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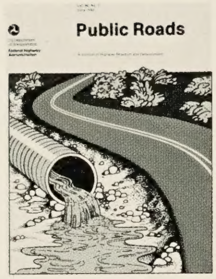

COVER:
Scour at culvert outlets is a concern of highway engineers today.

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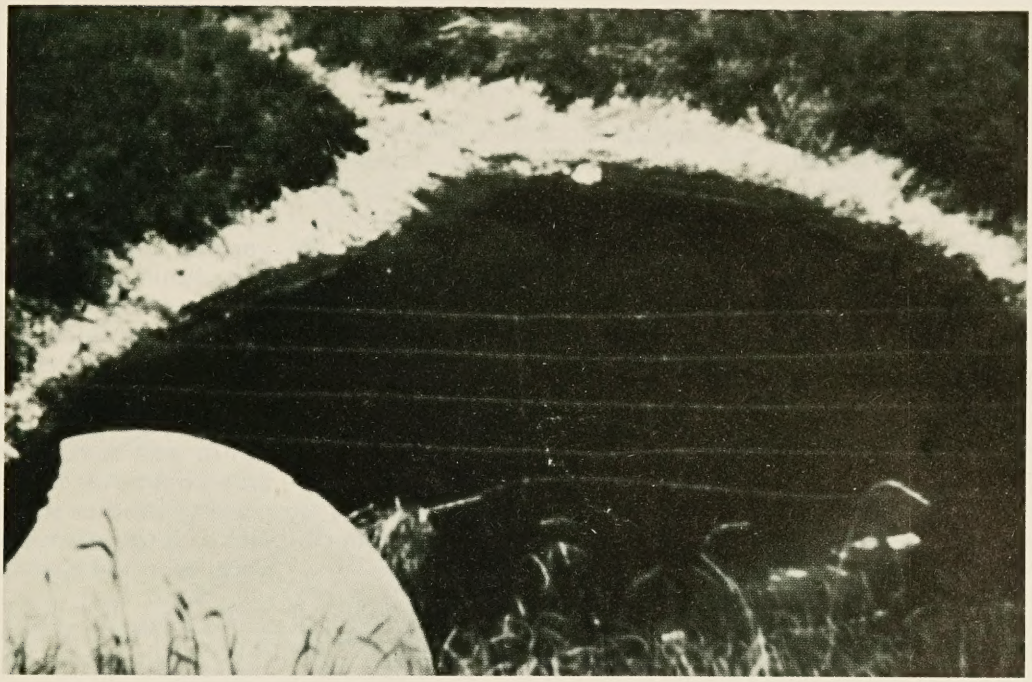
Scour at Culvert Outlets in a Sandy-Clay Material

by

Steven R. Abt, J. Sterling Jones, and James F. Ruff



Introduction

One of the major considerations in the design and construction of a highway system is strategically placed culverts of various shapes and materials to insure tributary drainage through the roadway embankment. As flow passes through the culvert and out of the culvert barrel, the resulting water jet impinges upon the material beneath the culvert outlet. The discharging water entrains and transports material particles downstream of the culvert outlet. The result of this scour process is the degradation of the roadway embankment, degradation of the area beneath and adjacent to the culvert outlet, and aggradation of the channel, land areas, or properties downstream of the outlet.

The Federal Highway Administration (FHWA) sponsored a research study in cooperation with Colorado State University to investigate the scour process at culvert outlets. Costly energy dissipators frequently are installed when *estimated* culvert outlet scour is high, and the study developed better methods to predict when dissipators are needed. Currently used procedures for estimating culvert outlet scour are based primarily on tests using a fine sand. (*1*)[1] The FHWA study was initiated to determine adjustment factors for materials that have more resistance to scour and was designed to augment a related study. (*2*) Because most material found adjacent to culvert locations are cohesive, a cohesive sandy-clay material was included in the experimental plan.

However, because so many parameters could affect scour in cohesive materials, there was no assurance that general conclusions could be drawn from tests on a single cohesive material. Nevertheless, the study did show that the inverted shear number, a parameter that can be determined from standard soils tests, has the potential for correlating scour depths not only in cohesive soils but in noncohesive soils as well. That potential, although it may require further development and verification, is encouraging because it means the scour process for cohesive soils can be defined reasonably well with a limited number of experiments. Otherwise, an extensive research program would be required to define the expected scour process in cohesive soils.

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

Testing Program

A hydraulic model study was performed at the Colorado State University research facilities to simulate field conditions of a newly placed culvert. An outdoor flume 30.5 m (100 ft) long, 6.1 m (20 ft) wide, and 2.4 m (8 ft) deep was constructed (fig. 1). The culvert outlet was centered between the flume sidewalls with the culvert invert adjacent to the bed material. Circular culverts with 254 mm (10 in), 356 mm (14 in), and 457 mm (18 in) diameters were tested in the cohesive bed.

The cohesive bed material used in the experiments was a Colorado sandy-clay with a sandy loam texture. The material was dumped into the facility, spread to a uniform depth of approximately 152 mm (6 in), and rolled with a specially designed and constructed roller (fig. 2) to insure a uniform density of 90 percent of the optimum density throughout the test bed. The material was layered in 152 mm (6 in) lifts to a depth of 1.8 m (6 ft) where the bed became adjacent to the culvert invert.

Discharges through the three culverts ranged from approximately 0.057 to 0.850 m^3 per second (2 to 30 ft^3 per second). Each test with the cohesive material was run for 1,000 minutes with data collected at intermediate times. During and after testing, each scour hole was contoured, and the influence of aggradation downstream of the scour hole was recorded (fig. 3).

Results

A series of scour hole dimensions for various flow and soil conditions was developed from the experiments. General observations recorded during the cohesive soil testing include the following:

- When the culvert flowed full, the scour holes were oval shaped. When the culvert did not flow full, scour holes tended to be circular.
- A small mound developed downstream of each scour hole. The mound extended several scour hole lengths downstream of the culvert outlet.
- The bottom of the scour hole, areas adjacent to the scour hole rim, and the mound downstream of the scour hole became armored.
- In some cases, vertical walls were observed in the scour hole. As the hole drained and dried, the walls collapsed into the bottom of the hole.
- As the pipe size and/or the discharge increased, the scour hole dimensions increased.

Traditionally, scour data have been depicted with scour hole dimensions—depth, length, width, and volume—as functions of the discharge intensity, which is a ratio of culvert discharge to the culvert diameter. Model to prototype similitude was verified by comparing test results from various culvert models. Acceptable similitude occurs when dimensionless scour hole characteristics are related to the dimensionless discharge intensity parameter as illustrated in figure 4. In other words, although this figure was developed from a small diameter model, it may be used to predict scour at the outlets of large diameter field culverts with the same soil type.

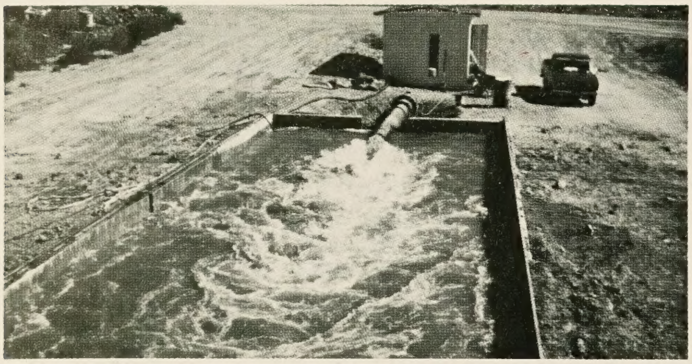


Figure 1.—Outdoor testing facility.

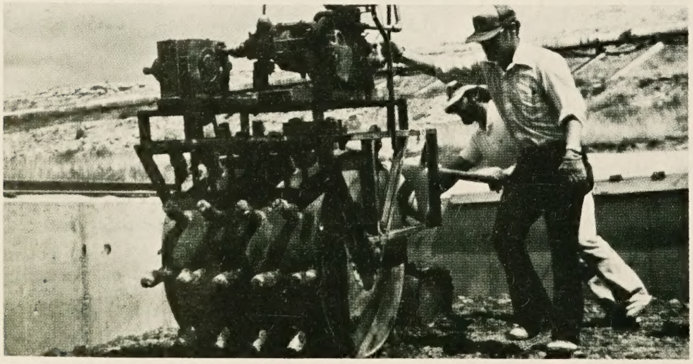


Figure 2.—Roller used to compact the sandy-clay bed material.

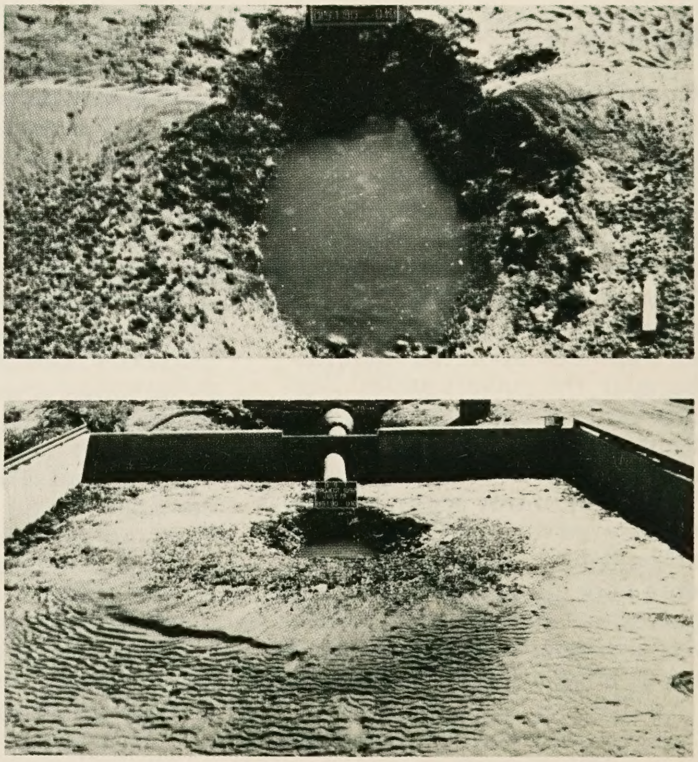


Figure 3.—Scour hole after 1,000 minutes of testing in a 254 mm (10 in) diameter pipe (top), and aggradation downstream of the scour hole (bottom).

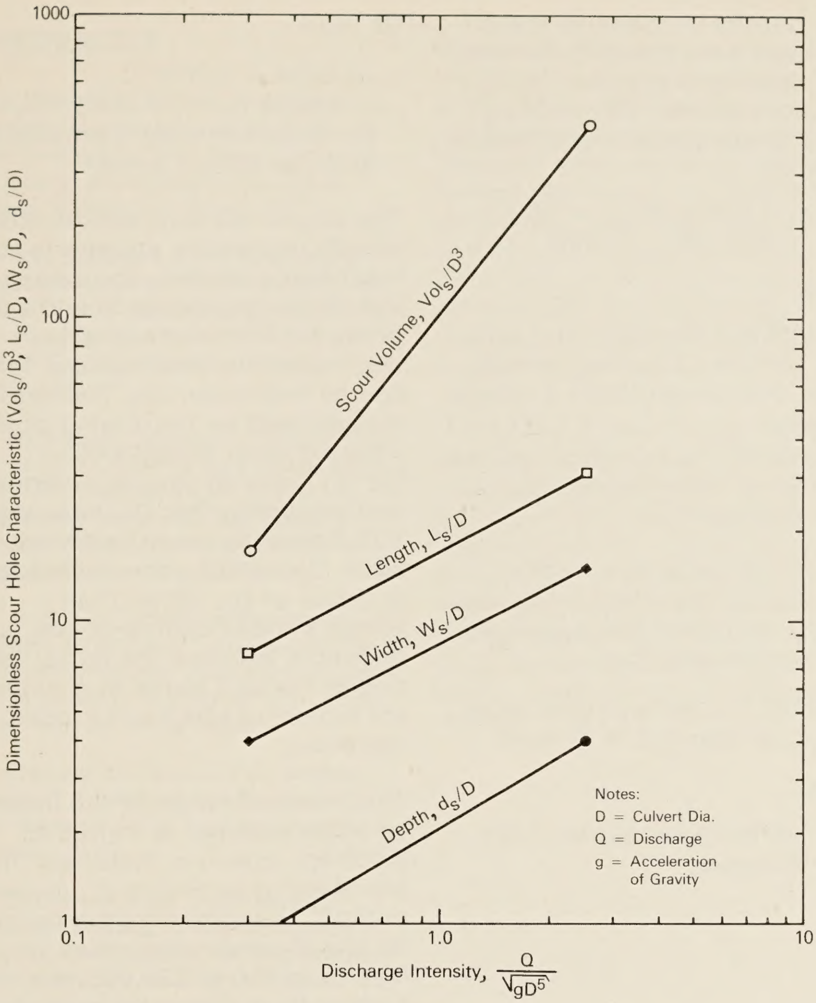
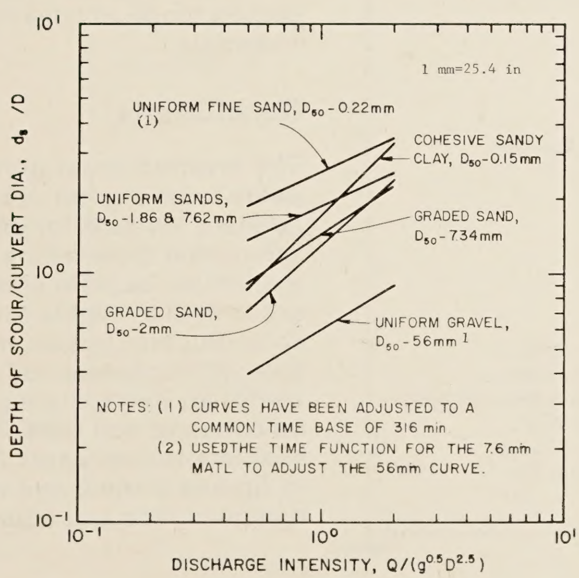


Figure 4.—Scour hole characteristics versus discharge intensity for a cohesive sandy-clay (time =5 hours).



[1] Data for the 56 mm uniform gravel are from T. R. Opie, "Scour at Culvert Outlets," M.S. thesis, Colorado State University, Fort Collins, Colo., December 1967.

Figure 5.—Cohesive and cohesionless material, d_s/D versus D.I. curves adjusted to a common time base of 316 minutes.

To compare the effects of various soil types, figure 5 shows the dimensionless scour *depth* versus discharge intensity for most of the soil types that have been tested either in prior research or in this study. Other scour hole dimensions—length, width, volume—would have a similar pattern for various soil types.

Figure 5 also illustrates the traditional means for estimating scour at culvert outlets. The top curve of figure 5 is the basis of an FHWA procedure. (*3*) Some State highway agencies have applied constant adjustment factors to the values in the FHWA procedure for various soil types, but those adjustment factors have little experimental basis. Although figure 5 is adequate to estimate culvert scour in noncohesive bed materials by interpolating between curves, it is not adequate for cohesive soils. An extensive testing program would be necessary to bracket the various cohesive soils. Lacking the resources for such a program, a more expedient procedure was developed using data for noncohesive soils to supplement very limited data for cohesive soils.

In analyzing the data for the cohesive soil, the investigators at Colorado State University found good correlation between scour hole dimensions and an inverted shear number. The inverted shear number is defined as follows:

$$ISN = \rho V^2/\tau_c$$

Where,

ρ = Mass density of water.
V = Average culvert outlet velocity.
τ_c = Critical shear stress.

The numerator of the inverted shear number is proportional to (but not equal to) the shear stress, which tends to erode the soil; the denominator is the level of stress at which the soil can resist erosion. Intuitively, this combination of terms should correlate well with scour.

Empirical relationships were derived for scour dimensions as functions of the inverted shear number for the one cohesive soil that was tested. The applicability of these relationships to soils other than a sandy-clay material then was tested.

If the shear number relationships are to be generally applicable, they should work as well for noncohesive as for cohesive materials. Although only one cohesive material has been tested, several noncohesive materials have been tested over the years. Figure 6 is a plot of points for both cohesive and noncohesive materials. Like figure 5, figure 6 illustrates the concepts rather than design curves. Figure 6 illustrates that the curves of figure 5 for various soils can potentially be reduced to a single line when the inverted shear number is used as the independent variable plotted along the abscissa.

Except for the critical shear stress, the variables in the inverted shear number are readily available. The critical shear stress is somewhat of a problem for cohesive materials, but there is a much better data base for the critical shear stress than there is for scour depths in cohesive materials. Based on a literature review, the following expression (*4*) is recommended for determining critical shear stress in a cohesive material:

$$\tau_c = 0.001\ (Sv_{sat} + 180)\ \tan\ (30 + 1.73PI)$$

Where,

Sv_{sat} = Shear strength of a saturated sample of the soil, which can be determined from a triaxial soil test.

PI=Plasticity index, which can be determined from the Atterburg limits soil test. (*5*)

The critical shear stress for a noncohesive material can be adequately estimated (for scour prediction purposes) from

$\tau_c = 0.0164\ D_{75}$ for sediment sizes larger than 0.2 in (5 mm)

Where,

τ_c is in pounds per square foot.
D_{75} is in inches.

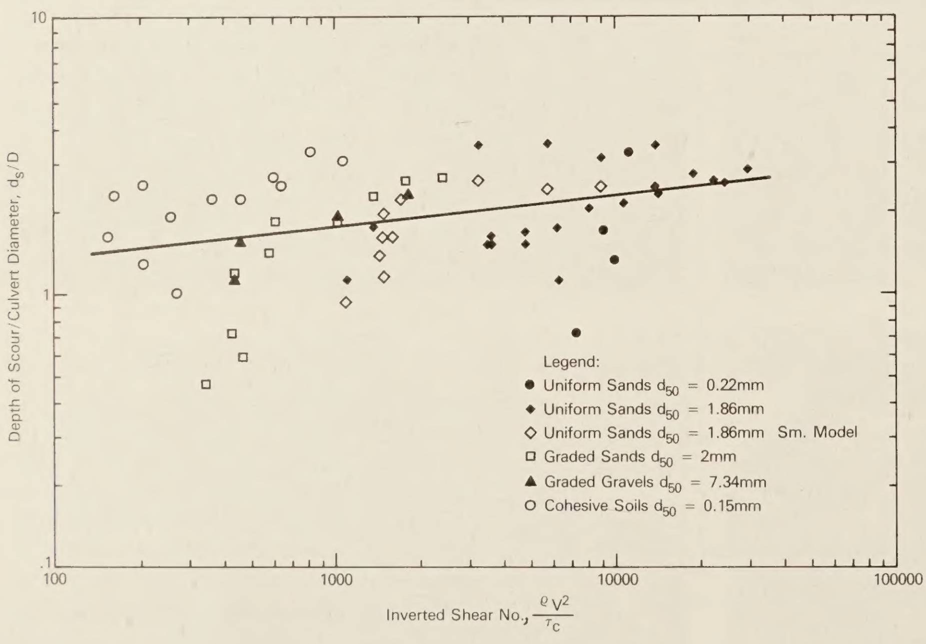
Or from

$\tau_c = 0.0024 + 0.0039\ D_{75} + 0.0033\ D_{75}^2 + 0.00027\ D_{75}^3$ for sediment sizes from 0.008 to 0.2 in (0.2 to 5 mm)

The above two expressions are simply regression equations that yield approximately the same critical shear stresses as Shield's diagram. (*6*) The first expression was recommended by Lane for coarse bed materials. The second was derived by regressing points selected from Shield's 60° F (16° C) curve for quartz sediment and assuming that D_{75} sizes were 1.25 times the mean sediment sizes. Developing the expression in terms of D_{75} rather than Shield's mean sediment size is desirable because the larger fraction of the soil tends to account for armoring effects of graded materials.

The practical range of the inverted shear number is from 5 to 5,000 for cohesive materials that are likely to be found at culvert outlets. The experimental range for the inverted shear number was from 150 to 220,000, but the higher values were for noncohesive materials. The range for cohesive materials was from 150 to 1,000. The line through the data in figure 6 is a reasonable basis for estimating scour for the expected range of cohesive materials.

Figure 6.—Scour depth versus inverted shear number (time=5 hours).



Conclusions

The inverted shear number appears to be a good primary independent variable for estimating scour hole dimensions based on the limited experimental culvert scour data available for cohesive soils. Superimposing noncohesive with cohesive soil data was useful for extrapolating the limited cohesive soil data. FHWA will evaluate the concepts illustrated in figures 5 and 6 and will update design curves and equations. (*3*)

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(*3*) "Hydraulic Design of Energy Dissipators for Culverts and Channels," Hydraulic Engineering Circular No. 14, *Office of Engineering, Federal Highway Administration*, Washington, D.C., December 1975.

(*4*) I. S. Dunn, "Tractive Resistance of Cohesive Channels," *Journal of the Soil Mechanics and Foundations Division, American Society of Civil Engineers*, Vol. 85, June 1959.

(*5*) "Manual on Foundation Investigations," *American Association of State Highway and Transportation Officials*, 1978.

(*6*) "Sedimentation Engineering," American Society of Civil Engineers Manuals and Reports on Engineering Practice No. 54, edited by Vito A. Vanoni, Headquarters of the Society, New York, N.Y., 1975, pp. 98–99.

Steven R. Abt is an assistant professor of civil engineering at Colorado State University. He was the principal investigator for the research study on scour at culvert outlets sponsored by FHWA and personally conducted most of the experiments using the cohesive materials. Dr. Abt currently is involved in several hydraulic model studies and an open channel flow measurement study.

J. Sterling Jones is a hydraulic research engineer in the Environmental Division, Office of Research, FHWA. He has been with FHWA since 1971 and has been involved with studies on bridge and culvert scour, risk analysis, and energy dissipators. Mr. Jones initiated and managed the research study on scour at culvert outlets.

James F. Ruff is in charge of civil engineering projects for a firm in Laramie, Wyo. Previously, he was an associate professor of civil engineering at Colorado State University and was the original principal investigator for the FHWA research study. Dr. Ruff currently is involved in energy development, water resource, and water supply projects in Wyoming.

Reduction of Truck-Induced Splash and Spray

by
George B. Pilkington, II

Introduction

A truck traveling on a roadway can adversely affect the safety of adjacent motorists in smaller vehicles by causing aerodynamic disturbance and, on wet pavements, splash and spray. Aerodynamic disturbance, pressure or suction forces induced by a truck on an adjacent vehicle, can alter the adjacent vehicle's path. Splash results when the impact of a tire on the pavement forces water out of the tire-pavement interface. Generally, these water drops follow a ballistic path away from the tire and are larger than 1 mm (0.04 in) in diameter. Spray is formed when water droplets, generally less than 0.5 mm (0.02 in) in diameter and suspended in the air, atomize upon impact with a smooth surface.

Previous research shows that aerodynamic disturbance is the most hazardous of the three effects. (*1*)[1] However, because splash and spray are visible, they are perceived as more hazardous.

Many factors must be considered in studying the effects of splash and spray. Splash and spray occur only when the following five elements combine:

- Water in the tire path.
- Pavement surface water retention. Water generally is retained on a nonporous pavement, such as portland cement concrete or dense-graded asphaltic concrete, or in depressions in rutted or rough pavements.
- High velocity air in a turbulent flow pattern.
- High velocity air induced by truck speed.
- Turbulent air flow patterns around the wheels and through gaps caused by truck configuration.

Previous Research

Research completed in 1972 for the Federal Highway Administration (FHWA) analyzed and evaluated the effect of truck-induced aerodynamic disturbances on the control and handling of passenger vehicles. The following were found:

[1] Italic numbers in parentheses identify references on page 12.

• The aerodynamic disturbance induced by trucks has a measurable adverse effect on the control and handling of an adjacent passenger car. The magnitude of this effect increases with an increase in the vehicles' speed or size and decreases as the lateral separation of the two vehicles increases. The maximum aerodynamic disturbance effect occurs when the relative speed of the two vehicles is between 5 and 35 km/h (3 and 22 mph) and the passenger vehicle is downwind, traveling in the same direction as the truck. For example, on a two-lane highway having a lane width of 3 m (10 ft), the passenger vehicle could be drawn toward the truck or blown toward the shoulder depending on the ambient wind direction. (*1*)

• The critical areas of induced aerodynamic effect for a truck combination are the front of the tractor (bow), the gap between the cab and trailer and around the driving wheels, the rear semitrailer wheels, and the rear of the combination (tail) (fig. 1). If there are additional trailers in the truck combination, the additional gaps between trailers and around front trailer wheels also become critical areas. (*1*)

• A truck combination near a passenger vehicle causes stress in the vehicle driver. (*1*)

Based on early research on the formation of splash and spray (*2*), the National Highway Traffic Safety Administration (NHTSA) sponsored research to develop a technique to contain splash and spray generated by truck wheels. This research resulted in a prototype fender (the Department of Transportation Spray Protector [DOT fender]) that effectively contained splash and spray. (*3*) However, the DOT fender never was implemented because subsequent operational tests showed that it reduced the air circulation around the wheels causing the brakes to overheat and fade. (*4*) The NHTSA field tests demonstrated that techniques to reduce splash and spray should be evaluated operationally to insure that solving one problem does not cause a new problem. (*1*)

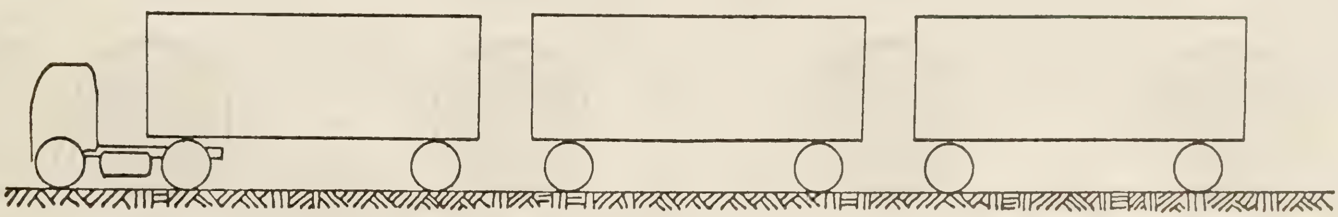
Full-scale testing techniques used in England and Sweden to measure spray volume and density were combined with the basic full-scale test setup used in the NHTSA field tests to develop the setup for subsequent full-scale splash and spray research. (*4–6*)

Research for the Transportation Systems Center (*7*) and the National Science Foundation (*8*) developed several efficient methods to reduce aerodynamic drag. It was determined that the efficiency of a splash and spray reduction technique could be enhanced when used with a drag reduction device.

Splash and Spray Research

A major FHWA study on splash and spray was conducted under Project 1U, "Safety Aspects of Size and Weight of Heavy Vehicles," in the Federally Coordinated Program of Highway Research and Development. (*9*) The research study included wind tunnel experiments, driver simulator experiments, full-scale tests with various truck configurations and truck-mounted devices to improve air flow around the trucks and reduce splash and spray, cost effectiveness analyses, and over-the-road evaluations in coordination with manufacturers.

Figure 1.—Critical areas of vehicle-induced aerodynamic disturbance.



Wind tunnel experiments

Two series of wind tunnel experiments using one-tenth scale models were conducted. The first series of experiments determined the magnitude and direction of the air flow patterns around a single combination truck. Figure 2a shows the experimental setup for the single truck experiments. The "tufted" model and "tufted" rake[2] are mounted on the wind tunnel yaw table. This photograph, taken during an experiment, shows the free end of the tufts alined with the direction of the air flow. Figure 2b graphically displays the data collected from the same experiment. It is apparent that the cab wake and the tandem wakes are the regions of highest turbulence. Also apparent is the longitudinal distortion of these turbulent regions along the direction of air flow.

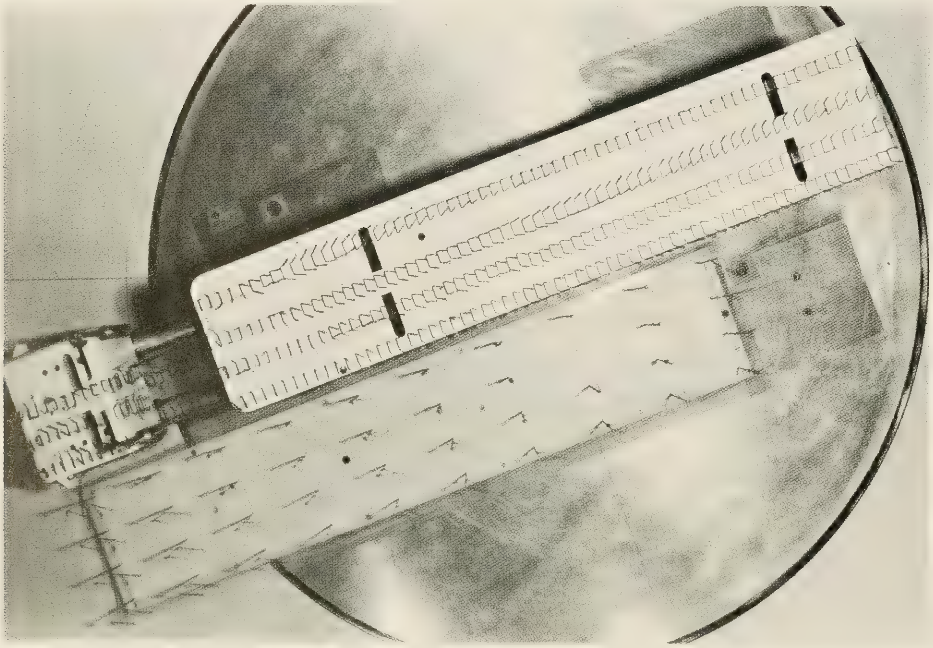
[2] A device having 40 pitot tubes to determine the air pressure at various locations.

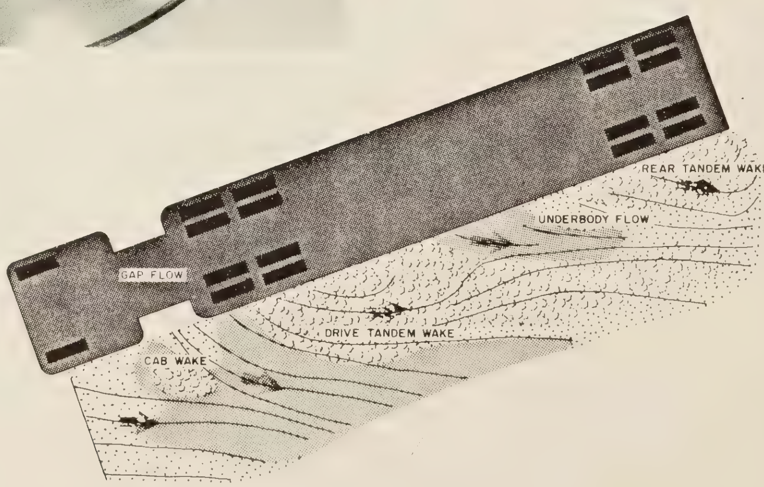
The second series of wind tunnel experiments determined the effect of the air flow pattern caused by a combination truck on an adjacent passenger vehicle. Figure 3a shows the two-vehicle wind tunnel experimental setup, and figure 3b illustrates the magnitude and direction of air pressure on the passenger vehicle caused by the truck.

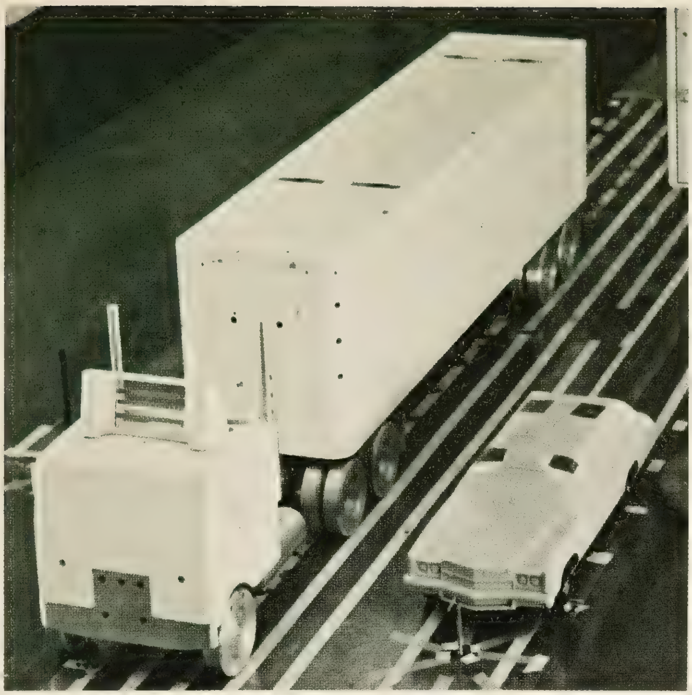
Driver simulator experiments

Subjects in FHWA driver simulator experiments were shown simulated spray clouds that obscured vision to different degrees. It was found that temporarily losing view of the highway because of a spray cloud did not cause a passenger vehicle driver to lose control of the vehicle. The driver simulation lacked the realism of the presence of the truck, which increases driver stress, but this was not

Figure 2.—(a) Single combination truck wind tunnel test; typical tuft photograph. (b) Interpretation of single combination truck wind tunnel data.







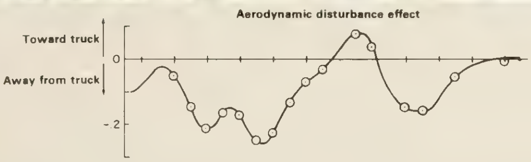


Figure 3.—(a) Two-vehicle wind tunnel test; basic truck with drag shield and station wagon. (b) Interpretation of two-vehicle wind tunnel data.

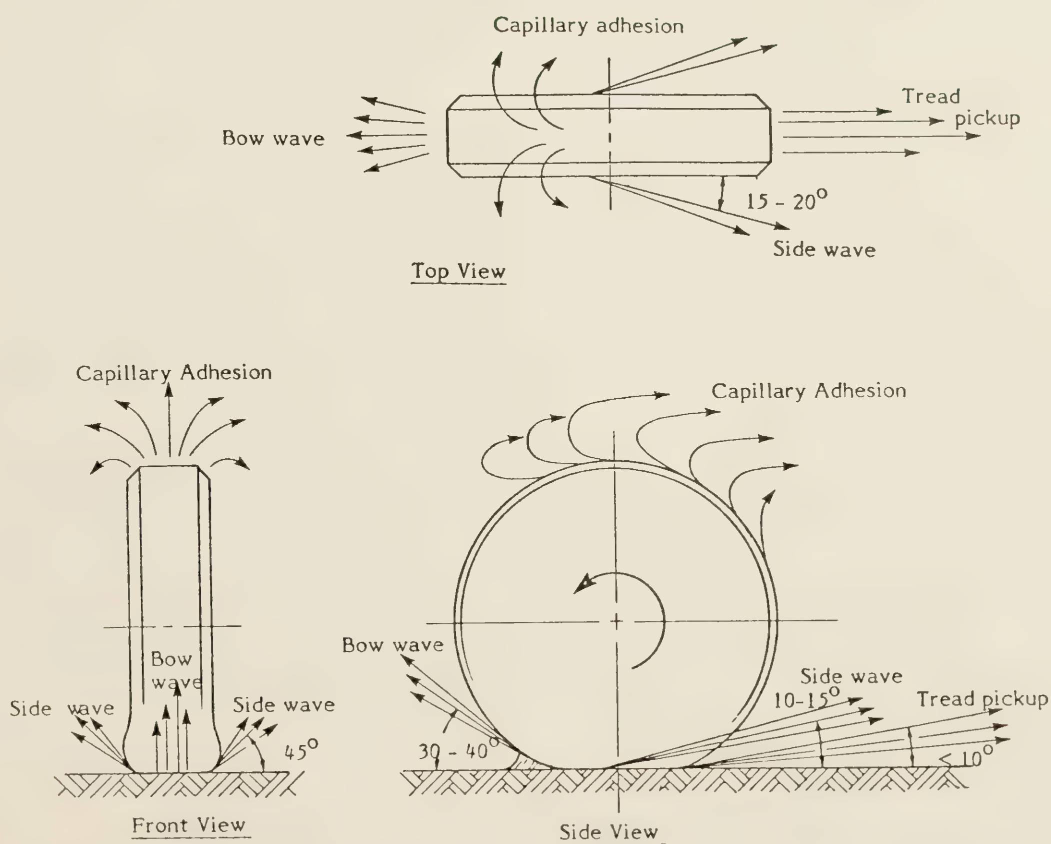
considered a detriment to the basic findings. Another purpose of the driver simulator experiments was to acquaint the drivers that would participate in the full-scale experiments with the visual loss they would experience when actually driving in a spray cloud near truck combinations.

Full-scale experiments

Three series of full-scale experiments were conducted. The first series determined how splash and spray from a single or double wheel are formed. These experiments demonstrated that the cause of splash is primarily from the side throw of water away from the wheel, and the ballistic path of the splash is generally below the wheel. The primary source of spray is water from tread pickup being thrown from the tire because of high-speed wheel rotation and atomizing upon impact with a hard surface. The only direct source of spray is the water that remains on the tire from capillary adhesion and is stripped from the top of the tire by the air flow. Spray from this source, however, constitutes only 1 percent of the spray cloud. The sources of splash and spray are shown in figure 4.

The second and third series of full-scale experiments were conducted in a desert to determine the most critical truck combination to splash and spray generation and the most promising splash and spray reduction device. Additional objectives included determining the

Figure 4.—Splash and spray sources.

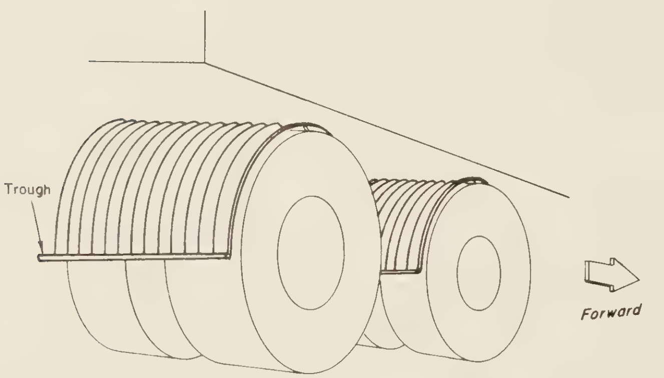


effect of truck weight on splash and spray generation, the characterization of spray, and subjective and objective assessments of splash and spray.

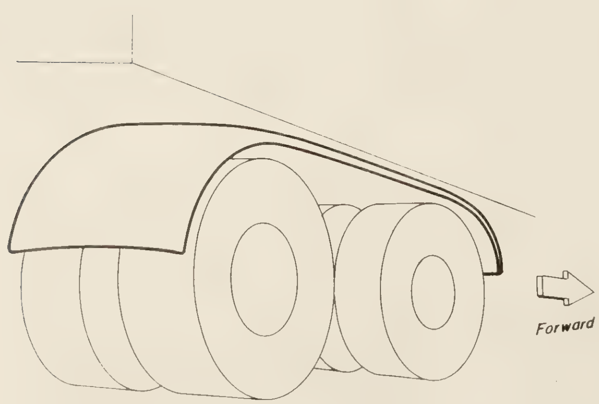
These experiments were conducted in the desert so that pertinent environmental conditions—wind and water—could be controlled. Previous aerodynamic disturbance research had shown that wind in the desert was relatively constant both in magnitude and direction. In these experiments, water was pumped to the site and evenly distributed on the 300 m (984 ft) test track pavement surface through holes in an irrigation pipe. The water depth was maintained at approximately 1.5 mm (0.06 in).

The truck combinations tested were cab-behind-engine (CBE) and cab-over-engine (COE) tractors with flat bed, tanker, and van semitrailers and trailers in single, double, and triple configurations. Off-the-shelf splash and spray reduction devices, such as those shown in figure 5, were evaluated as were prototype truck-mounted devices shown in figure 6.

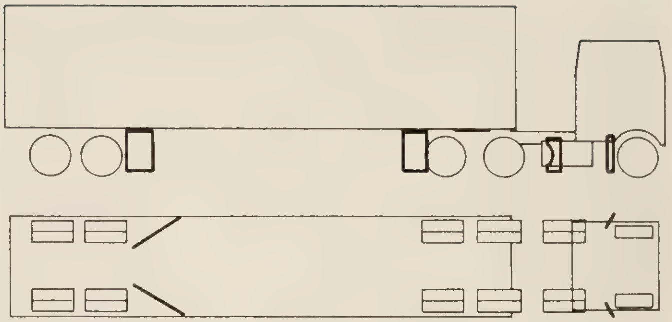
Figure 5.—Off-the-shelf splash and spray reduction devices.



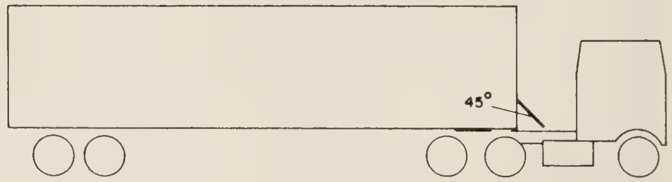
Roberts Fender



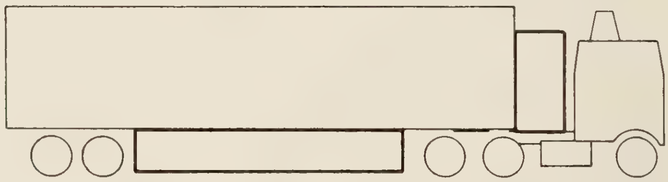
European Fender



Angled side vane



Partial gap panel concept



Underbody baffle and splitter panel

Figure 6.—Prototype truck-mounted devices to reduce splash and spray.

Loaded and empty van combinations were tested to determine the change in the quantity of splash and spray and pressure patterns caused by increased weight. The spray cloud was "fingerprinted" by capturing the water droplets on a screen for 1 minute to determine their size and frequency. The water volume of the spray cloud was collected at the same time. Spray-attenuation signals from a photometer and lasers parallel to the test track measured the spray cloud density. In addition, tractor cab passengers, passengers in adjacent vehicles, and observers at the ends of the test track rated the visibility of the highway and truck depending on their interpretation of the deterioration of safety caused by the spray cloud.

Data analyses indicated the following:

- The COE and van semitrailer was the most critical combination, causing the largest aerodynamic disturbance effect.

- The Reddaway System (fig. 7) was the most effective system in reducing splash and spray, though all devices and techniques showed promise with better product engineering.
- The weight of a truck combination had little effect on the splash, spray, and air flow patterns generated.
- Additional subjective ratings of visibility were unnecessary because objective measures using the lasers and photometer correlated well with the subjective ratings.
- The change in visibility caused by the various truck-mounted devices was a reliable indication of changes in aerodynamic disturbances and spray.

Using the results of the first desert experiments, the second desert experiments concentrated on obtaining more precise data on the change in visibility caused by various promising devices. Twenty-seven truck configurations were evaluated, and four "paired" test runs were made of the basic truck with each truck with a splash and spray reduction device. The modified truck traveled through the test area and appropriate measures were obtained. The basic truck traveled through the test area approximately 1 minute later—after the water film and environmental conditions had returned to pretest conditions. Of the 27 splash and spray reduction devices evaluated, visibility improved as much as 60 percent in some and decreased as much as 18 percent in others compared with a truck without a drag shield or reduction devices. The most effective reduction device combination was the Reddaway System and a drag shield. The Reddaway System without a drag shield was only two-thirds as effective in reducing splash and spray; the drag shield without the Reddaway System improved visibility only 5 percent. Table 1 gives the percent changes in visibility for each splash and spray reduction device tested. (*9*)

Cost effectiveness analyses

Cost effectiveness analyses indicated that the Reddaway System with drag shield and longitudinal baffle was the most cost effective of all devices tested. Its benefit-cost ratio was about 16:1. (*9*) The economic analysis considered the higher capital cost of the Reddaway System (approximately $800), the higher cost of maintaining the system (approximately $200 per year), and a 0.6 percent decrease in the revenue load (approximately 160 kg [352 lb]). These "losses" are offset by an approximately 2.7 percent savings in fuel because of reduced drag and cross flow. The overall net savings was approximately 1.25 cents per kilometre (2 cents per mile), or an annual savings of $400 per truck. (*9*)

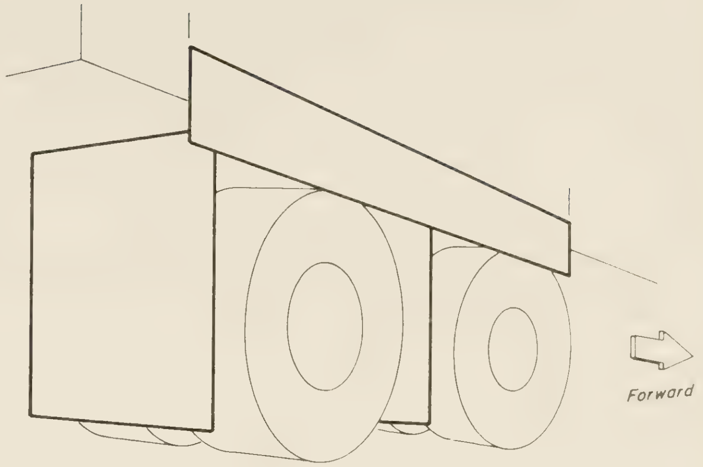


Figure 7.—Sketch of Reddaway Fender.

Table 1.—Visibility changes caused by splash and spray reduction devices

Devices	Description	Visibility changes
		Percent
M0	Reddaway System and drag shield	60
M6	Like M2, drag shield and longitudinal baffle	59
M7	Like M2 and drag shield	59
M2	Like M1, without flaps between the tandems	39
M1	Reddaway System	38
M3	Like M1, without front flaps	25
L1	Longitudinal baffle, gap splitter panel and drag shield	25
G1	Gap filler panel in upper position	23
V3	Like V2, without vanes behind tractor tandem	20
L2	Longitudinal baffle and gap splitter panel	20
R1, R2	Roberts Fender with and without drag shield	19
F3	Fuzzy truck drag shield and longitudinal baffle	17
V2	Angled side vanes and drag shield	16
M4	Like M2 without side flaps	15
L4	Longitudinal baffle and drag shield	15
V4	Angled side vanes and drag shield, reset	15
E2	European fender	15
F2	Fuzzy truck and drag shield	14
M5	Like M4, without rear flaps on tractor	14
G2	Gap filler panel in lower position	11
L3	Longitudinal baffle	10
P3	Partial gap panel and angled end plates	7
D1	Basic truck and drag shield	5
T	Basic truck	0
P2	Partial gap panel and straight end plates	-1
P1	Partial gap panel	-11
F1	Fuzzy truck	-12
V1	Angled side vanes	-18

Research Results and Benefits

This research successfully demonstrated that the adverse aerodynamic effects of large trucks can be reduced by devices that effectively reduce splash and spray. With the cooperation of several commercial truck lines, NHTSA currently is supplementing FHWA research by developing life-cycle costs—manufacture, installation, and maintenance costs—of spray reduction devices. NHTSA also is developing simpler test procedures than those used in the desert tests to determine the effectiveness of new spray reduction devices.

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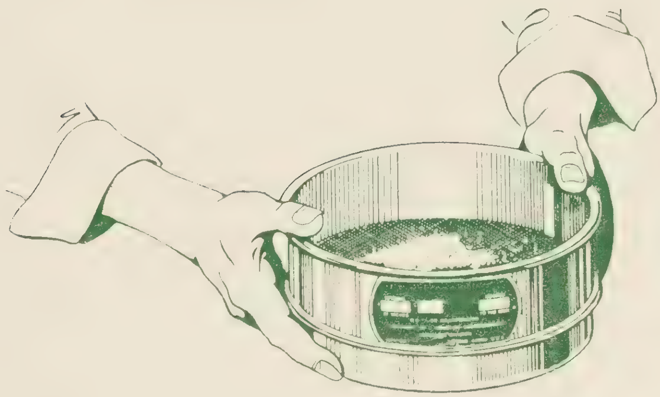
Aggregate Gradation Control: Part I—An Analysis of Current Aggregate Gradation Control Programs

by
Peter A. Kopac, Jose I. Fernandez, Stephen W. Forster, and Terry M. Mitchell



Introduction

The gradation test, probably the most frequently performed test in highway construction, is performed by all parties closely involved in actual construction work. The test is performed by technicians representing State highway agencies, contractors, aggregate producers, and materials suppliers that include bituminous concrete (BC) plants, portland cement concrete (PCC) plants, and concrete block plants. The test is performed when aggregate is manufactured, before and after aggregate is incorporated in the concrete mixture, at the job site, and at various testing laboratories. Furthermore, it is performed for both process control (controlling the product quality) and acceptance (determining product quality).

Although many State highway agencies recently have reduced their day-to-day process control activities, State personnel still perform a large, possibly disproportionate, amount of aggregate gradation process control testing. A recent research study sponsored by the Federal Highway Administration (FHWA) indicates that the total cost of aggregate gradation control—the overall combined testing-related costs for all parties involved—can be minimized by shifting the responsibility for most of the sampling and testing from the States to the contractors. (*1*)[1] The study reveals that States that perform their own aggregate gradation process control may be expending as much as 18 times the effort as States that have adopted more modern quality assurance-quality control (QA–QC) gradation programs. Wages for State inspectors performing gradation testing are $2 million or more per year in many States, so the potential for savings is considerable.

Should more States, then, shift to gradation process control by the contractor? What exactly are "QA–QC" programs? How do they work? Do they offer advantages to contractors, materials suppliers, and producers or only to State highway agencies? And what happens to product quality when the State transfers process control responsibilities? These questions, as well as others, were investigated in FHWA's research and will be addressed in this two-part article. Part I presents a comparative analysis of current gradation control programs to

[1] Italic numbers in parentheses identify references on page 24.

determine direct and indirect economic benefits and liabilities. Part II, to be published in the next issue of *Public Roads*, will provide guidelines for implementing an efficient gradation control program that can be used directly by highway agencies and that defines effective producer-contractor-highway agency functions and responsibilities.

Process Control of Aggregate Gradation

Process control is the maintenance or control of a certain characteristic or set of characteristics for a product during its manufacture or processing. In aggregate processing, one of the characteristics controlled is the gradation of the particles. The gradation testing is carried out because it is felt that uniformity in gradation is necessary to obtain the required quality in those materials or structures in which the aggregate is used. What is being tested, however, is the aggregate and not the quality of the final product.

Because State highway agencies usually do not produce aggregate, any use of aggregate by the State will involve at least two of the following parties: the producer who processes the aggregate, the trucker who transports the aggregate, the concrete (either PCC or BC) supplier who uses the aggregate as an ingredient of the product, the contractor who incorporates that product into the actual highway facility, and the State highway agency as purchaser and consumer.

State highway agencies traditionally have assumed the responsibility for the tests and inspections necessary to assure conformance with the aggregate specifications. Occasionally, this has created serious problems. Legally, the responsibility for providing materials and products of the specified quality rests with the construction contractor. Whenever a State gets involved in the contractor's quality control activities, the State assumes an implicit liability for the quality of the product. In recognizing this, many States have imposed specific gradation control testing requirements upon the producer and the contractor. However, until better methods are developed to evaluate the quality of the finished product, there must be a mechanism to determine the acceptability of the aggregate. Therefore, some amount of aggregate gradation testing usually is performed by the State, even in those States in which the primary responsibility for aggregate gradation control testing lies with the producer or the construction contractor.

Sampling for aggregate gradation testing may be performed at the aggregate source, the concrete plant, or the project site from conveyor belts, stockpiles, storage bins, trucks, or directly from the roadway. The point of sampling should be chosen so that the aggregate sampled is most representative of the aggregate in the final product. At the same time, impractical sampling requirements should be avoided.

The time and frequency of sampling and testing usually are related to working hours and production quantities. Again, practicality is important because the frequency of sampling directly impacts the overall costs of an aggregate gradation testing program.

Standard methods for gradation testing of aggregate should be followed to minimize problems in the event of a possible liability claim. These standard methods are prescribed by associations (*2, 3*) or individual State highway agency manuals; in many cases, rapid and simplified methods are available and may be followed.

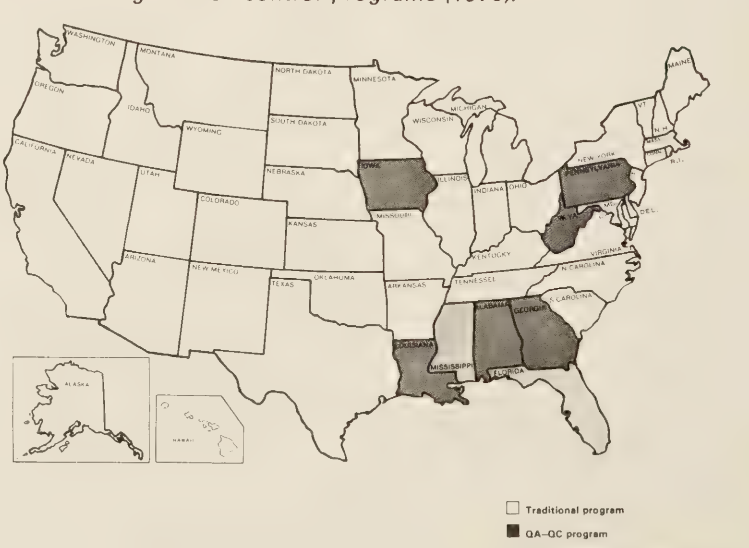
Current Gradation Process Control Programs

Aggregate gradation control programs can be divided into two broad groups based on who is responsible for performing the majority of aggregate gradation tests.

In "traditional" programs, the State highway agency has the traditional role of performing the majority of aggregate gradation control and acceptance tests. Producers and concrete suppliers may have an internal aggregate gradation control program for their own benefit; however, their tests seldom are used by the State.

In QA–QC programs, the State highway agency performs the testing for verification and/or acceptance (quality assurance), while the contractor, concrete supplier, and/or the producer performs the majority of aggregate gradation testing for process control (quality control). Currently, only a few States use this kind of program (fig. 1), and for most of

Figure 1.—Kinds of gradation control programs (1978).



these States, the program is relatively new. Most States using this program still retain responsibility for acceptance testing. Some require that control testing be performed at the aggregate source; others primarily are concerned with testing in the concrete plant. In some States, a pilot QA–QC program has been established for specific areas of the State; in still other States, a combination program using both traditional and QA–QC features is being used, depending on the application of the aggregate.

The concept of statistical variability can be incorporated in either kind of program by including statistical tolerances on the aggregate gradation specifications, statistically evaluating test results, statistically analyzing the correlation between control tests and verification tests, or any combination of the above.

Program descriptions

Gradation control programs in three States were investigated in detail. State A represents a QA–QC program with emphasis on testing at the aggregate source, State B represents a QA–QC program with emphasis on testing near the point of use, and State C represents a traditional program.

To more easily compare different gradation control programs, three entities within each State highway agency—the central laboratory, the district laboratories, and the offices of the Resident Engineers—must be defined. The central laboratory is the principal laboratory facility maintained by the Materials Section. The district laboratories (sometimes called the regional laboratories) are laboratory facilities maintained by the Materials Section at locations that conveniently service a specifically designated geographical area. At the project level, the office of the Resident Engineer represents the primary point of contact and interaction between the State and the construction contractor during the execution of the project. The Resident Engineers usually are under the jurisdiction of the Construction Section of the State agency, not the Materials Section.

State A program

The aggregate gradation control program of State A is a QA–QC program with the aggregate producer responsible for the quality control testing of aggregates. Each shipment of aggregate to a project site or concrete plant must be accompanied by a certificate of compliance. Producers are required to employ State-certified technicians at each source to perform process control gradation testing. One gradation test is required for each 1.4 Gg (1,500 tons) of each class of aggregate produced.

The State agency has 21 Resident Engineers. The office of the Resident Engineer is responsible for acceptance of aggregates and products at the project level, including all sampling and any necessary testing of base and subbase materials and PCC aggregates. Aggregate used for base or subbase material requires only visual inspection, but testing also may be conducted if the material appears to be marginal. At the PCC plant, three samples of aggregate are taken for each 191 m^3 (250 yd^3) of concrete produced, with a minimum of three samples per each day's production. Usually, only one of these samples is tested; the other two are tested only if the first sample fails to meet the specifications. The Resident Engineer's staff is responsible for taking three samples of BC hot mix each day and delivering the samples to the district laboratory for testing. In addition, because of the timelag in receiving those test results from the district laboratory, the Resident Engineer's staff samples and performs gradation tests on the cold feed aggregate mixture used to manufacture BC. These tests, however, are only advisory and are not used for acceptance.

Six district laboratories perform daily extraction and gradation tests on the hot mix samples delivered by the Resident Engineer personnel. Again, as with PCC aggregate, usually only one sample from each group of three samples is tested. These gradation tests performed on the extracted aggregate then are used for acceptance by the Resident Engineer. The district laboratory also is responsible for monitoring the producer's gradation testing and performing verification tests. One verification gradation test is performed for each 5.4 Gg (6,000 tons) of each class of aggregate produced. Lack of correlation between the producer's tests and those of the district laboratory could increase testing requirements, prompt an immediate request for corrective action, and, in the worst case, shut down production.

The central laboratory primarily determines the physical characteristics of the aggregate materials, such as abrasion resistance, soundness, and specific gravity, to evaluate new sources of aggregate production, designate approved uses for aggregate from a particular source, and monitor aggregate quality in connection with construction projects. Tests to verify the physical characteristics of the aggregate are performed at least once per project. In addition, tests are performed in the central laboratory on BC hot mix samples provided by the district laboratories. These assurance tests serve as internal quality control on the testing procedures used by the district laboratories.

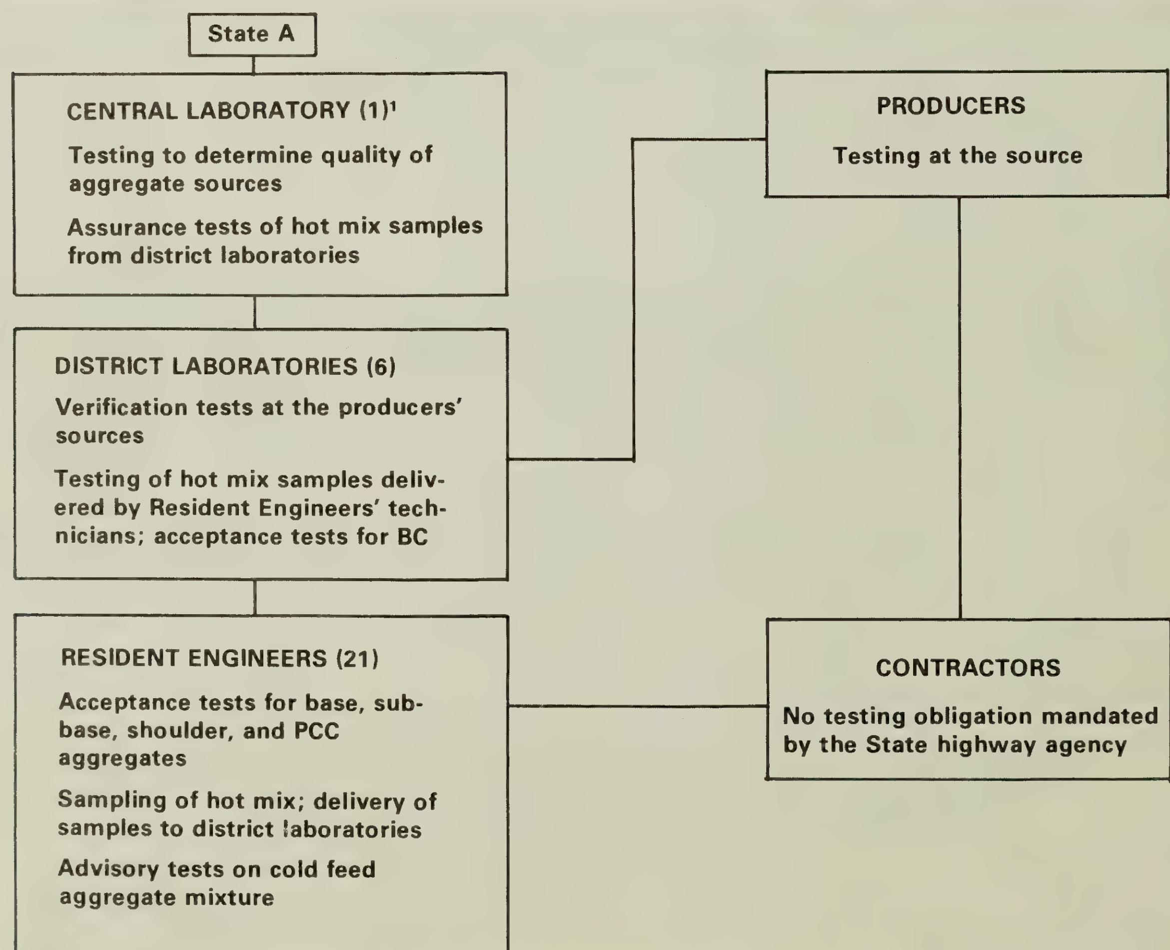
A schematic diagram of the State A program structure is shown in figure 2.

State B program

The aggregate gradation control program of State B is a QA–QC program with the construction contractor responsible for the quality control testing of aggregates. Aggregates are sampled at the "point of use"—the last point before being incorporated into their intended product. This point is the project site for base and subbase aggregate material and the concrete supplier's plant for aggregate used in PCC or BC. As a result, many construction contractors delegate the responsibility for aggregate gradation testing to their concrete suppliers, although the contractor still remains legally responsible. Quality control sampling and testing by the contractor's (or concrete supplier's) certified technicians is required at the rate of two aggregate samples per day for PCC used for pavements and one sample per day for PCC used for structures. For BC, two samples per day are taken for extraction and gradation testing. There are no requirements for gradation testing at the source, possibly because the State imports nearly 50 percent of the total aggregate used for highway construction. The program also incorporates statistical end-result specifications, including provisions for price adjustments, for the acceptance of products in which the aggregates are used.

Because the number of active Resident Engineers varies in relation to the number of active highway construction projects in the State, the number of personnel engaged in aggregate gradation testing activities also fluctuates. The Resident Engineer's staff does not engage in gradation testing except for aggregates used directly as base, subbase, or shoulder materials. Instead, the staff's aggregate gradation testing responsibilities are limited to monitoring the sampling and testing activities at the concrete suppliers' plants and to obtaining and delivering samples for verification testing to the district laboratories. At the concrete suppliers' plants, these verification samples are obtained by splitting

Figure 2.—Schematic diagram of State A program.



[1]Numbers in parentheses designate the number of organizational entities within the State.

the samples taken by the contractors' technicians at a frequency of one per day per class of PCC and one per day for the BC hot mix.

The State agency maintains nine district laboratories. All the samples for projects located within a district are received at the district laboratories, where the actual gradation testing is performed.

The central laboratory, involved in testing for approval of aggregate sources, does not participate in the aggregate gradation control program. However, the central laboratory does provide an internal quality control function for the gradation control program by periodically providing the district laboratories with "identical samples" for gradation testing, the results of which are used as a check on the testing procedures used by the district laboratories.

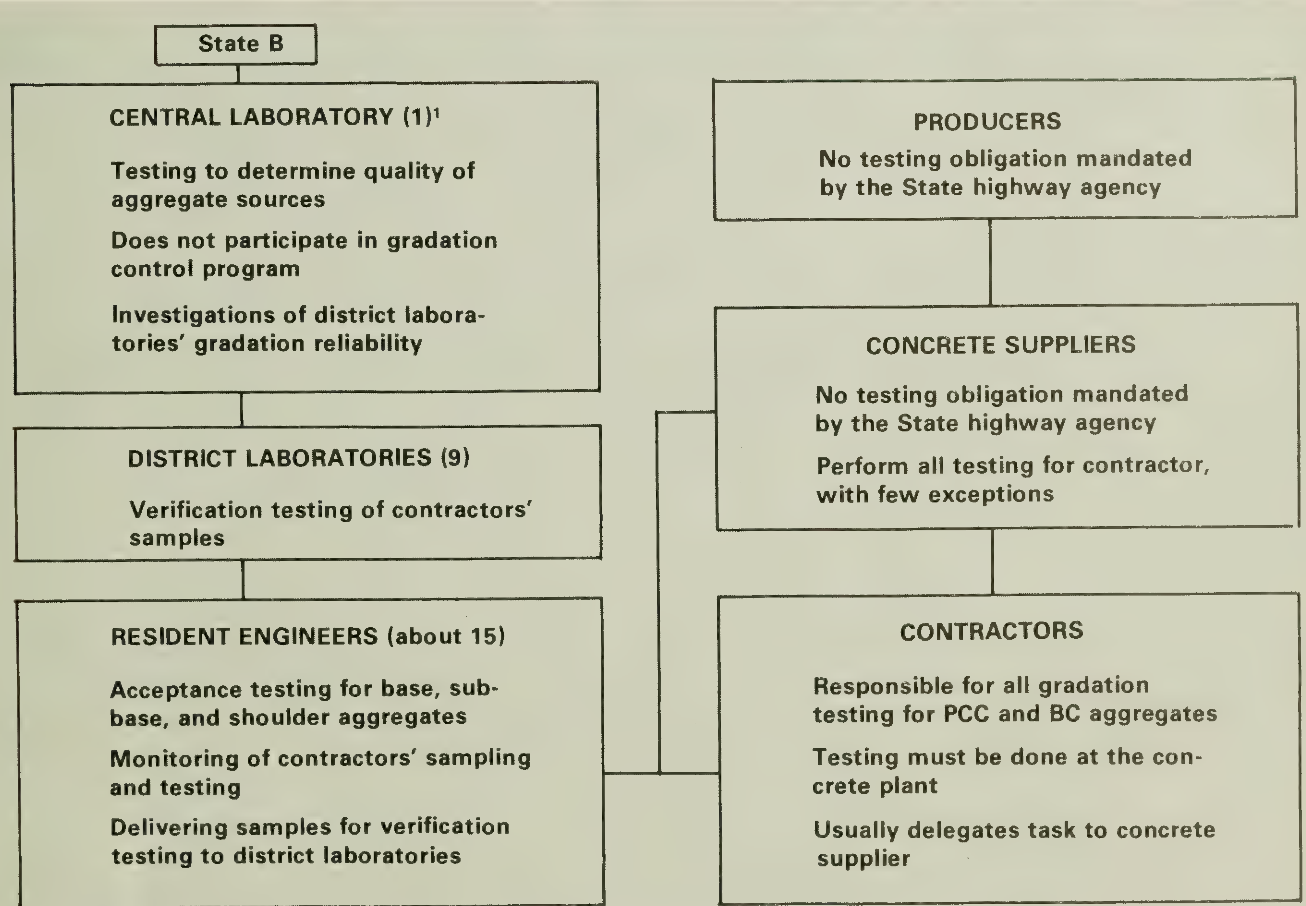
A schematic diagram of the State B program structure is shown in figure 3.

State C program

State C has a traditional program of aggregate gradation control; State personnel perform nearly all sampling and testing for aggregate gradation. Because of the particular geographic and demographic characteristics of the State, the program is administered differently in the rural areas than in the single large metropolitan area in the State. Accordingly, rural and urban areas are distinguished when presenting the corresponding program structures.

The majority of the State is rural. Here, samples for aggregate gradation testing are collected and tested by the Resident Engineer's staff. The actual sampling may be performed by employees of the contractor, the concrete supplier, or the producer under the direct supervision of the State inspector. The samples often are tested at the project site but also may be tested at the Resident Engineer's office or, if more conveniently located, at a district laboratory. In the rural areas, time spent transporting samples can be a significant portion of the total time spent in aggregate gradation testing activities. The State has 49 Resident Engineer offices, 36 of which fall in the rural category.

Figure 3.—Schematic diagram of State B program.



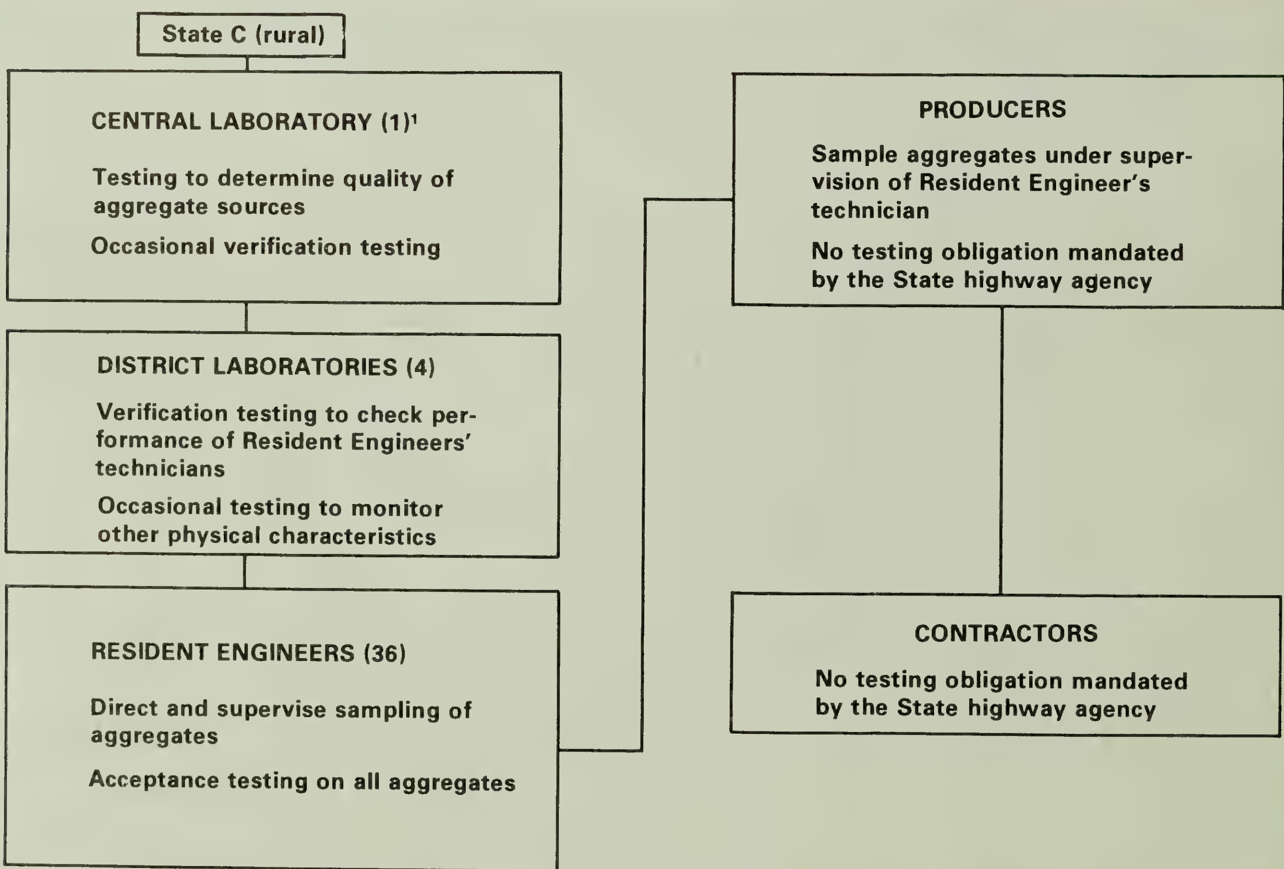
[1] Numbers in parentheses designate the number of organizational entities within the State.

Four of the five district laboratories are located in rural areas, and verification tests are primarily performed there. Such verification testing is a checking of results of tests performed by the State's own Resident Engineer's staff. Whenever possible, samples are provided for verification testing by splitting the samples collected by the Resident Engineer's staff, in which case the district laboratory technicians may collect such samples at the Resident Engineers' offices. In addition to performing gradation tests on the verification samples, several of the district laboratories are equipped to perform tests to determine other physical characteristics of the aggregates to monitor the quality of the aggregate after the initial qualification of a source.

Testing physical characteristics of the aggregate for qualification of new sources and annually conducting similar tests on aggregates from approved sources primarily are performed in the central laboratory. Occasional gradation tests on verification samples also are performed in the central laboratory. In addition, the central laboratory may perform unscheduled gradation tests whenever there is a recurrence of nonconforming gradations from a given source, as evidenced by the monitoring of verification test results.

The collection and testing of the primary quality control samples for aggregate gradation in the urban area differs from the method used in rural areas in that a branch of the Materials Section of the State agency is located within this metropolitan area. This branch assists the Resident Engineers' offices and the district laboratory in handling the greatly increased workload, which results because the urban area uses nearly 50 percent of the State's aggregate production. The responsibility for collecting and testing aggregate samples in the urban area primarily depends on the final aggregate product. The Resident Engineer's technicians collect and test all samples of aggregates to be used as base or subbase material and still assist in collecting and testing other samples. However, a district laboratory technician collects and tests all the BC hot mix samples, and a group of technicians employed by the branch of the Materials Section collects and tests

Figure 4.—Schematic diagram of State C program—rural area.



[1] Numbers in parentheses designate the number of organizational entities within the State.

most of the PCC aggregate samples. Testing of verification samples is divided between the staff of the district laboratory and the staff of the Materials Section branch, jointly using the facilities of the district laboratory.

Schematic diagrams of the State C program structures for rural and urban areas are shown in figures 4 and 5.

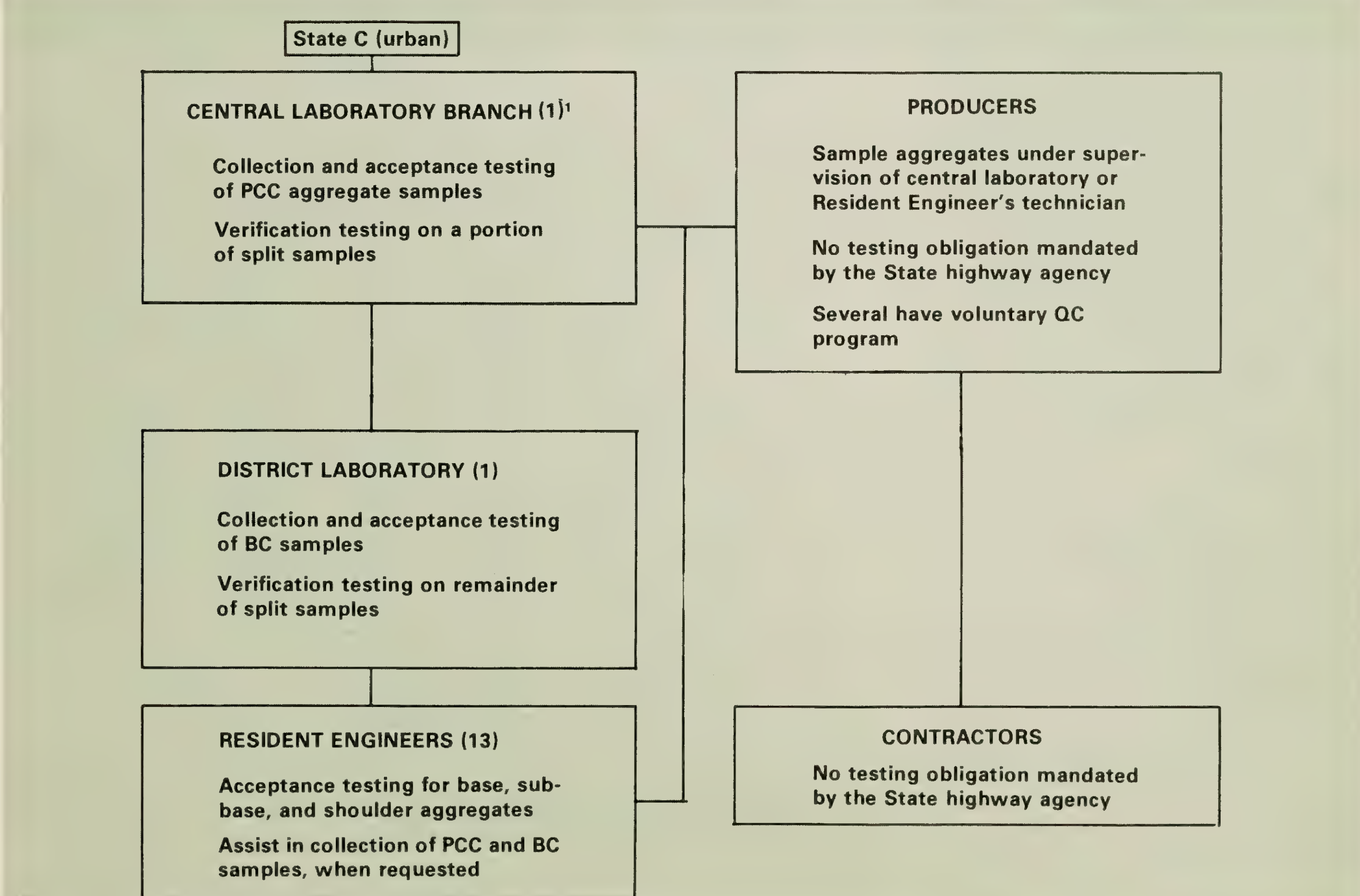
The required frequencies of testing for project control and verification depend on the aggregate's intended use. The project control tests are the primary quality control tests and are performed at the rate of one per 3.6 Gg (4,000 tons) of aggregate intended as subbase material; one per 1.8 Gg (2,000 tons) at the source plus one per 4.5 Gg (5,000 tons) at the project site for aggregate intended as base course material; one per 1.8 Gg (2,000 tons) at the plant plus one per 1.8 Gg (2,000 tons) at the project site for BC aggregates; and one per 1 223 m^3 (1,600 yd^3) of concrete for pavements and one per 765 m^3 (1,000 yd^3) of concrete for structures in the case of PCC aggregates. Verification tests are performed at the rate of one per project for subbase aggregates; one each at the source and at the project site per 36.3 Gg (40,000 tons) of base course aggregate; one per 3.6 Gg (4,000 tons) at the plant plus one per 9.1 Gg (10,000 tons) at the project site for BC aggregates; and one per 15 291 m^3 (20,000 yd^3) of concrete, regardless of use, for all PCC aggregates.

Comparison of Programs

An economic analysis was structured to compare the three States' programs. In structuring the analysis, a common denominator was sought to allow relative costs to be compared more easily by eliminating or minimizing variables such as hourly wages and production quantities.

Labor, equipment, facilities, and transportation costs were analyzed. It was determined that the only significant differences among the programs were in labor costs. The equipment used in

Figure 5.—Schematic diagram of State C program—urban area.



[1] Numbers in parentheses designate the number of organizational entities within the State.

aggregate gradation testing is simple and relatively inexpensive; even a heavy-duty, motorized sieve shaker costs only a small fraction of a technician's annual wages. The total equipment costs for any of the programs investigated are not insignificant; however, the differences in cost are negligible when compared with labor costs. The same is true of the testing facilities. In most cases, aggregate gradation testing activities are conducted in one or two rooms of a building used for several other purposes. The overhead costs for such a small area also are insignificant relative to labor costs. Transportation costs, on the other hand, are comprised of the vehicles, the fuel, and the labor costs involved in travel time. The number of vehicles in use probably would not be significantly reduced by restructuring aggregate gradation control activities, and fuel costs would vary in direct proportion with the labor costs represented by the travel time. Accordingly, travel time, in person-hours, represents transportation costs with a sufficient degree of accuracy.

Therefore, labor costs are a major element of the common denominator needed to compare aggregate gradation control programs. The other major element is the quantity of aggregate that is controlled as the result of labor efforts. Therefore, the common denominator selected for the analysis was the ratio of labor to aggregate production or consumption, expressed in person-hours per 900 Mg (1,000 tons) of aggregate.

In analyzing the labor data for each State, the concept of full-time equivalents is used. A full-time equivalent is equal to the number of individuals involved in a given activity multiplied by the percentage of their time spent working on that activity. On an annual basis, one full-time equivalent is assumed to equal 2,080 person-hours. Overtime is not taken into account. The differences that might result among programs from including overtime are not considered significant and, in any event, determining what portion of the overtime should be allocated to aggregate gradation control activities virtually is impossible.

Labor estimates were derived by sampling the different entities and extrapolating results to all entities of the same kind within the given program. The validity of this economic analysis therefore is related to the validity of the extrapolation. For this reason, veri-

Table 1.—Labor used for aggregate gradation control in State A

Labor used by State highway agency

Entity	Number of technicians	Work in gradation testing	Full-time equivalents	Number of entities surveyed	Number of entities represented	Extrapolated full-time equivalents	Annual person-hours
		Percent					
Central laboratory	9	30	2.70	1	1	2.70	5,616
District laboratory	6	100	6.00				
District laboratory	5	100	5.00	2	6	33.00	68,640
Resident Engineer	7	40	2.80	1	21	58.80	122,304

Total labor (person-hours)	Total aggregate consumption (millions of tons, 1978)	Person-hours per 1,000 tons
196,560	12.8	15.4

Labor used by producers

Producer	Number of technicians	Work in gradation testing	Full-time equivalents	Annual person-hours	Annual production
		Percent			*Millions of tons*
P–A1	2	100	2.00	4,160	4.0
P–A2	5	60	3.00	6,240	4.0
P–A3	14	60	8.40	17,470	6.0
P–A4	6	100	6.00	12,480	3.5

Total labor (person-hours)	Total aggregate production (millions of tons, 1978)	Person-hours per 1,000 tons
40,350	17.5	2.3

1 ton=0.9 Mg
1 person-hour per 1,000 tons=1.1 person-hour per 1.0 Gg

fication was obtained from at least two different sources to insure that the entities sampled were representative of a particular State.

The total labor efforts expended for aggregate gradation control activities in States A, B, and C are calculated (in person-hours per 900 Mg [1,000 tons]) in tables 1–3. The State highway agency efforts are calculated separately from the producer/supplier/contractor efforts. It should be noted that the total aggregate production tonnage is the total for the sampled producers rather than a Statewide total. If the total aggregate production tonnage is not limited to highway aggregate and includes aggregate used in other States, this production tonnage may be larger than the State highway agency's total aggregate consumption tonnage, as in States A and C.

Table 2.—Labor used for aggregate gradation control in State B

Labor used by State highway agency

Entity	Number of technicians	Work in gradation testing	Full-time equivalents	Number of entities surveyed	Number of entities represented	Extrapolated full-time equivalents	Annual person-hours
		Percent					
Central laboratory	—	0	0	1	1	0	0
District laboratory	2	100	2.00	2	9	18	37,440
District laboratory	2	100	2.00				
Resident Engineer	2	30	0.60	1	15	9	18,720

Total labor (person-hours)	Total aggregate consumption (millions of tons, 1978)	Person-hours per 1,000 tons
56,160	20	2.8

Labor used by producers (suppliers)

Producer	Number of technicians	Work in gradation testing	Full-time equivalents	Annual person-hours	Annual production
		Percent			*Millions of tons*
P–B1	2	20.0	0.40	830	4.00
P–B2	5	12.5	0.63	1,310	1.10
P–B3	1	12.5	0.13	270	0.20
P–B4	5	20.0	1.00	2,080	2.00
P–B5	0	0	0	380[1]	0.50
P–B6	2	12.5	0.25	520	0.05
P–B7	1	40.0	0.40	830	0.10

Total labor (person-hours)	Total aggregate production (millions of tons, 1978)	Person-hours per 1,000 tons
6,220	8	0.8

[1] Estimated annual effort by commercial testing laboratory.

1 ton=0.9 Mg
1 person-hour per 1,000 tons=1.1 person-hour per 1.0 Gg

Although the three State programs investigated represent current applications of a particular approach to aggregate gradation control testing, it is still difficult to make generalizations from only three programs. Each State has a unique combination of aggregate sources, sampling frequencies, sampling locations, aggregate production and consumption quantities, and interactions among user agencies. The maximum value of the economic analysis would be realized if other States analyzed and compared their own aggregate gradation control programs with those of the three States.

Table 4 summarizes the comparison of labor for the three States. There is a large variation in State highway agency labor for aggregate gradation testing—a ratio of 18:1 between the largest and smallest levels of effort. By contrast, despite the dissimilarity of programs, the producers' efforts vary only by a ratio of 7:1. Moreover, the total producer effort is fairly low even in State A where the gradation control program places considerable testing requirements on the producers.

Another interesting point is the amount of labor expended by State A's highway agency on its gradation control program. Although this State implemented a QA–QC program, the State still performs considerable verification and acceptance testing. Lesser effort by the State would probably be sufficient for adequate gradation control.

Table 3.—Labor used for aggregate gradation control in State C

Labor used by State highway agency

Entity	Number of technicians	Work in gradation testing	Full-time equivalents	Number of entities surveyed	Number of entities represented	Extrapolated full-time equivalents	Annual person-hours
		Percent					
Rural areas							
Central laboratory	2	75	1.50	1	1	1.50	3,120
District laboratory	2	20	0.40	1	4	8.00	3,328
Resident Engineer	2	30	0.60				
Resident Engineer	2	50	1.00	2	36	28.80	59,904
Urban area							
Central laboratory branch	PCC 7	25	1.75	1	1	1.75	3,640
District laboratory	BC 1	100	1.00				
	3	40	1.20	1	1	2.20	4,576
Resident Engineer	2	20	0.40	1	13	5.20	10,816

Total labor (person-hours)	Total aggregate consumption (millions of tons, 1978)	Person-hours per 1,000 tons
66,352 (rural)	0.85 (rural)	78.1 (rural)
19,032 (urban)	0.85 (urban)	22.4 (urban)
85,384	1.7	50.2

Labor used by producers

Producer	Number of technicians	Work in gradation testing	Full-time equivalents	Annual person-hours	Annual production
		Percent			*Millions of tons*
P–C1	2	20	0.40	830	2.5
P–C2	1	25	0.25	520	1.3
P–C3	1	25	0.25	520	2.0
P–C4	2	30	0.60	1,250	1.0
P–C5	2	25	0.50	1,040	1.0
P–C6	3	33	1.00	2,080	1.3

Total labor (person-hours)	Total aggregate production (millions of tons, 1978)	Person-hours per 1,000 tons
6,240	18.2[1]	0.3

[1] Production tonnage has been doubled to include producers in rural areas who generally do not have QC programs.

1 ton=0.9 Mg
1 person-hour per 1,000 tons=1.1 person-hour per 1.0 Gg

All three States reported good aggregate quality resulting from their gradation control programs. Although quality is subjective and aggregate acceptable in one State might be unacceptable in another, it would appear that adequate quality can be maintained with any of the programs examined. At least for the levels of effort presently being expended in gradation control, it cannot be shown that the product quality resulting from different programs varies significantly.

The analysis indicates that the traditional program of State C is approximately three times more expensive than the producer-oriented program of State A and almost 15 times more expensive, in terms of person-hours per 900 Mg (1,000 tons), than the contractor-oriented program of State B. It was not known until after the detailed field investigation was underway that the total annual aggregate consumption in State C was much lower than in the other two States. Nevertheless, it would take a threefold increase in aggregate consumption, without increase in labor, for the traditional program to yield costs comparable to those of the producer-oriented program. The increase in consumption would have to be almost 15 times as large to arrive at costs similar to the contractor-oriented program. Such consumption increases could not be handled feasibly without significantly increasing labor.

The high labor effort expended by State C's highway agency is partly because of travel time involved in collecting samples in the rural area of the State. The urban area of State C, which may be more representative of many States, has a considerably lower labor effort. Nevertheless, the urban area effort is still higher than the efforts of the other two States. It can thus be concluded that both urban and rural States using traditional programs can benefit through a QA–QC program, especially rural States that can decrease sample collection travel time by adopting producer- or contractor-oriented programs.

Table 4.—Comparison of labor for States A, B, and C

State program	Person-hours per 1,000 tons: State highway agency	Person-hours per 1,000 tons: Producers	Total person-hours by State highway agency
A	15.4	2.3	196,560
B	2.8	0.8	56,160
C	50.2	0.3	85,384

1 ton=0.9 Mg
1 person-hour per 1,000 tons=1.1 person-hour per 1.0 Gg

Impact of a QA–QC Program

In addition to considering costs, the impact of a QA–QC program must be examined. For the State highway agency, the cost savings represent the most immediate tangible benefit; however, the substantial although intangible benefit of avoiding potential liabilities from the State's performance of quality control tests on intermediate products should not be underemphasized.

A QA–QC program with the contractor fully responsible for the quality of aggregate used in construction also should offer significant advantages to the contractor. Although most of the cost for gradation testing is absorbed by the contractor, actual costs are relatively low, as substantiated by the relatively small differences in producer/supplier cost data derived from the three States investigated. In addition to low costs, test results are always immediately available, allowing more timely adjustments to be made. Also, by being responsible for testing, contractors can better monitor their contractual relationships with the producers for quality control. Contractors face additional costs and responsibilities under QA–QC programs, but most contractors surveyed during the investigations of the States using such programs indicated that they were satisfied with the QA–QC approach used in those States. It has not yet been demonstrated whether a small contractor has greater initial difficulty than would a large contractor in establishing an aggregate gradation control program.

Implementation of a QA–QC program probably would have a significant impact on aggregate producers and concrete suppliers, because in most cases contractors would delegate the responsibility for testing. On the other hand, aggregate producers and concrete suppliers, unburdened by State-mandated quality control programs, could perform only the testing they felt necessary to achieve adequate process control for the characteristics of their particular aggregate and their particular facility. In this manner, the cost to the producer and supplier would represent a voluntary quality control effort dictated by market forces, not one imposed by the State.

Consumers in local and county jurisdictions may be adversely affected by a QA–QC program if they are relying on the State's efforts for aggregate gradation control for their own projects. However, by using their own QA–QC approach, those agencies could minimize their own effort for adequate quality assurance. They would have to carry their own share of the aggregate gradation control costs rather than being subsidized by the State. At the same time, local and county agencies may find that the implementation of a QA–QC program by the State results in a better quality product for their own projects because of the improved process control by the contractor.

Summary

This article describes detailed economic analyses of aggregate gradation control programs in three States. Other States are encouraged to perform a similar analysis of their own program and make comparisons. Although each State's program is unique, conclusions can be drawn about relative costs of the kinds of programs. The cost of aggregate gradation control is lowest where the State highway agency does not involve itself in process control testing. Although process control should be exercised at various steps in the production, transportation, and handling of the aggregate, it is not efficient for the State highway agency to do such testing.

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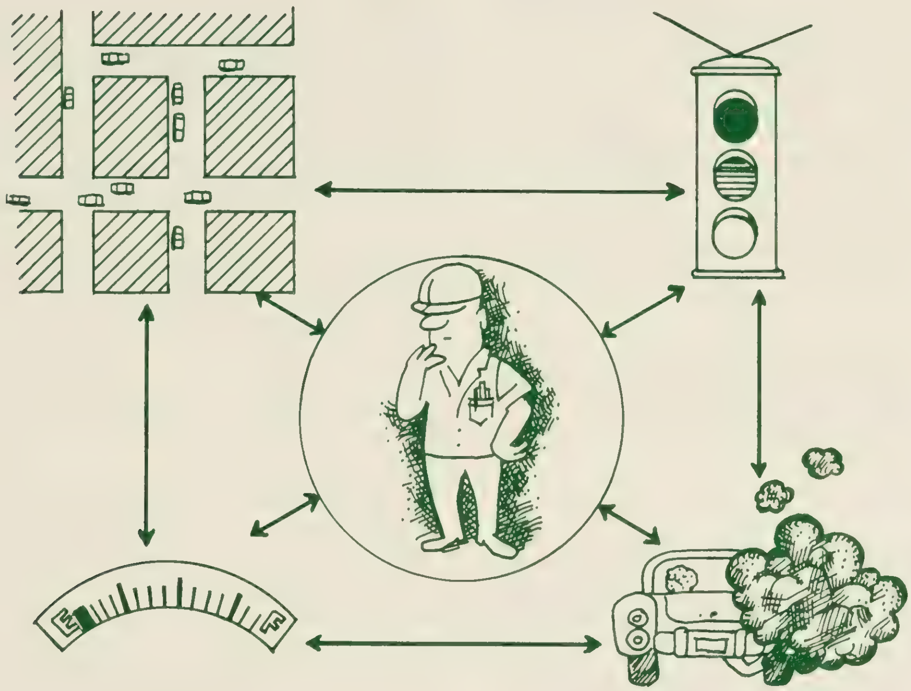
Update of the Fuel Consumption and Emission Values in the NETSIM Traffic Simulation Model

by
Alberto J. Santiago



Introduction

In the United States it has been estimated that all modes of highway transportation account for 74 percent of the total transportation energy and 45 percent of all U.S. fuel consumption. (*1*)[1] Additionally, it has been estimated that highway transportation accounts for 50 percent of the total annual emissions of air pollutants such as carbon monoxide, hydrocarbons, nitrogen oxides, sulfur oxides, and particulates. (*2*) These statistics dramatically demonstrate the seriousness of the energy and environmental problems related to highway transportation.

The Problem

The problem is very simple to state: "How can we reduce fuel consumption and emissions from vehicles operating on a street network?" Unfortunately, the answers are quite complex.

To resolve this problem a dual approach is required. First, we need cleaner and more energy-efficient vehicles; second, we need a means of accurately estimating and predicting fuel consumption and emissions from vehicles operating on a network to assess accurately the energy and environmental impacts of traffic control strategies and roadway designs.

Breakthroughs in technology, achieved by automotive engineers, have provided the means for manufacturing cleaner and more efficient vehicles. Today, automobiles averaging 12.8 to 17.0 km/L (30 to 40 miles per gal) are common, and all automobiles manufactured and sold in the United States have some kind of emission control system to insure environmental protection. The problems still remaining for the traffic engineer are how to predict vehicular fuel consumption and emissions in a given operating environment and how to enhance roadway designs and traffic control strategies to provide an environment where vehicles can operate more efficiently.

In response to these problems, the Federal Highway Administration (FHWA) and others have developed computer programs to evaluate geometric designs

[1] Italic numbers in parentheses identify references on page 29.

and traffic control strategies (primarily for urban areas) from environmental and energy conservation standpoints. Extensive use of these models has demonstrated their potential as effective tools in the development of traffic engineering measures that reduce (1) motorist operating costs; (2) fuel consumption; (3) costs associated with planning, designing, and implementing new traffic control strategies; and (4) costly and inconvenient retrofits when problems in a strategy are detected only after implementation. These computer programs can be categorized into three major groups:

- Simulation models (NETSIM, TRAFLO, TRANSYT, SIGOP)—simulate the performance of traffic under a given set of geometrics and control strategies.
- Optimization programs (SOAP, PASSER, MAXBAND, TRANSYT[2], SIGOP[2])—optimize traffic signal settings by reducing delay and fuel consumption.
- Control programs (UTCS Enhanced, UTCS Extended)—control traffic signal settings based on traffic flow fluctuations and/or time-of-day operation on a real-time basis.

The NETSIM Model

This article focuses primarily on the NETSIM simulation model, which is the most sophisticated of the current traffic models. By using this model, engineers can test and evaluate a range of feasible traffic control strategies and geometric designs quickly, efficiently, and economically. NETSIM simulates the operations of urban traffic by generating the trajectory of each type of vehicle—automobiles, trucks, and buses—in the system as it traverses a specified network of urban streets (links) and intersections (nodes). Each such vehicle responds to local conditions, primarily the signal control and the influence of neighboring vehicles. At the conclusion of each second of simulated time each vehicle's position, speed, and acceleration are determined. (*3*, *4*) This 1-second resolution permits highly accurate simulations of traffic flow in an urban network.

As an output, NETSIM estimates vehicular fuel consumption and emissions for the condition modeled based on a series of tables embedded in the program. These tables, developed in 1976, represent the vehicular fuel consumption and emissions of the 1971 vehicle fleet and were derived from computer simulations of engine performance. (*3*, *5*) However, fuel consumption and emissions calculations are limited because the number of tables in NETSIM is restricted to one per vehicle type. This implies that tables used by the model have to be representative of the vehicle population within the vehicle type.

The energy crises of 1973–1974 and 1979, in addition to the Clean Air Act Amendments of 1977, triggered changes in vehicle manufacturing policy. New vehicles were to be smaller, lighter, cleaner, and most important, more energy efficient. In a short time, these changes have made the fuel consumption and emission tables in NETSIM obsolete.

FHWA, recognizing the need to update the tables, currently is sponsoring the study "Fuel Consumption and Emission Values for Traffic Models." The development of fuel consumption and emission tables for vehicles representative of the entire 1980 fleet would be time consuming and costly. Because of budget and personnel limitations, the FHWA study is limited to passenger vehicles.

The scope of the study is to determine vehicular fuel consumption and emissions for the passenger vehicle fleet in two phases. Phase I is already completed and Phase II is currently underway.

Phase I—Present and Near Future Vehicle Fleet

The main objectives of this phase were to define the present and near future passenger vehicle fleet and to determine the vehicles for which fuel consumption and emission tables should be developed.

To make the project cost effective, the boundaries of the time frame defining "current" and "near future" had to maximize the period of time for which the fuel consumption and emission tables would be valid. Based on this constraint, 1979 was selected as the lower boundary and 1985 as the upper boundary for the following reasons:

- Between 1975 and 1977 vehicle manufacturers responded to the energy crisis of 1973–1974 by manufacturing more fuel-efficient vehicles than those manufactured before 1973. Unfortunately, this manufacturing policy started to fade in 1976 and 1977, and by 1979 most vehicles manufactured in the United States were eight-cylinder engined vehicles. (*6*)
- In 1979 a second energy crisis convinced the U.S. vehicle manufacturing industry and the general public of the severity of the energy problem.
- As of May 1981 none of the manufacturers of vehicles sold or manufactured in the United States had developed product plans beyond 1985. (*7*)

After determining that 1979–1985 would define the current and near future passenger vehicle population, all the passenger vehicles that were and will be manufactured and sold in the United States (including domestic and foreign) during that time were investigated. These vehicles were defined by

[2]Contain simulation capabilities.

engine size (displacement) and engine-drivetrain combination (engine and transmission) instead of by model because of the availability of different engine sizes and transmissions within the same vehicle model.

The 1979–1985 passenger vehicle population was divided into two groups—the 1979–1981 population and the 1982–1985 population. The 1982–1985 population was defined in terms of the 1979–1981 population so that fuel consumption and emission maps (graphical representations of the relationships between variables that affect fuel consumption and emissions) could be developed for the nonexistent vehicles.

From an analysis of the 1979–1981 passenger vehicle population, 57 engine sizes were identified ranging from 1.1 to 6.0 L of displacement (70 to 368 in^3 of displacement). These engines were in 176 vehicle models, yielding over 500 engine-drivetrain combinations (transmissions were classified as automatic or manual and by the number of forward gears). (*6*, *8*) Of these 500 engine-drivetrain combinations, over 350 combinations will be available between 1982 and 1985. (*7*)

It is not cost effective to develop fuel consumption and emission maps for over 350 engine-drivetrain combinations, so accurate sales figures[3] were used as weighting factors to determine the "most common" combinations in the 1979–1985 passenger vehicle population. (*6*, *7*) From an analysis of these data, 21 engine-drivetrain combinations were identified to account for 74 percent of the 1979–1985 passenger vehicle population.

Because of budget limitations, 15 of the 21 engine-drivetrain combinations will be selected for testing in Phase II (table 1). In the worst case, where the 15 combinations selected for testing are the "less common," the resulting fuel consumption maps will be representative of 57 percent of the 1979–1985 passenger vehicle population. In the best case, where the 15 combinations selected are the "most common," the resulting fuel consumption maps will be representative of 66 percent of the 1979–1985 passenger vehicle population. Maximizing the percentage of representation will be attempted; however, the final selection of vehicles will depend on their availability from rental and leasing agencies.

The development of a fuel consumption and emission table representative of the entire automobile fleet requires that individual tables be developed for different categories, such as four-, six-, and eight-cylinder vehicles, and subsequently pooled using sales figures as weighting factors. The resulting table is statistically representative of the automobile fleet.

[3]Confidential figures submitted by the vehicle manufacturers to the National Highway Traffic Safety Administration for Corporate Automobile Fuel Economy certification.

Table 1.—Engine-drivetrain combinations to be representative of the 1979–1985 passenger vehicle population

Engine size	Cylinders	Transmission[1] and number of forward gears
Cubic inches of displacement		
90	4	A3 and M5
97	4	A3 and M4
105	4	A3 and M5
107	4	A3 and M5
108	4	A3 and M5
140	4	A3 and M4
151	4	A3
156	4	A3
173	6	A3
200	6	A3
229	6	A3
231	6	A3
267	8	A3
302	8	A4
350	8	A3

[1] A=automatic; M=manual.
1 in^3=0.016 L

Projections indicate that if the vehicle manufacturers remain relatively close to the 1981–1985 product plans developed in 1981, the tables to be developed in Phase II will be valid until 1992. This rationale is based on the fact that tables will be developed for 15 engine-drivetrain combinations, and by using the pooling procedure discussed above, updates could be made without having to develop additional tables.

Phase II—Development of Fuel Consumption and Emission Maps

The objective of this phase is to develop accurate fuel consumption and emission tables for 15 of the 21 engine-drivetrain combinations specified in Phase I. These tables will be derived from fuel consumption and emission maps developed, to the extent possible, from field experimentation.

In the past, research has been oriented toward developing fuel consumption and emission maps from computer simulations of engine performance or chassis dynamometer testing. These approaches produce accurate maps that describe the performance of the engine *exclusively* and not the performance of the vehicle as it operates on the road. This, then, justifies developing maps from field experimentation.

Following are discussions on the procedures to be used in Phase II of this research study and the expected results.

Development of fuel consumption maps

Three systems—the engine, the vehicle (which includes body and engine), and the driver—must be analyzed in detail to assess vehicular fuel consumption. Only the first two systems will be discussed in this article because the driver (the system that controls the operation of the engine and vehicle) is simulated by the model. NETSIM calculates the speed and acceleration of the vehicle using car-following algorithms derived from driver behavior. Fuel consumption is then derived from the modeled speeds and accelerations. This implies that the fuel consumption maps to be developed in this study must cover the range of speeds and accelerations that the vehicles are capable of so that fuel consumption can be accurately estimated for any given driving cycle.

The engine and the vehicle must be analyzed as two separate systems because the engine is the element that actually consumes fuel and the vehicle is the medium by which loads are applied to the engine. This analysis encompasses the development of the following two separate data bases that describe fuel consumption from each system.

- A data base developed through chassis dynamometer tests relating fuel flow to engine revolutions per minute (RPM) and manifold vacuum. This data base will describe the engine.
- A road-test data base relating vehicle speed and acceleration to engine RPM, manifold vacuum, fuel flow, and operating temperatures for each gear. This data base will describe the vehicle.

Maps derived from chassis dynamometer testing are extremely useful because fuel flow rate is identified uniquely by engine RPM and manifold vacuum independent of the secondary effects of temperature and atmospheric pressure on the combustion efficiency itself. The resultant maps are independent of driveline efficiencies, lubricant temperatures, and rolling resistance because any changes in these parameters will change the manifold vacuum pressure at a given RPM.

These dynamometer maps are necessary because in carbureted engines it is not possible to measure fuel flowing into the engine itself without extensive modifications to the carburetor. If carried out, these modifications may affect the operating characteristics of the engine. Therefore, only the fuel flowing into the carburetor can be measured.

At low speeds and high accelerations, the combined effects of fuel sloshing in the carburetor bowl and the timelags induced by the filtering effects of the bowl make it impossible to draw any conclusions concerning fuel flow rate into the engine. On the dynamometer, fuel sloshing effects are negligible, as it is possible to remain at any operating point sufficiently long to overcome the filtering effects of the carburetor bowl.

On-road testing of vehicles is necessary to assess vehicular fuel consumption in the vehicles' operating environments. These tests consist of fully instrumenting each vehicle and driving it through all possible combinations of speed and acceleration until sufficient data have been collected to characterize fully the behavior of the vehicle. To obtain statistically valid results, the tests are repeated several times randomizing the order of the individual runs to prevent any systematic bias in the recorded data.

The instrumentation installed in the vehicles consists of the data logger, which samples and records data, fifth wheel assembly, inclinometer, electronic tachometer, pressure transducers, electrical thermocouples, fuel flow meter, and power supply.

The data logger records each data element every 0.05 seconds on a cassette tape that is later analyzed in a computer. The fifth wheel assembly measures distance, speed, and acceleration, and the inclinometer measures road grades to correct the acceleration readings to what they would have been on a level road. The electronic tachometer, pressure transducers, and electrical thermocouples measure engine RPM, vacuum pressure, and engine temperature, respectively. The equipment weighs approximately 68 kg (150 lb) and fits in the rear passenger area of a vehicle.

On-road tests will be conducted on an airport runway because of the safety advantages over conducting the tests on public roads. The tests require that fuel consumption data for high speeds and abrupt accelerations must be collected, and this might be hazardous if carried out on public roads. Additionally, conducting the tests on a smooth, leveled pavement increases the accuracy of the data collected by the fifth wheel assembly. Bumps, cracks, potholes, and joints in pavements make the fifth wheel bounce, resulting in erroneous measurements of speed, acceleration, and distance.

Subsequently, the data bases generated by the dynamometer testing and the on-road testing are merged and run through statistical mapping procedures to produce maps that relate fuel flow rate to the vehicles' speed and acceleration for each available gear.

Development of emission maps

The relatively long response times of current emission analyzers coupled with their bulk, weight, and high power requirements relegate any testing program to one of steady-state determinations on a chassis dynamometer. In this study, it is anticipated that test procedures for hydrocarbon and carbon monoxide emissions can be developed that are analogous to and compatible with those used for the fuel consumption tests. That is, if each engine operating point, as defined by engine RPM and manifold vacuum, determines the emission rates of the vehicle[4], then emission maps can be developed on the dynamometer that can be linked to on-road performance through measurements of the determining factors in an on-road test in a manner similar to the methodology used in developing the fuel consumption maps.

Summary and Recommendations

From a transportation perspective, the scenario for the 1980's is restricted by energy and environmental concerns. The era of abundant energy supplies is past, and reducing air pollution is imperative. It is time to work with greater commitment and urgency toward implementing environmentally safe and energy-efficient solutions.

Future research should be oriented toward developing fuel consumption and emission maps for trucks and buses in a manner similar to the one described in this article. Also, efforts should be directed toward developing feasible roadway design practices that would provide an operating environment where vehicles could operate efficiently.

To cope with environmental and energy problems, major traffic engineering actions, requiring accurate analysis tools, must be planned and pursued aggressively over many years. The successful completion of this study will update and improve the capabilities of the NETSIM model in accurately estimating fuel consumption and emissions from passenger vehicles in an urban network. This enhancement will provide the traffic engineering community with a powerful tool for developing, testing, and evaluating traffic control strategies in addition to determining the environmental and energy impacts of such strategies in an urban setting.

[4]Subject to verification through this study.

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[5]Report with PB number is available from the National Technical Information Service, 5285 Port Royal Rd., Springfield, Va. 22161.

Grade Severity Rating System

by

Paul Abbott

Introduction

Many research projects have focused on the causes of heavy truck accidents on downgrades and on countermeasures for these accidents. (*1–4*)[1] Despite the money and time expended on such research, no fully satisfactory countermeasures have been developed; the effectiveness of various countermeasures is not known nor is it known which countermeasures work best in given situations. The lack of accurate information about the effectiveness of a countermeasure has hampered the efforts of design and safety engineers to minimize the adverse effects of downgrades on heavy trucks and to choose appropriate countermeasures for different situations.

States have tried various advisory signs, which are intended to prevent accidents by giving drivers information on the percent of downgrade slope, length of hill and degree of slope, use of a lower gear, and downgrade configuration (fig. 1). In addition to signs, brake inspection areas (fig. 2) have been constructed at the crests of hills, and some States require that drivers of heavy trucks stop at these areas. Another countermeasure that has received increasing attention in recent years is the escape ramp (fig. 3).

All of these countermeasures have advantages and disadvantages. For example, escape ramps are effective only if drivers are willing to use them and if the ramps can be built to adequate design standards on terrain surrounding the downgrade. Signs are inexpensive and easy to install but are effective only if drivers understand and follow the advice.

As a result of continuing interest in truck downgrade accident prevention and the lack of information on preventing or mitigating such accidents, the Federal Highway Administration (FHWA) initiated research in 1977 to investigate heavy truck downgrade accident problems and develop a grade severity rating (GSR) model to determine the severity of a downgrade and a method of informing truck drivers of the best gear for descending a specific downgrade. (*5, 6*)

This research initiated further study to determine the most effective advisory sign by testing in a simulator a set of weight-specific speed signs and developing criteria for road testing the most effective sign.

[1] Italic numbers in parentheses identify references on page 34.

History of Grade Severity Rating Models

One of the first GSR models, proposed in the early 1960's, expanded the three U.S. Bureau of Public Roads grade categories into 10 categories with finer distinctions between grades based on grade length and degree of slope. (*7*)

In 1975 another GSR model introduced the following important new ideas: (*8*)

• The concept of rating hills by their effect on a representative truck.

• The inclusion of the effect of hill length by considering brake fade effects.

• The use of a stopping distance criterion as a measure of available braking capacity.

This model, based on the "work energy theorem," applied to braking on a grade. The work energy theorem equation can be solved for the descent speed, which will allow stopping in a criterion distance. To use the equation, the total retarding force must include brake and nonbrake terms. The brake terms for unfaded brakes were derived from field test results and modified for fade effects using a brake fade factor. (*7, 8*) This brake fade correction was derived from temperature measurements made during brake dynamometer tests. To use the brake fade factor, the concept of brake equivalent time—hill descent time multiplied by the percent brake use—was introduced.

Limitations in the model because of a lack of knowledge of the effects of nonbrake forces and the effects of brake fade prevented this from being a functional GSR model. Research indicates driver inexperience, failure to downshift, and inadequate signing can be affected by informational signs, and therefore these factors essentially define the requirements for a functional GSR model.

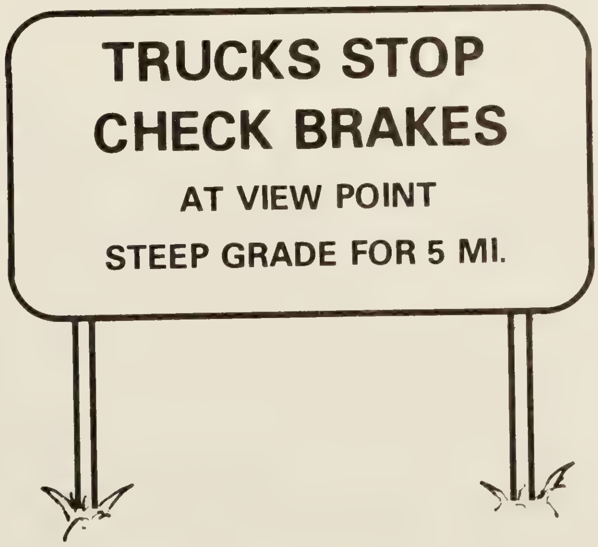
Development of a Grade Severity Rating Model

Developing a standard method of rating downgrades based on grade severity requires an in-depth understanding of the relationships among speed, brake usage, vehicle weight, and brake fade. This is complicated by the fact that hills having entirely different geometric characteristics may place the same braking requirements on vehicles. For instance, a 7 percent 11.3 km (7 mile) downgrade may place the same total braking load on a vehicle as a 9 percent 6.4 km (4 mile) downgrade and, thus, may require the same initial speed for a safe descent. Further, downgrades are not always constant nor continuous. A grade might be 9 percent for 3.2 km (2 miles) and 5 percent for 11.3 km (7 miles); another grade might be 8 percent for 4.8 km (3 miles), level for 1.6 km (1 mile), and 6 percent for 11.3 km (7 miles). All of these grade configurations might place the same braking requirements on a vehicle. The GSR model overcomes this problem by allowing each downgrade to be rated according to its specific characteristics.

Research indicated that determining how to measure brake effectiveness was necessary before a functional GSR model could be developed. Computer simulation and field testing were used to collect data on the effect of truck weight, length and slope of downgrade, and truck speed on brake fade and brake effectiveness. Field testing was done on both level roads and downgrades using a calibrated 34.3 Mg (75,650 lb) truck with a retarder (engine brake). After initial testing, truck brake temperature was determined to be the most important factor to consider in developing a GSR model so subsequent field testing concentrated on collecting these data. A speed brake temperature prediction model was developed.

Figure 1.—Standard downgrade advisory signs.

Figure 2.—Combined advisory sign for brake test area and grade severity.



The model was field tested on seven downgrades in the Western United States using a single instrumented truck. Brake temperatures were predicted for the test vehicle and compared with the actual tested brake temperatures. The correlation coefficient between predicted and actual brake temperatures was 0.85.

In another field test, 25 randomly selected trucks were tested on the Grapevine, a downgrade on I–5 south of Bakersfield, Calif. Using the speed brake temperature prediction model, the brake temperature at the bottom of the downgrade was calculated based on truck weight, brake temperature at the start of the descent, vehicle speed on the grade, and length and degree of slope. The correlation coefficient between the predicted and actual temperatures at the bottom of the grade in this test was 0.81.

As a result of field tests on both level roads and downgrades and an analysis of truck transmission characteristics and associated engine braking forces, a model was developed to determine the maximum safe descent speeds for beginning a grade for specific weight trucks. A safe descent speed is that speed at which the driver can maintain control of the truck without having to apply more than 44.5–66.7 N (10–15 lb) brake pressure for the length of the grade. This enables the brakes to dissipate the heat caused by braking without overheating, thus allowing the truck to maintain constant speed on the downgrade and to stop on the downgrade.

Figure 3.—Example of a gravity escape ramp (top). Example of a gravel escape ramp (bottom).

The Grade Severity Rating System

The Grade Severity Rating System (GSRS) includes the process of determining the severity of a grade, a method of calculating a safe descent speed for a truck of a specific weight, and a means of conveying the weight-specific speed information to the truck driver.

The relationship among truck speed, engine speed in revolutions per minute (RPM), and transmission gears is important in developing a GSRS. Heavy trucks are designed so that they operate within a narrow band of engine RPM's. The driver learns to maintain a specific vehicle speed by matching engine speed with the appropriate gear. Thus, an experienced driver, when given a slower speed to drive, immediately recognizes the appropriate gear and slows down by downshifting until the correct gear is reached. A driver with little experience in a specific truck would not know the exact gear to use but would go through the same procedure of slowing down and downshifting until the appropriate engine and vehicle speeds were reached, at which time the truck would be in the appropriate gear.

Initial research indicated that it was possible to assign a downgrade a grade severity rating from 1 to 9 based on length and degree of slope. A truck of a specific weight could safely negotiate different hills having the same severity rating.

To implement a GSRS an "in-cab-truck specific gear selection model" had to be developed. This was complicated by the number of combinations of transmissions, weights, and hills and the complexity of the calculations a driver would have to make to select the

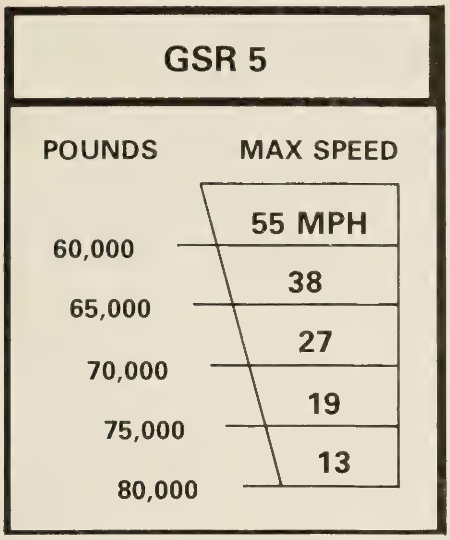


Figure 4.—Combined grade severity rating and weight-specific speed sign.

proper speed given such data as truck weight and severity rating. As the research progressed, it became apparent a trade-off existed between giving every driver of every weight truck enough information to determine maximum safe descent speed and correct gear and developing a system that could be used under actual operating conditions.

As a result, the grade severity rating sign was combined with a weight-specific speed sign (fig. 4) allowing the truck driver to select the appropriate gear for descending a specific hill based on the grade severity rating of the hill and recommended speed based on vehicle weight and transmission characteristics. Although this approach to developing the GSRS is different from the in-cab gear selection approach discussed above, it provided the truck driver with information necessary to drive safely on downgrades.

Development of Weight-Specific Speed Signs

A primary consideration in developing a usable GSRS is the number of weight ranges that should be used—the more weight ranges, the more specific the weight speed information. Too many weight ranges, however, would make the GSRS sign confusing and difficult to use.

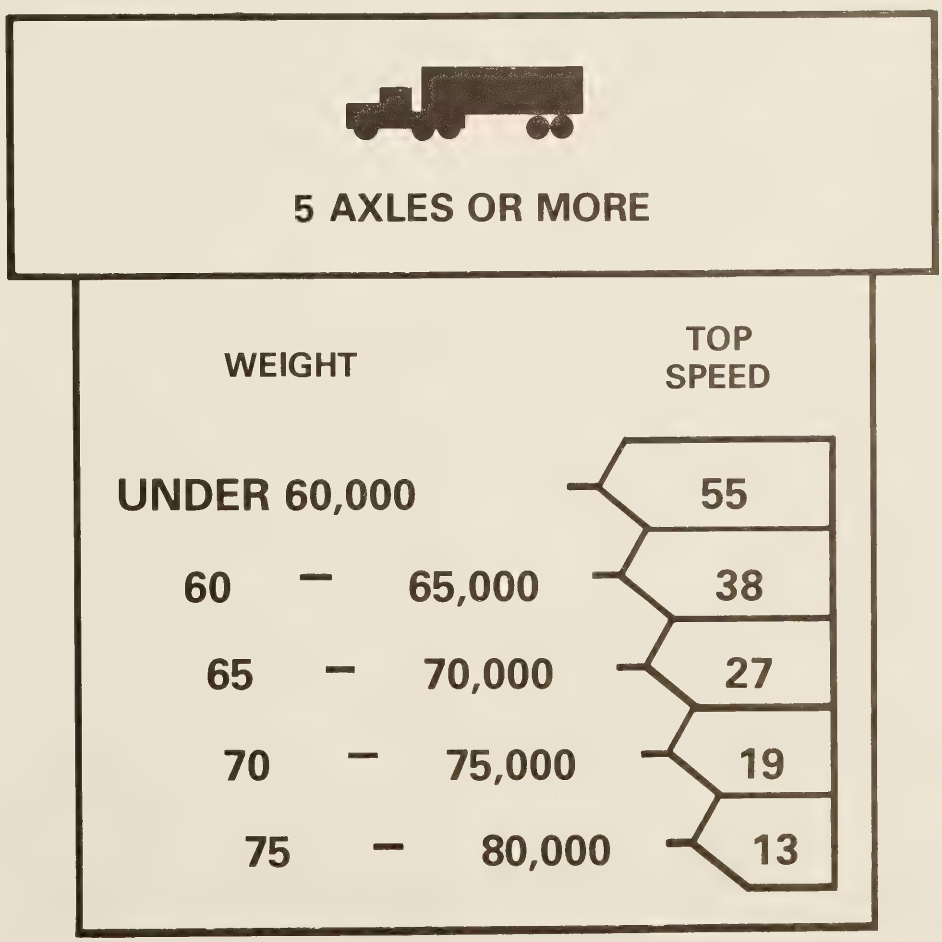
To determine the weight ranges for a weight-specific speed classification, the effects of slight changes in vehicle speed and weight on braking requirements were investigated. This research determined which weight ranges and corresponding speeds would allow the maximum number of trucks to safely descend a grade with a minimum reduction in speed at the lower limit of each weight range.

Additional research indicated a potential problem with combining the grade severity rating with the weight-specific speed signs. For the most severe downgrades—those with a rating of 7, 8, or 9—the severity rating would be different for different weight trucks. For example, for a 36.3 Mg (80,000 lb) truck, a severe downgrade might need to be rated 9; for a 27.2 Mg (60,000 lb) truck, the same downgrade might need to be rated 7. Thus, for safety the same downgrade would have to be assigned two ratings based on truck weight. However, assigning more than one or only one grade severity rating to such a hill could mislead some drivers and create an unsafe driving situation.

Another finding of simulator tests was that the weight-specific speed sign alone allows drivers to select the appropriate gear; therefore, the grade severity rating was unnecessary. As a result, it was determined that weight-specific speed signs were the most effective method for conveying necessary information to truck drivers (fig. 5).

The proposed GSRS consisted of a formula for calculating safe speeds on downgrades by truck weight and the use of weight-

Figure 5.—Weight-specific speed sign.



specific speed signs. The best display format for the weight-specific speed signs will be tested later in the study.

Weight-specific speeds are determined with tolerances built into the calculations to allow for the fact that not all trucks have new brakes and that some trucks operate at less than maximum efficiency because of dust or oil on the brakes.

Conclusions

Although weight-specific speed signs still have to be developed and tested fully, research indicates that the implemented GSRS will improve heavy truck safety on downgrades and also improve traffic flow on hills that have a significant amount of truck traffic.

A set of tables and instructions has been developed that allows safe operating speeds on a specific hill for trucks weighing up to 36.3 Mg (80,000 lb) to be determined quickly. (*6*) The basic formula also is included so safe descent speeds can be calculated for trucks operating with specific use permits that allow gross vehicle weights greater than 36.3 Mg (80,000 lb). Length of grade and degree of slope must be measured accurately if the weight-specific speed calculations are to result in safe operating speeds.

Ongoing Research

Research continues on selecting and simulator testing signs to identify the most effective sign for transmitting weight-specific speed information to truck drivers. After the conclusion of the study, FHWA, with the cooperation of one or more States, expects to field test the GSRS using various methods to gather data on the effectiveness of the system.

- Weight-specific speed signs will be placed at beginnings of downgrades on highways with weigh stations close to the beginning of the downgrade to enable researchers to record speeds at the bottom of the downgrade and match them with the truck's gross vehicle weight.

- Speed readings on a downgrade will be taken before and after installing weight-specific speed signs to determine if the signs impacted the average truck speed at the bottom of the grade.

- Weight-specific speed signs will be installed on hills with frequently used escape ramps. Sign effectiveness will be measured by the change in the use of the ramps. This approach might work best where gravel beds instead of gravity ramps are used for escape ramps. Some trucks can be backed out of a gravity ramp and driven away, making it difficult to accurately assess the number of times the gravity ramp is used. On the other hand, a driver may be able to back out of a gravel arrester bed, but the tire marks in the gravel indicate the escape ramp has been used.

Initial results of the proposed field test probably will not be available before early 1984.

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(*2*) J. R. Allison, K. C. Hahn, and J. E. Bryden, "Performance of a Gravel-Bed Truck Arrester System," Transportation Research Record No. 736, *Transportation Research Board*, Washington, D.C., 1979.

(*3*) Earl C. Williams, Jr., "Emergency Escape Ramps for Runaway Heavy Vehicles," Report No. FHWA–TS–79–201, *Federal Highway Administration*, Washington, D.C., March 1978. PB No. 81 104283.

(*4*) "Interim Guidelines for Design of Emergency Escape Ramps," Technical Advisory T5040.10, *Federal Highway Administration*, Washington, D.C., July 5, 1979.

(*5*) Thomas T. Myers, Irving L. Ashkenas, and Walter A. Johnson, "Feasibility of a Grade Severity Rating System," Report No. FHWA–RD–79–116, *Federal Highway Administration*, Washington, D.C., August 1980.

(*6*) Walter A. Johnson, Richard J. DiMarco, and R. Wade Allen, "The Development and Evaluation of a Prototype Grade Severity Rating System," Report No. FHWA/RD–81/185, *Federal Highway Administration*, Washington, D.C., March 1982.

(*7*) Paul Hykes, "Downhill Control Prediction Procedure," SAE Paper No. 630A, *Society of Automotive Engineers*, January 1963.

(*8*) Richard A. Lill, "Development of Grade Severity Rating System," *American Trucking Association*, December 1975.

[2]Report with PB number is available from the National Technical Information Service, 5285 Port Royal Rd., Springfield, Va. 22161.

Paul Abbott, a program analyst in the Environmental Division, FHWA Office of Research, is contract manager for the research study "Evaluation of Techniques to Counteract Truck Accidents on Steep Downgrades." This study is part of FCP Project 1U, "Safety Aspects of Increased Size and Weight of Heavy Vehicles." Mr. Abbott also is contract manager of research studies in the areas of social and economic impact assessment and highway safety.

Recent Research Reports You Should Know About

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

Stop, Yield, and No Control at Intersections, Report No. FHWA/RD–81/084

by FHWA Traffic Systems Division

Observations and measurements were made at 140 low-volume intersections (less than 500 vehicles per day on the minor roadway) in Texas, Florida, and New York, three geographically different States. Kind of control—stop, yield, or no control; location—urban or rural; geometry—three-leg or four-leg; major roadway volume; and sight distance were examined to determine their individual and interactive effects on driver behavior, accident experience, and travel time through the intersection. Findings indicated that region, location, and geometry have a negligible effect on safety and traffic operation at low-volume intersections. Yield signs had the lowest road user costs of the three kinds of control considered. Stop signs had the highest user costs.

Limited copies of the report are available from the Traffic Systems Division, HRS–30, Federal Highway Administration, Washington, D.C. 20590.

Methods for Evaluation of Rail-Highway Grade Crossing Improvements, Report No. FHWA/RD–81/114

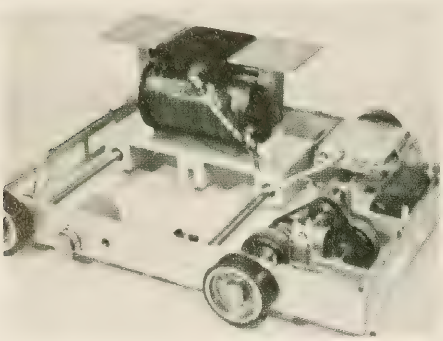
by FHWA Traffic Systems Division

This report discusses the results of a staff study that was performed to identify statistical methods for evaluating rail-highway grade crossing improvements. Six statistical concepts were identified. Three methods provide summaries and graphical displays of data. The other three methods provide tests of significance in comparative studies. National Grade Crossing Inventory and Accident data for 1975–1977 were considered in the study. The methods in the report can be used to compare data for 1975–1977 with data for 1978–1980.

Limited copies of the report are available from the Traffic Systems Division, HRS–31, Federal Highway Administration, Washington, D.C. 20590.

Detection of Flaws in Reinforcing Steel in Prestressed Concrete Bridge Members, Report No. FHWA/RD-81/087

by FHWA Structures and Applied Mechanics Division



In recent years there has been concern that corrosion could be developing in the prestressing steel of inservice prestressed concrete highway bridge members, threatening the structural integrity of the bridges. Currently used inspection procedures rely heavily on visual evidence (rust staining and cracking or spalling of the concrete) that a problem may be developing.

This report describes research to develop a practical nondestructive evaluation (NDE) technique for detecting deterioration in the prestressing steel of prestressed concrete bridge structural members. Fifteen available NDE methods were evaluated, and a magnetic field method was deemed the most promising way of detecting anomalies in ferromagnetic materials embedded in concrete. In this method, a steady-state magnetic field is applied to the prestressed concrete girder being inspected and a magnetic field sensor simultaneously scans stepwise along the length of the girder parallel to each stressing steel element. A perturbance in the scanned field indicates a break or other kind of metal anomaly in the girder. Experiments were conducted on large specimens with simulated steel flaws to determine the influence of a range of conditions and test parameters on the detectability of loss-of-section or fracture. The experiments explored the effects of varying degrees of steel deterioration, presence of adjacent unflawed steel elements, kind of duct, kind of steel, and transverse reinforcing steel configuration.

The magnetic field inspection equipment is installed on a self-propelled, remotely controlled inspection cart that travels along a lightweight track suspended by hangers clamped to the girder being inspected. The hangers are designed to permit an unobstructed scan to be made of the full length of the girder. The inspection hardware attached to the girder weighs approximately 209 kg (460 lb). The magnetic sensor assembly on the inspection cart may be positioned at any transverse location across the width of the girder, and the hangers can be adapted to permit inspection of a variety of prestressed concrete girder shapes.

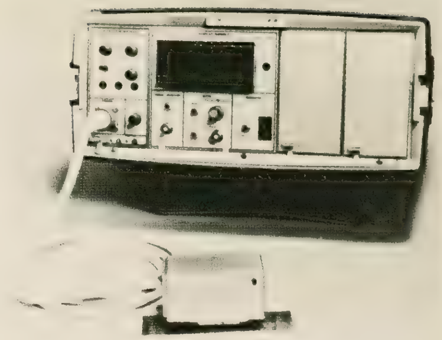
The report is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 81 241630).

Residual Stress Measurements in Structural Steels, Report No. FHWA/RD-81/086

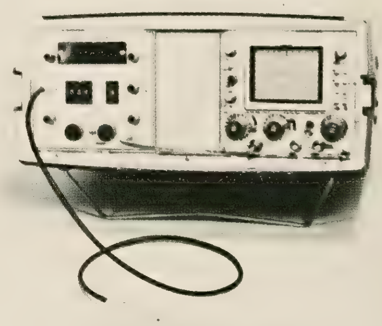
by FHWA Structures and Applied Mechanics Division

The presence of locked-in residual stresses that can occur in structural steel elements in service has been recognized as a significant design factor only in recent years. In general, residual stresses and working load stresses in steel members add vectorially. It is therefore important to account for residual stresses in design because these stresses can be of significant magnitude.

This report presents the results of a study to develop methodology and instrumentation for nondestructive measurement of residual stresses in structural steel bridge members. An initial state-of-the-art literature survey identified 26 candidate methods for measuring residual stresses, and each was assessed for its applicability to steel bridge components. This screening resulted in the selection of the Barkhausen noise analysis method for measuring surface stresses and



Barkhausen Noise Analysis System



Prototype Ultrasonic Birefringence Velocimeter

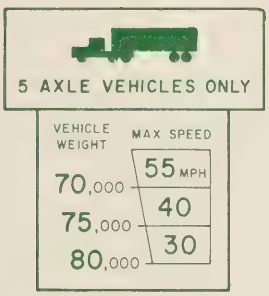
the ultrasonic shear wave birefringence method for measuring average bulk stresses. Although the theory and measurement methodology for both techniques were available before the start of this research study, Barkhausen noise analysis had not been used for field measurements, and ultrasonic birefringence instrumentation suitable for reliable quantitative measurements of residual stresses had not been developed. Because the methods complement one another, two experimental instrumentation systems were assembled and laboratory experiments were conducted to develop the potential of each method for field measurement of residual stresses in steel eyebar heads, girders with cover plates, and high-strength bolts. The success of these preliminary feasibility tests led to the development of prototype portable field instrumentation systems.

Subsequent field evaluations showed that the two new instrumentation systems could provide repeatable and reliable field data from which comprehensive analyses of residual stresses in steel elements of highway bridges could be made. The instrumentation can be used to obtain measurements in the structural steel fabrication shop, on the bridge during erection, or on existing bridges. Only nominal surface preparation of the structural member is required for making the measurements.

The report is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 81 241499).

The Development and Evaluation of a Prototype Grade Severity Rating System, Report No. FHWA/RD–81/185

by FHWA Environmental Division



This report presents a model for calculating downgrade severity and the maximum safe descent speed for a truck of a given weight and presents a prototype sign for conveying the weight-specific speed information to drivers. The method used to calculate the maximum safe descent speed considers length and degree of slope, vehicle weight, beginning brake temperature, and engine braking capacity. The data used to calculate the recommended descent speeds were collected through computer simulation and in road tests using an instrumented test truck. The recommended descent speed is calculated to allow the driver to negotiate the downgrade without overheating the vehicle brakes and to stop at the bottom of the grade or at any point on the grade.

Testing results indicate the best sign configuration displays vehicle weight by categories on the left and recommended speed on the right. Only vehicle weight and recommended speed are included on the sign because simulator testing results indicated that truck drivers downshift to an appropriate gear when given a specific speed to drive.

Limited copies of the report are available from the Environmental Division, HRS–43, Federal Highway Administration, Washington, D.C. 20590.

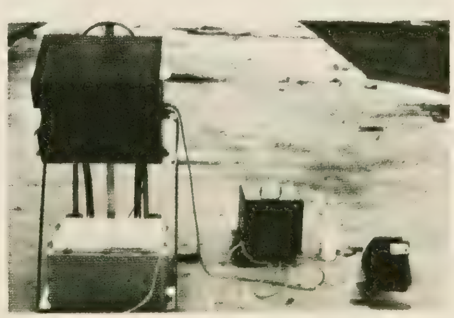
Rapid Determination of the Chloride Permeability of Concrete, Report No. FHWA/RD–81/119

by FHWA Materials Division

Techniques have been developed for rapidly determining the permeability of various concretes to chloride ions. The most promising method involves applying a 60 to 80 d.c. voltage for 6 hours to either a section of a reinforced concrete bridge deck or to a core taken from a concrete structure. Both variations require conditioning of the specimen before the test to eliminate test anomalies caused by low sample moisture contents.

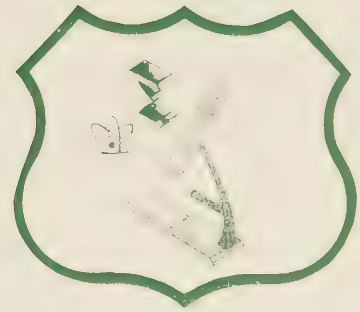
One core specimen per day can be tested, and a complete test, including conditioning, takes 2 days. The field apparatus can conduct four tests in 5 days on a given bridge deck. Results have correlated well with FHWA 90-day ponding data on companion specimens. Concretes can be ranked according to high, moderate, low, or very low chloride permeability. Further work is needed to make the test more applicable to field testing of bridge deck overlays.

The report is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 82 140724).



Usage Guide for Rapid-Set Epoxy Adhesive (118-AF) for Traffic Markers, Report No. FHWA/RD–80/032

by FHWA Materials Division



This report describes a new rapid-set, two-component epoxy adhesive for bonding traffic markers to roadway surfaces and provides guidance for its purchase. This adhesive is designed for machine mixing and dispensing and has the following principal features: Polymercaptan cure, which imparts rapid set at low temperatures; fibrillated polyethylene as the thixotrope (nonasbestos); and low viscosity, which allows good mixing even at moderately low temperatures. The rapid-set adhesive enables traffic to pass over the markers in less than 15 minutes after being placed at temperatures of 22° to 28° C (72° to 82° F).

This guide is designed to provide users and purchasers detailed information on the background of the development of the adhesive; composition of the adhesive; properties and experience in the field, including comparisons with the California Rapid-Set Epoxy Adhesive; use of the adhesive in the field and hauling precautions; and raw material costs. A proposed specification is presented.

Limited copies of the report are available from the Materials Division, HRS–23, Federal Highway Administration, Washington, D.C. 20590.

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

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

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

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

Durable Pavement Marking Materials Workshops, Report No. FHWA–TS–81–221

by FHWA Implementation Division

This report summarizes information presented at five workshops held in 1981 on the evaluation of six durable pavement marking materials. The workshops included presentations on paints, thermoplastics, epoxies, polyesters, preformed materials, and epoxy thermoplastic. The primary objective was to present the most current information on pavement marking materials. The characteristics, application techniques, and performance of each material are discussed and the advantages, disadvantages, and costs are summarized. The information presented at the five workshops was based on field testing of the materials in several States.

This report is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 82 140260).

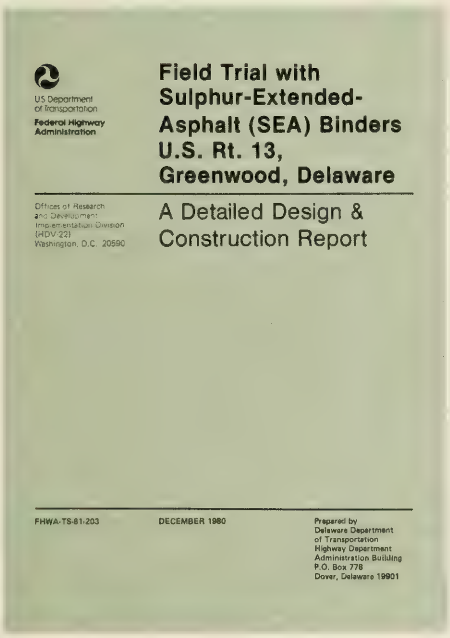
Field Trial with Sulfur-Extended-Asphalt (SEA) Binders, U.S. Rt. 13, Greenwood, Delaware, Report No. FHWA–TS–81–203

by FHWA Implementation Division

This report is part of a series of reports that describe the procedures and testing used to design and construct pavement overlays with SEA binders for comparison against overlays with conventional asphalt binders. SEA pavement field trials in Minnesota, Washington, and Mississippi will be evaluated in future reports.

This report describes the materials, equipment, and quality control procedures used to construct the SEA pavement sections and highlights the design procedures and emissions control monitoring used. The performance of pavement overlays whose SEA binders are formulated with an "in-line blender" before introduction into the pugmill are compared with overlays whose SEA binders are formulated by mixing sulfur and asphalt in the pugmill. The report indicates that pugmill mixing of sulfur and asphalt is sufficient to insure satisfactory blending.

The report is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Stock No. PB 82 131814).



US Department of Transportation
Federal Highway Administration

Field Trial with Sulphur-Extended-Asphalt (SEA) Binders U.S. Rt. 13, Greenwood, Delaware

Offices of Research and Development
Implementation Division
(HDV-22)
Washington, D.C. 20590

A Detailed Design & Construction Report

FHWA-TS-81-203

DECEMBER 1980

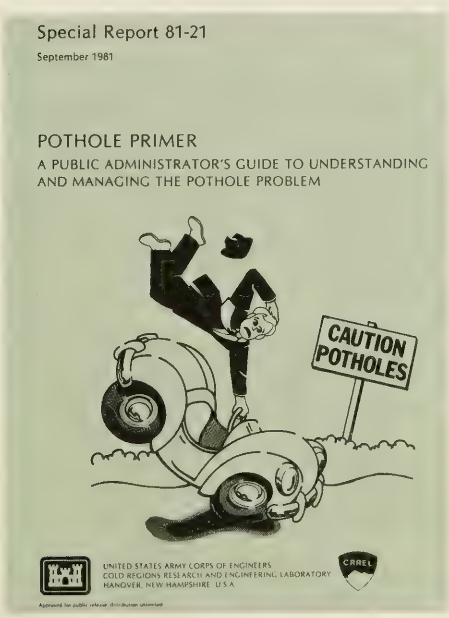
Prepared by
Delaware Department of Transportation
Highway Department
Administration Building
P.O. Box 778
Dover, Delaware 19901

Pothole Primer, Special Report No. 81–21

by the Cold Regions Research and Engineering Laboratory

This report was prepared to help elected city, town, and county officials understand and manage their pothole problems in asphalt pavements. In addition to these public administrators, the report should be of interest to city and county engineers in establishing a pothole repair program. Because the report is intended as a primer, it only highlights the major causes of and general solutions to the pothole problem.

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



Special Report 81-21

September 1981

POTHOLE PRIMER

A PUBLIC ADMINISTRATOR'S GUIDE TO UNDERSTANDING AND MANAGING THE POTHOLE PROBLEM

CAUTION POTHOLES

UNITED STATES ARMY CORPS OF ENGINEERS
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
HANOVER, NEW HAMPSHIRE U.S.A.

CRREL

Approved for public release; distribution unlimited

Post Construction Evaluation of U.S. 69 Sulfur-Extended-Asphalt (SEA) Pavement Test Sections in Lufkin, Texas, Report No. FHWA–TS–80–235

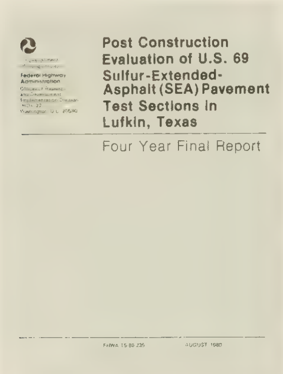
by FHWA Implementation Division

This report presents a post construction evaluation of an experimental SEA pavement field trial on U.S. 69 north of Lufkin, Tex. It also describes the materials, equipment, and quality control procedures used during construction.

The binders used in this field trial consist of pure asphalt cement for the control sections and a 30/70 weight percent blend of sulfur and asphalt cement for the SEA test binder. All elements of the structural design, including thickness, were produced in pairs for comparison of SEA sections with asphalt sections. The thickness designs used in the test sections were the same as those specified by the Texas State Department of Highways and Public Transportation for the conventional sections of this highway. Two thinner sections with SEA binders were constructed to see if distress would appear in 2 to 3 years.

Because of the excellent performance of the SEA pavement sections to date, the evaluation program was extended, and a final field evaluation report will be published and distributed at the end of the extended evaluation period in 1983.

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



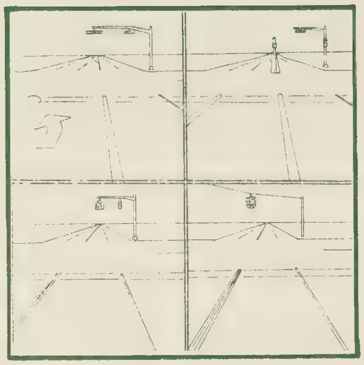
Guidelines for Signalized Left Turn Treatments, Implementation Package 81–4

by FHWA Implementation Division

This report presents easy-to-use guidelines for selecting the best left turn treatment to use at a signalized intersection. The information contained in this report is based on a synthesis of current research and the operational experiences of over 200 practicing traffic engineers.

The guidelines will be useful for traffic engineers considering left turn phasing at an intersection. The advantages and disadvantages of numerous phasing schemes are discussed as are signal displays for left turn phasing. Attention is given to highway capacity, fuel consumption, and safety trade-offs of the various kinds of left turn treatments. Also presented is a specific set of guidelines for daily use by traffic engineers.

The report may be purchased for $3 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock No. 050–001–00243–4).

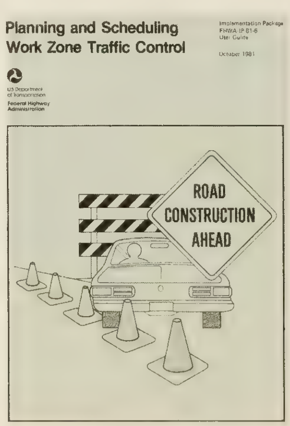


Planning and Scheduling Work Zone Traffic Control, Implementation Package 81–6

by FHWA Implementation Division

Traffic control problems arise whenever traffic must be moved through or around highway construction, maintenance, or utility work sites. Because emphasis in the next decade will be on reconstruction and maintenance activities instead of new construction, higher traffic volumes will be affected. Effective work zone traffic control must be planned carefully, applied systematically, and maintained continuously.

This users guide provides highway, traffic, and design engineers with analytical procedures and decision methodologies that can be applied in the early planning and design stages of a major highway project to select the most appropriate and cost-effective traffic control strategy to be implemented. The guide is intended for planning long term, stationary work zones, not for moving or short term work zones.



The user guide may be purchased for $4.50 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock No. 050–001–00235–3).

UTCS Functional Description—Enhanced First Generation Software, Report No. FHWA–TS–79–228

by FHWA Implementation Division

This report is the first in a series of reports that documents the Urban Traffic Control System (UTCS) Enhanced First Generation Software for computer-based traffic control systems in States and municipalities throughout the United States. The report will aid potential users and suppliers in specifying a software system tailored to their needs as the software is organized by functional module to meet specific traffic control requirements. The software's functional organization and hierarchical structure enable future expansion or modification by inserting or modifying specific functional modules at the appropriate hierarchical level. The report describes the functional elements of the enhanced software and the minimum hardware and operating system program requirements necessary to implement the software.

Final acceptance testing of the software is scheduled for November 1982 after the software has been installed in Birmingham, Ala. This pilot city installation is expected to demonstrate software portability and its ability to control at least 250 intersections.

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

Type 170 Traffic Signal Controller System Reports

by FHWA Implementation Division

The California, New York, Oregon, and Kentucky Departments of Transportation are pursuing a unique approach to acquiring microcomputer-based intersection controllers. Rather than purchasing traditionally available controller equipment from traffic signal manufacturers, these States are purchasing and installing general purpose microcomputers according to their own jointly developed specifications. California and New York also are collaborating on the development of software and acceptance test procedures. These unique controllers are known as Type 170's, and currently there are over 1,500 in service in these four States. New York and California state that the advantages are reduced purchase cost, improved flexibility, and expediency.

The controllers currently are manufactured by several companies and low bid purchasing is possible. Because 170 controllers manufactured by different companies are interchangeable, it is possible to replace malfunctioning controllers with a spare microcomputer-based controller.

Local Intersection Program, Report No. FHWA–IP–79–10, is intended for traffic signal planning and operations. The manual presents operational features, general information on the control program, narrative description of program routines, and a program listing. The local intersection control program is designed to accommodate most typical intersection control strategies. It can function in semiactuated, fully actuated, or volume-density modes.

Diamond Interchange Program Users Manual, Report No. FHWA–IP–80–4, presents operational features and general information on the diamond interchange control program.
Diamond Interchange Program Software Documentation, Report No. FHWA–IP–80–5, presents program routines, flow charts, and a program listing.

The diamond interchange program can accommodate three diamond interchange strategies and function in three modes. Time of day and traffic conditions are used to select between modes of control.

Report No. FHWA–IP–79–10 may be purchased for $6, Report No. FHWA–IP–80–4 may be purchased for $5, and Report No. FHWA–IP–80–5 may be purchased for $6.50 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock Nos. 050–001–00168–3, 050–001–00224–8, and 050–001–00225–6).

New Research in Progress

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

FCP Category 1—Improved Highway Design and Operation for Safety

FCP Project 1A: Traffic Engineering Improvements for Safety

Title: Reevaluation of Traffic Control at Nonsignalized Intersections. (FCP No. 41A1974)
Objective: Evaluate use of yield, two-way stop, and four-way stop control at intersections with emphasis on the effects of less restrictive control on intersection safety.
Performing Organization: University of Maryland, College Park, Md. 20742
Expected Completion Date: October 1982
Estimated Cost: $31,000 (HP&R)

FCP Category 2—Reduce Congestion and Improve Energy Efficiency

FCP Project 2J: Practicality of Automated Highway Systems

Title: FHWA Program on Automated Highway Systems. (FCP No. 22J1104)
Objective: Document the FHWA program on the automated highway system including its objectives, scope, approaches used to reach project objectives, major accomplishments, and recommended future activities.
Performing Organization: Federal Highway Administration, Washington, D.C. 20590
Expected Completion Date: September 1982
Estimated Cost: $30,000 (FHWA Staff Research)

FCP Project 2L: Detection and Communications for Traffic Systems

Title: Field Hardware Problems With Traffic Control Devices. (FCP No. 22L1092)
Objective: Investigate field reliability and operational performance problems with active, electronics-based, traffic control devices.
Performing Organization: Federal Highway Administration, Washington, D.C. 20590
Expected Completion Date: January 1983
Estimated Cost: $9,000 (FHWA Staff Research)

Title: Assessment of Data Communications for Traffic Control. (FCP No. 22L2102)
Objective: Survey current practices, trends, problems, and costs associated with data communications for traffic control.
Performing Organization: Federal Highway Administration, Washington, D.C. 20590
Expected Completion Date: December 1982
Estimated Cost: $11,000 (FHWA Staff Research)

Title: Artificial Speech for Highway Advisory Radio. (FCP No. 22L2122)
Objective: Investigate the state of the art of speech synthesis technology and provide a technological assessment of its use in audio signing applications.
Performing Organization: Federal Highway Administration, Washington, D.C. 20590
Expected Completion Date: September 1983
Estimated Cost: $26,000 (FHWA Staff Research)

Title: Assessment of Status, Trends, and Needs in Motorist Aid Communications. (FCP No. 22L3012)
Objective: Update the status, trends, and needs in motorist aid communications since definitive contractual effort of 1975–1976.
Performing Organization: Federal Highway Administration, Washington, D.C. 20590
Expected Completion Date: December 1982
Estimated Cost: $11,000 (FHWA Staff Research)

FCP Project 2N: Improved Traffic Signing and Motorist Information Systems

Title: Evaluation of Variable Aspect Sign. (FCP No. 22N1102)
Objective: Assess the effectiveness of the variable aspect sign in terms of improving the conspicuity of warning and regulatory displays.
Performing Organization: Federal Highway Administration, Washington, D.C. 20590
Expected Completion Date: December 1982
Estimated Cost: $17,000 (FHWA Staff Research)

Title: Nonilluminated Opaque Background Guide Signs. (FCP No. 22N2092)
Objective: Determine whether overhead guide signs should be permitted to have nonreflectorized backgrounds and whether it is important for the driver to view the green sign background at night.
Performing Organization: Federal Highway Administration, Washington, D.C. 20590
Expected Completion Date: October 1983
Estimated Cost: $18,000 (FHWA Staff Research)

FCP Category 4—Improved Materials Utilization and Durability

FCP Project 4D: Remedial Treatment of Soil Materials for Earth Structures and Foundations

Title: Design of Laterally Loaded Drilled-In Piers for Landslide Correction Anchored in Sedimentary Rocks. (FCP No. 44D5212)
Objective: Develop design procedure for laterally loaded piers used in landslide corrections. Write computer program to increase efficiency and capability for slope stability analyses of drilled-in piers supporting slopes or retaining structures. Develop users manual for the computer program.
Performing Organization: Purdue University, West Lafayette, Ind. 47907
Funding Agency: Indiana Department of Highways
Expected Completion Date: December 1983
Estimated Cost: $51,000 (HP&R)

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

Title: New Systems for Delamination Rebonding Prior to Cathodic Protection. (FCP No. 34K2102)
Objective: Develop a material that can be injected, can rebond delamination areas of bridge decks, and is conductive when moist to allow the uniform passage of cathodic protection current through the rebonded area.
Performing Organization: Pandalai Coating Company, Brackenridge, Pa. 15014
Expected Completion Date: September 1982
Estimated Cost: $111,000 (FHWA Administrative Contract)

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

FCP Project 5L: Safe Life Design for Bridges

Title: Evaluation and Modification of Weigh-In-Motion System. (FCP No. 45L3172)
Objective: Evaluate weigh-in-motion system and implement one in Pennsylvania.
Performing Organization: Bridge Weighing Systems, Warrensville Heights, Ohio 44128
Funding Agency: Ohio Department of Transportation
Expected Completion Date: November 1983
Estimated Cost: $145,000 (HP&R)

FCP Category 0—Other New Studies

Title: Comparison of Conventional Field and Photogrammetric Cross Sections. (FCP No. 40M4133)
Objective: Determine if cross sections obtained from mapping photography (before clearing and grubbing) are accurate enough to be used as original cross section for pay quantities.
Performing Organization: Office of Location, Forest Park, Ga. 30050
Funding Agency: Georgia Department of Transportation
Expected Completion Date: September 1982
Estimated Cost: $9,000 (HP&R)

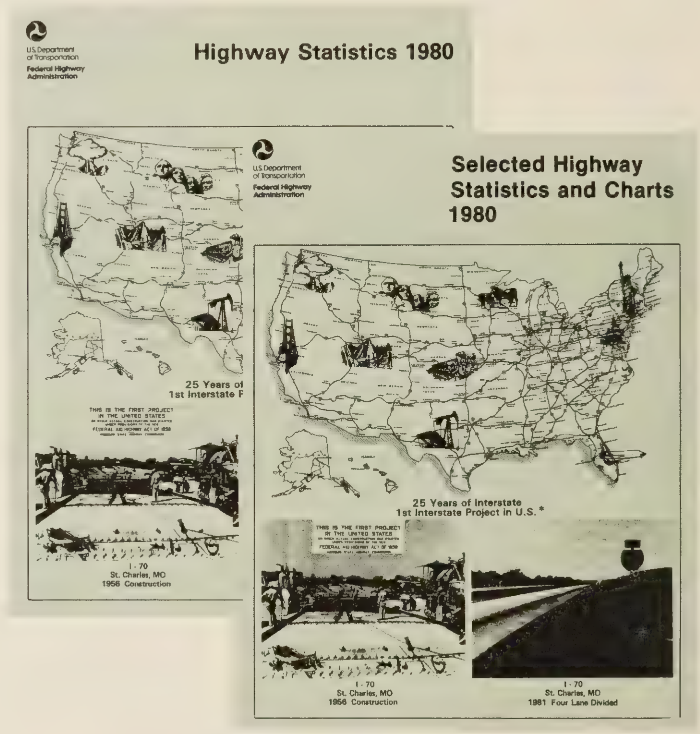
New Publications

Highway Statistics 1980, a 167-page book, the 36th in the annual series, presents statistical and analytical tables of general interest on motor fuel, motor vehicles, driver licensing, highway user taxation, State and local highway financing, road and street mileage, Federal-aid for highways, and highway usage and performance. Also reported are 1979 highway finance data for municipalities, counties, townships, and other units of local government. A listing of the data is given in the table of contents, and a brief discussion is given in the text accompanying each section.

The publication may be purchased from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock No. 050–001–00236–1). It is also available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161 (Report No. FHWA–HP–HS–80) in microfiche and paper copy.

The Highway Statistics series has been published annually since 1945, but the earlier editions, except 1974–1979, are now out of print. Much of the earlier data is summarized in **Highway Statistics, Summary to 1975**. These documents also may be purchased from GPO or NTIS.

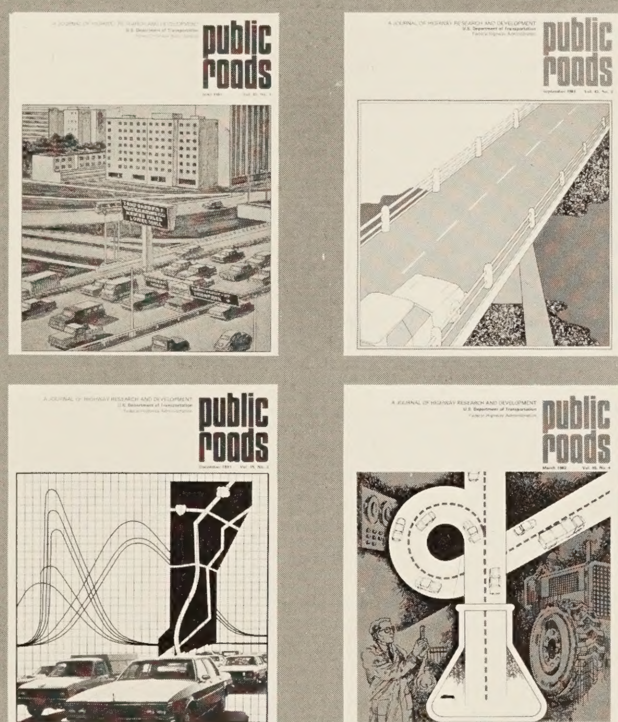
Selected Highway Statistics and Charts, 1980 is a 30-page compilation of statistical highlights and charts prepared as a convenient summary supplement to various tables published in **Highway Statistics 1980** and prior years. Historical trends, as well as 1981 estimates, are included. Copies may be obtained from the Office of Public Affairs or the Highway Statistics Division, HHP–41, Federal Highway Administration, Washington, D.C. 20590.



Beginning with this issue, vol. 46, No. 1, June 1982, *Public Roads* has a new logo and is reduced in size. In accordance with the 1981 *Graphics Standards for the U.S. Department of Transportation* manual, the magazine is now 8 ½ × 11 inches and the title is now in upper and lower case TransBold type. These changes comply with an effort to create a uniform visual communications system and establish overall identity with the Department.

☆U.S. Government Printing Office: 1982—341–783/104

TITLE SHEET, VOLUME 45



public roads

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Federal Highway Administration

June 1981–March 1982

The title sheet for volume 45, June 1981–March 1982, of *Public Roads, A Journal of Highway Research and Development*, is now available. This sheet contains a chronological list of article titles and an alphabetical list of authors' names. Copies of this title sheet can be obtained by sending a request to the editor of *Public Roads*, U.S. Department of Transportation, Federal Highway Administration, HDV–14, Washington, D.C. 20590.

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