed audible pedestrian signals of one type or another.

As more cities look to install these devices, two key questions will recur:

- At what intersections should audible pedestrian signals be installed?
- To what uniform standards or criteria should the devices conform?

This article reports on a 1988 audible pedestrian signal feasibility study conducted under a graduate research fellowship awarded by the Federal Highway Administration (FHWA). This study examined existing audible signal sites and surveyed visually impaired individuals and their advocate organizations, traffic engineers, audible signal manufacturers, and relevant specialists (e.g., audiologists) to determine, among other issues, how the above two questions are being answered.

[1] Italic numbers in parentheses identify references on page 38.

Approach

The study gathered information on the state of the art in audible pedestrian signal use through a comprehensive literature review and survey. In municipalities having the signals, city traffic engineers, audible signal manufacturers, organizations for the visually impaired, and relevant specialists were interviewed. In addition, visually impaired individuals, members of the general public, representatives of handicapped organizations, and mobility instructors from schools for the visually impaired were consulted to provide further insight.[2]

Subjects addressed in the formal survey included:

- Criteria used to install signals.
- Cost per signal.
- Community response to the devices.
- Responses to the devices from organizations for the visually impaired.
- Sounds used.
- Before/after accident rates.
- Benefits and drawbacks of audible signals.
- Alternatives to audible signals.
- Cities in which specific systems have been installed.

Criteria for Installation

As mentioned above, a key concern for municipalities planning to install audible signals is determining if a signal is needed at a particular intersection and if so, what is that intersection's priority. A comprehensive method for making these determinations is exemplified by the quantitative evaluation and ranking system developed by the Committee for the Removal of Architectural Barriers (CRAB) for San Diego's Transportation and Land Use Committee in 1985. (*2*)

The CRAB system identifies the following as basic considerations in installing an audible pedestrian signal at a given intersection:

- The intersection must be signalized for vehicle traffic.
- The signalization hardware must be capable of retrofitting to the existing signal device with little or no rewiring.
- Audible signals should be equipped with pedestrian signal actuators (push buttons).

The intersection's location must be suitable in terms of land use, noise level, and neighborhood acceptance. Signals should be installed only where the visually impaired want them and where they will not draw noise complaints from residents and businesses.

- There must be a demonstrated need for the audible signal device. Visually impaired pedestrians must make their need for an audible signal at a given site known to the city's traffic engineers or public works department.

To evaluate specific intersections, CRAB has devised 12 factors within 4 categories: intersection safety, pedestrian usage, traffic conditions, and mobility. Each factor can receive a score from 1 (signals of lowest priority) to 5 (signals of highest priority). For 7 of these 12 factors, it is possible to score 0 points. Scores for each factor are assigned for the selected sites by a three-person team comprised of a mobility instructor, a traffic engineer, and a visually impaired person. Locations having optimum conditions for an audible signal would receive a maximum of 60 points; other locations are arranged in descending order with the highest point total indicating the highest priority. A discussion of each of the 12 CRAB factors follows. (*2*)[3]

1. *Pedestrian Accident Record.* Four-year pedestrian accident records for the intersection in question should be obtained from the police department. (*2*) The number of points awarded for each accident condition is presented in table 1.

2. *Intersection Configuration.* The geometry of an intersection, including the number of approaches, has much to do with the crossing difficulty experienced by the visually impaired. According to the CRAB study, three-leg intersections are difficult to cross because they do not provide adequate audible cues concerning the traffic phases. Also, traffic circles and intersections involving more than two streets are among the worst conditions for the visually impaired pedestrian. (*2*) Table 2 shows the CRAB scores given for the various intersection configurations.

3. *Width of Crossing.* Wider streets are more difficult and dangerous to cross since the pedestrian is in the roadway for a longer time. (See table 3.) Pedestrian phasing should permit the visually impaired to cross in one continuous movement regardless of whether there are medians or pedestrian islands. Intersection width is measured along the widest pedestrian crossing and includes medians. (*2*)

4. *Vehicle Speed.* The higher the vehicle speed, the more danger to the visually impaired for two primary reasons. (See table 4.) First, high speeds mean short vehicle closing times and less time for the visually impaired to get out of the way of an approaching vehicle. Second, the higher the speed, the greater the severity of the accident should it occur. Intersection speeds for this purpose are the 85th percentile speed measured along the fastest approach leg. (*2*)

5. *Proximity to Facilities for the Blind or Visually Impaired.* These facilities include: Departments of Rehabilitation, Social Security offices, organizations of and for the visually impaired, public housing facilities,

[2] Mobility instructors are persons who teach the visually impaired how to navigate through city streets.

[3] Note that the bracketed values within the following tables are revisions to CRAB findings.

and senior citizen complexes with one or more visually impaired persons. Points are assigned based on the intersection's proximity (1 block equals 400 ft [122 m]) to such a facility. As table 5 shows, the closer a facility is to an intersection, the more points allotted. (*2*)

6. *Proximity to Key Facilities Utilized by All Pedestrians—Both Visually Impaired and Sighted.* Medical, educational, recreational as well as commercial and governmental facilities come under this heading. As shown in table 6, points are assigned using the distance between the intersection and the facility as in factor 5. Points are awarded based on the proximity of the closest facility. (*2*)

7. *Number of Transit Stops and/or Routes Within One Block of the Proposed Audible Signal Site.* Since the visually impaired generally do not drive, they depend heavily on public transportation such as buses and subways. Table 7 shows transit stops and routes within one block. Special consideration should be given to crossings that have heavy general use, are located near any of the facilities listed in evaluation factors 5 and 6, serve as a transfer point between modes of travel, or serve two or more transit routes within a one-block walk. (*2*)

8. *Passenger Usage.* The passenger usage factor is assigned points based on the total number of passengers each day—both sighted and visually impaired—who get on or off at a transit stop or transfer point within a one-block walking distance. This passenger usage is shown in table 8. (*2*)

9. *Heavy Traffic Flow.* The visually impaired listen for vehicle sounds to determine when traffic is moving and from which direction. Under heavy traffic flow conditions when the sum of the approaching traffic on all legs is greater than 2,000 vehicles per hour during any peak hour there are regular gaps to indicate when one direction has stopped and another has started. (*2*) Table 9 shows that sums less than 2,000 vehicles per hour receive no points.

10. *Light Traffic Flow.* It is more difficult to determine when crossing is safe in light traffic flow because passing traffic gives few audible cues. Light flow is defined as when the sum of the approaching traffic on all legs is less than 900 vehicles per hour during any 1-hour period between 6 a.m. and 6 p.m. (*2*) As table 10 shows, sums greater than 900 vehicles per hour receive no points.

11. *Uneven Traffic Flow.* Since it is much easier for the visually impaired to determine gaps in traffic when there are platooning vehicles than when the traffic is erratic, uneven traffic flow presents additional problems. (*2*) Although table 11 only gives the two extreme point values, it is left to the evaluation team to choose intermediate values.

12. *Mobility Evaluation.* Based on the judgment of the evaluation team, additional points may be assigned based on observed or special conditions not covered by the previous factors. (*2*) Among such special conditions are the right-turn-on-red volume and complexity of the signal phasing sequence. Table 12 shows the points ranging from 0 to 5 for this subjective evaluation factor.

Table 1.—Pedestrian accident records

Pedestrian Accidents in 4 Years	*Points*
[0]	[0]
1	1
2	2
3	3
4	4
5 or more	5

Table 2.—Intersection configuration

Configuration	*Points*
Four-leg right angle intersection	1
Three-leg tee intersection	2
Three- or Four-leg skewed (nonorthogonal) intersection	3
Four-leg intersection with uneven corners	4
Other complex or multiple-leg intersections (e.g., traffic circles, multistreet intersections)	5

Table 3.—Width of crossing

Width of Crossing	*Points*
40 ft or less	1
41 to 52 ft	2
53 to 68 ft	3
69 to 78 ft	4
79 ft or more	5

1 ft = 0.3048 m

Table 4.—Vehicle speed

Speed Range	*Points*
0 to 25 mi/h	1
26 to 30 mi/h	2
31 to 35 mi/h	3
36 to 40 mi/h	4
41 mi/h or over	5

1 mi/h = 1.609 km/h

Table 5.—Proximity to facilities for the blind

Proximity	*Points*
4 to 6 blocks	1
3 blocks	2
2 blocks	3
1 block	4
At subject facility	5

Table 6.—Proximity to facilities used by all pedestrians

Proximity	*Points*
4 to 6 blocks	1
3 blocks	2
2 blocks	3
1 block	4
At subject facility	5

Table 7.—Transit routes and stops within one block	
Number of Routes and Stops	*Points*
[0 routes and 0 stops]	[0]
1 to 2 routes and 1 stop	1
3 or more routes and 1 stop	2
1 to 2 routes and 2 stops	3
3 or more routes and 2 stops	4
3 or more routes and more than 2 stops	5

Table 8.—Passenger usage	
Passengers Boarding and Debarking Each Day	*Points*
[0]	[0]
[1 to 249]	1
250 to 499	2
500 to 999	3
1,000 to 1,499	4
1,500 and over	5

Table 9.—Heavy traffic flow	
Vehicles per Hour	*Points*
[0 to 1,999]	[0]
2,000 to 2,999	1
3,000 to 3,999	2
4,000 to 4,999	3
5,000 to 5,999	4
6,000 and over	5

Table 10.—Light traffic flow	
Vehicles per Hour	*Points*
[900 and over]	[0]
800 to 899	1
700 to 799	2
600 to 699	3
500 to 599	4
Under 500	5

Table 11.—Uneven traffic flow	
Traffic Flow Condition	*Points*
Platooning vehicles	0
Erratic traffic flow	5

Table 12.—Mobility evaluation	
Mobility	*Points*
No special circumstances	0
Many special circumstances	5

Operational Uniformity

Presently, there is a wide variety of devices and procedures used and followed throughout the country. This lack of standards may cause confusion among pedestrians and vehicle operators, prompt wrong decisions, and contribute to accidents.

Comparable traffic situations *must* be treated in the same manner. (*3*) This section first surveys the available devices and then provides recommendations for their uniform operation to eliminate confusion.

Audible signal devices

There are numerous audible signal devices available, all of which are either pedestrian actuated or automatic. In the pedestrian-actuated system, once the button is pressed and the appropriate phase for pedestrian traffic occurs, a sound is emitted to indicate safe crossing. Automatic signals are activated by the cycle change at pre-timed traffic intersections. Many of the automatic devices emit different sounds to indicate the direction and time available for crossing. (*4*) The two most popular audible pedestrian devices in the United States use either a buzzer or a bird call sound.

The most frequently used signal in the eastern United States is the Mallory Sonalert buzzer, specifically, the SC 110E and SC 110Q. (*5*) Models are available to provide tones from 1,900 to 4,500 Hz; these tones cannot be changed on the individual model. For equal sound pressure, the 1,900 Hz signals sound softer and more pleasant than the 2,900 and 4,500 Hz signals. (*6*) The Sonalert buzzers are general-purpose, cost about $10 to $20 apiece, and can be purchased through any electronic components distributor. (*5*)

An interesting use of the Sonalert device is in the Cincinnati, Ohio, system. Cincinnati installed its first audible pedestrian signal in May 1983. The system consists of a constant tone for east-west crossings provided by the SC 110E and a buzzer sound for north-south crossings provided by the SC 110Q. (*7*) During the **Walk** signal, the devices emit either a constant tone or a buzzer sound depending on which crossing is clear. During the pedestrian clearance interval, a sound pulses in cadence with the flashing **Don't Walk** indicator. (*7*) This pulsing tone aids the visually impaired person by:

- Communicating what the sighted pedestrian observes.
- Directing them to an audible target.
- Indicating to the pedestrians in the crosswalk that they have adequate time to complete their maneuver, but those still on the sidewalk should not enter the intersection. (*7*)

Since Cincinnati installs the devices at crossings with pedestrian actuation, the sound is emitted only upon demand.

The cost of duplicating the Cincinnati system will vary according to the number of units needed and installation and maintenance required. Eight buzzer units are required at a standard four-leg intersection. At semiactuated intersections, installation costs are less than $500 (1988 dollars); costs at pre-timed controller sites are from $7,000 to $8,000 (1988 dollars), because a new controller and additional wiring must be installed. (*7*)

The audible signal used most frequently in the western United States is manufactured by Nagoya Electric Works (Nagoya, Japan), and imported by Traconex of

Santa Clara, California. (*5*) The devices are 5 in (127 mm) high, 3.75 in (95.2 mm) wide, 5 in (127 mm) deep, and weigh 3 lb (1.4 kg). The output is 90 dB at 3.28 ft (1 m) and is self-switching to one of two adjustable output levels depending on ambient noise conditions. The tone for the east-west direction is "peep-peep"; the north-south tone is "cuckoo." The units cost about $400 each (1988 dollars). A standard four-leg intersection can be effectively equipped with four units, but optimal results are achieved with eight. It takes about 20 minutes to install the signals, which can be used in conjunction with all standard pedestrian signals. (*8*)

Salt Lake City has been using the Traconex bird call device since 1978 and currently has 24 locations equipped with these audible units. Figure 1 illustrates the device. Installation performed by the Salt Lake City signal division crews varied between 32 and 64 person-hours at a cost of $16 per hour. Miscellaneous materials ranged from $20 to $300 per intersection. Total costs for the products, materials, and labor was between $3,700 to $4,500. (*9*)

Figure 1.—Audible pedestrian signal: Traconex bird call device.

Recommendations for signal devices and operation

Huntington Beach, California, is one of the country's pioneer cities in terms of installing and operating audible pedestrian signals. The Huntington Beach traffic engineers developed the first known criteria for the operation of these signals: many cities, such as Salt Lake City, have since adopted these criteria. The 12 criteria for operating audible pedestrian signals are that the devices: [4]

1. Must not be annoying to the average pedestrian or resident.
2. Must have sound output levels within the 10 to 120 dB range.
3. Must be low cost.
4. Must have upper and lower sound output limits.
5. Must require simple and inexpensive installation.
6. Must require no, or very little, maintenance in a harsh environment.
7. Must be mechanically adjustable for direction.
8. Should not require any extra wiring to the cabinet.
9. Should not interfere with normal signal operation in any way.
10. Must only operate when the **Walk** indication is displayed.
11. Must have a different, easily distinguished sound for each direction. (*10*) In this regard, note that intersections should not be equipped solely with an audible device used in conjunction with a scramble crossing (i.e., a special pedestrian phase in which pedestrian traffic in all directions is allowed while all vehicle traffic is stopped). At nonorthogonal intersections, there is neither a sound to allow pedestrians to orient themselves at the corner nor one to allow the visually impaired to "home in on" the adjacent corner. No directional information is given to inform pedestrians whether they are crossing east-west or north-south. (*11*)
12. Should be actuated either by pedestrians, time clock, or both. (*12*) Any of these methods will bring up the sound during times when it is most needed and avoid unnecessary intersection noise. Signals which sound at all hours, regardless of the pedestrian demand, are highly undesirable.

It should also be noted that intermittent pulses in the frequency range of 300 to 1,000 Hz are the most effective sounds for the human ear to localize; 750 Hz is optimal. (*1,13*) Further, pulses do not require a high volume level to be effective. (*12*) Frequencies in the alpha-rhythm range (8 to 14 Hz) should be avoided because they may incite epileptic seizures. (*1*)

Conclusions

Audible pedestrian signals are feasible, but only at certain complex or confusing intersections frequented by visually impaired persons. Such areas include public transit stops, shopping centers, medical and educational facilities, and offices for associations for the visually impaired. Intersections near these areas/facilities should be evaluated using these installation criteria to determine their priority for having audible signals installed.

Audible signals only indicate that the **Walk** message is displayed and do not indicate if there are vehicles still

[4] The first 11 criteria are those developed by Huntington Beach; the additional criterion has been suggested by this study.

clearing the intersection, though vehicle detector technology may soon be applied to relieve this situation. The devices are not meant to be a substitute for a visually impaired person's orientation and mobility skills, but rather an aid to them.

Further studies on the development of uniform installation and operational standards for audible pedestrian signals are needed. Many companies are producing these devices, and the possibility exists for a wide variety of audible systems which are not uniform. An inclusion of standards in the *Manual on Uniform Traffic Control Devices* would help avoid confusion. Developing warrants for the installation of such devices should also be considered.

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Load Equivalency: Issues for Further Research

by Rita Trapani and Charles Scheffey

Background

The effects of trucks on pavement performance are usually estimated using a system based on the American Association of State Highway Officials (AASHO) Road Test data collected in the late 1950's. Analyses of these data established empirical formulas for assessing the relationships between pavement performance, vehicle loads, and pavement design variables. These equations allow load equivalency factors (LEF's) to be determined. LEF's express varying axle loads in terms of a common denominator. LEF's are used to estimate pavement life for mixed traffic and allocate costs to users.

LEF's represent the ratio of the number of repetitions of any axle load and configuration, to the number of applications of the standard 18,000-lb (80 kN) single-axle load necessary to cause a specified reduction in user perceived rideability. The ratio between the AASHO LEF for any two axle loads of the same configuration can be approximated by the "Fourth Power Law." This function implies that the ratio between the LEF's for any two-axle loads of the same configuration equals the ratio of the axle weights raised to the fourth power.

Although the AASHO design equations have provided a valuable and durable standard, the Road Test's limited parameters have raised concerns regarding the equations' adequacy and accuracy. As an accelerated test, the AASHO Test could not consider the effects of environment, age, and traffic patterns. Tests took place on limited pavement types, on one soil type, and in one climate. Loads tested and test speeds were also limited. Finally, the LEF's are related to loss of roadway serviceability only.

These LEF issues have been compounded by the growth, change, and diversification of U.S. heavy-vehicle traffic. For instance, today's researchers and pavement managers must address vehicle weight, axle and wheel spacing and configuration, suspension systems, tire type, tire inflation pressure, expanding truck volumes, and aging pavements.

Truck-Pavement Interaction: A High Priority Area

In 1988, the Federal Highway Administration (FHWA) designated truck-pavement interaction as a High Priority National Program Area (HPNPA). The ultimate goal of this HPNPA is to build a model of truck-pavement interaction that encompasses both cost prediction and pavement damage. (*1*)[1] Achievement of this goal may entail development of:

- An improved system for determining LEF's.
- A new approach to assessing truck-pavement interaction.

In September 1988, the FHWA sponsored a 3-day Load Equivalency Workshop to facilitate the effort. This event brought together some 70 specialists from 6 countries and 3 continents representing national and local government agencies, universities, the tire and vehicle manufacturing industries, and independent consulting groups.

Throughout the workshop held at the Turner-Fairbank Highway Research Center (TFHRC) in McLean, Virginia, participants worked together to identify key issues for future load equivalency research. Based on facts and theories brought out in 27 formal presentations and ideas generated in group discussions on vehicle loads, tire characteristics, pavement response, and load equivalency models, participants identified these issues for future research:

- The influence of road profiles on the dynamic forces imposed on pavement.
- The role of road simulators.
- Inconsistencies in the results of tire research.
- Integration of vehicle, tire, and pavement dynamic models.
- The need for a uniform definition of pavement response.
- The need for distinct load equivalency models for different user classes.

The following sections highlight workshop discussions of these topics.

Influence of Road Profile on Pavement Damage

How does road profile influence the dynamic forces imposed on pavement? Does existing pavement roughness alter the effects of truck-pavement interaction? Will the amount of damage imposed by a given passing vehicle increase in proportion to the amount of damage already done to the roadway?

According to speaker David Cebon of Cambridge University, the magnitude of dynamic wheel forces is significantly influenced by road roughness. In 1985, using a simplified theoretical road response

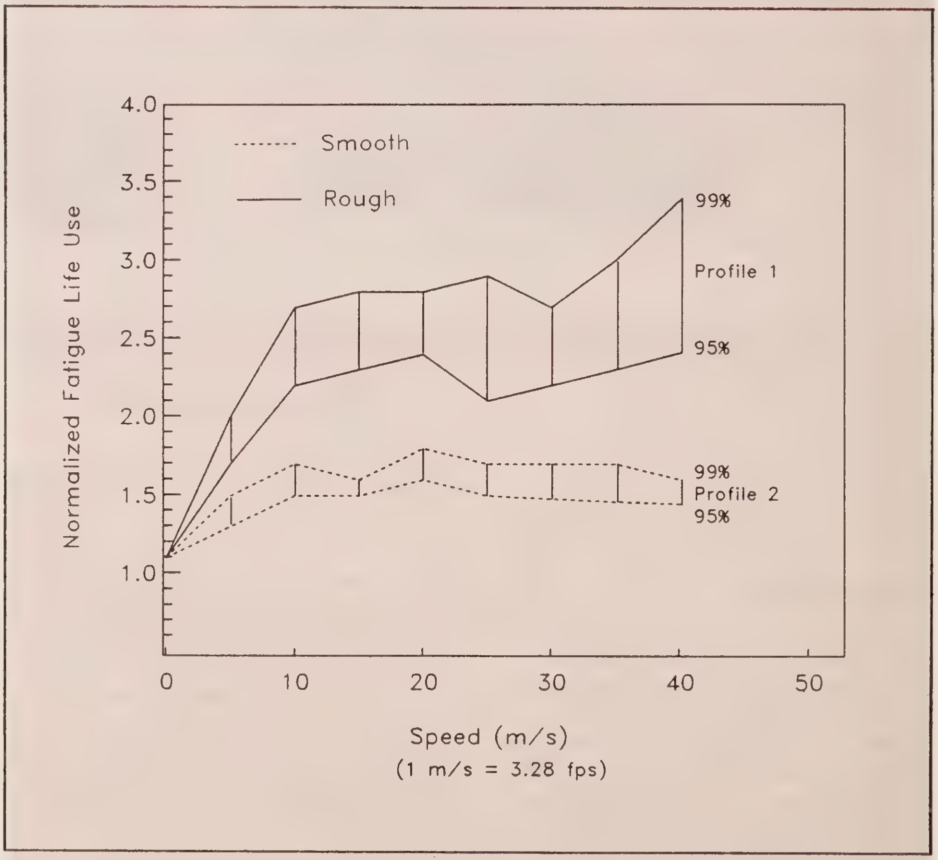

Figure 1.—The effect of speed on simulated road damage caused by a three-axle vehicle model.

[1] Italic numbers in parentheses identify references on page 45.

model, Cebon conducted a pilot study of theoretical fatigue damage caused by different vehicles traveling at various speeds. As shown in figure 1, study results indicate that for a vehicle traveling over two different road profiles at comparable speeds, more damage is imposed on the profile with a rougher surface (profile 1). Also, while road surface dynamic response increases on a rough profile as speed increases, smooth surfaces do not suffer from such increased response.

The results of an extensive Australian Road Research Board (ARRB) study, which ended in 1983, support the theory that road profiles influence truck-pavement interaction. As reported to the workshop by ARRB's Peter Sweatman, the study tested and compared nine suspension systems installed on vehicles traveling at three speeds and on two tire pressures. Each vehicle traveled over six road roughnesses, ranging from "as-new" to "desirable reconstruction limit." Although the test's purpose was to assess the impact of various suspension systems, Sweatman concluded that road roughness—as well as suspension type and traveling speed—has a significant effect on dynamic wheel forces.

Thomas Gillespie of the University of Michigan Transportation Research Institute (UMTRI) also emphasized the importance of road profile in describing a mechanistic truck dynamic model. Specifically, he described the components of road roughness and their significance in model use.

Models typically receive "excitation," or input, which consists in part of road roughness. Roughness is comprised of vertical bounce, primarily described by the random deviations in elevation along the roadway's wheel tracks, and roll, which results from phase differences in the right and left wheel paths.

Roll, commonly considered less significant than vertical bounce, is usually ignored. However, axle tramp mode—a movement in which the left and right wheels go up and down alternately—is a type of roll that may be significant. Gillespie noted that little is known about axle tramp mode and that its significance should be determined.

Role of Road Simulators

The dynamic forces imposed on pavement by vehicles using a wide variety of suspension systems can be assessed satisfactorily by road simulators. Garrick Hu of PACCAR, a truck manufacturer, shared the results of suspension-system tests carried out at the PACCAR Technical Center using a road simulator. These results were compared to those derived from actual road tests: figure 2 indicates how well the results of the two methods coincide.

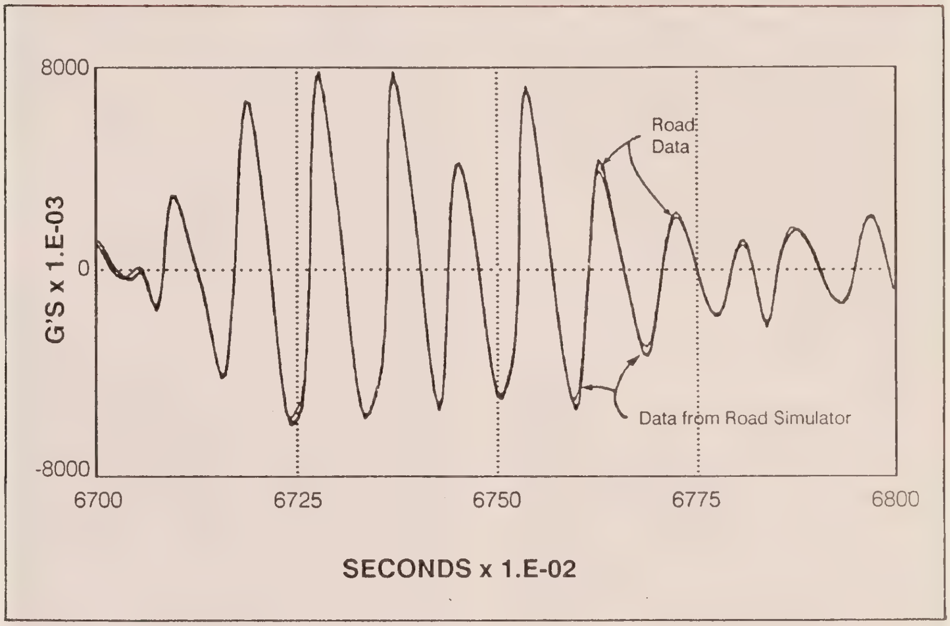

Figure 2.—Comparison of measured and simulated acceleration time histories.

Several workshop participants commented that to obtain most accurate results, simulator tests require that all axles of the vehicle be on controlled actuators. Thus, even the elementary combination vehicle needs at least six actuators and significantly more for exotic combinations.

Furthermore, as Hu noted, even the six-actuator system is inadequate for testing certain vehicles. For example, pure sets of road responses can be input when testing a standard tractor, but the PACCAR simulator does not respond in the same way when the tractor is coupled with a trailer. To remedy this, numerous adjustments must be made to the measured responses. PACCAR hopes to install a 10-actuator road simulator in the near future.

Participants agreed there is a need for field verification of a representative set of laboratory simulations with instrumented vehicles and/or vehicles running on instrumented pavements. Finally, both Cebon and Sweatman cautioned that, while the road simulator is a dependable choice, it is also an expensive one.

Inconsistencies in Results of Tire Research

There are many apparent inconsistencies in the data from various laboratory efforts measuring the distribution of contact pressures between tire and pavement. It is not known to what extent the observed differences are due to the actual load distribution behavior of the type of tire tested, the methods of pressure measurement used, and the differences in load and inflation pressure.

Participants at the workshop generally agreed that a "round robin" series of tests should be used in which all investigators would test identical tires under the same sets of conditions. Further analytical work with existing or improved tire structural models can provide critical guidance to this effort.

From the standpoint of probable pavement damage, the most significant discrepancy lies in the part of the tire contact footprint found to have higher pressure. Freddy Roberts of Auburn University used a finite element tire model developed by John Tielking of Texas A&M University to analyze contact pressure distribution. Roberts' findings indicate higher pressure at the tire sidewall than at the centerline. Tielking reported similar findings using the same model, as did Kurt Marshek of the Center for Transportation Research (CTR) at the University of Texas at Austin, who employed pressure-sensitive film to test contact pressure.

Although Matti Huhtala of Finland's Road and Traffic Laboratory Technical Research Center found such a pattern for passenger auto tires, truck tires—tested by rolling the tire over a set of closely spaced sensors—showed maximum pressures along the tire's centerline. Huhtala also reported on an instrumented test pavement in which the relative damage potential of various European tire types was evaluated under a range of axle loadings and tire inflation pressures. It was assumed that the damage could be related to measured strains in the pavement and appropriate cumulative damage criteria. Data show a wide range of damage by the various tires for the same axle load. (See figure 3.)

Marshek shared that when load remains constant, increased inflation pressure tends to shift contact forces toward the center. When inflation pressure is constant, increased load usually shifts the higher contact forces toward the sidewall areas. Figures 4 and 5, which Marshek used to illustrate results of the CTR study, demonstrate this shift. Radial tires may be less sensitive to these effects than bias-ply tires.

Finally, although most investigators agree that contact pressure is seldom uniform, many pavement models assume uniformity. Marshek pointed out that pavement

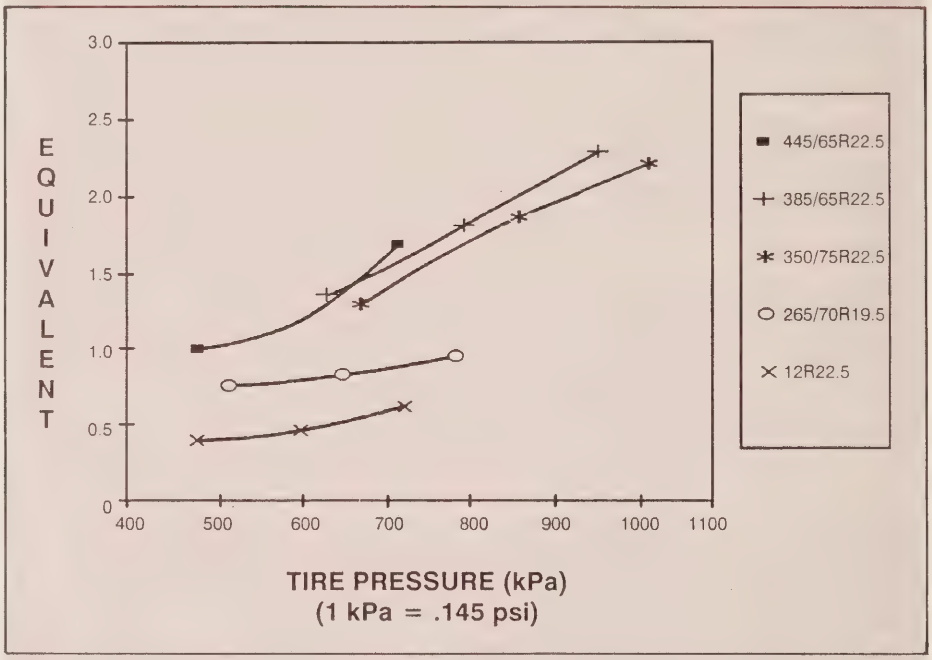

Figure 3.—Equivalencies as a function of tire pressure, axle load 18,885 lb (84 kN), and thickness of bituminous layers 3.15 in (80 mm).

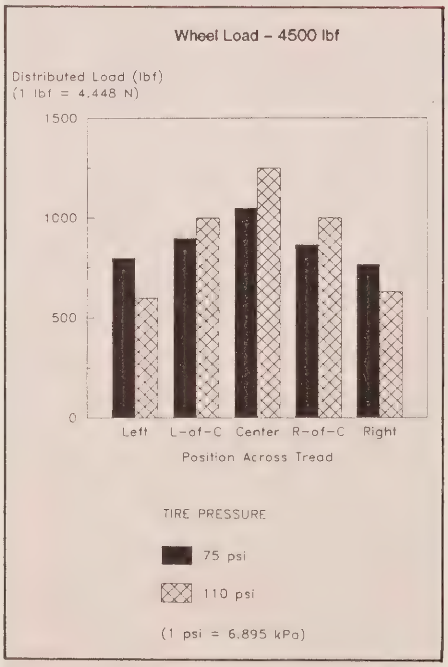

Figure 4.—Change in load distribution with inflation pressure (bald).

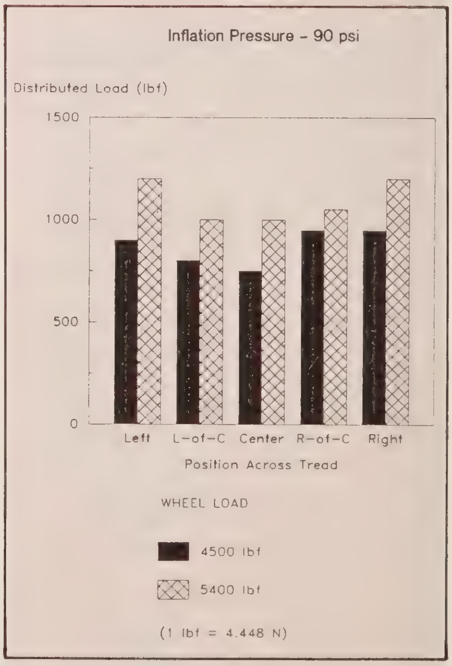

Figure 5.—Change in load distribution with wheel load (treaded).

designers historically have assumed uniform tire contact pressure, not because they believed this to be true, but rather because the technology did not exist to determine actual pressure distribution. Assuming uniformity simplified analysis. Today, however, technology is being developed that can represent the actual conditions.

Integration of Vehicle, Tire, and Pavement Dynamic Models

Another issue that arose from discussions of tire models is the need for integrating vehicle, tire, and pavement dynamic models so they can adequately represent the correct interactions such as surface profile deterioration, which increases with time. The discussions indicated additional work is needed to determine force distributions at the tire-pavement interface.

Participants agreed that a followup workshop or seminar should be held to continue the discussion on integrating models. Ideally, the topic should be discussed by a small working group of pavement and tire experts.

Pavement Response: New Insights and Need for a Uniform Definition

Several presenters shared new insights drawn from the study of pavement response to heavy vehicles.

- Thomas D. White of Purdue University stated that recent assessment of the AASHO Road Test results has shown these data may be viewed in new ways to provide important insights. For example, the raw data on the test sections may be plotted as survivability curves rather than as pavement serviceability index (PSI) versus time or number of loadings to failure.

- In his paper on instrumented pavements, Ernest Barenberg of the University of Illinois also advocated the probability of survival curves plotted against measured pavement strain and deflection responses. He also stressed the importance of instrumented pavements in validating models that predict pavement responses.

- M.E. Harr of Purdue University presented the case for using deflections as the principal index of pavement performance, relating performance to pavement life expectancy through transfer functions.

- Brian Brademeyer, an independent consultant, reported on pavement models that were adapted to include the effect of vehicle force profiles as functions of the pavement surface roughness.

It became apparent during presentations and discussions that there is no one accepted definition of pavement response. It was agreed that continued dialogue is needed to distinguish between primary static and dynamic load response, between environmental condition and environmental response, and between primary response and the development of various types of distress under repeated loads or extended-time environmental changes. Some term these effects "performance"; others refer to them as "ultimate response," reserving the term "performance" for the aggregate effect of all types of distress on surface profile and ride quality.

Need For Distinct Load Equivalency Models

Load equivalency models of different levels of sophistication need to be developed to cover the different user classes. Relatively simple models, based perhaps on only the primary static response, may be adequate for cost allocations. This simple level is feasible, however, only if more sophisticated and thoroughly validated load equivalency models also exist to define the accuracy and limitations of the simpler models.

The more detailed models may well be required to define separate LEF's for each type of pavement distress and to provide modification or correction factors for environmental conditions. According to Paul Diethelm, a Minnesota Department of Transportation engineer and chairman of the Load Equivalency Models session, there is general consensus on this point among pavement designers and planners, the cost-allocation community, researchers, government officials, and legislative bodies. "We need to choose models for all these different things, rather than hoping one will take care of all of them," he said.

Diethelm added there are several good models already available in the U.S. and Europe. For instance, Brent Rauhut, of Brent Rauhut Engineering (BRE), Inc., reported results of some of his work using predictive damage models. Allowing that the primary reason for LEF's is the "need for fair allocation of pavement construction and maintenance costs to highway users," Rauhut nevertheless recognized the benefits of models that can be used to develop more comprehensive LEF's.

Rauhut described the methods and results of the 1982 Highway Cost Allocation Studies (HCAS) which, in response to a Congressional mandate, factored the impact of the environment on pavement damage into cost allocation. HCAS simulated four environments and three subgrades using a computer testing system.

"HCAS, said Rauhut, "advanced the state of the art for the development of load equivalency factors," going beyond loss of serviceability and including factors for fatigue cracking and rutting. Figure 6 shows LEF plots comparing HCAS, BRE computer predictions of fatigue cracking, and AASHO Road Test fatigue cracking. AASHO data is based on the initiation of class 2 cracking and the most common factors of the loss of PSI.

Rauhut added that a more recent project, conducted by the Texas Transportation Institute (TTI) in 1986, resulted in new LEF's for three factors not considered in HCAS: tire type, inflation pressure, and the number of tires on an axle.

Robert L. Lytton, of Texas A&M University and the TTI, concurred with other participants that load equivalencies can be used not only as a cost-allocation method, but also as an aid in pavement design. Cost allocation, said Lytton, was the use for load equivalency factors recognized in the AASHO Road Test; their impact on pavement design was a "discovered use." This discovery led to the recent realization that separate load equivalencies are needed for the various types of distress.

A valuable by-product of detailed models is the possibility that design changes may be indicated. With modest investment, this could eliminate or delay some types of distress and balance the investment in the pavement structure to provide more uniform life expectancy for the remaining types of distress. Looking to possible new uses for damage functions, Lytton emphasized that as we gain more knowledge, the highway community must try to develop models that make reasonable predictions by including additional relevant factors. Then researchers should try to normalize the predicted damage to see how it is affected by these factors.

Lytton predicted a great need in the future for network-level damage functions. These will be particularly useful for policy studies and may be helpful in deciding what percentages of cost ought to be common cost and what should be borne by different vehicle classes.

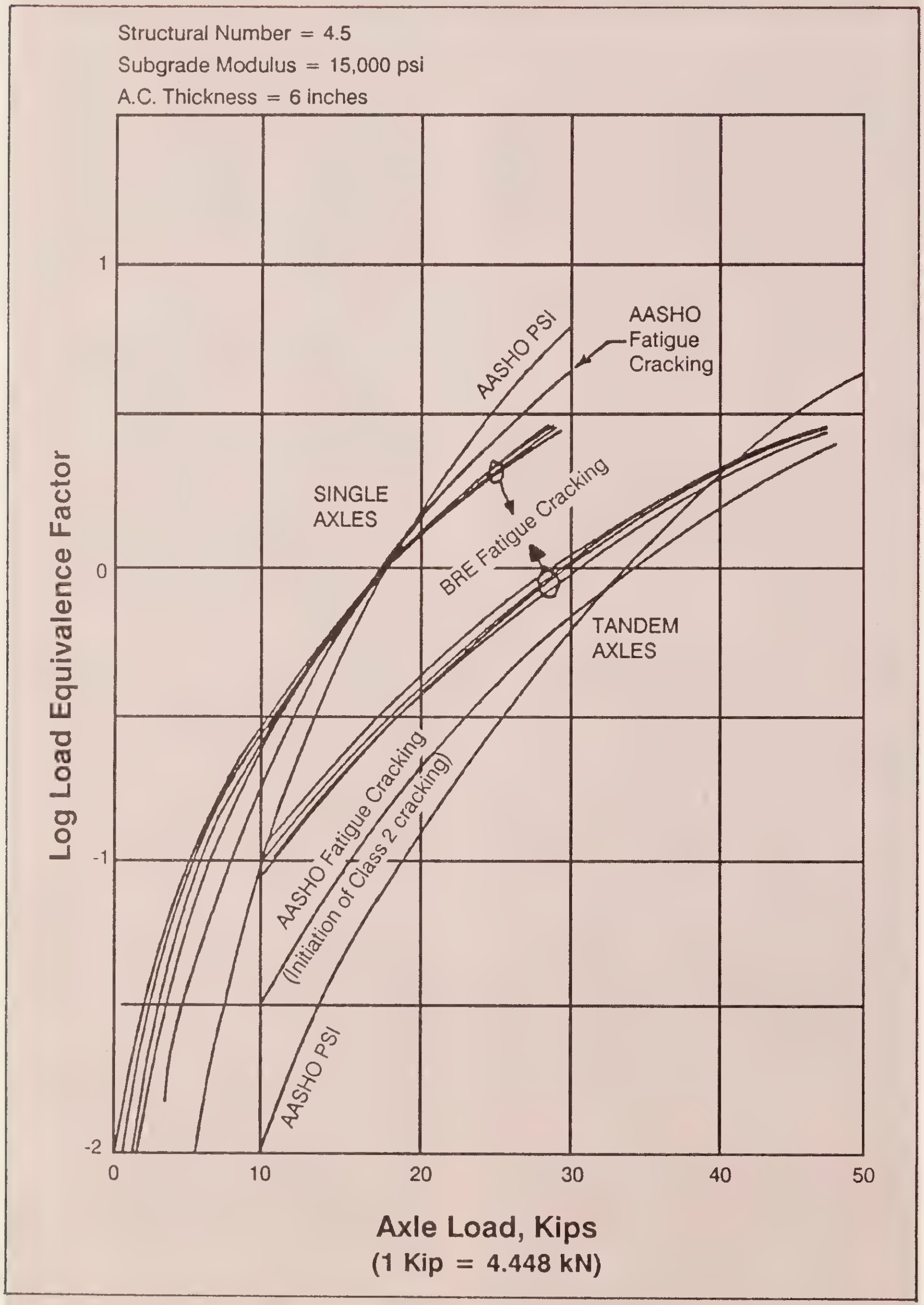

Figure 6.—Load equivalence factors for fatigue cracking.

Workshop Recommendations

Participants repeatedly recommended not only continuation of the dialogue begun at the workshop, but also the formation of small work groups or task forces to focus on particular issues. The general consensus was that the FHWA should organize these small work groups so that all could benefit from data and resources—information available outside the highway community—which could be useful in pavement design or cost allocation.

Work efforts must continue to cross industry lines. As Vehicle Loads Chairman Newt Jackson of the Washington State Department of Transportation put it, "Because pavements break trucks and trucks break pavements, the combined work with industries is really, truly needed."

According to UMTRI's Gillespie, the National Aeronautics and Space Administration (NASA) has used strain gauges to study aircraft tires. Gillespie suggested that the data collected by NASA could benefit the FHWA research efforts. In addition, Harr described extensive pavement tests he has conducted for the airfield industry. The results of tests like these, and others performed by the U.S. Air Force, could prove useful to the FHWA. This combined work can mean a sharing of data and resources previously unavailable to researchers.

Session chairs and participants specifically recommended the FHWA pursue information sharing among representatives of the pavement engineering community, vehicle and frame manufacturers, and the tire industry. Topics for their consideration should include:

- Design adjustments needed to reflect fleet changes.

- Best approaches to interfacing pavement, vehicle, and tire models.

Several persons recommended formation of an expert, special task force. The task force—to be drawn from research, industry, and government so as to represent all sides of the highway vehicle community—could be used to achieve consensus on the issues brought out during the workshop. Said Sweatman, "We really need a group to get in-depth on [the issues], to get quantitative about it." Alternatively, the task force could be a coordinating oversight group whose periodic meetings would aim at developing a cooperative, meaningful research program.

FHWA Response to Issues

The FHWA expressed sincere thanks to everyone who participated in the Load Equivalency Workshop. The workshop triggered a number of actions on the part of the FHWA. For example, after the workshop FHWA representatives visited two truck manufacturers to discuss the design and operation of their shaker table. The FHWA tire research at the accelerated loading facility—specifically, those tests of a super single tire—is being coordinated with University of Texas tests on a super single tire using pressure sensitive film. The FHWA also proposes to assemble expert panels on the issues identified in the workshops and at appropriate points in conducting the following research:

- Because of the workshop's emphasis on the influence of road profile on dynamic loads, an added task is being considered for inclusion in the pavement response tests to be conducted at the FHWA using three different trucks. The proposed task will measure force profiles for the trucks at various levels of roughness and vehicle speed. These measurements will be compared with the wheel force transducer, road simulator, the instrumented pavement section at TFHRC and at other instrumented sections, and vehicle-pavement dynamic model.

- Despite recommendations to include at least 10 actuators in the road simulator, the FHWA will continue as proposed in its 1987 Truck Pavement Interaction HPNPA Work Plan. Road simulators currently in use are designed to check the limits of various truck components and driver fatigue. The FHWA's primary testing purpose will be to relate relative loading to roughness level, thus testing the vehicle dynamics model. Research is under way at the FHWA's TFHRC to design experimental equipment for measuring dynamic wheel loads. This consists of a simulator for laboratory measurements and wheel force transducers for measuring wheel forces in over-the-road operation. The current design for the road simulator is for six actuators; only four will be installed initially. In addition, four wheel force transducers will be built and over-the-road data compared with the laboratory actuator data obtained using roughness inputs from the same roads. Future plans include potential for additional actuators as required.

- Vehicle, tire, and pavement dynamic models have, in the FHWA's opinion, already been integrated—to the extent that current models are capable of integration—to explain the interactions between the tire and the road. However, the effects of tires will be known better as research progresses and the FHWA models will include these improvements in later pavement models.

- The FHWA will, for the present, continue to use the definitions given in the 1987 HPNPA Truck-Pavement Interaction Work Plan, since these have been adopted by the Organization for Economic Cooperation and Development (OECD) for worldwide use.

- The FHWA accepts the recommendation to conduct a series of round robin tests to measure contact pressure distributions using various methods for the same tire under the same conditions.

References

(*1*) William J. Kenis. "Truck Pavement Interaction: High Priority National Program Area," paper presented at the FHWA Load Equivalency Workshop, Turner-Fairbank Highway Research Center, McLean, VA, September 13, 1988.

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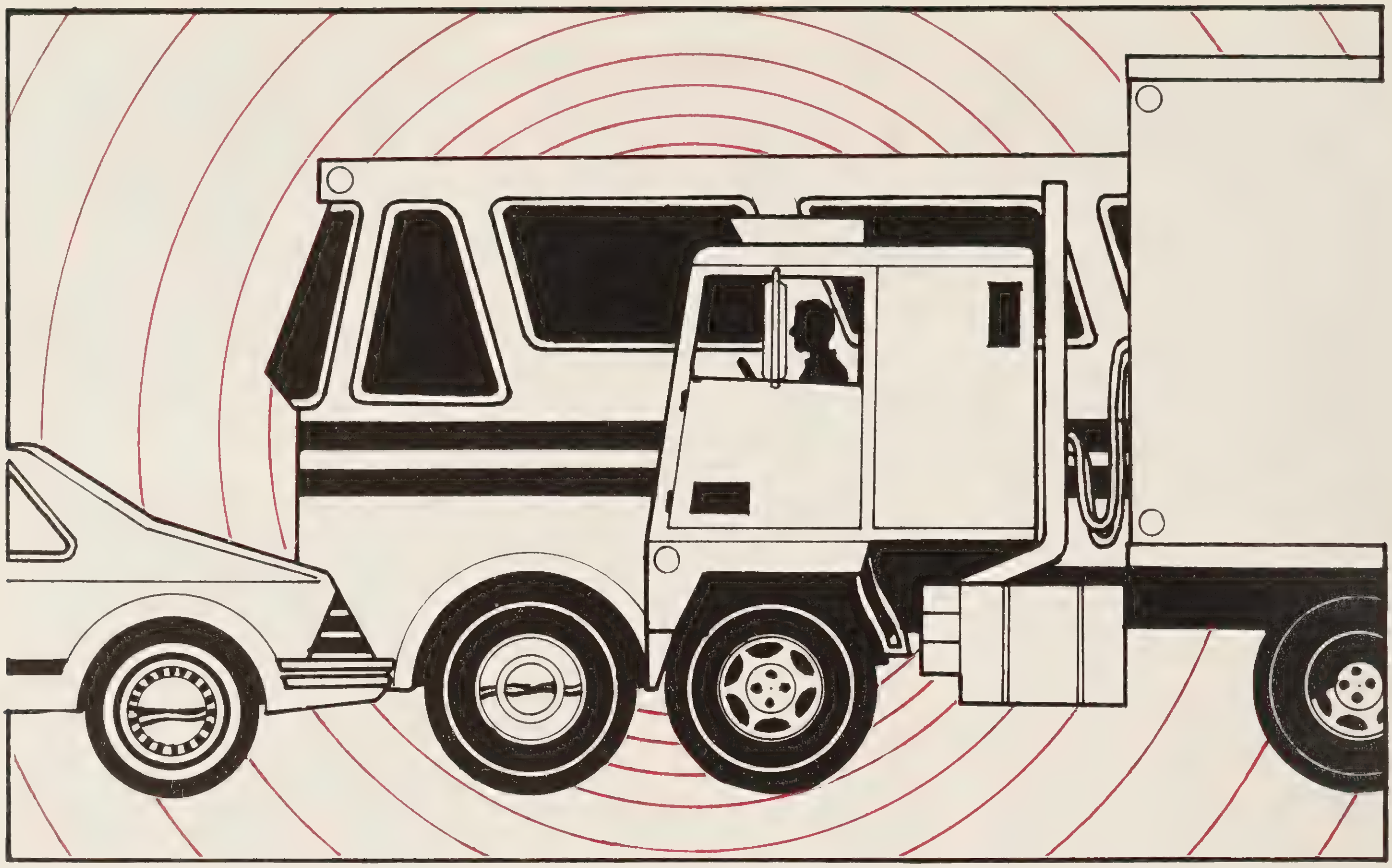

Evaluation of Absorptive Sound Barrier Samples in Freeze/Thaw Environments

by Susan N. Lane

Introduction

While sound barriers frequently line our Nation's major urban thoroughfares, absorptive sound barriers are a relatively new development. Created by a single manufacturer, absorptive sound barriers consist of porous concrete and are designed to absorb unwanted noise rather than deflect it. To determine the resistance of absorptive sound barriers to repeated cycles of freezing and thawing, the Federal Highway Administration (FHWA), in conjunction with the Maryland Department of Transportation State Highway Administration, conducted the experiment described below. The experimentation was intended to help determine the acceptability of the sound barrier samples; it was not intended to provide a quantitative measure of the service life of a particular product.

The Test Specimens

Testing was performed on two absorptive sound barrier samples, each 2 ft by 3 ft (0.6 m by 0.9 m). The 4-in (101.6 mm) thick samples consisted of 2-in thick (50.8 mm) porous concrete on one side of the panel and 2-in thick (50.8 mm) normal concrete on the other. Embedded only in the surface of the porous concrete were 1-in (25.4 mm) smooth aggregate pieces. The two concretes differed in such properties as strength, mix proportions, and density. However, given the proprietary nature of this information, the values of these properties were not released to the FHWA.

Metal carts were used to support the panels and transport them between the freezing and thawing chambers. These carts did not restrict air flow to the normal concrete sides (back sides) of the panels. The specimens were weighed and their surface appearance and condition evaluated at various points during the test.

Testing

The testing conformed to procedures described in the "Interim Method of Test for Resistance of Porous Concrete to Freezing and Thawing" which was developed internally by the FHWA.[1] The freezing and thawing apparatus consisted of chambers where the specimens were subjected to specified reproducible freezing and thawing cycles. Freezing occurred in a walk-in freezer set at 0 °F (-18 °C) where the specimens were exposed to air only. Thawing took place in a moist room set at approximately 68 °F (20 °C); where a fog spray was injected continuously into the room. Thermocouples were used to measure temperatures at the specimens' centers to an accuracy of 2 °F (1.1 °C). Panels were weighed on a moveable platform scale.

Both specimens were placed in the moist room on November 20, 1987, and were kept there for a minimum of 48 hours before the start of the test. Free water was allowed to drain from the specimens for 15 minutes after their removal from this room, and the initial (saturated) weights of the samples were recorded. The specimens were then placed in the freezer.

The samples were exposed to regular cycles of freezing and thawing. Thawing took place for 4 to 6 hours during the day; samples were stored in the freezer each night. During the testing, the specimens were situated randomly in both the freezer and the moist room so as to negate any location-specific effects.

Results

The initial saturated weights of specimens No. 1 and No. 2 with their carts were 278.8 lb (126.5 kg) and 253.0 lb (114.8 kg) respectively. The condition of both the porous and normal concrete was very good for both panels (see figure 1).

Figure 1.—Specimen No. 1 (left) and specimen No. 2 (right) at the onset of the test.

After 50 cycles and then again after 95 cycles, the samples were weighed and their conditions evaluated. No significant changes were noted in either samples' weight or condition. After 97 cycles, however, specimen No. 1 exhibited some weathering along the base of the porous concrete surface.

The samples were weighed and evaluated again after 158 cycles (July 22, 1988). Specimen No. 1 had lost approximately 9 lb (4.1 kg) and specimen No. 2 had lost approximately 4 lb (1.8 kg). The condition of both specimens had deteriorated: almost one-third of the aggregate and surrounding porous concrete had flaked off specimen No. 1, and approximately one-quarter had flaked off specimen No. 2. When the samples were thawed and still moist, the mortar of the porous concrete had the consistency of wet packed sand. Porous concrete should remain hard even when moist.

[1] This report was patterned after American Society for Testing and Materials (ASTM) Standard C666–84 and American Association of State Highway and Transportation Officials (AASHTO) Standard T161–86: "Standard Method of Test for Resistance of Concrete to Rapid Freezing and Thawing."

On the other hand, the normal concrete underlying the porous concrete and at the back of the panels was hard and still in very good condition.

Testing ended on September 26, 1988, after 200 cycles had been completed. The final weight of specimen No. 1 was 264 lb (119.7 kg)—a loss of approximately 15 lb (6.8 kg) since the beginning of the test. Specimen No. 2 weighed 241 lb (109.3 kg)—a 12 lb (5.4 kg) loss. The porous concrete surface of the specimens was severely deteriorated, with both losing approximately 60 percent of this surface (see figure 2). The normal concrete showed no signs of deterioration.

Figure 2.—Specimen No. 1 (left) and specimen No. 2 (right) after 200 cycles at the conclusion of the test.

Conclusion

The resistance of the porous concrete specimens to freeze/thaw conditions was poor and resulted in considerable loss of section. Therefore, these porous concrete samples were determined to be unsuitable as absorptive sound barriers in situations where they will be subjected to repeated freeze/thaw cycles.

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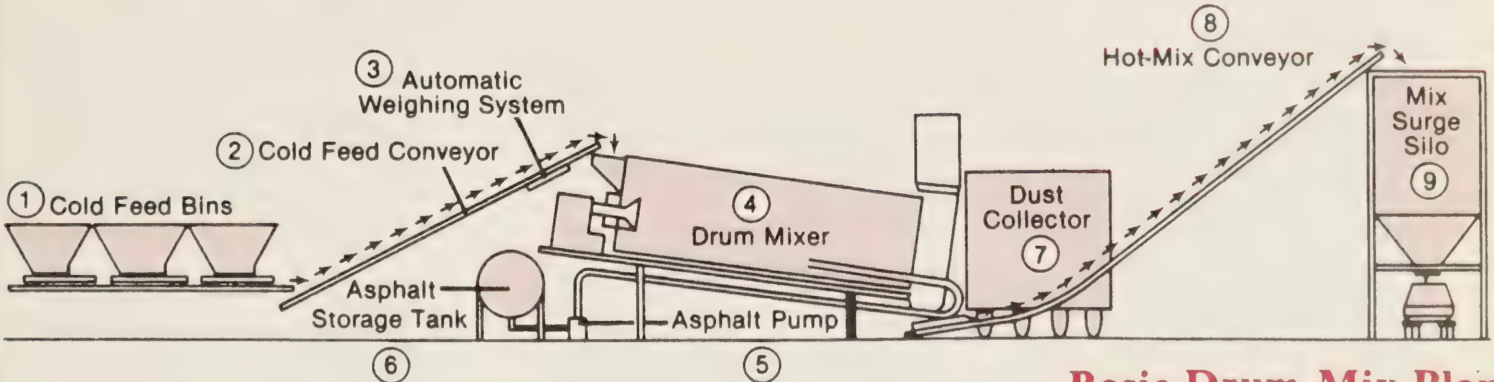
Changes Occurring in Asphalts During Drum-Dryer and Batch Mixing Operations

by Brian H. Chollar, Joseph A. Zenewitz, John G. Boone, Kimberly T. Tran, and David T. Anderson



Basic Drum-Mix Plant

Introduction

Asphalt-aggregate mixtures for pavements have been produced for many years using conventional batch (pug-mill) mixing equipment. In a batch plant process, heated, dried aggregate is mixed with heated asphalt in batches to obtain an asphalt concrete mix used for paving highways. One of the most important steps in this mixing procedure is predrying and heating the aggregate to between 250 °F and 350 °F (121 °C and 177 °C) before combining it with asphalt. (*1*)[1]

In the last 20 years, a drum-dryer mixing technology has been developed for obtaining pavement mixtures. In the drum-dryer process, a drained but undried aggregate is continuously fed into the rotating drum mixer, flame-heated from 250 °F to 300 °F (121 °C to 149 °C), and then mixed with a continuous stream of liquid asphalt to produce a mix that continuously exists at the mixer's discharge end. (*2*) The procedure's chief advantage is that, as a continuous process, it generates asphalt-aggregate mixtures much faster and more cheaply than do conventional batch mixing methods. Furthermore, aggregates do not have to be predried, but only drained, before they enter the mixer. Drum-dryer mixers are now used extensively to produce mixtures for constructing asphaltic concrete pavements.

Problem

In recent years, the paving industry has produced more and more asphaltic concrete mixtures using drum-dryer mixing procedures. Paving personnel have reported that mixtures produced by the drum-dryer procedure appear to have different physical properties than those produced by conventional batch mixing methods. (*3,4*) Concern has been voiced in the highway community that certain asphalts can be "steam-distilled" during hot-mix production in drum mixers. (*5*)

Steam distillation—the distillation of an organic compound in the presence of steam—takes place when the sum of the vapor pressures of the compound and water exceeds the pressure in the distillation apparatus (in the case of a drum mixer, normally one atmosphere); the compound can then distill at a lower temperature than its normal boiling point. (*6*)

Allegedly, drum-dryer mixers provide an environment in which "light ends," or low boiling materials, are stripped from the asphalt by a steam distillation process, leading to an immediate problem of possible baghouse fires and a long-term problem of poor pavement performance because of unanticipated asphalt changes during the mixing process. (*5*)

Fuel oil is obtained from the incomplete combustion of fuel when the aggregate is flame-heated. It is hypothesized that mixing this fuel oil with aggregate and asphalt causes these problems. (*7*) More likely, the asphalt's lowest boiling point components are lost in the process. The major difference in the behavior of an asphalt run through a drum mixer as opposed to a batch is that little oxidation of the asphalt would be expected in the drum mixer. More oxidation would be expected in batch operations. A laboratory test, thin film oven (TFO), simulates these batch operation changes to asphalt. (*8*)

[1] Italic numbers in parentheses identify references on page 56.

The Florida Department of Transportation investigated the steam distillation hypothesis. (*9*) It constructed pavements using one aggregate and two asphalts, either steam distilled for 36 hours or not, mixed in either a drum-dryer mixer or in a batch mixer. After 3 years, all pavements are performing well with no difference in pavement performance.

Approach

The Federal Highway Administration (FHWA), Office of Engineering and Highway Operations Research and Development, recently completed a study to identify the changes in asphalt as it is mixed with aggregate during drum-dryer and batch mixing operations. (*10*) During the summer of 1985, 104 loose mixes were collected from drum-dryer mix operations used for paving projects throughout the country. Using these samples, two distinct approaches were applied:

1. A variety of laboratory conditioning (aging) procedures, including steam distillation, were run on virgin asphalts. These residues and their paired asphalts recovered from drum-dryer mixtures were characterized. By comparing the properties of each recovered asphalt with its laboratory-conditioned partner, conclusions could be drawn concerning the fidelity of any given laboratory procedure to the conditions occurring in drum-dryer mixers.

2. Georgia sent 24 mixes and corresponding virgin asphalts as part of this study; 11 from batch mixing procedures and 13 from drum-dryer operations. Some of these 24 virgin asphalts could be physically and chemically the same. The ones judged the same could have been used in two different operations. If identical asphalts used in the two operations could be identified and the recovered residues from the corresponding operations characterized, comparison of these characteristics of the recovered asphalts would enable any differences between the two processes to be identified.

Experimental

To make the study manageable, 27 mixes and their corresponding virgin asphalts (various grades) were arbitrarily selected from various States. The asphalts were extracted and recovered from their mixes using a standard Abson Method, and the recovered (REC) and virgin asphalts (VIR) were characterized. (*11*) The 24 Georgia loose mixes were also extracted and the residues were recovered and characterized. The corresponding virgin asphalts used to produce these mixes were also characterized.

Conditioning procedures

The following laboratory conditioning techniques were conducted using each of the 27 virgin asphalts. The resulting residues from each conditioning procedure were characterized.

- *TFO Exposure*. (*12*) This standard test involves exposing a thin film of asphalt to air at 325 °F (163 °C) for 5 hours. The film of asphalt is then collected and characterized. No evaporated materials are collected. This test stimulates the effects of conventional batch-mix procedures as shown by the changes in asphalt characteristics. (*8*)

- *Rolling Thin Film Oven (RTFO) Exposure*. (*13*) In this form of the standard TFO exposure, the asphalts are exposed at 325 °F (163 °C) to air streams in rolling bottles, coating the bottles on all inner sides with films of asphalt. RTFO differs from the TFO exposure in its use of a smaller sample size spread over a larger area in a continuous rolling manner, thus allowing for a more efficient oxidation of the test asphalt in less time. The residue asphalt is then collected and characterized. No evaporated material is collected.

- *Small Steam Distillation (SSD)*. (*14*) This modified American Society for Testing and Materials (ASTM) procedure using 2.65 oz (75 g) of asphalt simulates what many believe to be the actual drum-dryer operation process. (*5*) Steam is bubbled through hot asphalt and removes volatile asphalt components (water-distillable light ends) from the resulting residue. The residue asphalt is then characterized. This procedure was conducted with duplicate samples.

- *Forced Air Distillation (FAD)*. (*10*) A laboratory distillation was developed in which an air stream was forced over an asphalt film heated to 662 °F (350 °C) in a closed system, and any evaporated asphaltic materials are trapped and collected. The asphalt residue is then characterized. This procedure is designed to simulate the TFO procedure and also catch any volatile materials generated. (*12*) The FAD was conducted on duplicate samples.

- *Revolving Forced Air Distillation (RFAD)*. (*10*) A laboratory distillation of asphalt is set up much like the FAD procedure with an air stream but using asphalt films in a revolving container in a closed system at 325 °F (163 °C). Evaporated components are also collected. The asphalt residue was characterized. This procedure was designed to simulate RTFO procedure with trapping effluent and was conducted on duplicate samples. (*13*)

Analytical procedures

Various analytical laboratory test procedures were used to ascertain any like attributes (or lack thereof) in the laboratory comparisons of asphalts and asphaltic residues. Comparisons were made of physical properties (penetration and viscosity), thermal properties (differential thermal analysis), functional group composition (infrared analysis), and molecular size distribution (gel permeation chromatography). The resulting data permitted a differentiation among the residues from various exposures and a characterization of the changes occurring both physically and chemically in the asphalts during conditioning. The data also were used to identify the identical Georgia virgin asphalts and the differences between recovered asphalts from batch and drum-dryer mixtures of like virgin asphalts.

- *Penetrations (Pen).* Penetrations of virgin asphalts, asphalts recovered from mixes, and residues from various laboratory conditioning experiments were obtained at 85, 77, 60, and 50 °F (29, 25, 16, and 10 °C) following the procedures described in the American Association of State Highway and Transportation Officials' (AASHTO's) Standard Specification T49. (*15*) All penetrations at various temperatures used the time and weight specified for the penetration at 77 °F (25 °C).

- *Viscosities (Vis).* The procedures in AASHTO Standard Specification T201 and T202 were used to conduct the kinematic viscosities at 275 °F (135 °C) and the absolute viscosities at 140 °F (60 °C) of virgin asphalts, asphalts recovered from mixes, and residues from various laboratory conditioning experiments. (*15*)

- *Differential Thermal Analysis (DTA).* Differential thermal analyses were conducted using a Perkin-Elmer System 4 Controller and a DTA 1700 Differential Thermal Analyzer. In this procedure, asphalts are heated in air and the energy of reaction or structure change measured. Approximately 1.18 X 10^{-3} oz (3 mg) of sample was used; samples were prepared and run according to the manufacturers' recommended procedures. Scans were made ranging from 212 °F to 1,112 °F (100 °C to 600 °C) at a heating rate of 9 °F/min (5 °C/min). Figure 1 shows typical thermograms. The data were derived from determining a ratio of two areas of the thermogram produced by dropping a perpendicular from the area of lowest exothermic energy between 572 °F to 752 °F (300 °C to 400 °C), calculating the areas of the resulting peaks 1 and 2, and taking the ratio of these areas (P1/P2). The temperature of the maximum of peak 2 (Tpk2) was read directly from each thermogram. Tpk2 was used because it showed appreciable variation among asphalts.

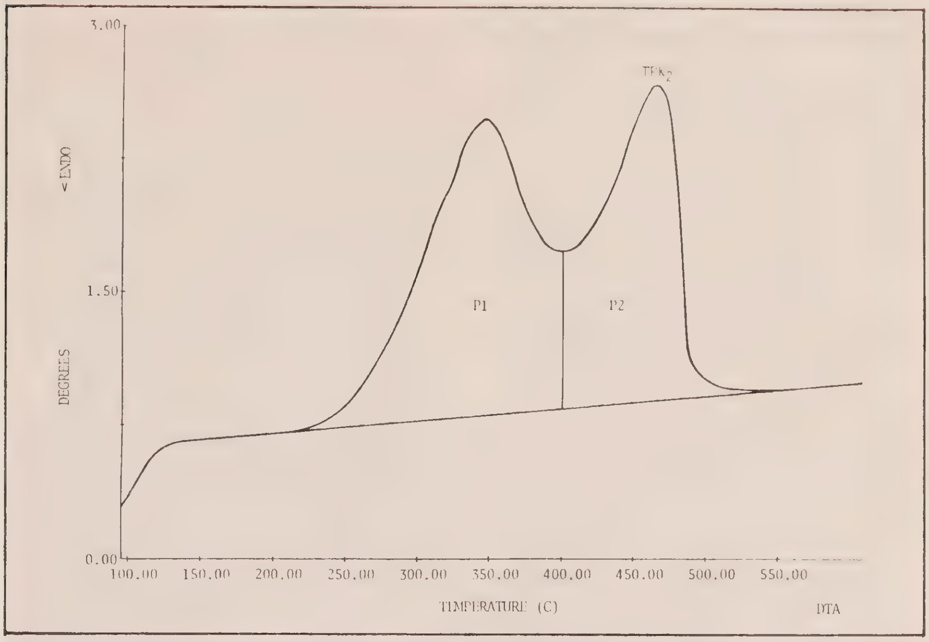


Figure 1.—Differential thermogram of an asphalt.

- *Infrared Spectroscopy.*

(a) Sample Preparation and Spectra Scan. All organic materials absorb infrared (heat) radiation at various energies—i.e., in units of cm^{-1}, according to their molecular structure, in particular, their functional group composition. In this procedure, infrared radiation was directed through asphaltic films. Absorbed radiation was measured by a detector and infrared spectra produced. Figure 2 shows a plot of infrared radiation absorbed versus energy. These spectra were obtained using a Nicolet 390 Fourier Transform Infrared (FTIR) Spectrometer. Asphalt was applied as a film to a potassium bromide (KB_r) plate with a spatula containing the hot asphaltic material. Sample scans were then obtained and

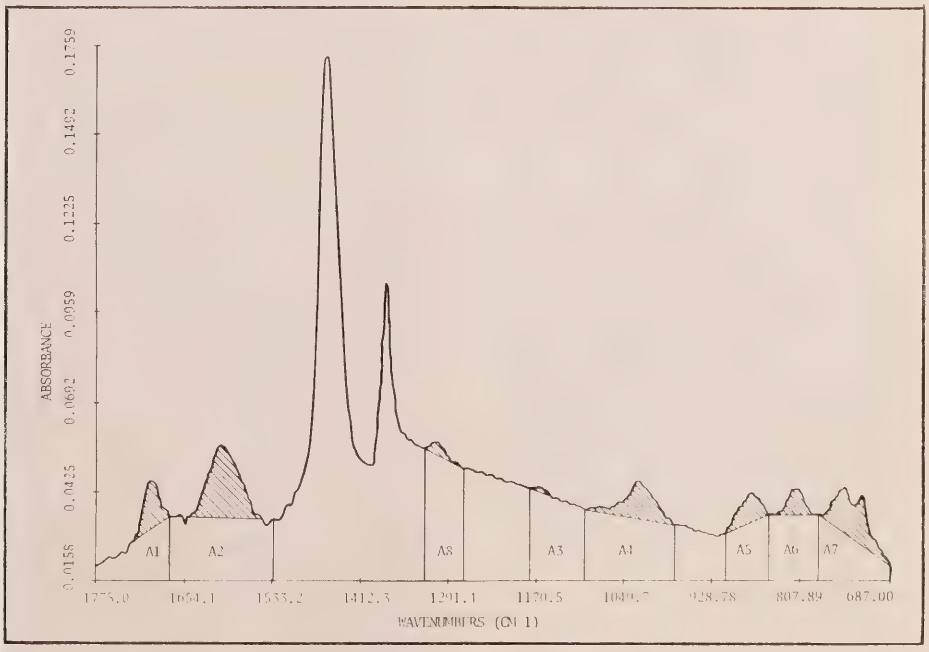


Figure 2.—Infrared spectrum of an asphalt.

the asphalt film thickness adjusted so the peak at 2,926.6 cm^{-1} fell between 10 and 20 percent transmission (0.7 to 1.0 absorbance unit). Ten scans of the sample were then taken and averaged.

(b) Interpretation of Infrared Spectra. Each infrared spectrum was analyzed in terms of the relative areas under peaks in different energy regions of the spectrum. Peak areas are roughly proportional to concentration for a given chemical molarity. Most differences in peak area values of radiation absorption between the virgin and recovered or laboratory-conditioned asphalts were found in the following eight spectral regions:

Area	Region, cm^{-1}	Assignments (*16,17*)
1	1,775 to 1,670	C=O (Carbonyl Stretch)
2	1,670 to 1,532	Unsaturated C=O, C=C (Olefinic Stretch)
3	1,180 to 1,113	Secondary & Tertiary C-O, S=O
4	1,113 to 983	Primary C-O, S=O
5	917 to 843	Polysubstituted Aromatic
6	843 to 785	Aromatic
7	785 to 687	Monosubstituted Aromatic C-H
8	1,325 to 1,281	Aromatic amine C-N or oxidized Nitrogen N-O

A computer program was prepared using procedures developed by David Stokes, Delaware Department of Transportation. This program integrates peaks in each of the above regions for each spectrum and obtains a ratio of the resulting area of each of the above regions over the total area of those eight regions. (*18*)

• *High-Pressure Gel Permeation Chromatography (HP-GPC)*. A high-pressure gel permeation chromatograph (Waters Associates) with three Ultrastyragel columns (Waters 1,000 °A [100 nm], 500 °A [50 nm], and 100 °A [10 nm]) connected in series and an ultraviolet (UV) absorption detector (Schoeffel 700) were used in this study. The data were calculated and reported as percent large molecular size (LMS), medium molecular size (MMS), and small molecular size (SMS) particles in each asphalt. (*19*)

Results

Comparisons of laboratory exposure residues with extracted drum-dryer mix residues

For valid comparisons of the effects of laboratory aging versus drum-dryer mixing on asphalt, the analytical data were manipulated to put the comparisons on a common basis. For example, different asphalts have different initial (virgin) penetrations and viscosities. Upon exposure to a given conditioning procedure, different asphalts undergo changes in penetration or viscosity. To compare these changes, the penetration of the recovered asphalt (REC) is divided by the penetration of the virgin (VIR) asphalt. If there is no change in an asphalt upon conditioning, REC/VIR = 1. If the asphalt hardens upon conditioning, as is typical, the penetration comparison is REC/VIR < 1 and the viscosity comparison, REC/VIR > 1. This ratio treatment was used for all analytical and derived parameters and for all types of conditioning used. Table 1 reports the average value of these ratios (with outliers omitted) and their standard deviations (SD).

Both the ratio of the two DTA peak areas (P1/P2) and the maximum temperature of the second peak (Tpk2) have values close to 1. Thus both of these DTA parameters show negligible change in the asphalts regardless of whether they are recovered from a drum-dryer mix or have undergone any of the five laboratory aging procedures. Similarly, the viscosity temperature susceptibility (VTS) ratios show virtually no change from unity. (*20*)

To decide whether steam distillation is occurring in drum-dryer mixing, the ratios for the five laboratory aging procedures for each of the 27 asphalts were compared with the ratio for the asphalt recovered from the drum-dryer mixture (REC/VIR). For penetration at 77 °F (25 °C), viscosities at 140 °F (60 °C) and 275 °F (135 °C), and penetration viscosity number (PVN_{140}), the ratio for the small steam distillation (SSD/VIR) deviates more from the ratio REC/VIR than do the ratios for any of the other four laboratory aging procedures (TFO, RTFO, FAD, and RFAD). (*21*) The HP-GPC data are not as clear cut. The large molecular size parameter for SSD/VIR is unlike that for the drum-dryer mix (REC/VIR) and three out of the four other laboratory aging techniques. Only FAD/VIR has a value near that of SSD/VIR. The small molecular size parameter is ambiguous, giving similar ratios for

Table 1.—Physical, thermal, and molecular size parameter ratios

Averages (Avg) and standard deviations (SD) of asphalts from drum-dryer mixes and laboratory-conditioned asphalts were compared with the virgin asphalts

Parameters		REC/VIR	TFO/VIR	RTFO/VIR	FAD/VIR	RFAD/VIR	SSD/VIR
Pen 77 °F	Avg	0.51	0.60	0.48	0.81	0.52	0.85
	SD	0.12	0.05	0.06	0.41	0.06	0.09
Vis 140 °F	Avg	4.64	2.61	3.45	4.10	3.24	1.41
	SD	2.49	0.57	0.98	6.26	1.60	0.24
Vis 275 °F	Avg	1.84	1.51	1.57	1.66	1.55	1.11
	SD	0.28	0.13	0.13	1.32	0.19	0.08
VTS	Avg	1.02	1.01	1.03	1.02	1.02	1.01
	SD	0.04	0.03	0.03	0.08	0.04	0.01
PVN_{140}	Avg	0.12	0.61	0.79	0.46	0.83	0.85
	SD	1.09	0.54	0.62	1.55	0.87	0.41
P1/P2	Avg	1.00	1.12	1.03	1.06	1.04	1.10
	SD	0.23	0.17	0.24	0.13	0.17	0.14
Tpk2	Avg	1.00	1.00	0.96	1.00	0.99	1.00
	SD	0.02	0.01	0.19	0.01	0.01	0.01
LMS	Avg	1.37	1.23	1.25	0.95	1.23	1.02
	SD	0.21	0.17	0.15	0.14	0.17	0.11
SMS	Avg	0.86	0.92	0.93	1.02	0.92	0.99
	SD	0.05	0.05	0.09	0.08	0.05	0.06

SI Conversions:
77 °F = 25 °C; 140 °F = 60 °C; 275 °F = 135 °C

all laboratory aging procedures; these are slightly higher than that of REC/VIR.

Laboratory treatment SSD is a steam distillation of the virgin asphalts according to ASTM D–255. (*14*) Its residues appear to be more unlike the asphalts recovered from drum-dryer mixtures than any of the other four laboratory treatments. This comparison negates claims of a steam distillation of light ends adversely affecting the quality of drum-dryer mixtures. (*5*)

In table 2, the infrared (IR) spectroscopy parameters are handled by comparing the infrared area ratios for the drum-dryer mix recovered asphalt, or laboratory-aged asphalt, to that for the virgin asphalt. The IR data are thus handled like the data recorded in table 1. Steam distillation (SSD/VIR) is different from the asphalt recovered from the mix (REC/VIR) and all the other laboratory aging procedures for four of the IR peaks: peaks 1, 4, 7, and 8. For the other peaks, SSD/VIR is different from REC/VIR, but not different from the ratios of at least some of the other laboratory aging procedures.

Although generally convincing that the effects of drum-dryer mixing on asphalt are less like steam distillation than any of the other laboratory aging techniques considered, the above procedures are not statistically based. Table 3 shows the results of the Student paired t-test, comparing the ratios listed in tables 1 and 2 of asphalts extracted from drum-dryer mixes to residues of like virgin asphalts aged according to the various laboratory procedures. (*22*) For any given parameter (penetration) the null hypothesis is that the mean for an asphalt recovered from a mix is the same as that for an asphalt subjected to each of the laboratory conditioning procedures. If the value of Student's t exceeds the critical value which is determined by the number of degrees of freedom (essentially the amount of data) at the confidence level sought, then the asphalt recovered from the mix is different from an identical asphalt subject to the particular laboratory conditioning procedure.

Table 3.—Student's paired t-test of various parameters for recovered asphalts versus laboratory residues++ (*22*)

Parameters	TFO/VIR	RFO/VIR	FAD/VIR	RFAD/VIR	SSD/VIR
Pen 77	-3.600**	1.161 NS	-3.555**	-0.557 NS	-10.026***
Vis 140	4.539***	2.331*	0.425 NS	2.046 NS	6.267***
Vis 275	5.588***	4.288***	0.723 NS	3.148**	10.569***
VTS	1.651 NS	-2.318**	-0.031 NS	0.258 NS	3.557**
PVN 140	-3.375**	-4.835***	-0.933 NS	-1.845 NS	3.356**
P1/P2	-2.763**	-0.570 NS	-1.472 NS	0.149 NS	-2.863**
Tpk2	-1.129 NS	1.068 NS	-1.986 NS	0.054 NS	-1.269 NS
LMS	4.758***	4.047***	9.193***	2.633*	9.478***
SMS	-5.640***	-5.554***	-9.160***	-3.317**	-9.297***
A1	-0.914 NS	-1.458 NS	-1.326 NS	-1.128 NS	-1.313 NS
A2	-5.909***	-5.890***	-10.242***	-5.942***	-5.367***
A3	-1.327 NS	-2.509*	-1.818 NS	-0.467 NS	-1.580 NS
A4	4.027***	5.548***	5.446***	4.287***	5.465***
A5	-6.340***	-4.805***	-8.961***	-6.944***	-9.631***
A6	-7.890***	-7.767***	-11.414***	-7.607***	-11.055***
A7	-4.071***	0.235 NS	-4.935***	-3.795**	-8.800***
A8	-5.633***	-7.930***	-4.076***	-5.085***	-12.172***

NS = Not significant.
* = Significant at 95% probability level.
** = Significant at 99% probability level.
*** = Significant at 99.9% probability level.
++ = The number of samples used to calculate t for the various ratio comparisons varied from 13 to 27. The degrees of freedom used for judging the significance of t was selected based on the appropriate sample number for each ratio comparison.

Table 2.—Infrared area ratios for eight areas

Averages (Avg) and standard deviations (SD) for asphalts from drum-dryer mixes and laboratory-conditioned asphalts were compared with the virgin asphalts

IR Area No.		REC/VIR	TFO/VIR	RTFO/VIR	FAD/VIR	RFAD/VIR	SSD/VIR
1	Avg	-1.06	0.68	0.56	-0.27	0.42	1.35
(C=O)	SD	5.78	2.68	0.94	3.38	2.72	3.31
2	Avg	0.89	1.00	1.10	1.08	1.06	1.06
(Unsat C=O)	SD	0.07	0.09	0.17	0.09	0.13	0.15
3	Avg	-0.19	0.87	1.16	1.33	0.19	0.80
(Tert. C-O)	SD	2.20	2.72	1.98	2.54	2.12	2.34
4	Avg	2.24	1.64	1.48	0.91	1.47	0.80
(Prim. C-O)	SD	1.37	1.27	0.87	0.66	1.38	0.54
5	Avg	0.81	0.97	1.01	1.02	1.03	1.05
(Polysub Ar)	SD	0.10	0.11	0.16	0.11	0.13	0.13
6	Avg	0.76	0.95	1.08	1.03	0.98	0.97
(Aromatic)	SD	0.07	0.11	0.21	0.14	0.12	0.09
7	Avg	0.81	0.96	0.76	0.93	0.94	1.02
(Monosub Ar)	SD	0.12	0.16	0.36	0.11	0.17	0.15
8	Avg	0.81	1.04	1.05	1.00	1.07	1.17
(Ar Nitrogen, C-N or N-O)	SD	0.16	0.17	0.17	0.22	0.20	0.14

The Student's t shows that 14 out of the 17 parameters are statistically different for the steam distillation (SSD/VIR) as compared to the drum-dryer mixer recovered asphalt (REC/VIR). This is a greater number of points of difference than for any of the other four laboratory aging procedures. The next most different procedure is the TFO with 13 points of difference, followed by the RTFO with 12 points of difference, then by a tie between the RFAD and the FAD with only 9 points of difference.

Comparisons of Georgia asphalts processed in drum-dryer mixers versus in batch plants

Because Georgia sent 11 mixes and corresponding virgin asphalts from batch plants in addition to the 13 from drum-dryer mixers, the opportunity existed to compare the two mixing processes. It was likely that among the 24 Georgia asphalts studied, there were instances where the same asphalt was used in both a drum-dryer mixer and in a batch plant. This could be investigated by characterizing the accompanying virgin asphalts and looking for drum-dryer mixer-batch plant pairs. Upon identifying such pairs, if any existed, the asphalt binders recovered from their associated mixes could be characterized. Any differences between asphalt processed in a drum-dryer mixer and in a batch plant could be determined.

It was assumed that asphalt pairs, if they existed, would be produced by the same manufacturer. Of the 24 Georgia asphalts, the manufacturers of 18 were known. The procedure used was to compare statistically the various characterization parameters (discussed above in the experimental section), for all possible pairs of asphalts within any one manufacturer category and for each asphalt of a known manufacturer with each asphalt of an unknown manufacturer. Tables 4 and 5 list the acceptable ranges for the various characterization parameters. Test virgin asphalt pairs were considered to be the same asphalt if 8 of 10 parameters for the pair in table 4 were within the acceptable range. There is a certain amount of arbitrariness in categorizing pairs, as each member of a pair probably was processed on different days using different processing conditions with slight variations within the crude state. Furthermore, storage, handling, and transportation for each member of a pair would probably be different.

Using this procedure, 22 asphalt pairs were identified. Five pairs were processed in a drum-dryer mixer, and nine pairs were processed in a batch mixer. Most importantly, eight pairs had one member processed in a batch mixer and the other member processed in a drum dryer. To further confirm the validity of these latter pairs, comparisons of the IR data showed that all drum-batch pairs had all eight infrared areas within the acceptable range. Note that in assigning these pairs, no asphalts of an unknown manufacturer matched against asphalts from more than one manufacturer. Also, in several cases, one batch processed asphalt is matched against more than one drum-dryer processed asphalt and vice versa.

Having assigned the identical asphalt pairs by characterizing the virgin asphalts, recovered asphalt residues from each drum-batch pair were then characterized and compared. The results of Student's paired t-tests are given in table 6. (*22*) It can be seen that only 5 out of 16 parameters, the penetration, the viscosity at 140 °F (60 °C), the HP-GPC large molecular size (LMS), and two IR peaks, are statistically different.

From the means of these five parameters, a consistent view of the statistically significant changes is that the asphalts extracted from drum-dryer mixtures are harder with a lower penetration and greater viscosity 140 °F (60 °C). They also are more "polymeric" with a larger LMS content, and possibly more oxidized with a higher carbonyl and oxidized nitrogen content than asphalt extracted from batch mixes.

Table 4.—Asphalt standard deviation (SD) and acceptable ranges of asphalt property differences for physical, thermal, and molecular size analytical methods

Parameter	SD	Acceptable Range
Pen 60	0.35 dmm[a]	1 dmm[a]
Pen 77	2 dmm[a]	3 dmm[a]
Vis 140		100 poise[b]
Vis 275		6 cst[c]
VTS		0.033[d]
PVN_{140}		0.11[d]
P1/P2	0.05[e]	0.2[f]
Tpk2	1.19 °C[e]	4.0 °C[f]
LMS	0.714%[e]	2.5%[f]
SMS	0.740%[e]	2.6%[f]

[a] Standard deviations and ranges obtained from ASTM. (*24*)
[b] This repeatability figure, based on 7% of the mean of the virgin asphalts, was used directly as the acceptable range. (*25*)
[c] This repeatability figure, based on 1.8% of the mean of the virgin asphalts, was used directly as the acceptable range. (*26*)
[d] Value obtained from Dr. David Anderson. (*27*)
[e] Standard deviations are from previous calculations in which 6 virgin asphalts were used. (*10*)
[f] The ranges were calculated using the SD's and multipliers given in ASTM proceedings. (*28*)

SI Conversions: 1 dmm = 0.1 mm; 1 poise = 0.1 Pa.s; 1 centistoke = 1.0 mm^2/s

Table 5.—Asphalt standard deviation (SD) and acceptable ranges of asphalt property differences for infrared analysis

Infrared Area	SD[a]	Acceptable Range[b]
1	0.0072	0.0222
2	0.0167	0.0513
3	0.0129	0.0397
4	0.0439	0.1353
5	0.0153	0.0470
6	0.0060	0.0185
7	0.0347	0.1069
8	0.0058	0.0180

[a] Standard deviations are from previous calculations in which 6 virgin asphalts were used. (*10*)
[b] The ranges were calculated using the SD's and multipliers given in ASTM proceedings. (*28*)

Penetration comparisons of TFO residues with drum-dryer residues

Table 7 shows the penetrations of 56 virgin asphalts. It also shows penetrations of the recovered asphalts from drum-dryer mixtures using these virgin samples, and residues from TFO conditioning of them. The average penetration of the recovered asphalt is lower than that of the TFO residues indicating that drum-dryer operations harden asphalt more than TFO conditioning does.

Table 6.—Student's paired t-test and selected means for various parameters for Georgia asphalt residues recovered from the drum-dryer versus the corresponding parameter for batch (pug-mill) residues (*22*)

Parameter	t		Mean Drum	Mean Batch
Pen 77	-3.379*		26.62 dmm	31.00 dmm
Vis 140	2.832*		19,556.0 poise	11,900.0 poise
Vis 275	0.989	NS		
VTS	-1.388	NS		
PVN_{140}	2.213	NS		
P1/P2	-0.424	NS		
Tpk2	-0.685	NS		
LMS	2.844*		27.46%	24.25%
SMS	-1.701	NS		
A1	-1.165	NS		
A2	4.981**		0.410	0.358
A3	1.188	NS		
A4	-1.900	NS		
A5	1.116	NS		
A6	1.593	NS		
A7	-2.230	NS		
A8	4.498**		0.024	0.021

NS = Not significant.
* = Significant at 95% probability level.
** = Significant at 99% probability level.
SI Conversions: 1 dmm = 0.1 mm; 1 poise = 0.1 Pa.s

Table 7.—Penetration at 77 °F (25 °C)[1] of the 56 virgin asphalts, recovered asphalts, and thin film oven residues

FHWA Code#	VIR	REC	TFO	FHWA Code#	VIR	REC	TFO
8509		38	135	8640	79	38	48
8517	93	38	56	8642	63	31	38
8519	142	70	86	8644	72	28	44
8521	96	34	53	8650	88	57	51
8523	73	24	44	8652	86	22	50
8525	67	38	41	8656	81	21	43
8527	108	38	64	8664	74	30	46
8533	73	32	45	8674	67	25	39
8535	73	45	45	8676	74	31	45
8537	109	53	65	8678	73	29	43
8543	104	41	63	8682	70	29	41
8561	175	28	99	8686	71	32	43
8570	98	51	66	8690	67	24	38
8572	97	61	55	8692	75	32	43
8576	102	32	56	8700	69	21	40
8588	114	52	61	8726	75	25	42
8590	66	58	43	8732	69	25	42
8592	72	26	48	8734	80	22	49
8596	145	44	77	8736	241	33	119
8600	90	35	56	8742	122	45	71
8612	134	45	75	8744	117	36	69
8615	117	53	64	8746	95	50	64
8619	116	40	65	8748	90	41	64
8621	128	55	71	8816	51	24	34
8626	125	66	67	8820	42	13	31
8628	90	35	55	8839	100	32	61
8633	87	39	60	8843	153	51	107
8637	91	43	59	8845	136	49	82

	VIR	REC	TFO
Average	95.7	37.7	58.2
SD	33.3	12.4	20.3

[1]All penetration values in dmm.

Granley and Olsen discuss test results of penetrations of asphalt residues from drum-dryer operations. (*23*) These tests were conducted in 1972 when drum dryers were first introduced as a means of producing asphaltic concrete for paving purposes. The authors compared penetrations of virgin asphalts with those submitted to TFO conditioning, and recovered from laboratory-simulated batch mixing procedures and drum-dryer operations. They found that the penetrations of 45 asphalts recovered from drum-dryer operations were much higher than those of the corresponding virgin asphalts submitted to TFO conditioning tests. The authors concluded that: "All penetration tests on recovered asphalt were well above the counterpart thin film oven test value(s) and also above those for simulated batch (pug-mill) mixing tests on the original asphalt." (*23*) Thus, the drum-dryer operation was not hardening asphalts as much as the TFO conditioning or batch mixing procedures were. FHWA endorsement of drum-dryer mixing procedures for producing asphaltic concretes was influenced greatly by these results.

The 1972 penetration results directly contradict the present results. When drum-dryer mixers were introduced, the mix temperatures were very low—250 °F (121 °C)—and moisture contents in the finished mix were usually very high (above 1 percent in many cases). Apparently water aided the compaction process such that it could be achieved below 250 °F (121 °C). These lower mix temperatures and higher moisture contents resulted in less premature hardening in drum mixes. (*23*) However, stripping problems occurred with these mixtures. As a result, States started to increase the mix temperature and reduce the moisture content in the finished mixture. Thus, increased aging of asphalts has occurred.

Conclusions

- Steam distillation of asphalts is not occurring in drum-dryer operations.

- The RFAD-, TFO-, and RTFO-conditioned asphalts appear to have the most properties similar to those of the recovered asphalts than those of the asphalts from steam distillation.

- The recovered asphalts from the drum-dryer mixtures—while only subtly different from the batch mixtures—were harder (lower penetration at 77 °F [25 °C] and higher viscosity at 140 °F [60 °C]), contained more polymeric content (higher LMS content), and were more oxidized (higher C=O and N-O content) than those recovered from a batch mixtures.

- Asphalts recovered from recent drum-dryer operations are harder than those recovered from drum-dryer operations 15 years ago.

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

Porshe—Preprocessor of Roadside Safety Hardware Evaluation, Publication No. FHWA–RD–89–069

by Safety Design Division

A program has been developed which can be used to prepare input data for four computer simulation programs. This program, called PORSHE (Preprocessor of Roadside Safety Hardware Evaluation), allows the user to select the computer program, the vehicle type, the barrier information, and to specify the initial impact conditions. From this, a standard input data file is created for the specified computer simulation program.

This manual consists of the users and programmers manuals for PORSHE and a description of the vehicle data base that was developed and is required for PORSHE to operate. A listing of the computer code is also provided.

This publication may only be purchased from the NTIS. (PB No. 89–187058/AS, Price code: A07.)

Fleet Experience of the Prototype Controlled Steering B-Dolly, Publication No. FHWA–RD–89–062

by Safety Design Division

The purpose of this task report is to provide an assessment of the performance of the controlled steering (CS) B-dolly throughout the field service trial program. Primary objectives of overall assessment considered fleet experiences with respect to dynamic stability, off-tracking, ease of operation, coupling, loading, backing, and life-cycle costs.

Actual experience with the CS B-dolly after 62,137 mi (100 000 km) has been very satisfactory for functional and operational considerations. An economic analysis indicates that use of the CS B-dolly represents a cost penalty within the current regulatory environment, except where operational benefits can provide a means for improved productivity and associated cost savings.

This publication may only be purchased from the NTIS. (PB No. 89–121339/AS, Price code: A04.)

Integrated Material and Structural Design Method for Flexible Pavements Vol. III: Laboratory Design Guide, Publication No. FHWA–RD–88–118

by Pavements Division

This research effort quantified relationships between structural and material design parameters and documented a laboratory test procedure for examining mix design from a structural viewpoint. Laboratory asphalt mix design guidelines are presented. The guidelines are based on the analysis of the results of laboratory static and cyclic load triaxial, indirect tensile, and flexural beam tests. The purpose of the guidelines is to allow the highway engineer and the laboratory technician to tailor the asphalt mix design procedure to optimize the structural properties of the mix. Two mix design methods are covered: Marshall mix design with minor modifications and indirect tensile test.

Analytical and statistical equations are also included to calculate the structural properties of the mix. This is the third volume in a series. The others are: Vol. I: Technical Report FHWA–RD–88–109; Vol. II: Appendixes FHWA–RD–88–110.

Limited copies of this publication are available from the RD&T Report Center. Copies may also be purchased from the NTIS. (PB No. 89–191027/AS, Price code: A03.)

Development of a Low-Cost Truck Weighing System, Publication No. FHWA–RD–89–121; Design and Operator Manual, Publication No. FHWA–RD–89–122

by Pavements Division

The report describes the work performed and results obtained from a research study conducted to develop a low-cost truck weighing system. The objective of this effort was to produce a prototype weigh-in-motion (WIM) system with a total cost of less than $5,000 and an accuracy of ± 10 percent for heavy axles. The system was intended to be portable, easily installed, and capable of providing information about speed, axle spacings, and vehicle type. The research covered sensor design, placement methods, locations in or on the pavement, effect of tire-pavement contact pressures on sensor output, and the effects of dynamic impacts, vehicle speeds, and road roughness.

The design and operator manual provides users with an overview of the system and a simple set of instructions for fabricating, installing, and collecting data. Detailed design drawings and technical specifications required for construction of the system, as well as a discussion of the theory of operation of the capacitive mat amplifier, are included in the appendix of the manual.

During extensive road tests, the system generated many erroneous outputs resulting in an unacceptably low reliability. Redesign of the data acquisition system is expected to correct this problem.

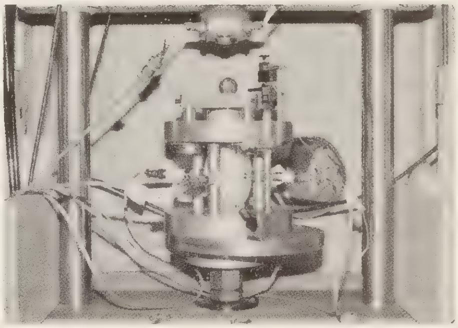
Limited copies of these publications are available from the RD&T Report Center. Copies may also be purchased from the NTIS. (PB No. 89–155816/AS, Price code: A07 for FHWA–RD–89–121 and PB No. 89–155824/AS, Price code: A05 for FHWA–RD–89–122.)

Integrated Material and Structural Design Method for Flexible Pavements Vol. I: Technical Report, Publication No. FHWA–RD–88–109

by Pavements Division

This research effort quantified relationships between structural and material design parameters and documented a laboratory test procedure for examining mix design from a structural viewpoint.

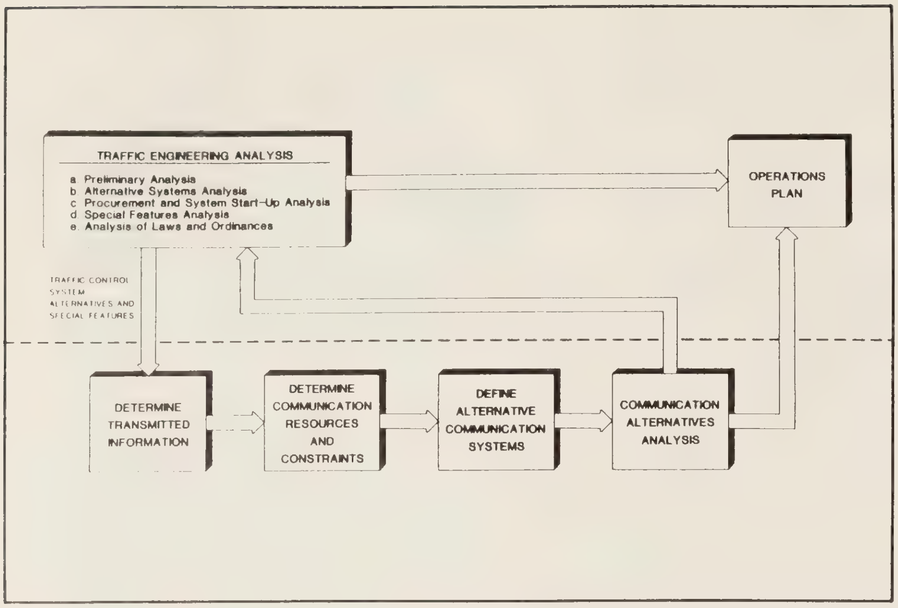
Results of static and cyclic load triaxial, indirect tensile, and flexural beam tests are presented, compared, and discussed. The test specimens were made using three types of aggregate, two gradations, three viscosity graded asphalts, and three air void levels. For all specimens, the optimum asphalt content was determined using the standard Marshall mix design procedure.



During the investigation, a new indirect tensile test apparatus was designed, made, and used. The test data indicated that the indirect tensile test can be used to establish the asphalt mix design and to determine its structural properties, permanent deformation characteristics, and fatigue life.

This is the first volume in a series. The others are: Vol. II: Appendixes FHWA–RD–88–110; Vol. III: Laboratory Design Guide FHWA–RD–88–118.

Limited copies of this publication are available from the RD&T Report Center. Copies may also be purchased from the NTIS. (PB No. 89–191019/AS, Price code: A15.)



Communications in Traffic Control Systems, Vol. I: Executive Summary, Publication No. FHWA–RD–88–011; Vol. II: Final Report, Publication No. FHWA–RD–88–012

by Traffic Systems Division

The communications element of a traffic control system has proved to have the greatest risk for the successful implementation, operation, maintenance, and expansion of a system. It is also one of the most costly elements.

Volume I summarizes the guidelines for conducting a communications trade-off analysis and presents an overview of communications media and technologies that may have applications for traffic control systems.

The purpose of Volume II is to provide general communications information and information on specific communication technologies to those persons involved in the planning, design, and implementation of computer-based traffic control systems. The report includes a brief tutorial on communications technology and terminology; guidelines for conducting a thorough communications trade-off analysis; a detailed discussion of communications media which have been widely used in traffic control systems and of how these may be successfully designed and installed; and a discussion of newly developed technologies that have had limited use in traffic control systems, but may have wider future application.

Limited copies of these publications are available from the RD&T Report Center. Copies may also be purchased from the NTIS. (PB No. 89–185813/AS, Price code: A03 for FHWA–RD–88–011 and PB No. 89–185821/AS, Price code: A07 for FHWA–RD–88–012.)

Guidelines for Successful Traffic Control Systems, Vol. I: Executive Summary, Publication No. FHWA–RD–88–013; Vol. II: Final Report, Publication No. FHWA–RD–88–014

by Traffic Systems Division

A traffic control system is generally considered successful if it meets the needs of the agency and the motorist, if it has been implemented within a reasonable time and budget, if it functions properly, and if it is utilized to its full potential over a number of years. This report presents guidelines for the planning, design, installation, operation, and maintenance of successful systems. Numerous examples are also included in the final report, along with the bibliography of basic technical references in the area of traffic control systems.

The focus of the guidelines is the system process—the procedures and practices by which system success may be achieved. The guidelines address system hardware and software, but with an orientation toward procedures and management.

The guidelines are structured to follow the logical process of a system's life from initial planning to continuing operations and maintenance, and overall management.

Limited copies of these publications are available from the RD&T Report Center. Copies may also be purchased from the NTIS. (PB No. 89–184782/AS, Price code: A03 for FHWA–RD–88–013 and PB No. 89–184790/AS, Price code: A08 for FHWA–RD–88–014.)

Safe Geometric Design for Minicars, Publication No. FHWA/RD–87/047

by Safety Design Division

Because minicars are less safe in both multivehicle and single vehicle accidents this project is designed to identify accidents (and accident-related circumstances) where the small vehicles are over represented in either crashes or crash injuries. The analysis involved accident and roadway data from Washington, Texas, and North Carolina, and computer simulation runs related to vehicle dynamics.

Results include the general finding of increased rollover propensity of these small vehicles in most accidents. The findings revealed specific problems with roadside shoulder and sideslope design, ditches in rural areas, pavement edgedrop, culverts and catch basins, median barrier faces, rural traffic islands, utility poles, and with head-on collisions on curves where the minicar is more often the striking vehicle. Potential treatments were identified for many of these issues and research plans were prepared.

Limited copies of the publication are available from the RD&T Report Center. Copies also may be purchased from the NTIS. (PB No. 89–185037/AS, Price code: A12.)

Noticeability Requirements for Delineation on Nonilluminated Highways, Publication No. FHWA–RD–88–028

by Traffic Safety Research Division

At night, on nonilluminated highways, delineation consisting of surface markings, raised pavement markers, post-mounted delineators, and warning signs is especially important in providing path guidance information to motorists. The visibility of these delineation elements depends on the extent to which headlight illumination is reflected back to the motorist by both the delineation and the roadway surface against which it is seen.

The driver's capacity to receive and use this visual information depends on the specific highway situation, which is defined by the combination of road geometry, traffic operations, glare from opposing vehicles, road surface conditions, and the visual complexity of the background. This research project investigated how those aspects of the driving environment interact and affect the need for delineation types and reflectivity to satisfy the motorist's need for path guidance information.

Limited copies of this publication are available from the RD&T Report Center. Copies also may be purchased from the NTIS. (PB No. 89–158463/AS, Price code: A06.)

Field Evaluation of Innovative Active Warning Devices for Use at Railroad Grade Crossings, Publication No. FHWA–RD–88–135

by Traffic Safety Research Division

Research was conducted to identify and evaluate innovative active warning devices with potential for improving safety at railroad-highway grade crossings. Candidate devices were identified and/or developed, and the most promising devices were evaluated in a detailed laboratory study. Three of these devices were chosen for field evaluation:

- Four-quadrant gate with skirts and flashing light signals.
- Four-quadrant flashing light signals with overhead strobes.
- Highway traffic signals with white bar strobes in all red lenses.

The report documents the methodology and results of the field evaluations, presents a summary of the research leading up to the field evaluations, and the results of cost-benefit analyses for the innovative devices and guidelines for their implementation.

All three of the innovative devices proved to be technically feasible and practical, and all three devices were accepted and understood by the driving public. Two of the systems, the four-quadrant gates with skirts and the highway traffic signals, significantly improved crossing safety at the test sites. The third system, four-quadrant flashing signals with strobes, did not produce measurable improvements in safety at the test crossing. Train predictors (and the constant warning time they provide) can have signifi-

cant positive effects on safety at crossings where flashing light signals or highway traffic signals are used.

Limited copies of this publication are available from the RD&T Report Center. Copies also may be purchased from the NTIS. (PB No. 89–163141/AS, Price code: A13.)

Time to Corrosion of Reinforcing Steel in Concrete Slabs, Vol. VI: Calcium Nitrite Admixture, Publication No. FHWA–RD–88–165

by Structures Division

In 1980, 18 large reinforced concrete slabs were fabricated using calcium nitrite admixture with black (uncoated) steel. Their performance is compared with uncoated steel in concrete without admixtures. The slabs were placed in two lifts: the bottom lift consisted of a bottom mat of reinforcing steel in chloride-free concrete, and a top lift consisted of the top mat rebars in concrete contaminated with various quantities of sodium chloride. All the electrical connections between the reinforcing mats were made exterior to the slabs so that the corrosion current flow could be measured.

After curing, the slabs were mounted above ground and exposed to the environment of the Washington, DC area. They were periodically subjected to additional chloride exposure while being monitored for the initial 1-year period.

Findings indicate that calcium nitrite can be effective in reducing the rate of corrosion for black reinforcing steel embedded in salt-contaminated concrete up to Cl^- / No_2^- ratio of 1.0.

Limited copies of this publication are available from the RD&T Report Center. Copies also may be purchased from the NTIS. (PB No. 89–162333/AS, Price code: A04.)

Effects of Spur Dikes on Bridge Backwater: Laboratory Report, Publication No. FHWA–RD–88–270

by Structures Division

This report describes a study done in the FHWA Hydraulics Lab to evaluate the effect spur dikes have on bridge backwater and other hydraulic parameters. Experimental results were compared to the analytical procedures found in the "Bridge Waterway Analysis Model" research report (FHWA/RD–86/108).

This publication may only be purchased from the NTIS. (PB No. 89–122592/AS, Price code: A04.)

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

The following are brief descriptions of selected items that have been completed recently by State and Federal highway units in cooperation with the Office of Implementation: Office of Research, Development, and Technology (RD&T), Federal Highway Administration. Some items by others are included when the items are of special interest to highway agencies. All reports are available from the National Technical Information Service (NTIS). In some cases limited copies of reports are available from the RD&T Report Center.

When ordering from the NTIS, include the PB number (or the report number) and the report title. Address requests to:

National Technical Information Service
5285 Port Royal Road
Springfield, Virginia 22161

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

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

Handbook on Planning, Design, and Maintenance of Pedestrian Facilities, Publication No. FHWA–IP–88–019

by Office of Implementation

Providing facilities that afford accessible and safe movement of pedestrians accomplishes more than increasing pedestrian safety. Urban redevelopment projects are rediscovering the importance of the pedestrian in the economy of urban areas.

Pedestrian safety and accessibility has long been a concern of Federal, State, and local agencies. The result has been a wide diversity of published reports, recommended practices, and changes in accessibility standards for the planning, design, and maintenance of pedestrian facilities. Much of this information is out of date, too technical to assist traffic engineering professionals and planners providing adequate pedestrian facilities.

This handbook consolidates the current information on pedestrian facilities. It is designed to provide up-to-date information on pedestrian facilities to serve the needs of planners and engineers. When additional information is required, the handbook serves to identify these relevant publications.

Limited copies of this publication are available from the RD&T Report Center. Copies also may be

purchased from NTIS. (PB No. 89–194849/AS, Price code: A01.)

Mailboxes May Be Hazardous to Your Health, Publication No. FHWA–TS–89–032 (Videotape)

by Office of Implementation

Many people are killed or seriously injured each year in collisions involving mailboxes. This is a tragic loss since many of these lives could be saved and serious injuries reduced by the use of safer mailbox supports.

The videotape emphasizes the mailbox safety problem and should be of interest to a wide audience including postal officials, State and local highway officials, and community groups. It highlights the severity of vehicle collisions with unsafe mailboxes and shows examples of both safe and hazardous mailbox supports.

Loan copies of the video (VHS format only) are available from the RD&T Report Center or through your State Technology Transfer Center.

Evaluation of the Pavement Data Collection Guide for Highway Safety, Publication No. FHWA–TS–89–024

by Office of Implementation

The Washington State Department of Transportation conducted a case study of 10 "high" accident locations to evaluate the "Pavement Data Collection Guide for Highway Safety" developed by the Texas Transportation Institute (TTI). Findings indicate that conditions other than a substandard roadway surface were the major contributing factors to the accidents which occurred at the study locations. These factors included: traffic volume; commercial roadside developments; limited sight distances; inadequately controlled intersections; and alcohol usage. Based on the results of the study, none of the analysis procedures developed by TTI were incorporated into Washington State's accident information system.

This publication may only be purchased from the NTIS. (PB No. 89–178370/AS, Price code: A05.)

Traffic Conflict Techniques for Safety and Operations: Observers Manual, Publication No. FHWA–IP–88–027

by Office of Implementation

This manual provides basic background information and step-by-step procedures for conducting traffic conflict surveys at signalized and unsignalized intersections. The manual was prepared as a training aid and reference source for traffic surveyors.

Based on previous research and experiences, the survey techniques described in this manual provide a standard, cost-effective method for accurately observing and recording traffic conflicts. The manual contains definitions with illustrations and examples of conflict types and instructions for field activities, including time schedules, forms, and other details. The results of traffic conflict observations are used to diagnose safety and operational problems and to evaluate the effectiveness of treatments. Observer training techniques and procedures for analyzing and interpreting the results of conflict surveys are presented in the engineer's guide (FHWA–IP–88–026).

Limited copies of this publication are available from the RD&T Report Center. Copies may also be purchased from the NTIS. (PB No. 89–184691/AS, Price code: A03.)

Developing Expert Systems, Publication No. FHWA–TS–88–022

by Office of Implementation

Expert Systems are computer programs designed to include a simulation of the reasoning and decision-making processes of human experts. This report provides a set of general guidelines for the development and distribution of highway-related Expert Systems. This expands the guidelines provided in Chapter X, Expert Systems, of the "Information Resources Management Manual." Included in this set of guidelines is information on developing, distributing, and maintaining Expert Systems.

The general development guidelines include discussions of:

- Representative set of problem types that may be solved using Expert Systems.

- Description of the major components of a typical Expert System and how these components interact in a problem solving situation.

Limited copies of this publication are available from the RD&T Report Center. Copies may also be purchased from the NTIS. (PB No. 89–178362/AS, Price code: A03.)

Ramp Metering: Signal for Success, Implementation Package/Publication No. FHWA–IP–89–15 (Videotape)

by Office of Implementation

This 17-minute video presentation, oriented to both laypersons and public officials, explains the principles and benefits of ramp metering by relating the experiences of transportation agencies who use ramp metering in Denver, Los Angeles, and Minneapolis. The video is designed to present objectively the merits of ramp metering and to encourage viewers to consider the potential for ramp metering in their own communities. In doing so, it explores the nature of congestion and addresses several key issues such as safety, efficiency, equity, and public relations.

Loan copies of the video (VHS format only) are available from the RD&T Report Center.

TRAF-NETSIM

by Office of Implementation

TRAF-NETSIM, the latest version of NETSIM, is now being distributed. TRAF-NETSIM is a microscopic simulation model that provides a detailed evaluation of proposed operational improvements on urban networks. For example, TRAF-NETSIM can evaluate the effects of converting a street to one-way operation, adding lanes or turn bays, moving the location of a bus stop, or installing a new signal.

Transportation-Related Electronic Bulletin Board Systems (BBS's)

by Office of Implementation

The use of microcomputers by transportation and traffic engineers has increased dramatically in the last few years. Because of the relatively low cost of microcomputers, it is common to find these machines in traffic engineering and public works offices. Expertise in using microcomputers has also improved. On a routine basis, traffic engineers not only use word processors, database managers, and spreadsheets but also traffic simulation and optimization models.

An often overlooked aspect of computing is communications. Microcomputers have the ability to communicate with other computers over standard telephone lines which gives users the capability to share information at incredible speed and at nominal cost.

Through the use of electronic bulletin board systems (BBS's), a form of microcomputer communications, one can obtain information from public-domain software, send and receive messages and announcements, learn about publication listings, and access other resources.

BBS's are microcomputer based information sharing systems. Physically, they are regular microcomputers running communications programs. The BBS's are literally waiting for telephone calls. When a remote call is made from another computer, the communications program answers the phone and makes files and information available. The caller can search for files, read information on the screen, print it, and, if desired, transmit (download) files to the computer over the telephone. BBS's promote the free exchange of information. The charge for using BBS's is usually the cost of the telephone call.

There are thousands of BBS's around the country. During the last couple of years, several BBS's dealing primarily with transportation-related topics have emerged. Information available from these bulletin boards includes:

- Thousands of files (programs) for transportation, public works, engineering applications, and utility programs.
- Message and electronic mail systems that allow callers to send and receive messages.
- Notices of upcoming conferences, workshops, training, and meetings.
- Listings of publications and videotapes available.
- Job vacancy announcements.
- Tips and techniques on using programs, and other information.

BBS's put all this information literally at your fingertips. Access to a microcomputer unlocks any BBS around the country. All that is needed is: a microcomputer; a modem; a communications software for the microcomputer and; a regular telephone line.

The table shown below contains telephone numbers for various transportation related BBS's around the country. Most of them operate at 1200 or 2400 baud, no parity, 8 data bits, and 1 stop bit (N,8,1). Check your communications software users manual for details on setting these parameters. An updated list of this table can be found in the FHWA Electronic Bulletin Board System (FEBBS).

For information on accessing and using a BBS, or if you are aware of other transportation related BBS's not included in this table, please call the number listed below.

Juan M. Morales, P.E.
Federal Highway Administration
Office of Implementation, HRT-20
6300 Georgetown Pike
McLean, VA 22101–2296
telephone: (703) 285–2499

Transportation Related BBS's

BBS Sponsor	*BBS Number*	*Voice Number*	*System Operator*	*Features*
FHWA Electronic Bulletin Board System (FEBBS)	(202) 366–3764	(202) 366–9022	Carl Shea	1,2,3,4,6
University of Kansas Transportation Center (PCTRANS)	(913) 864–5058	(913) 864–5655	Carl Thor	1,2,3, newsletters, catalogs
University of Florida (McTrans Center)	(305) 554–2145	(904) 392–0378	Bill Sampson	3,4, catalogs
FHWA/Texas Department of Transportation—Transporter	(409) 845–3858	(409) 845–5299	Nelda Bravo	2,3,4,6
Michigan Transportation Technology Transfer (T^2) Center	(906) 487–2148	(906) 487–2102	Derek Calomeni	1,2, more
Institute of Transportation Studies, University of California Berkeley	(415) 642–7088	(415) 642–1008	Philip McDonald	1,2,3,6
Colorado Department of Highways	(303) 757–9509	n/a	Beth Moore	1,2,3,4,5,6
Texas A&M University	(409) 845–2326	(409) 845–4369	Todd Schmidt	1,2, publication listings
NW T^2 Center and State Aid, Washington State Department of Transportation	(206) 586–1942	(206) 753–1065	Stan Sanders	1,2, more
FHWA Office of Planning	(202) 426–2961	(202) 366–4057	Howard Simkowitz	1,2, course bulletins, UTPS section, more
Highway Engineering Exchange Program (HEEPS)	(301) 333–3807	(301) 333–1693	Kathy Harryman	2,4, more
Institute of Transportation Engineers (ITE)	(703) 863–5487	(202) 554–8050	Pete Frentz	3, job openings, more
Kentucky Department of Transportation	(502) 227–9783	(502) 564–8900	John Crossfield	1,2,3,4,6
Arizona State University	(602) 965–1391	(602) 965–2744	Monsa Elaji	1,2,3,4,6
Las Vegas Computer Traffic System	(702) 386–6613	(702) 386–6611	Jim Poston	1,2,3,4,5

Legend

1 = file uploading — 3 = announcements — 5 = research abstracts

2 = file downloading — 4 = conferences — 6 = messages

Thanks to Lisa Pogue, of the American Public Works Association T^2 Clearinghouse, for her contribution to this list.

The result of the simulation is a detailed description of the traffic operations in the form of link-specific, operational measures of effectiveness (MOE's). The MOE's calculated include speed, volume, density, delay, stops, intersection spillback, queuing, turn movements, fuel consumptions, and pollutant emissions.

The simulation results can be displayed graphically. On request, TRAF-NETSIM will generate graphics files that can be read and displayed by the graphics package, GTRAF.

GTRAF allows the user to review the input and analyze the output of TRAF-NETSIM through static and animated color displays. These provide details of intersection geometrics or highlight potential problem areas in the network.

Both TRAF-NETSIM and GTRAF can be purchased from the McTrans (Tel: 904–392–0378) or PC-TRANS (Tel: 913–864–3787) software distribution centers.

New Research in Progress

The following new research studies reported by the FHWA's Office of Research, Development, and Technology are sponsored in whole or in part with Federal highway funds. For further details on a particular study, please note the kind of study at the end of each description:

- FHWA Staff and Administrative Contract research contact *Public Roads*.
- National Highway Traffic Safety Administration (NHTSA) Administrative Contract research contact NHTSA 400 7th Street SW, Washington, DC 20590.
- Highway Planning and Research (HP&R) contact the performing State highway or transportation department.
- National Cooperative Highway Research Program (NCHRP) contact the Program Director, NCHRP, Transportation Research Board, 2101 Constitution Avenue, NW, Washington, DC 20418.
- Strategic Highway Research Program (SHRP) contact the SHRP, 818 Connecticut Avenue, NW, 4th floor, Washington, DC 20006.

NCP Category A—Highway Safety

NCP Program A.1: Traffic Control for Safety

Title: Short-Term Pavement Markings in Work Zones (NCP No. 3A1E0242)
Objective: Conduct field evaluations on real-world projects with varying traffic conditions. These tests include the standard lane (10-ft [3.0 m] stripe and 30-ft [9.1 m] gap), the current short-term marking of a 4-ft (1.2 m) stripe and a 36-ft (11.0 m) gap, and a 2-ft (0.6 m) stripe and a 38-ft (11.6 m) gap. Conduct studies day and night during rainy weather on two-lane highway overlay projects in North Carolina.
Performing Organization: Scientex Corporation, Washington, DC 20006
Expected Completion Date: September 1991
Estimated Cost: $123,960 (FHWA Administrative Contract)

NCP Program A.2: Improved Driver Visibility of Roadway Environment

Title: Optimal Application and Placement of Roadside Reflective Devices for Curves on Two-Lane Rural Highways (NCP No. 4A2B0162)
Objective: Recommend to Ohio Department of Transportation a set of optimal application and placement guidelines for roadside delineation devices used on:

- Curves on two-lane rural highways with no intersections or drives.
- Curves with side road intersections or side drives.
- Curves with cross road intersections or drives on both sides.

Guidelines will be field tested and based on photometric and visual considerations.
Performing Organization: Ohio University, Athens, OH 45701

Funding Agency: Ohio Department of Transportation
Expected Completion Date: June 1992
Estimated Cost: $295,026 (HP&R)

NCP Program A.3: Highway Safety Analysis

Title: A Strategic Transportation Research Study for Highway Safety (NCP No. 3A3A4012)
Objective: Define areas within highway safety where research could produce significant results in terms of potential accident and fatality reductions. Develop a recommended priority program for all aspects of highway safety—vehicle, driver, highway, and information systems. Identify funding requirements and potential fund sources for program implementation.
Performing Organization: National Academy of Sciences, Washington, DC 20418
Expected Completion Date: September 1990
Estimated Cost: $175,000 (FHWA Administrative Contract)
$175,000 (NHTSA Administrative Contract)

NCP Program A.5: Design

Title: Roadway Widths for Low-Volume Roads (NCP No. 5A5A0282)
Objective: Develop an engineering analysis procedure for determining roadway width for construction and reconstruction of low-volume roadways. Develop "Minimum Width of Traveled Way and Shoulder" recommendations for consideration by the geometric design task force of the AASHTO Highway Subcommittee on Design for inclusion in future editions of the "Greenbook."
Performing Organization: Jack E. Leisch and Associates, Evanston, IL 60201
Expected Completion Date: October 1991
Estimated Cost: $247,799 (NCHRP)

Title: Evaluation of Performance Level Selection Criteria for Bridge Railings (NCP No. 5A5C0152)
Objective: Determine the adequacy and validity of the performance levels and the procedures for selecting them contained in the "AASHTO Guide Specification for Bridge Railings." Estimate the impact of implementing the "Guide Specification." Recommend appropriate improvements. Evaluate the feasibility of extending the multiple performance level approach to all longitudinal barriers.
Performing Organization: Texas Transportation Institute, College Station, TX 77843
Expected Completion Date: January 1991
Estimated Cost: $200,000 (NCHRP)

Title: Skid Resistance Implementation (NCP No. 4A5G0332)
Objectives:

- Determine the skid resistance and durability of various portland cement concrete (PCC) pavement textures.
- Gather and analyze data for adjustments due to seasonal variation of skid resistance.
- Develop a lab test method and specifications for aggregate prequalification for use in skid resistant surfaces.
- Analyze the life cycle performance of various surface mixes in terms of skid resistance.
- Investigate the various options for in-house calibration of pavement skid testing equipment.

Performing Organization: New Jersey Department of Transportation, Trenton, NJ 08623
Funding Agency: New Jersey Department of Transportation
Expected Completion Date: May 1992
Estimated Cost: $143,383 (HP&R)

NCP Category C—Pavements

NCP Program C.2: Evaluation of Flexible Pavements

Title: Resilient Modulus of Subgrade Soil Using Gyratory Testing Machine (NCP No. 4C2B1242)
Objective: Compare three methods for determining the resilient modulus of subgrade soils: triaxial testing; gyratory testing; and in-place testing using deflection measurements. Determine the suitability of using the gyratory testing machine for testing soils and establish guidelines for its use.
Performing Organization: University of Mississippi, University, MS 38677
Funding Agency: Mississippi State Highway Department
Expected Completion Date: September 1990
Estimated Cost: $136,398 (HP&R)

NCP Program C.4: Management Strategies

Title: Revision of AASHTO Pavement Overlay Design Procedures (NCP No. 5C4B2272)
Objective: Modify Chapter Five of Part III of the "1986 AASHTO Guide for the Design of Pavement Structures" so that pavement overlay design procedures will yield valid and acceptable designs. Tasks:

- Review and analyze overlay design procedures.
- Revise the methodology and/or design criteria.
- Test the revised procedures.

Performing Organization: Darter & Associates, Mahomet, IL 61853
Expected Completion Date: May 1990
Estimated Cost: $75,000 (NCHRP)

NCP Category D—Structures

NCP Program D.1: Design

Title: Long-Term Performance of Polyethylene Pipe Under High Fill (NCP No. 4D1D4042)
Objective: Install a 24-in (610 mm) I.D. corrugated polyethylene pipe under a 100-ft (30.5 m) embankment on a portion of I-279 north of Pittsburgh. Instrument this pipe and surrounding soil to obtain information on the pipe's performance. Continue observation of test pipe over a period of years since polyethylene has time-dependent properties and little information is available when the material is in compression. Compile results and present in a final report.
Performing Organization: University of Massachusetts, Amherst, MA 01003
Funding Agency: Pennsylvania Department of Transportation
Expected Completion Date: March 1992
Estimated Cost: $87,781 (HP&R)

Title: Implementation of Truck Weight and Bridge Behavior Monitoring for Heavy Concentrated Loads in the Toledo Area (NCP No. 4D1A1052)
Objective: Permit large heavy grain haulers from Michigan to use Ohio highways to travel to the Port of Toledo. These 154,000-lb (70 Mg) trucks are commonly called "Michigan Grain Trucks" (MGT) and could cause high stresses in bridges due to the concentrated nature of the load. Provide the Ohio Department of Transportation (ODOT) with the capability to monitor traffic year round on two routes used by the MGT's in order to determine the frequency of occurrence and the vehicle weights. Instrument four bridges so that the structural response and behavior of bridges can be measured for analysis by ODOT.
Performing Organization: Bridge Weighing Systems, Inc., Warrensville Heights, OH 44128
Funding Agency: Ohio Department of Transportation
Expected Completion Date: November 1991
Estimated Cost: $219,616 (HP&R)

Title: High-Load Multirotational Bridge Bearings (NCP No. 5D1A4082)
Objective: Develop a bearing selection guide for all types of bridge bearings and prepare specifications for High-Load Multirotational (HLMR) bearings that can be recommended to AASHTO. Pot bearings, disc bearings, and spherical bearings will be studied.

This study will develop and execute a laboratory testing program to determine rotational characteristics and lateral load capacity of HLMR bearings and sealing and lubrication requirements for pot bearings. From this, a bearing selection guide for designers and suggested specifications for use by AASHTO will be produced.
Performing Organization: University of Washington, Olympia, WA 98501
Expected Completion Date: November 1991
Estimated Cost: $250,000 (NCHRP)

Title: Computer Analysis and Design of Cable-Stayed Bridges—Phase II (NCP No. 4D1A4332)
Objective: Study the behavior of cable-stayed bridges with emphasis on segmental construction techniques. Currently, there are no cable-stayed bridges with segmental box girder decks in California. These designs may be considered as an alternative in the future to the conventional post-tensioned bridges that are supported on falsework. Investigate a variety of cable-stayed configurations including the designs of three bridges: Pasco-Kennewick, East Huntington, and Sunshine Skyway. Programs developed by Fleming at the University of Pittsburgh will be used to study the static and dynamic responses of these bridges.
Performing Organization: California Polytechnical Institute, Pomona, CA 91766
Funding Agency: California Department of Transportation
Expected Completion Date: April 1991
Estimated Cost: $144,626 (HP&R)

NCP Program D.2: Management

Title: Bridge Inspection Automation (NCP No. 4D2A1032)
Objective: Develop an automated electronic prototype system for reporting bridge inspection information.
Performing Organization: New York State Department of Transportation, Albany, NY 12232
Funding Agency: New York State Department of Transportation
Expected Completion Date: July 1991
Estimated Cost: $75,000 (HP&R)

NCP Program D.4: Corrosion Protection

Title: Monitoring of Cathodic Protection Systems (NCP No. 4D4B2152)
Objective: Study the long-term operation of existing cathodic protection (CP) systems and additional CP installations. Evaluate their effectiveness in controlling corrosion-induced concrete deterioration.
Performing Organization: Connecticut Department of Transportation, Wethersfield, CT 06109
Funding Agency: Connecticut Department of Transportation
Expected Completion Date: March 1995
Estimated Cost: $117,000 (HP&R)

NCP Category E—Materials and Operations

NCP Program E.2: Cement and Concrete

Title: Mechanical Behavior of High Performance Concretes (NCP No. 8E2D1012)
Objective: Obtain information on the mechanical properties of high performance concretes, particularly behavior in service under field environmental conditions—field curing, moisture, humidity, exposure to marine environment, and deicing agents. Develop improved engineering criteria for the mechanical properties and behavior of high performance concrete. Develop recommendations and guidelines for using these concretes in highway applications.
Performing Organization: North Carolina State University, Raleigh, NC 27695
Expected Completion Date: April 1993
Estimated Cost: $1,598,384 (SHRP)

NCP Program E.4: Paints and Coatings for Highways

Title: Inservice Testing of Premixed and Plain Traffic Paints (NCP No. 4E4D0152)
Objective: Determine the performance life of two paints ("NC-No Cone" and "NC Quick Dry") currently used by the North Carolina Department of Transportation and one previously used paint ("NC-Traffic Zone")—with and without beads. Evaluate equipment costs for operating the premixed and drop-on paint systems and operational and productivity advantages and disadvantages of premixed and drop-on paint systems. Determine the life-cycle costs, including materials, when using each of the three painting systems under different roadway conditions.
Performing Organization: North Carolina Department of Transportation, Raleigh, NC 27611
Funding Agency: North Carolina Department of Transportation
Expected Completion Date: June 1991
Estimated Cost: $178,010 (HP&R)

NCP Program E.5: Highway Maintenance

Title: Improvements in Data Acquisition Technology for Maintenance Management Systems (NCP No. 5E5F1042)
Objective: Identify and evaluate latest technological means to effectively and sufficiently acquire, record, field-verify, transmit, and receive field-related data for maintenance management systems.
Performing Organization: The Urban Institute, Washington, DC 20037
Expected Completion Date: April 1990
Estimated Cost: $100,000 (NCHRP)

Title: Engineering Properties of Brittle Repair Materials (NCP No. 4E5C3682)
Objectives: Provide simple and practical methods for: testing different repair materials under biaxle stress conditions; investigating bonding properties of the repair materials and ordinary concrete; and testing the load carrying capacities of repaired pavement joints to assess the performance of different repair materials. Develop a special purpose finite element program to evaluate the suitability of material behavioral models in predicting the response of repaired rigid pavement sections and joints by simulating the observed behavior of brittle materials and the tested pavement joints.
Performing Organization: Louisiana Transportation Research Center, Baton Rouge, LA 70804
Funding Agency: Louisiana Department of Transportation and Development
Expected Completion Date: June 1992
Estimated Cost: $172,520 (HP&R)

NCP Program E.7: Environmental Design

Title: Guidelines for the Replacement of Wetland Areas (NCP No. 5E7C4502)
Objective: Develop a wetland mitigative process.
Performing Organization: URS, Cleveland, OH 44122
Expected Completion Date: June 1991
Estimated Cost: $280,560 (NCHRP)

Title: Assessment of Workers Applying Herbicide Mixtures, Toxicity, and Fate (NCP No. 4E7C0042)
Objective: Assist in assessing the impact of pesticides on highway spray applicators and the roadside environment. Assessment techniques include: acute toxicity tests on selected aquatic biota and soil microorganisms; air samples in the area of application; urine samples from applicators; and soil, water, and grass sample analysis.
Performing Organization: Tulane University, New Orleans, LA 70118
Funding Agency: Louisiana Department of Transportation and Development
Expected Completion Date: April 1992
Estimated Cost: $399,779 (HP&R)

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