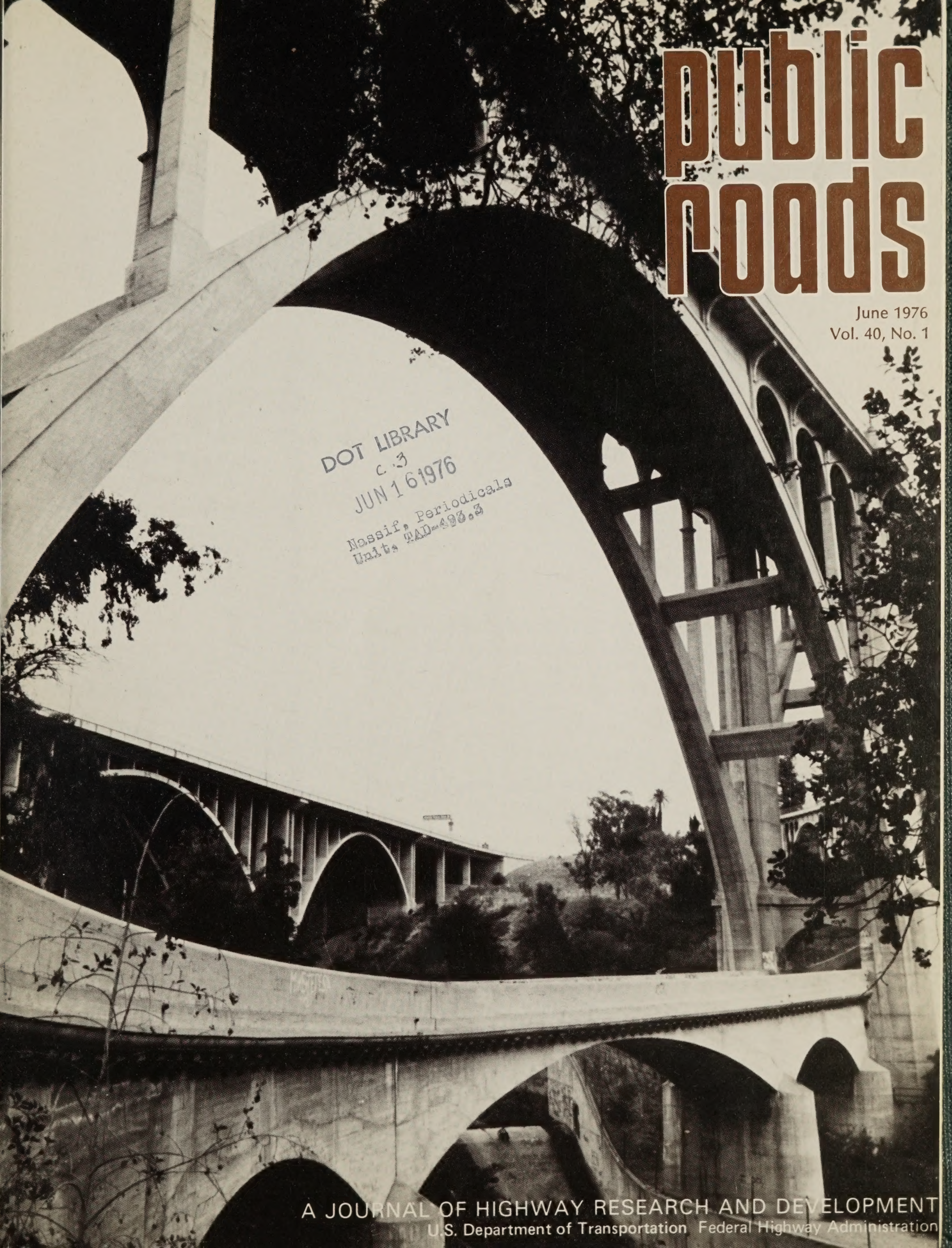

public roads

June 1976
Vol. 40, No. 1

A JOURNAL OF HIGHWAY RESEARCH AND DEVELOPMENT

U.S. Department of Transportation Federal Highway Administration

public roads

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FRONT COVER:
Pioneer Bridge, Route 134 Freeway, Pasadena, Calif., viewed through a span of the 1912 Colorado Bridge.

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NOTICE

The title sheet for vol. 39 is now available. (See inside back cover.)

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

Public Roads is published Quarterly by the Offices of Research and Development

Gerald D. Love, *Associate Administrator*

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Federal Highway Administration
Washington, D.C. 20590

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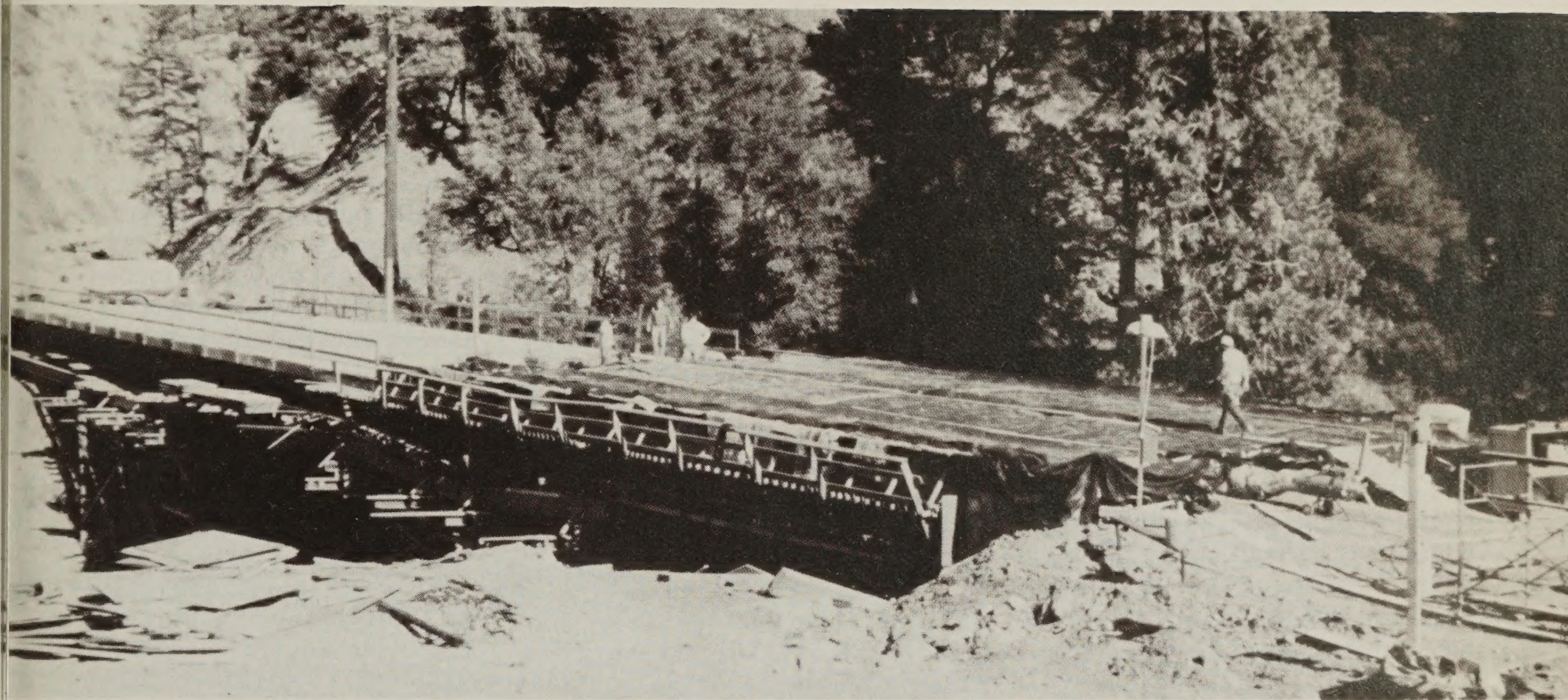
The Secretary of Transportation has determined that the publication of this periodical is necessary in the transaction of the public business required by law of this Department. Use of funds for printing this periodical has been approved by the Director of the Office of Management and Budget through March 31, 1981.



Surface Impregnation of New Concrete Bridge Decks

by W. Glenn Smoak

The Implementation Division of the Federal Highway Administration (FHWA) in cooperation with the Demonstration Projects Division of FHWA's Region 15 is now evaluating this process. During fiscal year 1976, approximately five bridge decks constructed on Federal and State highway projects will be polymer impregnated. The purpose of these projects will be to evaluate the process under field conditions and make any refinements necessary to adapt it to field use. The first deck impregnated under this evaluation program was on a Forest Highway Project in Idaho during July 1975. The results of this evaluation work will be reported at a later date.

The application of sodium and calcium chloride deicing salts to concrete bridges has resulted in extensive deck deterioration. Protective systems including overlays, impermeable membranes, and concrete quality control techniques have been used to reduce or eliminate this problem. But none have been completely successful in preventing the intrusion of chloride ions into concrete decks, and in some instances the protective systems have actually increased the rate of deterioration. This article presents the procedures, materials, and equipment used in the first polymer impregnation of a concrete bridge deck to provide protection against chloride ion intrusion; and includes a description of the research, laboratory program, and durability tests culminating in the development of the field process technology.

Introduction

The Bureau of Reclamation began research on polymer impregnated concrete (PIC) in 1965. It was prepared by using pressure vessels to fully impregnate precast conventional concrete with low viscosity monomers such as methyl methacrylate (MMA) or styrene followed by in situ polymerization of the monomer to form high strength, highly durable, composite material.

PIC was found to be virtually unaffected by freeze-thaw attack, acid environments, or exposure to sulfates. Its water absorption and water permeability properties were exceptionally low.

Because of the high strength and unique durability properties of polymer impregnated concrete, the Federal Highway Administration sponsored a research program by the Bureau of Reclamation in 1971. The aim of the program was to develop the process technology, materials, and equipment to impregnate new concrete bridge decks with polymeric materials to a depth of 1 in (25 mm) below the riding surface and to demonstrate the technology by treating a full-scale bridge deck in the field.

A technique was developed and laboratory tests performed on 2-ft (0.6 m), 3-ft (0.9 m), and 4-ft (1.2 m) square concrete test slabs to confirm the process technology and determine the impregnated concrete's resistance to chloride ion intrusion and freeze-thaw damage. Reinforced concrete slabs, 4 in (102 mm) thick, impregnated to a depth of 1 in (25 mm), were exposed to over 200 freeze-salt application-thaw cycles without significant buildup of chloride ion concentrations below the impregnated zone.

Additional tests were performed on a circular test track to determine the wear resistance and susceptibility to surface polishing of the surface treated concrete. The results showed that surface impregnation had no effect upon concrete's resistance to polishing or abrasion.

A concrete slab on grade approximately 15 ft wide by 30 ft long (4.6 m by 9.1 m) and one 12- by 30-ft (3.7 by 9.1 m) lane of a small concrete bridge located on the Denver Federal Center were treated to evaluate the surface impregnation process under field conditions. These tests were successful; and in October 1974, the field demonstration of the process was accomplished on a newly constructed bridge in the Denver, Colo., metropolitan area.

Field Demonstration

The bridge selected for the field demonstration was constructed using precast, prestressed box girders and a cast-in-place concrete deck 7 in (178 mm) thick. The riding surface was 30 ft (9.1 m) wide by 60 ft (18.3 m) long. At the time the bridge was treated, the concrete deck was 14 days old and test cylinders cast from the bridge deck concrete exhibited 3,000 lb/in² (20,700 kPa) compressive strength.

Surface Impregnation Process

This process is composed of four basic steps.

- The concrete is cleaned of surface contaminants such as oil, asphalt, or curing compounds which may interfere with monomer penetration or the polymerization reaction.

- The concrete is dried to a depth sufficient to permit the desired monomer penetration.

- The concrete is impregnated with a monomer system composed of 90 to 95 percent by weight methyl methacrylate (MMA) and 10 to 5 percent by weight trimethylolpropane trimethacrylate (TMPTMA). The monomer system also contains an azo-type polymerization catalyst normally added at the rate of ½ to 1 percent based on the weight of the monomer.

- After the monomer has penetrated to the desired depth, it is polymerized by heating the concrete to a temperature sufficient to activate the polymerization catalyst.

Surface preparation

The test bridge deck was newly constructed and had not been opened to traffic. The surface of the concrete was not contaminated, thus sand blasting or high-pressure steam cleaning was not necessary. Loose debris was removed from the deck by sweeping.

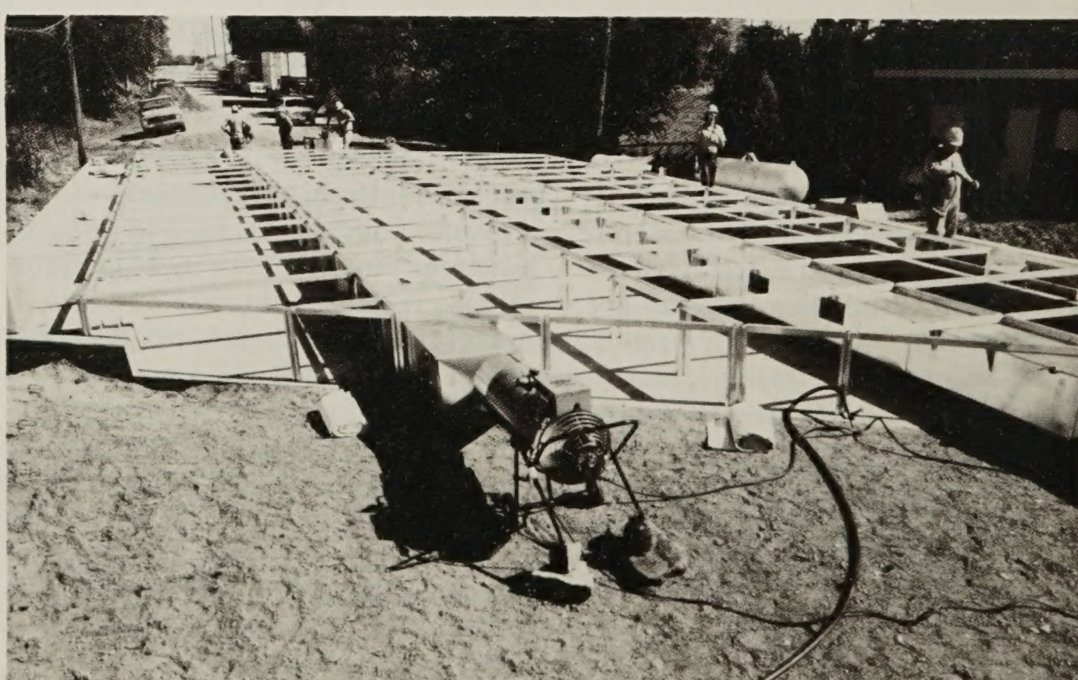


Figure 1.—Prefabricated aluminum frame for drying and polymerization enclosure.

Drying

Drying the bridge deck concrete was accomplished by constructing a 2-ft (0.6 m) high, insulated enclosure over it and heating the enclosed area with four 500,000-Btu (527,528 kJ) propane-fired space heaters.

Figure 1 shows the prefabricated aluminum frame for the enclosure and one of the space heaters connected to a galvanized sheet metal duct used to distribute hot air over the concrete surface within the enclosure. Two ducts were used with this enclosure and each had heaters attached to both ends. Temperature was controlled by a thermistor controller that cycled the heaters as needed.

Figure 2 shows the installation of semirigid ½-in (13 mm) thick fiber building board on the top and vertical sides of the enclosure frame. A 1-in (25 mm) space left between the concrete deck and the vertical sides ventilated the hot moisture-laden air during the drying operation.

Figure 2.—Fiber building board that formed the insulated top, ends, and sides of the enclosure.

Figure 3 shows the completed enclosure. A lightweight tarpaulin placed over the fiber board prevented heat loss from the joints. Then polyethylene membrane was used to cover the enclosure to prevent rain or snow from reaching the drying deck. Drying heat was applied to the deck for 73 hours. An average temperature of 225° to 250° F (107° to 121° C) was maintained at the surface of the deck.

During the drying period, temperatures were monitored with thermocouples on the concrete surface and at depths 1 and 2 in (25 and 51 mm) below the surface. After the drying cycle, the heaters were turned off and the concrete allowed to cool to ambient temperature over a 24-hour period. The enclosure was left in place during cooling to protect the concrete from rain.

Impregnation

The enclosure frame was designed so that it could be removed in large sections when the concrete had cooled (fig. 4). After removal of the

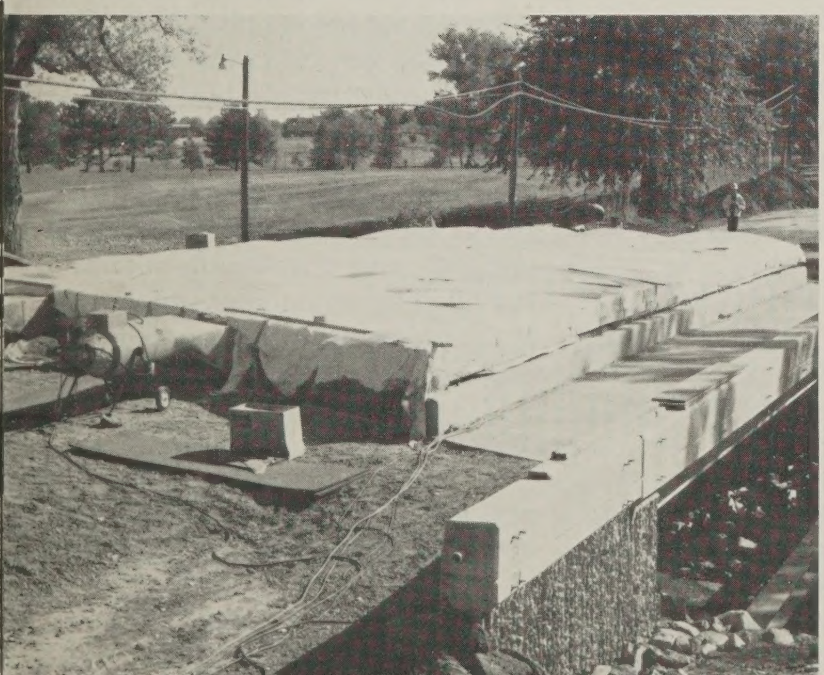


Figure 3.—Completed enclosure in operation on the bridge.

Figure 4.—One section of the enclosure frame being removed from the bridge prior to impregnation.

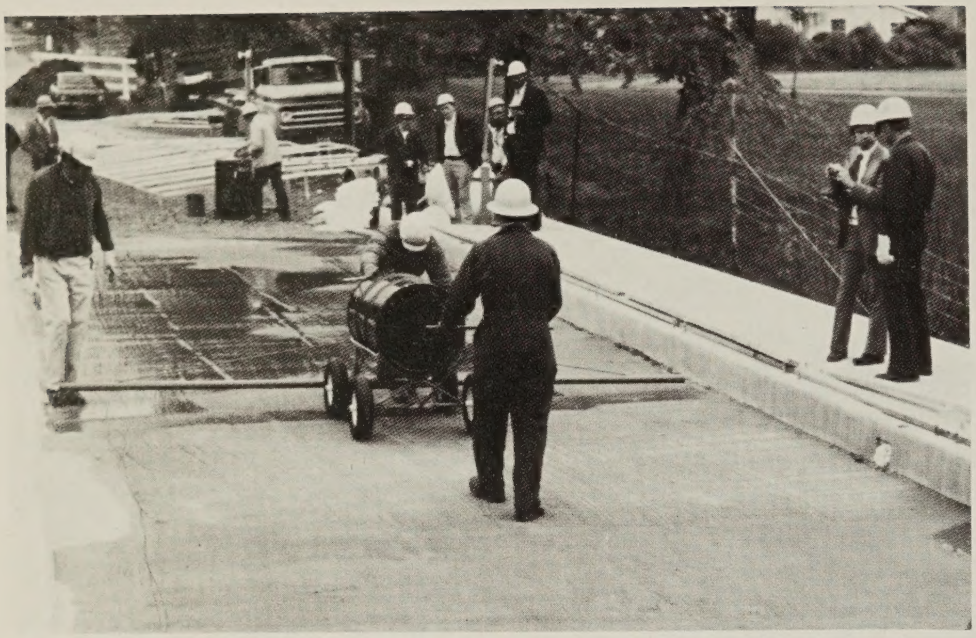


Figure 5.—Monomer application to one lane of the sand-covered bridge deck.

Figure 6.—Detail of test core drilled from the treated deck.

enclosure, a layer of clean, dry sand —¼ to ½ in (6 to 13 mm) thick— was spread over the riding surface of the bridge. The sand acted as a reservoir for the monomer, holding it on the crowned or superelevated roadway and reducing evaporative loss of the highly volatile liquid.

The monomer system, composed by weight of 95 percent MMA and 5 percent TMPTMA, was catalyzed with ½ percent 2,2 azobis (2,4 dimethylvaleronitrile) and applied to the sand in three applications.

A wheeled monomer cart was used to apply the monomer (fig. 5). The spray bar attached to the monomer drum was 14 ft (4.3 m) wide and covered one lane of travel. The initial application rate was approximately 1 lb of monomer per ft^2 of surface (4.9 kg/m^2).

Five hours later, a second application was made at the rate of approximately ½ lb/ft^2 (2.4 kg/m^2). After each application a polyethylene membrane was put over the monomer-saturated sand to reduce monomer evaporation. The monomer was left to soak into the deck overnight (9½ hours). The next day, the sand appeared slightly dry for polymerization and a final application of monomer, 0.2 lb/ft^2 (1.0 kg/m^2), was made. The total monomer applied to the bridge was 375 gal (1,420 l) at a combined rate of 1.7 lb/ft^2 (8.3 kg/m^2). This rate was slightly excessive for optimum results.

Polymerization

Following the final application of monomer, the polyethylene membrane was replaced, the enclosure frame with its heating system reinstalled, the fiber board and tarpaulin cover placed on the frame, and the heater fans turned on to ventilate flammable monomer vapors while the enclosure panels were installed. When the enclosure was clear of monomer vapor, the heater burners were turned on to begin the polymerization cycle.

The deck surface temperature was increased to 180° F (82° C) over the first 6 hours of heat application and then maintained for 12 hours to assure complete polymerization of the impregnated concrete. When the cycle was completed, the enclosure and the various equipment used to treat the bridge were removed and the deck swept to remove the loose sand. An inspection indicated that 5 to 7 percent of the roadway surface was covered with a polymer-sand composite tightly bonded to the concrete, primarily in the gutter areas of the deck.

Two factors contributed to this problem:

- First, the application rate was slightly excessive. A rate of 1.4 to 1.5 lb/ft^2 (6.8 to 7.3 kg/m^2) would have been sufficient.

- Second, the entrances to the drain scuppers in the deck were slightly higher than the roadway surface, thus allowing the excess monomer to remain on the deck where it subsequently polymerized in the sand.

This material had no effect upon the structural behavior or riding properties of the deck, but its presence was unsightly and it was subsequently removed by equipment similar to that used to groove airport runways and concrete highway surfaces.

Test Results

Test cores were taken from the deck and broken apart in tensile splitting

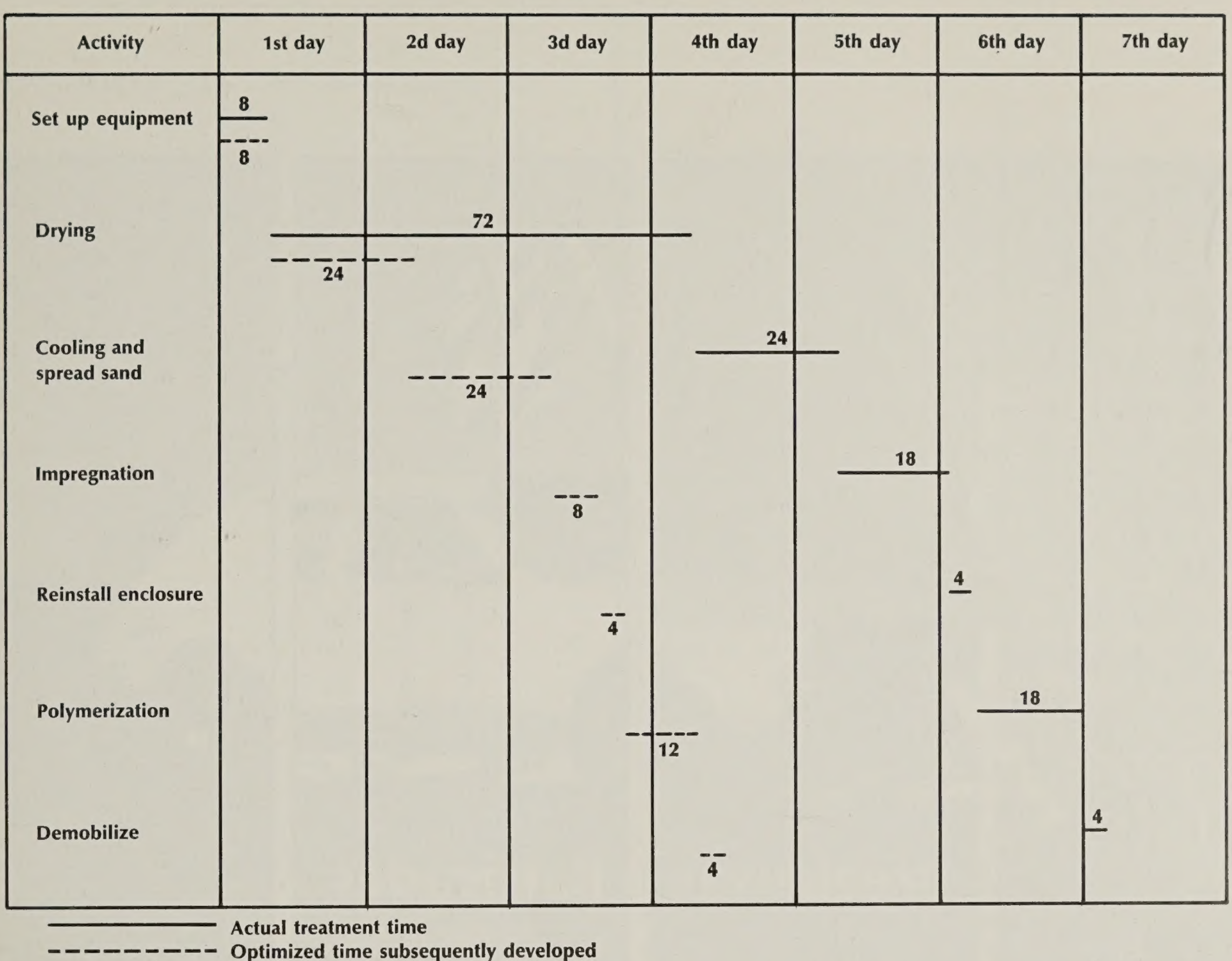


Figure 7.—Surface impregnation time schedule (in hours).

o determine the depth of polymer ›enetration into the concrete (fig. 6). 'he polymer is the dark zone in the ıpper half of the core segment. Pene- ration depths of 1 to 1½ in (25 to 8 mm) were apparent. The cracks า the lower part of the core segment esulted from the splitting test used o break the core.

Vater absorption tests indicated that vater absorption in the polymer im- ›regnated zone had been reduced to percent by weight. The untreated ›ortion had an average water absorp- ion value of 9 percent by weight. 'hese results compare favorably with vater absorption tests performed on est slabs prepared in the laboratory nd subsequently tested for freeze- haw and chloride intrusion dura- ›ility.

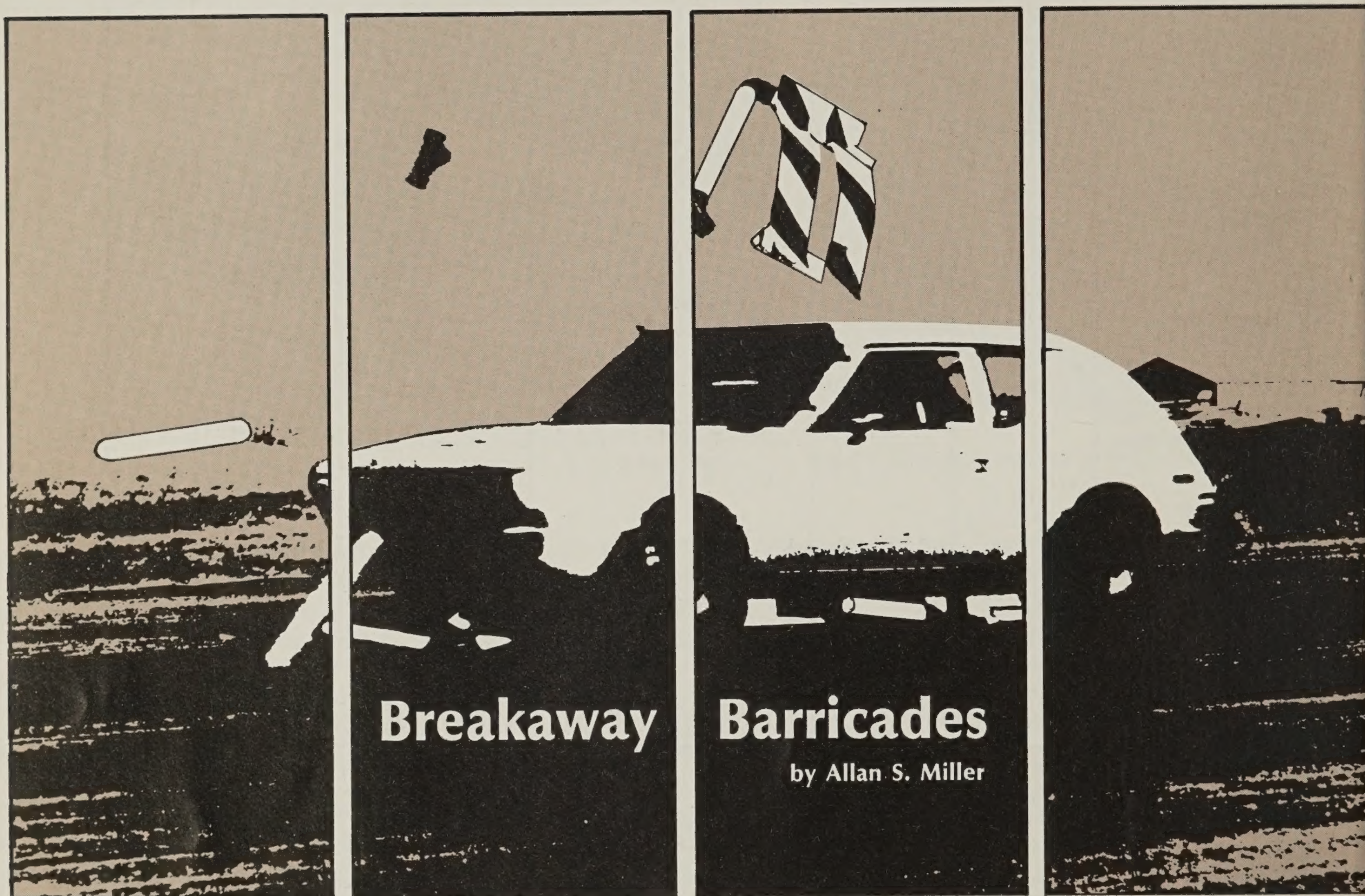
Treatment Schedule

The demonstration nature of this first full-scale field test required that extra care be taken to insure a successful project. The treatment schedule as actually performed is shown in figure 7.

Subsequent tests indicate that the various process times can be shortened without reducing the depth or quality of polymer penetration. With the optimized process, the drying operation is reduced to 24 hours at 250° F (121° C) with an 8-hour impregnation cycle and a 12-hour polymerization cycle at 158° F (70° C). Contractor scheduling may save additional time in equipment setup, removal, and reinstallation, but the 24-hour cooling cycle appears to be fixed. Using the optimized process the treatment could be performed in about 4 days. This optimized treatment schedule is also shown in figure 7.

Treatment Costs

The estimated cost of surface impregnating a concrete bridge deck will be approximately $\$27/yd^2$ ($\$32/m^2$) of treated surface. This includes costs of monomer, labor, and equipment, but does not include profit, overhead, or traffic control. Within this estimate the cost of the monomer system, $\$6.50/yd^2$ ($\$7.77/m^2$), was computed using the application rate of 1.5 lb/ft^2 (7.3 kg/m^2) proven successful in laboratory and small field studies. The labor and equipment costs may vary depending upon the bridge location and size, and the times a contractor can reuse his equipment.



Breakaway Barricades

by Allan S. Miller

Introduction

Standard Type III construction and maintenance barricades (fig. 1) are typically constructed of nominal 4 by 4 in. (100 by 100 mm) and 2 by 6 in. (50 by 150 mm) timbers joined with bolts and nails. These barricades are potentially hazardous to errant vehicles and their occupants and can seldom be salvaged after impact. In September 1971, the Nevada Department of Highways completed the design of a Type III barricade (fig. 2) constructed of polyvinyl chloride (PVC) pipe which is safer, easier to build and transport, and less expensive than conventional barricades. The component parts can generally be salvaged even after high-speed collisions.

Background

In April 1972, low-speed impact tests were conducted on the PVC barricade. The tests, although limited, proved the barricade to be superior in every respect to the conventional wooden barricade.

These tests were followed by some trial field installations in transition zones of Interstate 80 in the vicinity of Elko, Nev. To date, vehicles have hit more than 20 of these barricades with no resulting evidence of property damage or personal injury. Ninety percent of the components were salvaged and reused. In one instance, a Nevada highway patrolman observed a standard size automobile hit a barricade at an estimated speed of 80 mph (130 km/h). There was no loss of control and no injuries. The vehicle received a small dent in the hood and a cracked windshield.

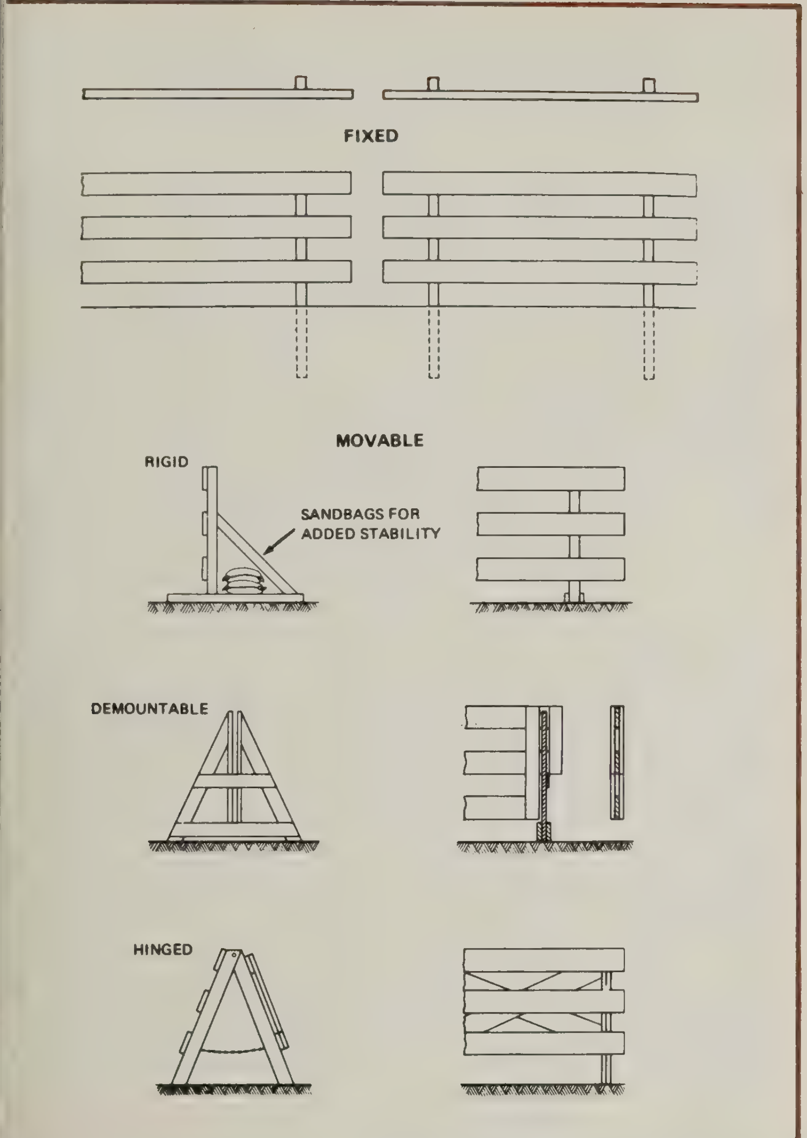


Figure 1.—Typical examples of conventional Type III barricades.

Figure 2.—Nevada's breakaway barricade.

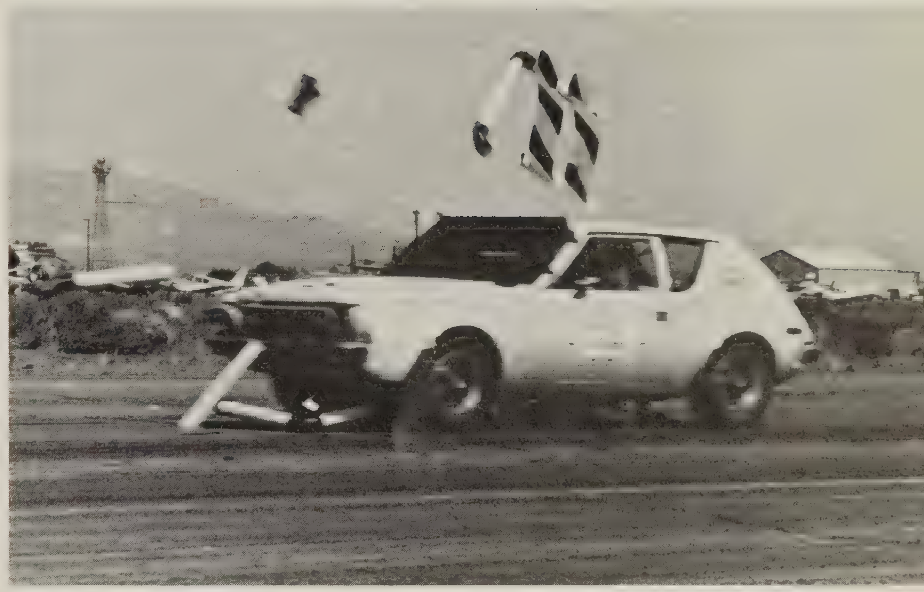


Figure 3.—Impact test.

Development

The Nevada Department of Highways is participating in a Basic Agreement/Task Order program with the Federal Highway Administration. Basic Agreements have been initiated with at least 25 State highway or transportation departments. Under this project by the Nevada Department of Highways, full-scale impact tests were conducted and analyzed, a documentary film was produced, and a report [1] published. Nevada also built sample barricades and packaged and shipped them to all 50 States. Nevada plans a followup evaluation on the use and effectiveness of the barricades.

Testing

In May 1974, initial impact tests were conducted using a 1970 four-door standard size car and a 1973 compact model. The tests were performed on an airport runway at 35, 45, and 55 mph (55, 70, and 90 km/h) (fig. 3). The only modification of the vehicles was the addition of rollover bars, and hardware cloth and tape applied to the windshields. Regular and slow-motion films were taken of each impact.

Although the initial tests were considered successful, an analysis of the films indicated some slight modifications of the design might improve the product. As a result, a second series of crash tests was conducted in October 1974. In all, a total of seven different barricade designs were tested. The same cars were used throughout the

[1] "Breakaway Barricades," by Jerry L. Hall, Implementation Package 75–6, *Federal Highway Administration*, Washington, D.C., September 1975.

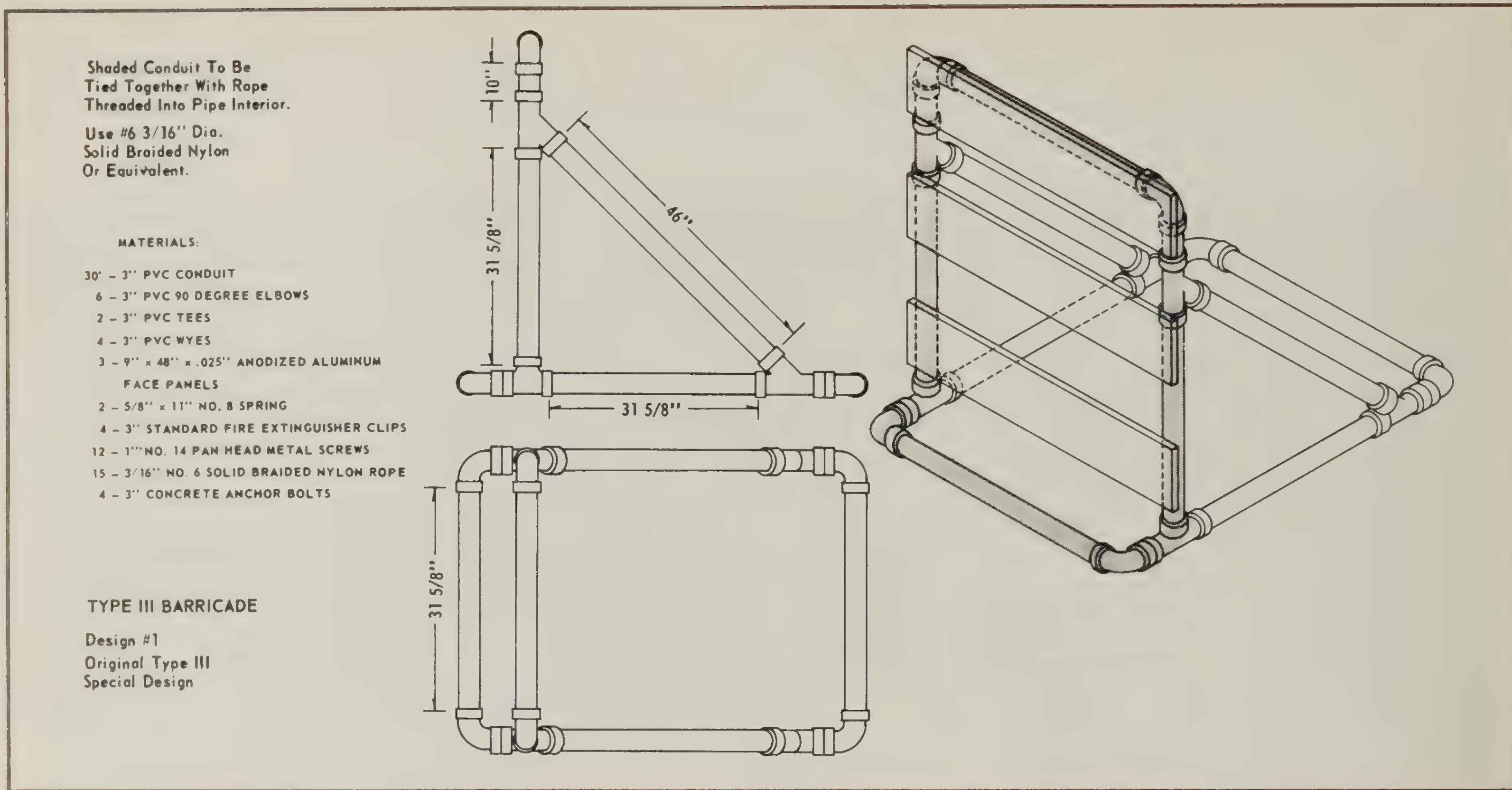


Figure 4.—Schematic of recommended design.

tests and the driver experienced little or no difficulty in handling the vehicles either during or after impact. The recommended design based on the tests and analyses is shown schematically in figure 4.

Since the barricades are lightweight—about 45 pounds (20 kg)—they would be very unstable next to moving traffic or in the wind. Sandbags are considered to be hazardous for stabilizing the barricades. Consequently, fire-extinguisher type U-clamps were lag-bolted to the pavement and proved to be safe and effective anchors. Approximately 90 percent of the components used in the barricades which were tested were undamaged and immediately reusable. The only damage sustained by the test vehicles was minor dents and broken windshields. The possibility of windshield damage should deter drivers from smashing installed barricades "for the fun of it."

Costs and Benefits

Detailed cost data were obtained during construction of the initial 60 breakaway barricades and compared with the cost of constructing a standard wooden barricade. The breakaway barricades cost $55.31 each compared to $78.15 each for the conventional barricade—a 29 percent cost reduction.

Advantages of the PVC barricades over the conventional wooden barricades are as follows:

- Breakaway design—The design allows the plastic components to scatter on impact resulting in minimum damage to both the barricade and the vehicle.
- Modular design—Standard and uniform dimensions facilitate component replacement and eliminate the need for a large inventory.
- Safety—The lightweight and breakaway characteristics combine to provide a much safer barricade.
- Replacement—Usually the barricades can be reassembled in 10 to 15 minutes on the scene thereby eliminatin replacement costs.
- Portability—The barricades can be easily moved about or broken down and loaded by one person.
- Transportability—Twenty Type III barricades ready for assembly can be carried in a pickup truck.

Implementation

The report and film have been widely disseminated. Sinc the advantages of this type of barricade are readily apparent to most potential users, no additional implementa tion effort seems warranted at this time. Further promotion of the barricades will be undertaken if Nevada's followup evaluation proves this necessary. Copies of the film are available from all FHWA regional offices. (See p. 31.)

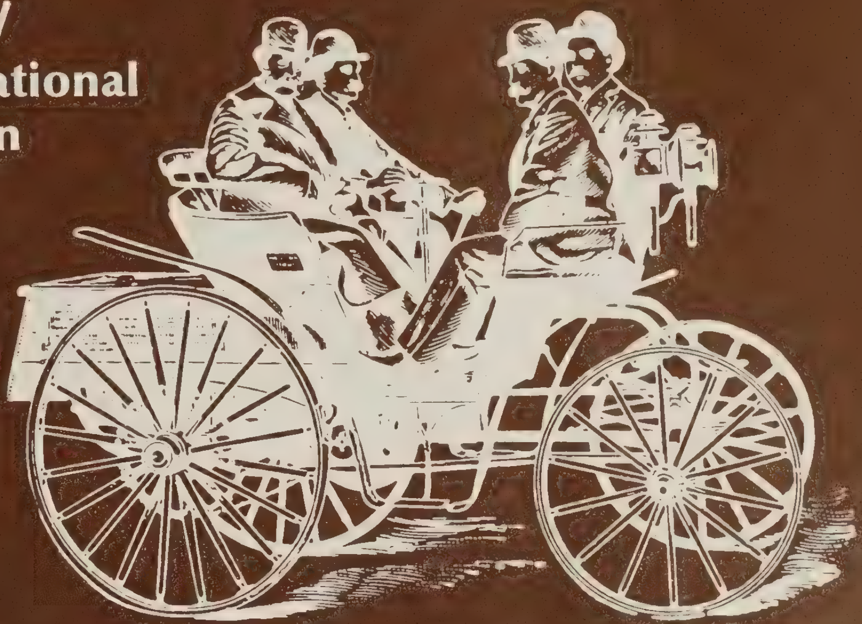
Conclusion

The Type III barricade developed by the State of Nevada is superior in all respects to the conventional Type III wooden barricades. There are, of course, many situation where the breakaway features would be undesirable (steep dropoffs, proximity to men and equipment). In these situations, portable guardrails or concrete median barriers may be more effective than wooden barricades.

Highway Design for Motor Vehicles—A Historical Review

Part 6: Development of a Rational System of Geometric Design

by [1] Frederick W. Cron



This is the sixth in a series of eight historical articles tracing the evolution of present highway design practices and standards in the United States. The Introduction and Part 1: The Beginnings of Traffic Measurement were published in vol. 38, No. 3, December 1974. Part 2: The Beginnings of Traffic Research was published in vol. 38, No. 4, March 1975. Part 3: The Interaction of the Driver, the Vehicle, and the Highway was published in vol. 39, No. 2, September 1975. Part 4: The Vehicle-Carrying Capacity of the Highway was published in vol. 39, No. 3, December 1975. Part 5: The Dynamics of Highway Curvature was published in vol. 39, No. 4, March 1976. The remaining parts, to be published in future issues, are 7: The Evolution of Highway Grade Design; and 8: The Evolution of Highway Standards.

[1] Frederick W. Cron's biography appeared with part 1 of his article in vol. 38, No. 3, December 1974.

As noted in Part 5, R. A. Moyer determined at the Iowa Engineering Experiment Station that when a side skid coefficient of 0.30 was developed by a vehicle while rounding a curve, the resulting sensation of side pitch outward was decidedly uncomfortable to the vehicle's occupants. Joseph Barnett of the Bureau of Public Roads (BPR) thought that this feeling of side pitch might be used as a basis for a rational system of geometric design, provided sufficient agreement could be found among individuals as to what was comfortable.

Road Tests by Volunteers

To obtain information on how side pitch affects the occupants of a vehicle, the BPR in 1935 asked ordinary drivers to perform road tests in their own vehicles on curves of known radii and superelevation. The drivers were asked to report the minimum speed at which the occupants of the test car began to feel a side pitch outward. This feeling of side pitch, as the BPR already knew from Moyer's work, was well below the speed at which side skidding occurs, so the researchers felt the corresponding speed would be a safe one to use in curve design.

Several hundred drivers in all parts of the United States responded to this appeal, making over 900 tests on many kinds of road surfaces. Side friction factors, f, were then worked out for each test, using the formula:

$$e+f=\frac{V^2}{15R}$$

Where,

e=Superelevation rate in feet per foot.

f=Side friction factor.

V=Speed in miles per hour.

R=Radius in feet.

As was expected, there was a wide spread among individual observations, but the average values were very close to f=0.16 on both dry and wet pavements at speeds below 60 mph, falling off to about 0.14 at 70 mph (figs. 1 and 2). (*1*)[2]

Design Speeds Proposed for Highways

After the 1935 road tests, Barnett proposed that superelevation on curves be designed to counteract only the centrifugal force for three quarters of the *assumed design speed,* relying on side friction to supply the remaining horizontal resistance, up to a maximum side friction factor of 0.16 at 60 mph. He defined assumed design speed as "the maximum reasonably uniform speed which would be adopted by the faster driving group of vehicle operators, once clear of urban areas" and urged that all features of geometric design—curve radii, superelevation, curve widening, transition curves, and even gradients—be made consistent with the chosen design speed. (*1*)

To understand the novelty of Barnett's proposals, one should realize that up to this time the design policy of most roadbuilding organizations was to locate roads on long tangents as much as possible and to join these tangents by the flattest curves commensurate with the topography and the available funds. There was little consistency in curve design except to avoid very sharp curves, especially at a hill crest or the foot of a steep grade. Most designers superelevated the curves to counteract all centrifugal force for a speed equal to the legal speed limit, which might be 35 to 45 mph,[3] but not exceeding a cross slope of 10 percent. If 10 percent was less than the theoretical superelevation for the legal speed, the driver was expected to slow down and round the curve at a lesser speed for his own safety.

In 1937 the Bureau of Public Roads published a curve manual setting forth Barnett's *balanced design concept.* The manual recommended that superelevation be designed for three-fourths of the design speed, with side friction limited to 0.16, and that transition spirals be applied to all curves of 3,800 feet radius or less using the American Railway Engineering Association's 10-chord spiral as the preferred transition curve. This manual, of which Barnett was the principal author, had a strong influence on subsequent geometric design practice in the United States and abroad. (*2*)

The design speed or *balanced design* concept became a permanent feature of geometric design policy in the

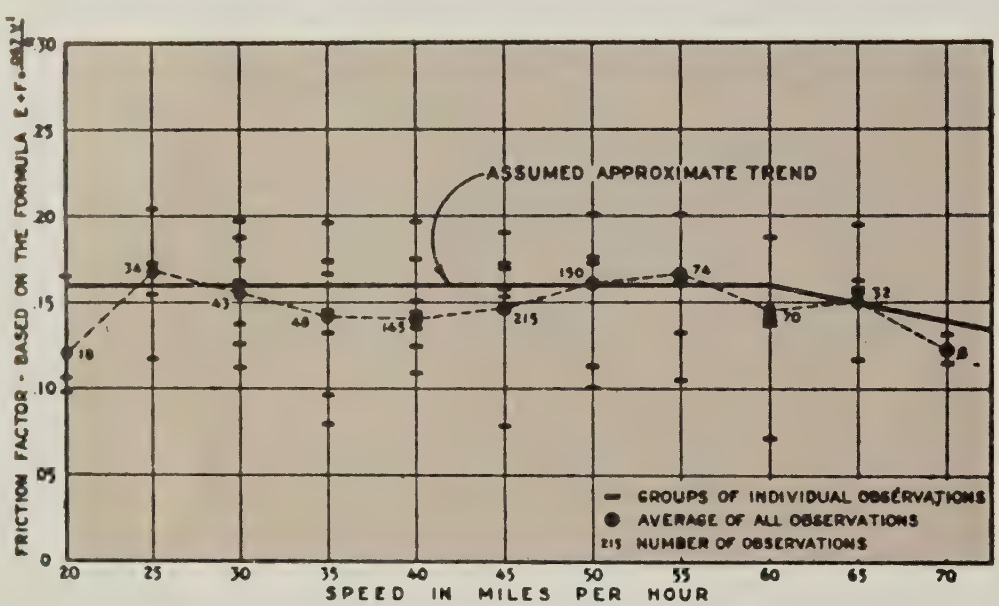


Figure 1.—Average side friction factor when side pitch is noticed. (1)

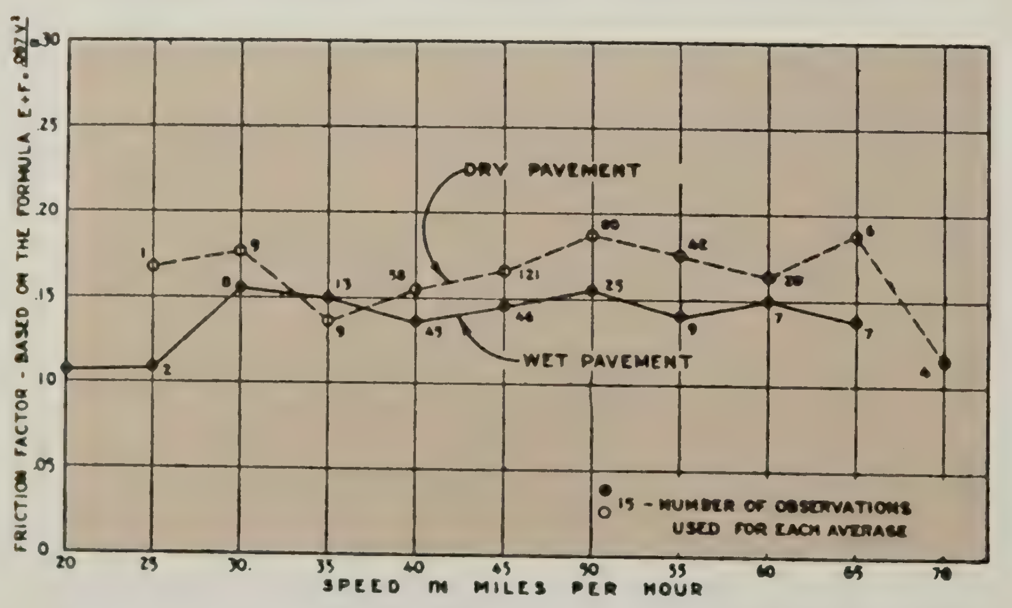


Figure 2.—Average side friction factor when side pitch is noticed. Dry vs. wet pavements. (1)

[2] Italic numbers in parentheses identify the references on page 18.

[3] In its 1930 Standards the American Association of State Highway Officials recommended that superelevation be calculated to offset the centrifugal force generated at a vehicle speed of 35 mph.

United States with its adoption by the American Association of State Highway Officials (AASHO) in 1938. AASHO defined design speed as "the maximum approximately uniform speed which probably will be adopted by the faster group of drivers but not, necessarily, by the small percentage of reckless ones," and then went on to state:

> A principal factor affecting the choice of a design speed is the character of the terrain. In general, rolling terrain will justify a higher design speed than mountainous country since the cost of constructing almost every highway detail will be less. An important highway carrying a large volume of traffic may justify a higher design speed than a less important highway in similar topography due to the fact that the increased expenditure for right of way and construction will be offset by the savings in vehicle operation, highway maintenance, and other operating costs.
>
> A low design speed should not be assumed for a secondary road, however, if the topography is such that vehicle operators probably will travel at high speeds. . . . Drivers do not adjust their speed to the importance of the road but to the physical limitations of curvature, grade, sight distance, smoothness of pavement. . . . *(3)*

Percentile Speed Studies

The main problem posed by the design speed concept was how to decide what the design speed should be for a particular set of conditions. Just what was the "maximum approximately uniform speed adopted by the faster group of drivers?" This would be impossible to determine for roads not yet built, but the BPR engineers thought they could find a solution to this problem by analyzing the speeds adopted by drivers on roads already under traffic.

Fortunately, the Bureau had available for analysis a large number of speed observations that had been made in 1934, 1935, and 1937 with its speed-measuring device—the *speedmeter*. This mass of data included speed measurements on over 260,000 vehicles at 40 different locations. When plotted accumulatively, the speeds measured at any location invariably assumed the familiar S-shaped curve characteristic of a random distribution. This was true regardless of the number of lanes or the traffic volume, and over a rather wide range of speeds (fig. 3). *(4)*

When they analyzed these curves, the BPR engineers found that although average speeds varied widely from road to road—from as low as 22 mph on some up to 47 mph on others—the average always fell in the 50 to 60 percentile of the drivers, clustering around the 55 percentile. With this relatively constant relation, the engineers could analyze and compare speed distribution patterns for many roads even though their average speeds might be quite different. From the speed distribution curve (fig. 3) for a particular road they read the speed traveled by, say, the 90 percentile[4] of drivers. They then divided this speed by the average speed of all drivers on that road to obtain a ratio *K*. When the *K* values

[4] The 90 percentile speed would be the speed exceeded by the fastest 10 percent of the drivers. It might be 28 mph for one road and 51 mph on another, depending on the design of the road and the traffic.

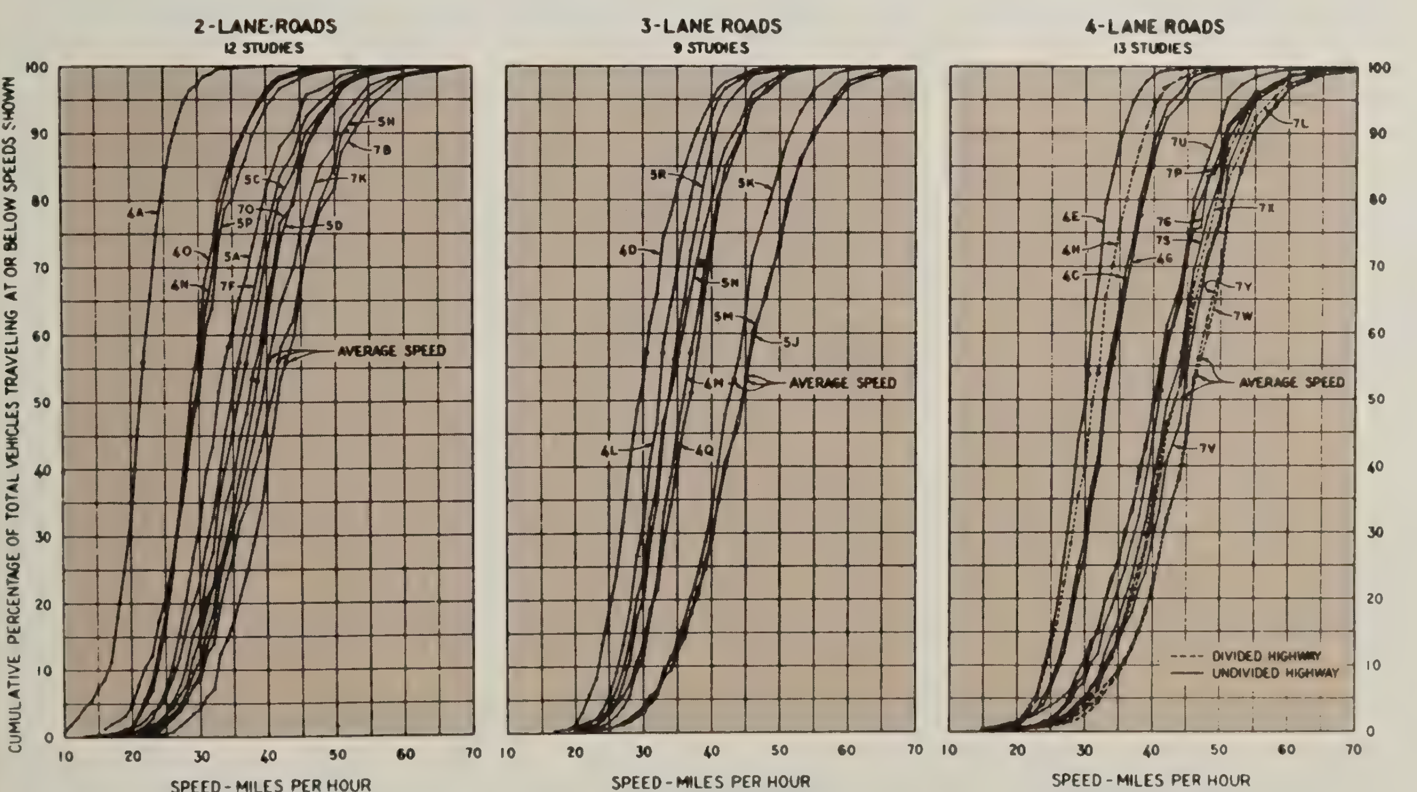


Figure 3.—Speed distribution curves for 34 roads of two, three, or four lanes. (4)

for the 90 percentile of all two-lane roads studied were plotted, as in figure 4, they fell into a straight-line curve with remarkably little scatter. In figure 4, for example, *K* for the 90 percentile of all two-lane roads was 1.240, showing that the fastest 10 percent of the drivers were traveling about 1¼ times the average speed regardless of what that average speed might be.

The researchers worked up similar curves for all percentiles and when they plotted the resulting *K* values accumulatively, a curve such as that shown in figure 5 resulted. In this curve, the value of *K* is 1.0 at the average speed, which is found to be that of 55 percent of the drivers; in other words, the average speed of travel is a 55 percentile speed. The 100 percentile speed is found to be 1.92 times the average and the 10 percentile is only about three-fourths of the average. Figure 5 shows that over half of the 236,734 drivers observed were traveling at or below the average speed and only 10 percent were traveling as fast as 1.2 times the average. The analysts' problem then became one of selecting a cut-off point in this upper range. In the end, they recommended that the *speed rating* of any existing highway be considered as the speed of the 95 percentile—or possibly even the 98 percentile—of the drivers using that highway. By analogy, the *design speed* of a future highway should be the speed that only 5 or possibly 2 percent of the drivers will exceed after the road is built. (4)

In defense of these percentile speed values the BPR analysts showed that if the curves on a highway were designed for maximum superelevation of 10 percent and 0.16 side friction at the 95 percentile speed, only 5 percent of the vehicles would require more than the designed side friction. Of these, only a minuscule proportion (0.2 percent) would require more than 0.30 side friction, considered by Moyer and others to be the maximum for safe operation on wet pavements.

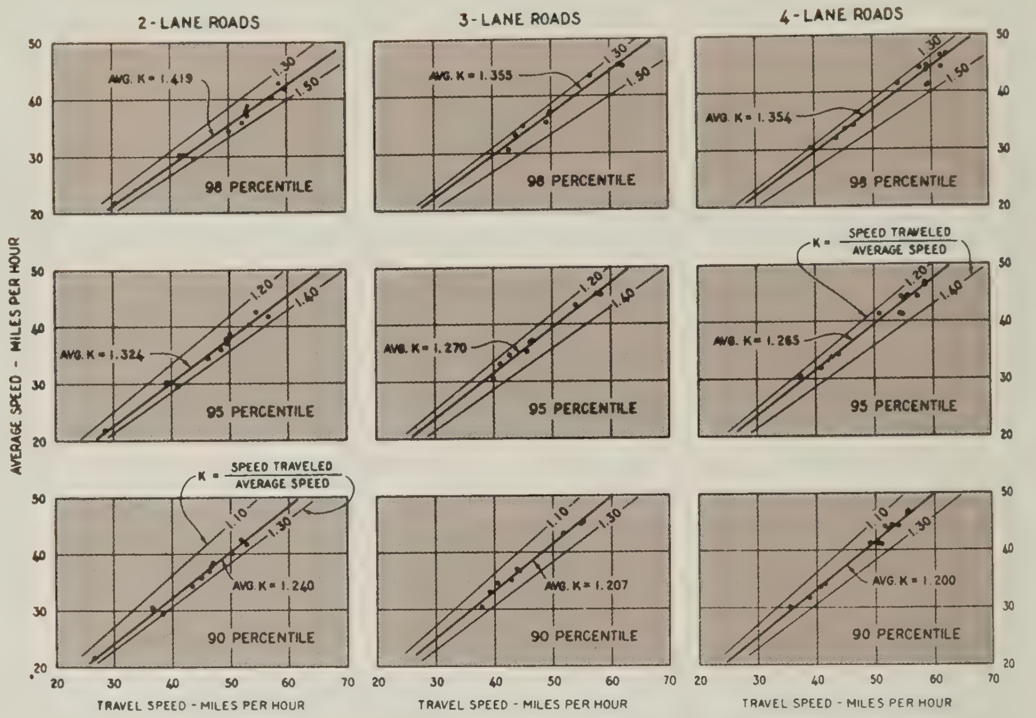


Figure 4.—Ratio of the speeds of the 90-, 95-, and 98-percentile drivers to the average speed of all drivers. (4)

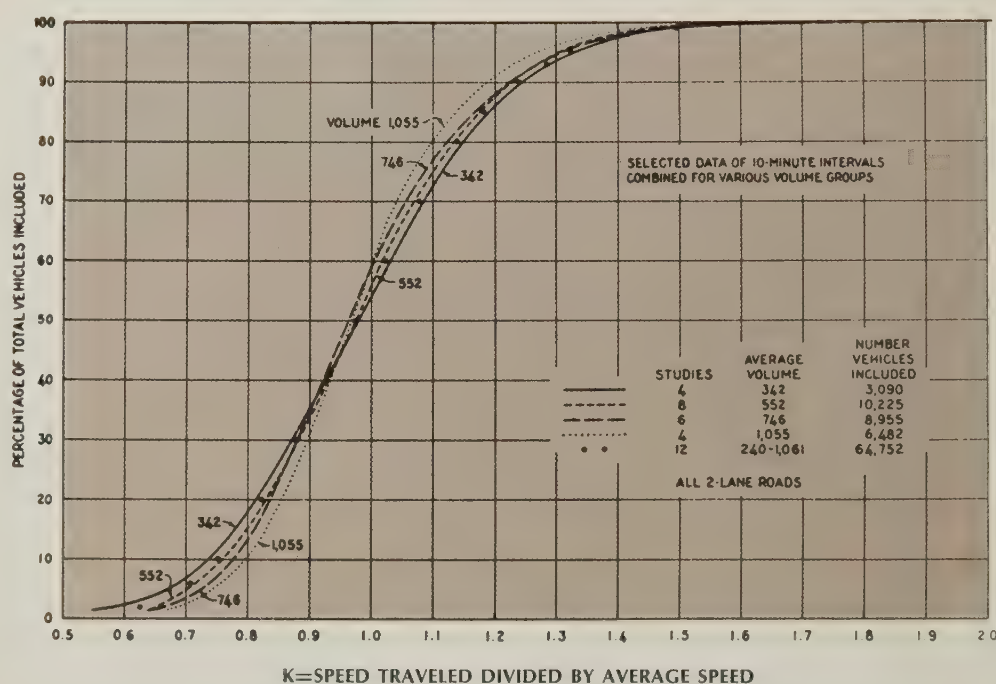


Figure 5.—Ratio of the speeds of the fastest drivers to the average speed of all drivers for various percentiles of total traffic. (4)

Further Driver Reaction Research

We have seen that in 1934 Moyer calculated the distances required to bring a vehicle to a stop on a level oad from various speeds, assuming perception-reaction time of one-half econd. For these calculations Moyer ısed the well-known kinetic energy ormula:

$$L=\frac{V^2}{30f}+0.73V$$

Vhere,

L=Total stopping distance in feet.

V=Speed in miles per hour.

f=Average effective coefficient of friction for straight skidding.

'he second part of this expression,).73V, is the distance the vehicle will ravel during the driver's perception-eaction time, assumed to be one-half second. This figure in turn was probıbly derived from the 1925 research of Moss and Allen with alerted drivers, which in effect measured only the subjects' motor-reaction ime, that is, the time for the driver o hear the stimulus (pistol shot) and or his nervous system to react and apply foot pressure to the brakes.

n 1934 the Massachusetts Institute of Technology carried Moss' and Allen's esearch a step farther. Test drivers in ordinary stock cars were instructed to follow a pilot car and to apply their brakes the instant they noticed the pilot car to be slowing down. In one series of tests the pilot car was equipped with a stoplight which lighted the moment the brakes of the lead vehicle were applied. Reaction times measured when the stoplight was used ranged from 0.2 second up to a second or more, with an average of 0.64 second. Five percent of the test drivers required more than 1 second and 20 percent occasionally registered as much as 1 second. (5)

When the tests were rerun without the stoplight, the test drivers required considerably longer times to perceive that the leading vehicle was slowing down. Drivers who reacted in 0.2 to 0.3 second to the stoplight required as much as 1.5 seconds to react without it. The researchers concluded that, making allowance for inattention—which had been eliminated from these tests—and for variations in personal capabilities, a perception-reaction time that would include most drivers should be between 2 and 3 seconds.

This range was adopted by AASHO in its first standard for stopping sight distance, approved February 1940, which allowed 3 seconds for a speed of 30 mph to 2 seconds for 70 mph. (Presumably drivers would be more alert at the higher speeds.) The AASHO standard also assumed a variable coefficient of friction ranging from 0.50 at 30 mph to 0.40 at 70 mph. These assumptions resulted in minimum sight distances of 200 feet at 30 mph up to 600 feet at 70 mph. The rate of deceleration with a friction factor of 0.50 was 16.1 feet per second per second, or one-half g, which according to the National Bureau of Standards, was the maximum for comfort. (6)

AASHO Special Committee Begins Intensive Study of Design Problems

By 1936 the fruits of research were becoming so abundantly available that the Bureau of Public Roads and the State highway departments began to feel the need for a special small working committee "to bring the available information on highway design up to date, develop new data based on research and experience and present them in usable form." (7) R. E. Toms, Chief of the Design Division of the BPR, proposed that the Bureau assign a small force of experts to devote full time to the work of the committee and that the American Association of State Highway Officials appoint a special committee consisting of senior State administrative design engineers to guide and review the work of the BPR task force. This proposal was approved by AASHO in February 1937 and a Special Committee on Administrative Design Policies was organized with Thomas H. MacDonald, Chief of the Bureau of Public Roads, as chairman, and Joseph Barnett of the BPR as secretary. Toms and 12 outstanding design engineers from the States made up the rest of the Committee. Later, this Committee became the Operating Committee on Planning and Design Policies. (7)

The Bureau of Public Roads furnished a small technical staff under the Secretary, and the Committee started work on what were then deemed the most urgent design problems. The Committee's mode of operation was to outline a general program of work, after which the BPR task force gathered together and evaluated all the known information on each subject. If there were gaps in the existing knowledge, the BPR engineers pointed them out for further study. Eventually, the staff prepared a tentative discussion, with conclusions and recommendations for each subject. This was then criticized, evaluated, and supplemented by the Committee members until a policy acceptable to them was hammered out. The resulting policy was submitted through the Committee on Standards to the AASHO Executive Committee for letter ballot by the several States; with a two-thirds favorable vote it became an *approved policy,* and also, in effect, the national design policy of the United States on that particular subject. (8)

The first fruit of the Committee's work was a "Policy on Highway Classification," approved by AASHO in September 1938. Subsequently, the Committee brought out policies on geometric highway types (1940), sight distances on highways (1940), marking and signing of no-passing zones (1940), intersections at grade (1940) and on rotary intersections (1941), and grade separations (1944). In 1941 it compiled design standards for primary highways, and in 1945 for secondary and feeder roads and for the National System of Interstate and Defense Highways.

General Motors Corporation Deceleration Tests

In 1940 General Motors Corporation (GMC) made a series of deceleration tests at its test tracks in Michigan. For these tests the vehicle operators were eight Proving Ground executives who were experienced drivers but not professional test drivers. The test vehicles were 15 stock cars weighing from 3,000 to 5,000 pounds. The tests were run on level, dry, concrete straightaways. The drivers were required to bring their vehicles to speeds of 50, 60, and 70 mph and then stop them as quickly as possible and still keep the car within a 12-foot traffic lane. This last requirement precluded a locked-wheel slide since under this condition the vehicle is not under good control and cannot always be kept in a 12-foot lane. Since the operator chose his own time to apply his brakes, perception-reaction time was eliminated from the tests, which then measured only braking distance. (9)

The results of these tests appear in figure 6 which shows average stopping distances of 120, 200, and 280 feet for speeds of 50, 60, and 70 mph. The rates of deceleration were very close to 20 feet per second per second for all speeds—considerably greater than the comfortable maximum of the Bureau of Standards.

In another series of tests passengers were carried in the test cars, the drivers were asked to make stops at various deceleration rates, and the reactions of the drivers and passengers were recorded. These tests demonstrated that stops at a rate of 13.9 feet per second per second were severe and uncomfortable to passengers, causing packages to slide off the seats. Such stops were classified as *emergency stops* by the drivers. Stops made at 11.05 feet per second per second were undesirable but not alarming to passengers, and those made at 8.55 feet per second per second were comfortable to all and also preferred by the drivers.

From these tests the GMC researchers concluded that their vehicles were capable of much greater decelerating performance than was comfortable for the human occupants, and that highway sight distances should be based on human performance factors assuming a deceleration rate of 8.5 to 9.0 feet per second per second. Such a rate, with a perception-reaction time of 3 seconds would result in a minimum sight distance of 927 feet for a speed of 70 mph.

German Autobahnen Designed for High Speeds

We must now back up a few years to an important event which occurre

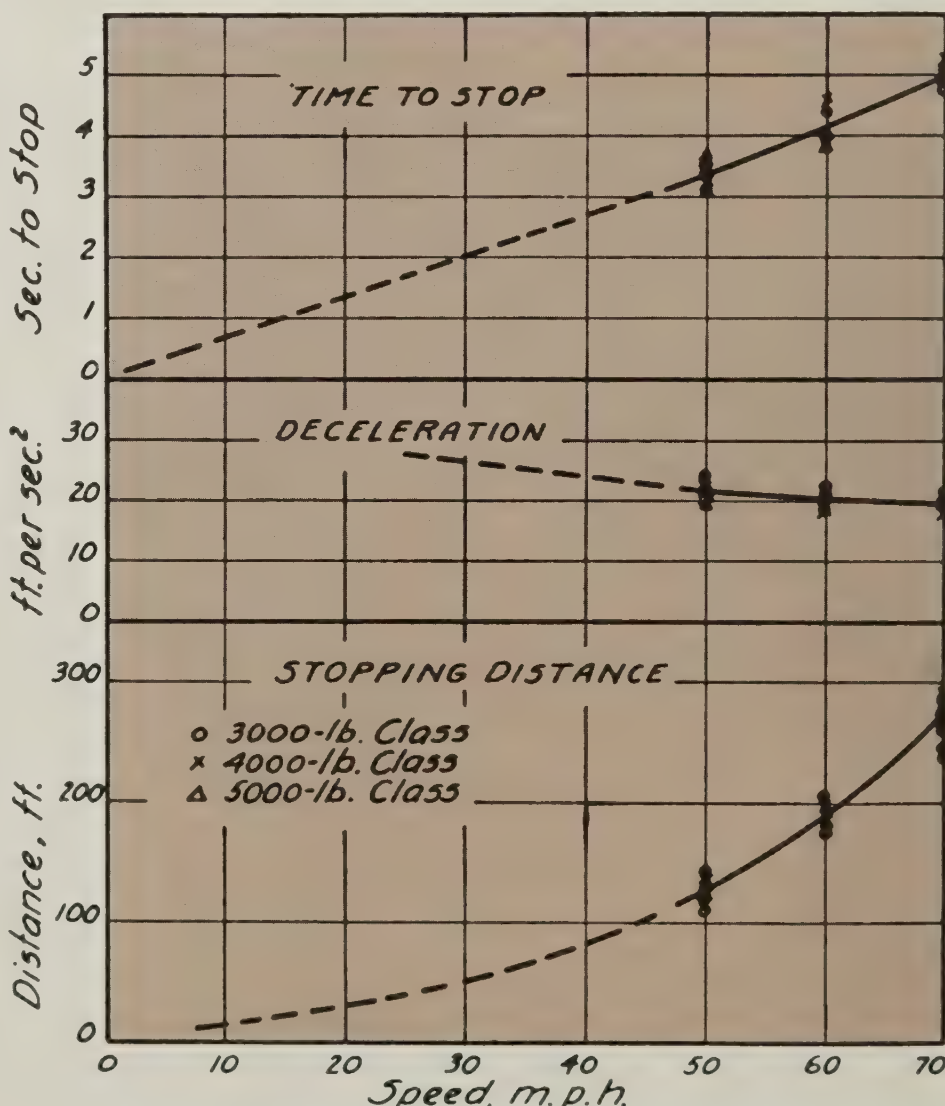


Figure 6.—Maximum deceleration tests. Level grade. (9)

In Germany. On September 23, 1933, Chancellor Hitler turned the first spadeful of soil for an express highway from Frankfurt/Main to Mannheim—the first unit of an elaborate system of modern motor roads (*Reichsautobahnen*) that was to link all of the important cities of Germany. The new expressways were to be divided highways with full access control. In flat country the curves were to be designed for a speed of 180 kilometers per hour (112 mph) with 6 percent maximum superelevation. Curvature design was governed by safe stopping sight distance as calculated in the formula:[5]

$$L=0.00394\frac{V^2}{f\pm\tan\ a}+0.278V$$

Where,

L=Sight distance in meters.

V=Velocity in kilometers per hour.

f=Friction coefficient between tires and pavement, assumed to be 0.4.

a=Gradient expressed in degrees. (*10*)

According to this formula, the safe stopping distance for 180 km/h and 0.4 friction factor was 370 meters on the level, 347 meters for a 3 percent up-grade, and 395 meters for a 3 percent down-grade. In rolling and mountainous country, to save construction expense, the Germans arbitrarily reduced the minimum sight distance to 200 meters which in effect reduced the permissible speed to about 140 km/h (87 mph).

In the German sight-distance formula the expression, 0.278V, represents the distance traveled by the vehicle during the driver's perception-reaction time, assumed to be 1 second. For measuring sight distance to a potential obstacle on the road, the eye of the driver was assumed to be 1.19 meters above the road and the obstacle was assumed to be either another vehicle or an object projecting 20 cm from the road surface upwards. For the worst condition, that is, a curve in cut concave to the hill, a horizontal curve radius of about 2,000 meters was needed to provide safe stopping distance in flat country. In rolling country, a radius of 1,000 meters was needed. The absolute minimum radius for mountainous country was 400 meters.

At this time the German *Autobahn* curve design was the most advanced in the world. The concept of tying horizontal and vertical curvature and sight distances to speed, which the *Autobahn* engineers pioneered, was one of the great advances in the history of geometric design. Later research has shown that their assumed reaction times were rather low and friction factors somewhat high, but this was more than compensated for by an unrealistically high design speed. Consequently, although 40 years have passed, the alinement of these roads is still adequate for today's traffic.

The United States did not have a modern highway comparable to the German *Autobahnen* until 1939, when the 160-mile Pennsylvania Turnpike was completed. In planning the alinement for this toll road the designers applied the lessons of more than 15 years of high-speed operation on the European expressways as well as the fruits of a decade of research on driver behavior in the United States. The varied terrain traversed by the Turnpike permitted long tangents in the eastern part of the route but required some curves of 955 feet radius crossing the Allegheny Mountains. The designers went to great pains to obtain *consistency* in curve design. They joined extremely long tangents by extremely long, flat curves. Where sharper curves were necessary because of topography, they led up to them with a series of flatter curves. They spiraled all curves of 3,300-feet radius or less; provided sight distance for a speed of 70 mph for curves up to 1,910-feet radius; and provided sight distance for a speed of 60 mph for the sharper curves, only eight of which were of radii less than 1,433 feet. They designed superelevation for a side-friction factor of f=0.10 with a maximum cross-slope of 10 percent, attained at a radius 1,146 feet.

Speed Trials on Pennsylvania Turnpike

Upon completion of the Turnpike, its owners arranged with the General Motors Proving Ground to test the superelevation and curvature theories used in the design by actual speed trials. These tests were made in 1940 with new elaborately instrumented stock cars driven by highly experienced test drivers. One of the objectives of the speed trials was to determine at what speed the driver felt impending loss of steering control when rounding a curve. At this point the vehicle instrumentation would record the *unbalanced side friction*, that is, the centrifugal force not countered by the built-in superelevation of the road (also known among automotive engineers as the *centrifugal ratio* or *cornering ratio*). Another objective was to determine the efficacy of spirals for keeping drivers in their proper lanes when entering curves at high speeds.

The greatest speed attained in these tests was 106.75 mph on a curve of radius 1,910 feet, running downhill on a 3 percent grade at the vehicle's top speed. This velocity was far above the speed of 70 mph for which this

[5] This is the familiar kinetic energy formula used by Moyer and others, expressed in metric units.

curve was designed, yet the driver at no time felt that loss of control was impending, even when the centrifugal ratio went as high as 0.31.

On the other hand, the drivers had to use their utmost skill to retain control when entering spiraled 955-foot radius curves at 80 mph when centrifugal ratios of 0.32 to 0.41 were developed. These curves had been designed for 60 mph with 10 percent maximum superelevation and had spiral transitions 360 feet long. These speeds were, of course, far higher than any that would be encountered in ordinary highway operation, and were possible only because of the skill and experience of the professional test drivers.

After these tests the researchers recommended that for speeds above 70 mph no more than $f=0.10$ of the unbalanced side friction should be used in designing superelevations. The drivers and the engineer observers agreed that the spiral easement curves were highly effective for keeping drivers in their proper lanes at high and moderate speeds, and in fact their use ". . . is imperative if inherent safety is to be provided." (*11*)

BPR Stopping Distance Tests

By 1953, average speeds on U.S. highways had increased to about 52 mph with 12 percent of drivers exceeding 60 mph and others occasionally traveling as fast as 80 mph. The performance of new vehicles, compared to that of pre-war vehicles, had improved considerably and several millions of the older types had been retired. The Bureau of Public Roads thought the time was ripe to reevaluate highway stopping distances, and ordered a series of tests to be made. (*12*)

Braking test from high speed at Andrews Air Force Base, Maryland *(12)*

The test track for these experiments was an unused concrete taxiway at an air base near Washington, D.C., the surface of which had a clean, broomed finish of good anti-skid properties. All testing was on dry pavement. The test vehicles were 53 stock cars ranging in age from new to 10 years, operated by amateur drivers. The tests were designed to measure the braking distance—the distance traveled from the moment the operator applied brake pressure until the vehicle came to a stop—separately from the perception-reaction distance, at speeds up to 90 mph. The results of these tests are shown in figure 7.

According to theory, the braking distance required to stop a vehicle varies with the vehicle's kinetic energy at the time the brakes are applied, which, in turn, varies as the square of the speed. However, the BPR engineers found that for high speeds the stopping distance varied as some greater power than the square. For example, the average stop from 30 mph was made in 40 feet. If the braking distance varied as the square of the speed, a stop from 90 mph should have taken 360 feet; but the actual distances logged in the tests averaged 580 feet, and the shortest crash stop from that speed was 490 feet. The researchers accounted for part of the discrepancy by the fact that brake pressure is not instantly exerted on the brake drums—it take a fraction of a second to depress th pedal, to compress the brake fluid, and expand the brake shoes. Also, i braking from speeds of 70 mph and greater, the brakes seemed to *fade*, or lose effectiveness from heat buil up shortly after application, even though the brake pedal was jamme down as far as it would go.

The BPR engineers also observed rather wide differences in the stopping distances from high speeds logged for different runs by the same vehicle and operator. At 80 mph these differences might be as much as 164 feet, even though all the conditions of the test appeared to be identical.

Because of the rather wide differences in the braking performance of different vehicles and also of the same vehicles at different times, the researchers recommended that values of stopping distance used for design of roads be based on the 85 percentile of drivers, rather than the average. Figure 8 shows the average and 85 percentile values recorded during the test project.

The research just described, along with a number of extensive studies of skid resistance on various roadway surfaces, suggested to AASHO's Committee on Planning and Design Policies the need for some revision of its Policy on Sight Distance, originally issued in 1940. The problem facing the Committee was not lack of information but rather extracting a workable practical policy from research results covering a rather wide range of values. With measured perception-reaction times varying all the way from 1 second or less up to 3 seconds, what was the proper value to use for safe sight distance? With pavement coefficients of friction ranging from 0.3 to 0.8 depending on speed, surface type, and wetness, what values would provide reasonable safety without prohibitive construction cost? After weighing the trade-offs the Committee finally decided as follows:

- To continue to use the kinetic energy formula:

$L = \frac{V^2}{30f}$ for computing braking distance;

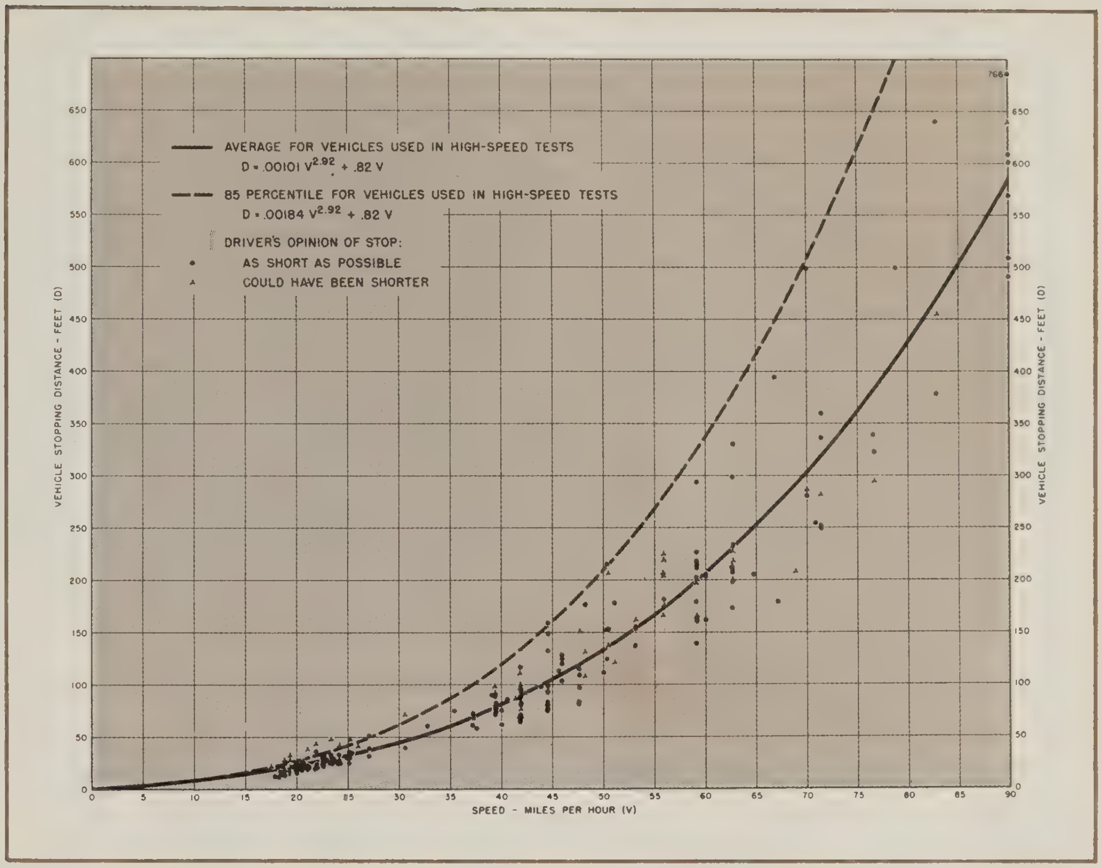


Figure 7.—Braking distances during high-speed tests. (12)

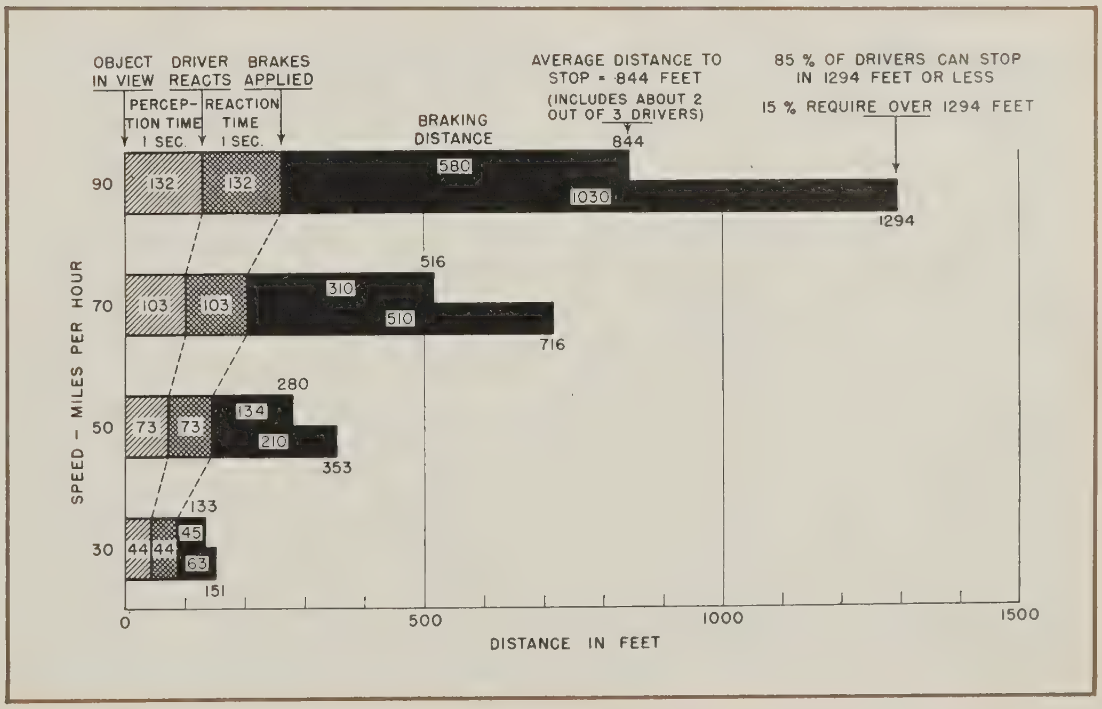


Figure 8.—Driver stopping distance on dry concrete. (12)

- To adopt 2.5 seconds as the perception-reaction time at all speeds;

- To use the friction coefficient for wet concrete surfaces for figuring all stopping distances. This was quite generally accepted to range from 0.36 at 30 mph to 0.29 at 70 mph.

- To assume that during wet weather, traffic would be traveling slower than the design speed when the brakes were applied.

With these assumptions, stopping distances on a level road varied from 200 feet at 30 mph up to 600 feet for 70 mph.

AASHO Publishes Policy on Geometric Design

The Policy on Sight Distance was not the only one needing revision by 1954. The rapid evolution of highway engineering had made all of the original eight policies obsolete in some respects. Rather than attempt to revise the policies, the Committee decided to incorporate them in an entirely new publication eliminating duplications and obsolete information and adding much new material. The resulting publication, "A Policy on Geometric Design of Rural Highways," was issued by AASHO in 1954. (*13*) Known as the *Blue Book* from the color of its cover, this manual went through seven printings and has had an immense influence on highway design in the United States and abroad.

The Blue Book firmly established the principle of balanced dynamic design—the design speed concept—in highway engineering. We have seen how this concept evolved for horizontal alinement, where the dynamic forces to be overcome are momentum and centrifugal force. In Part 7 we will examine the other side of the coin, the vertical alinement of the highway, where the main antagonist is gravitational force.

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Right Turn on Red

by Hugh W. McGee and Davey L. Warren

This article identifies the right turn on red (RTOR) rule of each State and their experiences with RTOR. Information on RTOR accidents, vehicle delay, fuel savings, and signing, as well as preliminary results of a public opinion survey of driver and pedestrian attitudes toward RTOR are reported.

Introduction

Right turn on a red signal (RTOR) is a practice which has become popular in recent years. Even though RTOR was once used almost exclusively in Western States, it is now permitted in some form in 48 States. Yet RTOR remains controversial. Some States believe RTOR saves time and fuel without compromising safety and permit RTOR at all signalized intersections except where prohibited by a sign. Other States believe that the benefits from RTOR are at the expense of safety and permit RTOR at only a few intersections where signed.

This article describes the first phases of a research project undertaken for the Federal Highway Administration (FHWA) to determine whether or not RTOR should be permitted, at which locations, and how. It updates an interim study report which documents in more detail the current practices and state of the art for RTOR. (*1*)[1]

What Is RTOR?

RTOR means permitting a right turn on a steady red traffic signal after stopping and yielding the right-of-way to vehicles and pedestrians. It is not to be confused with allowing right turns at a signalized intersection using channelizing islands and YIELD signs or allowing right turns on a flashing or steady green or yellow arrow.

RTOR began in 1937 when California first permitted the movement with an authorizing sign. California changed in 1947 to permit the RTOR movement except where prohibited by a sign. However, the acceptance of RTOR by other States was slow to come. According to a survey on RTOR conducted by an Institute of Traffic Engineers Committee in 1968, only 20 States reported using RTOR.[2] Furthermore, it was not until the 1971 edition of the Manual on Uniform Traffic Control Devices (MUTCD) that RTOR was recognized as acceptable by the National Advisory Committee on Uniform Traffic Control Devices, and then only with an authorizing sign. In July 1975, the National Committee of Uniform Traffic Laws and Ordinances approved a revision in the Uniform Vehicle Code (UVC) which would allow drivers to turn right on a steady red light *unless* a sign prohibited the turn. (*2*) The revised UVC, Section 11-202(c) also allows drivers

[1] Italic numbers in parentheses identify the references on page 31.

[2] "Right Turn on Red," Unapproved unpublished report by the Institute of Traffic Engineers, Committee 3M (65), May 1968.

to turn left from a one-way street into a one-way street unless a sign bans the turn.

Although RTOR is now a rather widespread practice, it is not without controversy. The slow acceptability of RTOR is partly due to differences in opinion. Supporters of RTOR argue that it increases intersection capacity, reduces delay, and does not lead to more accidents. The opponents argue that the time savings benefits are not significant and that the accident potential is greater, especially to pedestrians. Because of the basic disagreements on whether, where, and how RTOR should be permitted, RTOR has not been implemented uniformly. Rules vary within and throughout the States and, even under a similar law, guidelines and signing practices differ.

RTOR Rules

Right turn on red is governed by two basic rules: generally prohibited or generally permitted.

Under the *generally prohibited* rule, RTOR is prohibited at all signalized intersections except where there is a sign permitting such movement. For this reason, the rule is sometimes labeled sign permissive. Where signed, the RTOR vehicle is required to stop and yield the right-of-way to pedestrians and other traffic using the intersection. Figure 1 shows a location that has been signed to permit RTOR under this rule.

Contrary to the sign permissive rule, various State codes are written to allow RTOR after the vehicle stops and yields to pedestrians at all signalized intersections, unless signed otherwise. The *generally permitted* rule began in Western States and is gaining wider acceptance. Two intersections using different signs to prohibit RTOR under this rule are shown in figure 2.

State Practices

One of the specific requirements of the research being reported was to survey States and cities to determine RTOR rules and operational experi-

Figure 1.—Intersection signed to permit RTOR.

Figure 2.—Intersections signed to prohibit RTOR.

ence. To accomplish this, a questionnaire was sent in 1974 to each State highway and transportation agency, including the District of Columbia. Several States were recently contacted in order to update this RTOR rule inventory.

Figure 3 shows each State's RTOR practice. As of December 1975, 30 States had adopted the generally permissive RTOR rule. Nevada, New Mexico, and Oregon are included in this group even though their laws do not authorize a sign for prohibiting RTOR at any intersection. However, in actual practice, Oregon does prohibit RTOR at a few intersections.

Eighteen States follow the sign permissive rule. Four of these—Alabama, Massachusetts, Pennsylvania, and South Carolina—do not have explicit laws permitting RTOR but do allow RTOR when signed. RTOR is even permitted without a sign in some local jurisdictions in Alabama. Michigan uses a flashing red arrow instead of a sign to permit RTOR. (For reporting purposes, Michigan and Arkansas are included in the sign permissive category even though both States recently adopted the generally permissive RTOR rule.)

Only Rhode Island, Vermont, and the District of Columbia still do not permit RTOR in practice or by law even with a sign.

As illustrated in figure 3, most States either following the sign permissive rule or totally prohibiting RTOR are in the East, and those allowing RTOR at most or all intersections are in the West. Furthermore, there is a definite trend toward adopting the "western" variety of the RTOR rule as evidenced by the following:

- In 1968, Florida was the only State east of the Mississippi River that followed the generally permissive rule compared to 10 now.
- Ten States changed to this rule in 1974, while Ohio, Georgia, West Virginia, Wisconsin, Idaho, and New Hampshire changed in 1975.

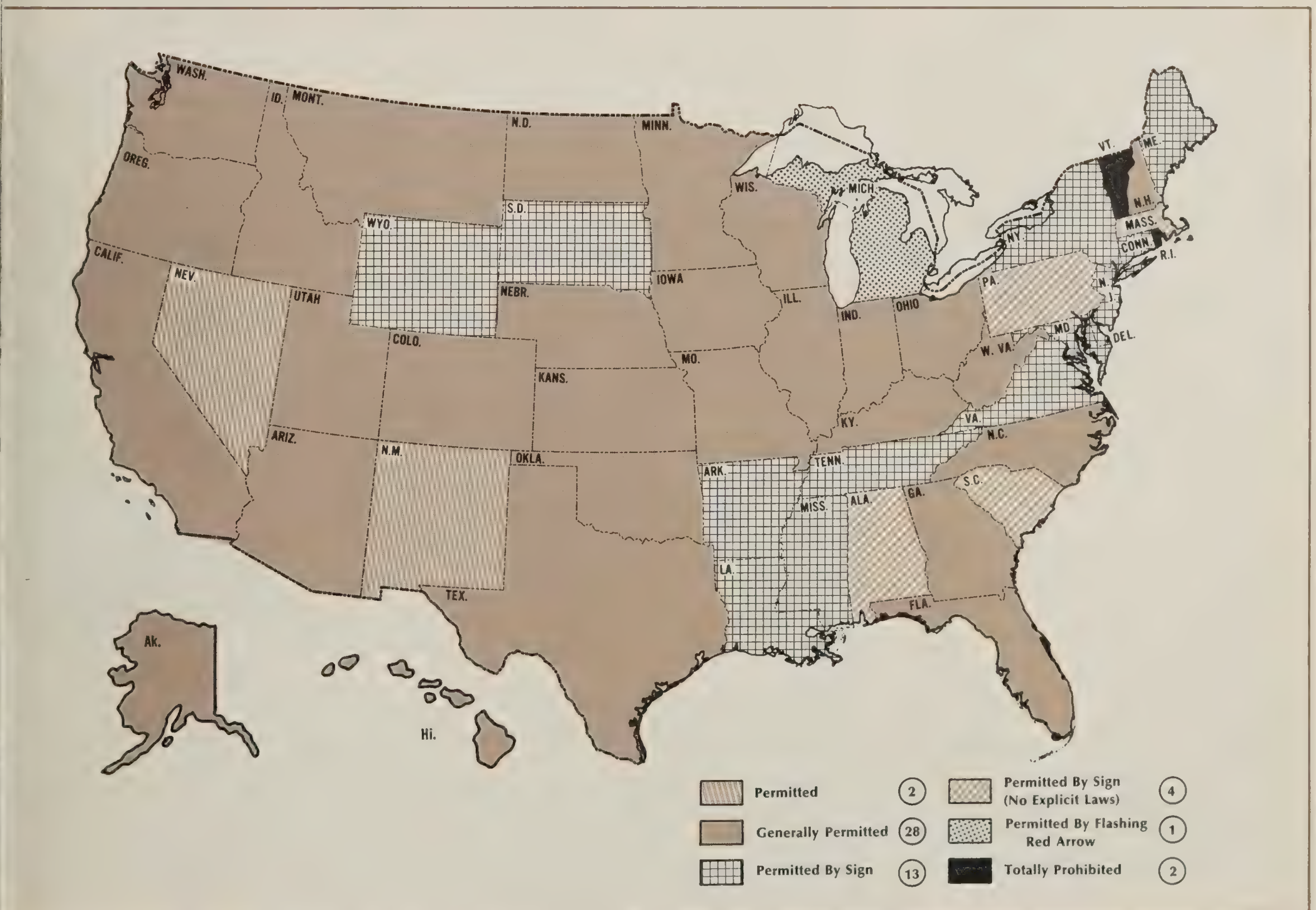


Figure 3.—Inventory of RTOR State practice.

■ Arkansas and Michigan changed to this rule in April 1976.

■ Rhode Island, South Dakota, Virginia, and Tennessee have passed legislation to adopt the generally permissive rule which will become effective later this year.

When the recent changes in RTOR laws take effect, the number of States permitting RTOR only where posted will decrease to 13. Thirty-six will permit RTOR at all intersections unless prohibited by sign.

RTOR Provisions

RTOR is prohibited by a sign at only a small percentage of the intersections in those States where it is generally allowed. Nine States do not prohibit RTOR at any of their signalized intersections.

Missouri has signed 28 percent of its signalized intersections to prohibit RTOR. This was the highest percent of RTOR prohibitions reported for States where RTOR is generally permitted. North Carolina restricts the RTOR movement at 25 percent of their intersections due to a policy of signing all but the most obviously safe cases. However, as experience is being gained with the generally permissive RTOR regulation, the prohibitive signs are gradually being removed.

In States where RTOR is permitted by sign, only a small percentage of the State controlled intersections are so signed. Massachusetts and, for practical purposes, New Jersey do not allow RTOR at any of their signalized intersections and it is seldom used in Connecticut, Pennsylvania, Maryland, and South Carolina. But two States, Delaware and South Dakota, sign for RTOR at 50 percent or more of their State controlled intersections.

On the average, the States that generally permit RTOR do so at 90 percent of their signalized intersections. On the other hand, those States that permit RTOR only when signed do so at only 8 percent. These figures reflect the underlying philosophy of the two rules—those following the generally permissive rule consider the feature to be safe and prohibit the movement only when it is considered hazardous, whereas those permitting RTOR with a sign consider the feature to be unsafe and allow it only under special situations.

It is interesting to note that the percentage of State controlled intersections where RTOR is prohibited by sign is nearly the same as where RTOR is permitted by sign (10 percent vs. 8 percent).

RTOR Guidelines

The States were also asked to identify any guidelines, warrants, or criteria developed to select sites for prohibiting or permitting RTOR. Twenty-five States replied that they have developed guidelines ranging from engineering judgment to a formal list of numerical warrants.

Sign permissive RTOR guidelines

Of the 18 States that follow the sign permissive rule (including Michigan), 10 indicated that guidelines were developed to determine where RTOR should be permitted. Several States indicated that while no formal guidelines exist, a traffic engineering review is required (as in Maine).

After New York passed legislation authorizing RTOR when properly signed, the State Department of Transportation prepared a set of guidelines for the selection of suitable intersections and approaches and required that a traffic engineering study be made for each approach under consideration. In general, the State feels that RTOR should not be allowed when it would cause undue interference or safety problems for either vehicles or pedestrians. The guidelines recommend permitting RTOR under the following conditions

■ Volume (undetermined) of right turning traffic does not require signal modification or unduly interfere with pedestrians.

■ Adequate capacity on the departur lanes.

■ Cross street traffic with speeds less than 40 mph (64 km/h).

■ Adequate sight distance.

■ Signal intervals which do not have a red ball and a right green arrow signal displayed simultaneously.

The New York sight distance curve (fig. 4) was adopted from the set of curves used in determining the neec for an intersection warning sign.

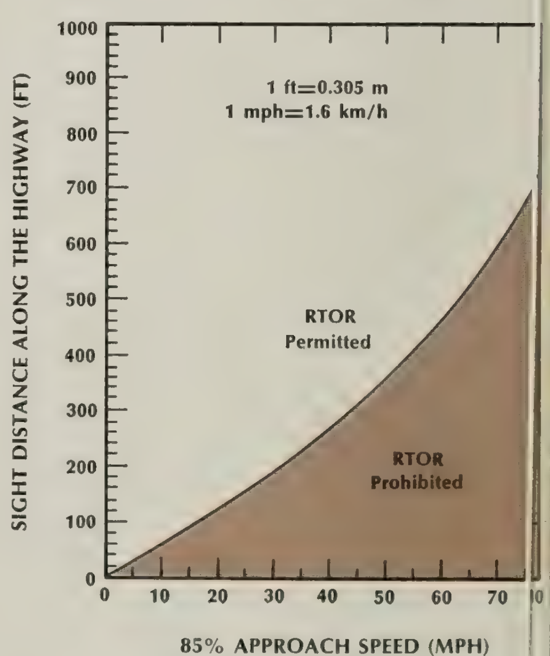


Figure 4.—Sight distance requirement for RTOR in New York.

All the factors cited by each of the States for permitting RTOR under the sign permissive rule are listed in order of frequency in table 1. Ten separate factors were identified from various State guidelines. Each of the factors requires situations or conditions that should exist in order to permit RTOR. They are somewhat conservative and reflect the general philosophy of the sign permissive rule, that is to provide for RTOR only when it can substantially improve traffic operations and does not create a hazardous situation.

Table 1.—Summary of factors considered in permitting RTOR under sign permissive rule

Factor	No. of States
Exclusive right-turn lane	2
Preferably two lanes into which right turn is made	2
Adequate sight distance	2
Safety conditions conducive to RTOR	2
Significant right-turn volume	1
Low pedestrian volume	1
Preferably two-lane approaches	1
Need for additional capacity	1
Availability of lane to turn from and turn into without conflict	1
Adequate gaps in traffic and pedestrian stream	1

Table 2.—Summary of factors considered in prohibiting RTOR under sign permissive rule

Factor	No. of States
Heavy pedestrian movement	5
Sight distance	2
School crossing	2
Approach speed	2
High cross-street volumes	1
Presence of pedestrian signal	1
Left-turn phase for opposite direction	1

The seven primary factors cited by the States that would preclude the use of RTOR at an intersection are summarized in table 2. Five States indicated that they would not authorize an RTOR sign at an established major pedestrian crossing. Some States, such as Virginia, have specified a certain level of pedestrian traffic to define a major crossing, while others leave it to engineering judgment.

Generally permissive RTOR guidelines

Of the 30 States with a generally permissive RTOR rule, 16 indicated established guidelines exist for identifying locations where RTOR should be prohibited. Surprisingly, there are more factors cited by the States in considering the restriction of RTOR under the generally permissive rule than for permitting it under the sign permissive rule. Table 3 lists 16 factors taken from the guidelines provided by the States. They are listed in order of the number of States that incorporate that particular factor into their guidelines. Nine States noted restrictive geometrics as a consideration for prohibiting RTOR. This is a catchall phrase which could include items such as tight turning radii, five or more approaches, inadequate sight distance, and other factors that restrict the right-turn movement or visibility of conflicting traffic. Also, nine States specifically indicated that they prohibit RTOR where there are five or more approaches. Similar to the factors noted under the sign permissive rule, several States apply numerical levels to the various factors.

The State of Indiana has prepared warrants that stipulate when RTOR *should* or *may* be prohibited. The warrants were developed from a study conducted at Purdue University. (*3*) The researchers felt that RTOR should be prohibited only when there was a significant hazard resulting from RTOR. In their studies they found that RTOR did not cause a significant accident problem. However, they recommended three situations where it *should* be prohibited: (1) where sight distance was restricted, (2) where a separate signal phase for left turning movements existed, and (3) at intersections with more than four approaches. The warrants also suggest locations where RTOR *may* be prohibited because of little benefit or adverse public reaction.

Table 3.—Summary of factors considered in prohibiting RTOR under generally permissive rule

Factor	No. of States
Restrictive geometrics	9
Five or more approaches	9
Significant pedestrian volume	7
Inadequate sight distance	7
Speeds through intersection	5
Exclusive pedestrian phase (all-red)	4
Vehicle conflict is serious	3
RTOR conflicts with other vehicle movements, e.g., left-turn phase	3
History of accidents related to RTOR (5 or more)	2
Complex signal phasing	2
Signals under school crossing warrant	2
No appreciable right turns	1
Short red interval	1
Pedestrian signal locations	1
Fully actuated signals	1
Right turn from more than one lane	1

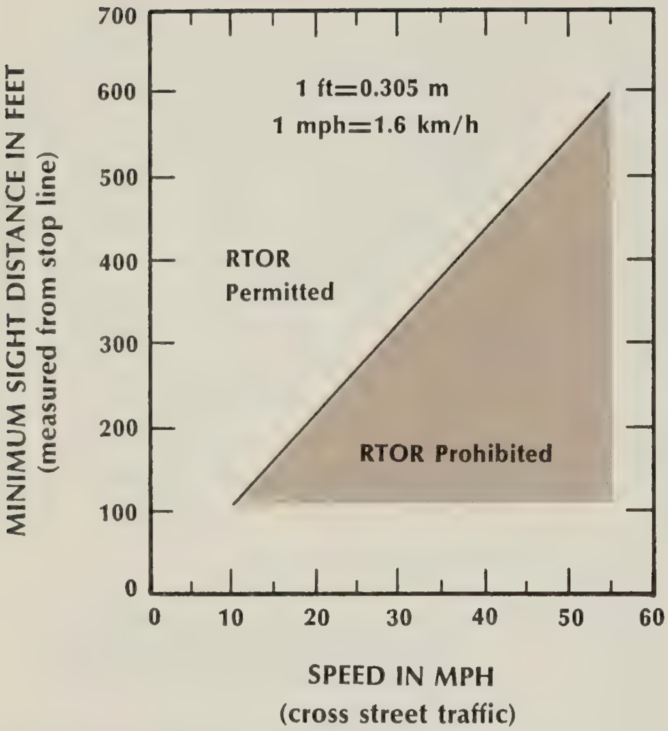
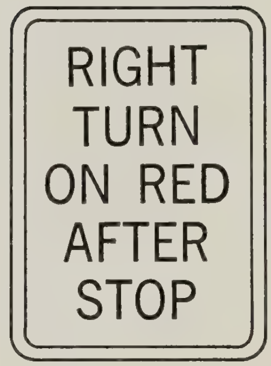


Figure 5.—Indiana sight distance requirement for RTOR.



18 in. by 24 in.
(457 mm by 610 mm)

Figure 6.—MUTCD standard RTOR sign.

18 in. by 24 in.
(457 mm by 610 mm)

24 in. by 30 in.
(610 mm by 762 mm)

Figure 7.—Pennsylvania standard RTOR s

The sight distance requirement for RTOR in Indiana is shown in figure 5. Indiana chose to use a longer sight distance requirement than some other States because it was felt that an RTOR vehicle should not cause any delay to the oncoming cross-street traffic by forcing the vehicle to decelerate. The sight distance standards set by other States are based on more lenient stopping sight distance requirements.

Signing Practices

The type of signing varies with the type of RTOR law. In keeping with the two basic RTOR policies, there are two types of signing practices. For those States following the sign permissive rule, a positive sign is required that indicates RTOR is authorized at particular intersections. Nearly every State that follows the sign permissive rule indicated that it uses the sign recommended in the Manual on Uniform Traffic Control Devices (MUTCD) (fig. 6). However, some States vary the letter size and message of their sign. The States of Louisiana, New York, and South Dakota allow the use of the sign RIGHT ON RED AFTER STOP instead of the MUTCD version. Wyoming uses an 18 in. by 24 in. (457 mm by 610 mm) sign reading AFTER STOP RIGHT TURN PERMITTED ON RED. Pennsylvania uses the same message as the MUTCD sign but increases the size of the word STOP for emphasis (fig. 7).

For those States following the generally permissive rule, RTOR is prohibited by a sign facing the turning vehicle. Figure 8 illustrates the signs used to prohibit right turn on red. Many States have chosen the message NO TURN(S) ON RED as shown in figure 8a, c, d, and e because it can apply to left turns at a one-way street as well as to the right-turn-on-red situation. The signs shown in 8c and 8e are now recommended in the MUTCD. Generally, however, the States use the sign shown in 8b as their standard for the RTOR restriction sign. The sign format shown in 8f is followed in some cities in Nebraska. This sign merely adds an ON RED plate to the MUTCD R3–1 sign.

Although not reported in any of the State questionnaires, several cities us different versions of these signs. On version frequently used at school crossings in Denver, Colo., reads NC TURN ON RED WHEN CHILDREN PRESENT (fig. 9). Another version of this sign carried the message NO TURN ON RED DURING SCHOOL HOURS. A YIELD TO PEDESTRIANS sign is used in Colorado Springs, Colo., to emphasize to RTOR motorists that pedestrians have the right-of-way. In California where the generally permissive rule is followed, a RIGHT TURN ON RED AFTER STOP sign is installed at a few locations where traffic is reluctant to turn righ because of local conditions.

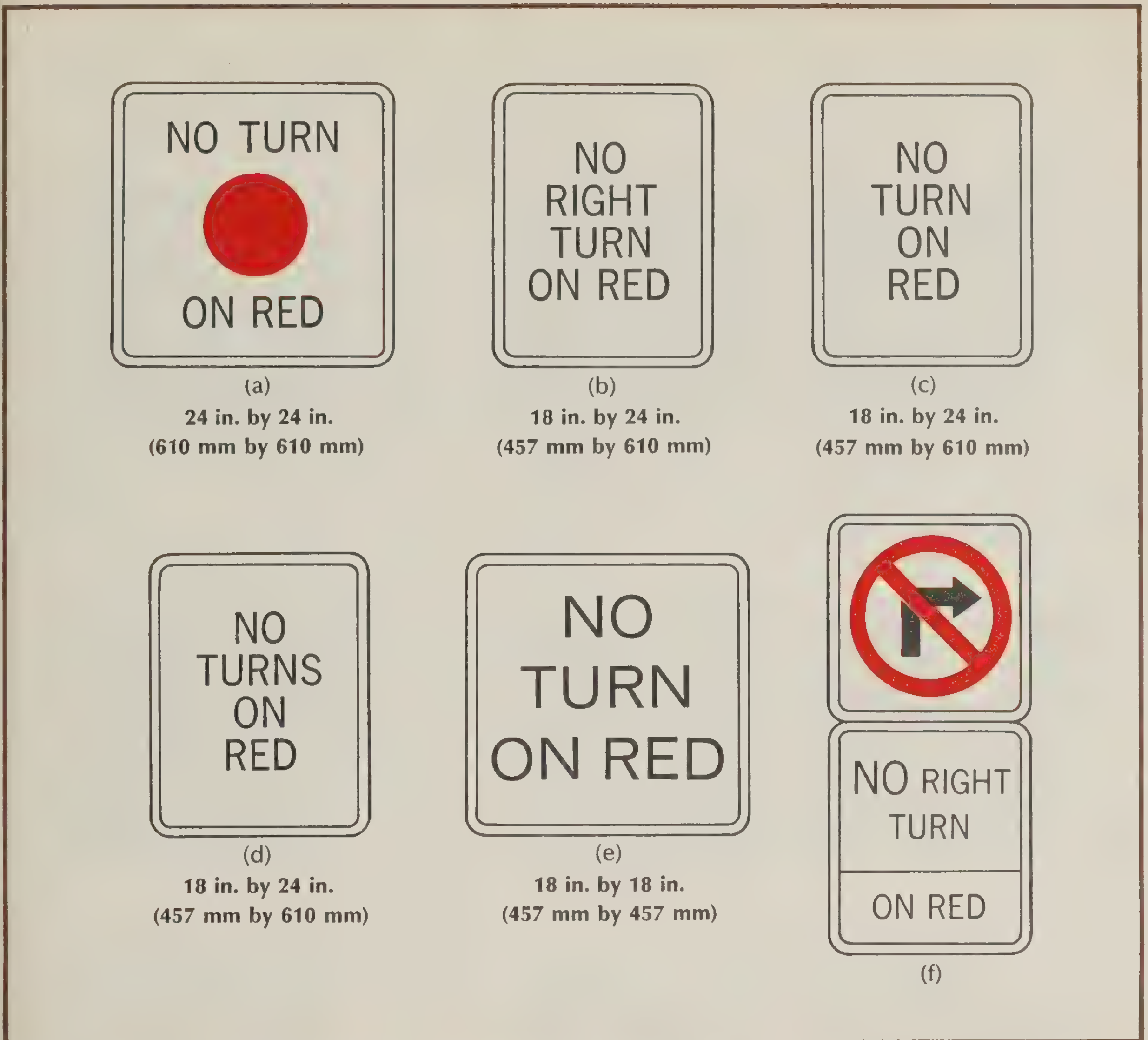


Figure 8.—RTOR prohibition signs.

Figure 9.—Intersection signed to protect children from RTOR motorist.

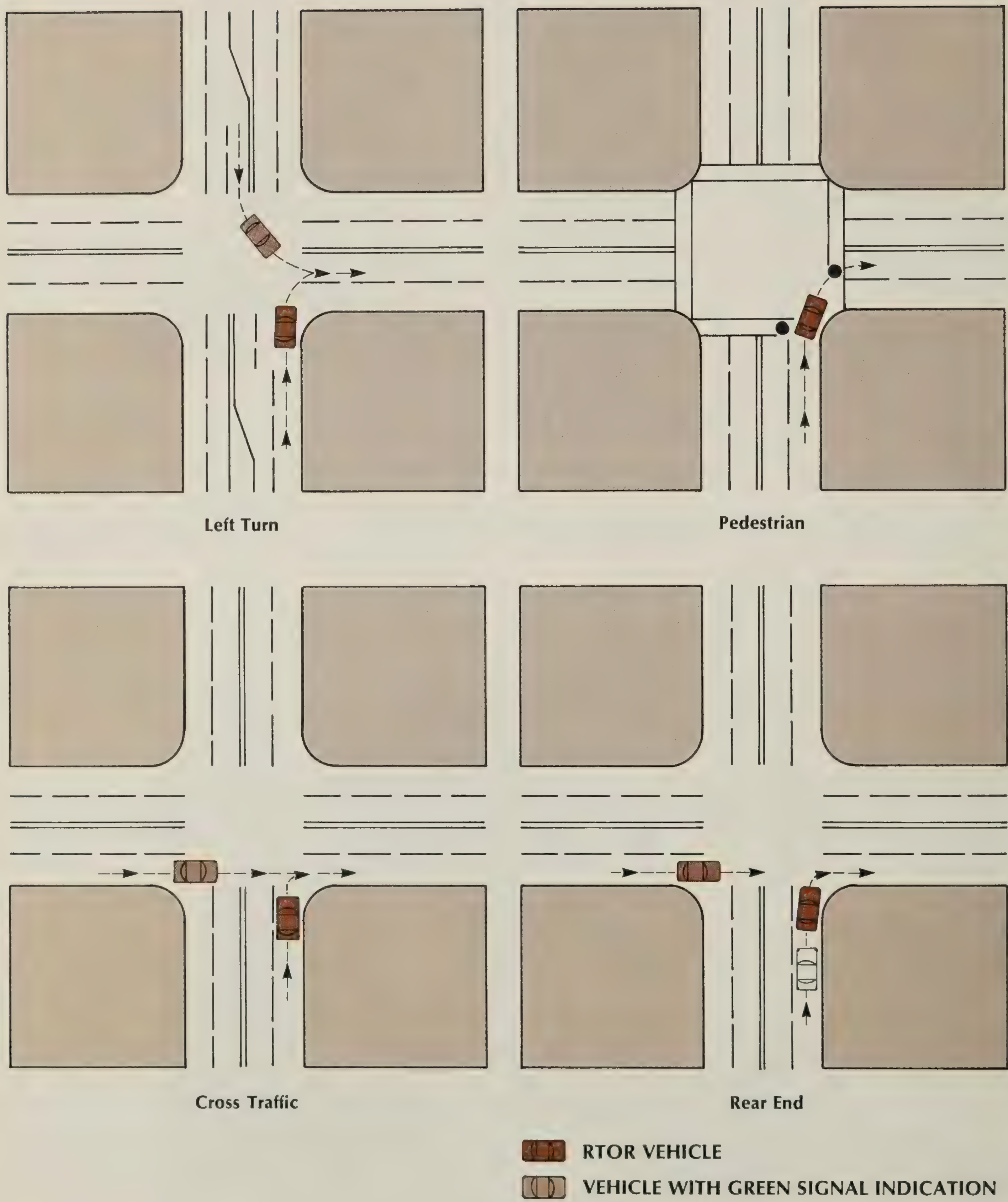


Figure 10.—Basic types of RTOR accidents.

RTOR Effects on Safety

Probably the biggest objection to permitting the right turn on red movement is that it is a source of accidents, particularly pedestrian accidents. There are four basic types of accidents that can occur as a result of an RTOR vehicle not stopping or yielding the right-of-way to pedestrians or other vehicles using the intersection legally (fig. 10). The RTOR vehicle could interfere or collide with vehicles turning left onto the same street or with vehicles passing through the intersection on the cross street. The RTOR vehicle could hit pedestrians crossing the intersection or the RTOR vehicle could stop abruptly and be hit in the rear by a trailing vehicle.

Table 4 shows a summary of previous accident studies related to RTOR as well as accident information collected as a part of this current research project. The data show the number of RTOR accidents at signalized intersections to be very small. RTOR accidents as a percent of all intersection accidents ranged from a low of 0.36 percent (San Francisco, Calif.) to a high of 3.14 percent (Virginia).

It is interesting to note that those localities with the generally permissive rule had a lower accident rate than those under the sign permissive rule. The lower accident rate under the generally permissive rule is weighted heavily by west coast cities where experience is greatest. It should be pointed out that in Columbus, Ohio, where one of the higher accident rates was reported, two-thirds of the accidents occurred during the first 6 months of the 13-month study. All of the accidents reported were minor property damage accidents with no personal injuries. No pedestrian accidents were reported even though six of the intersections signed to permit RTOR were in areas with heavy vehicle and pedestrian traffic. Ohio has since switched to the generally permissive RTOR rule.

Table 4 shows that RTOR pedestrian accidents as a percent of all pedestrian accidents vary widely. Although less than 4 percent of total pedestrian accidents in Los Angeles involved a right turn on red vehicle, nearly 20 percent of all RTOR accidents involved pedestrians. In Chicago, nearly one-half of all RTOR accidents involved pedestrians.

A graphic representation of the Chicago accident results is shown in figure 11. The accident information was collected at 78 locations in Chicago for the years 1972–1974 under different RTOR rules. In 1972, RTOR was totally prohibited; in 1973, RTOR was permitted with a sign at all study locations; and in 1974, RTOR was generally permitted.

The graph not only shows how accidents were affected by RTOR under the different rules but also illustrates the relationship of RTOR accidents to RTOG (right turn on green) accidents. When compared to all intersection accidents or to RTOG accidents, the percent of accidents occurring because of RTOR is small. RTOR accidents accounted for less than 1.5 percent of the total accidents at these signalized intersections, whereas RTOG accidents were about 13 percent of the total.

Even though the frequency of RTOR accidents is very small, right turn pedestrian accidents have increased since RTOR was introduced (fig. 12).

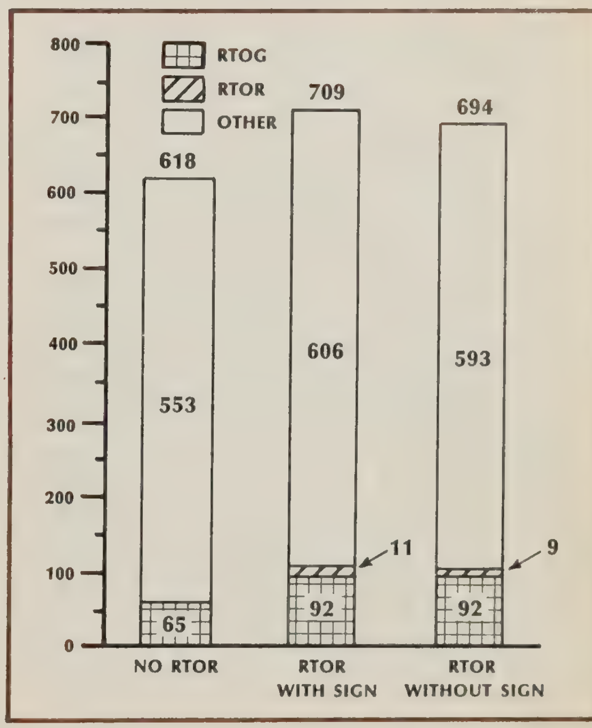


Figure 11.—Number of intersection accidents in Chicago (based on 78 locations).

Table 4.—RTOR accident experience

Location	Total accidents	RTOR accidents	Percent of total	Pedestrian accidents	RTOR pedestrian accidents	Percent of total pedestrian accidents
			Generally permissive RTOR rule			
Portland, Oreg.	52,677	253	0.48	Unknown	20	Unknown
Los Angeles, Calif.	42,424	287	0.67	1,487	54	3.63
Denver, Colo.	7,431	50	0.67	125	0	0
San Francisco, Calif.	3,328	12	0.36	14	4	29.0
Dade County, Fla.[1]	700	9	1.29	Unknown	0	0
Omaha, Nebr.[1]	497	11	2.21	Unknown	0	0
Salt Lake City, Utah[1]	600	8	1.33	Unknown	0	0
Chicago, Ill. (1974)	694	9	1.29	24	4	16.7
			Sign permissive RTOR rule			
Chicago, Ill. (1973)	936	11	1.18	57	4	7.0
Columbus, Ohio	415	11	2.65	Unknown	0	0
Virginia	478	15	3.14	1	0	0

[1] Source: Paul C. Box & Associates

Unlike the comparison of all intersection accidents, RTOR and RTOG accidents are more equal when only pedestrian accidents are considered.

Since these results represent only a limited portion of the total accident analysis, it is not possible to draw firm conclusions on the RTOR accident problems. Information on RTOR usage and exposure is being collected and when viewed with the accident statistics should provide a basis for evaluating the safety of RTOR.

RTOR Effects on Vehicle Delay and Fuel Savings

The most positive reason for permitting RTOR is the time savings gained by the motorist from reduced vehicle delay. Also, associated with the reduction in delay are the benefits of fuel savings, reduced auto emissions, reduced traffic congestion, and reduced driver frustration.

As a minimum, the time savings accrued to the right-turning motorist is equal to the time remaining on the red phase. Moreover, other vehicles back in the queue save time, and it is even possible for through vehicles to reduce their delay time. As a motorist proceeds through a network of signalized intersections, these incremental time savings would help to reduce his overall travel time, especially if many right turns are involved.

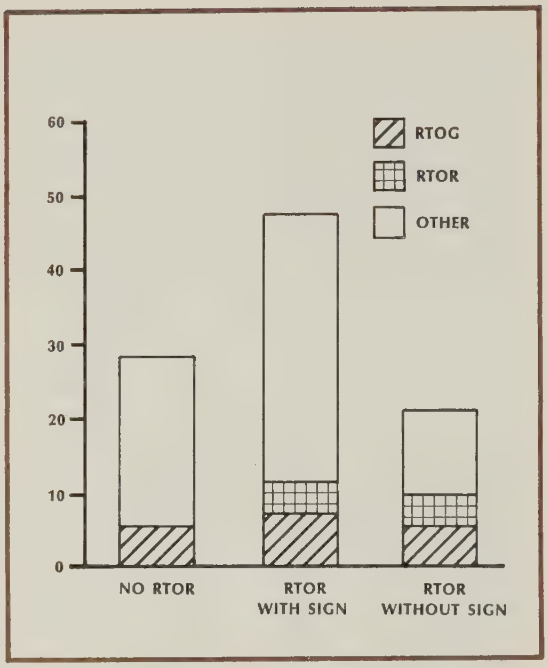


Figure 12.—Chicago pedestrian accidents (based on 78 locations).

Several studies have been done on the reduction in right turn vehicle delay. (*4, 5, 6, 7, 8*) Although each study had a different methodology and set of conditions which preclude comparison of each, one fact stands out in reviewing the results: RTOR provides the motorist with a significant time savings ranging from a low of 7 seconds to a high of 15 seconds per right turning vehicle. The amount of time saved at each particular intersection depends upon several factors, including signal phasing, actuation, traffic volumes, and geometrics.

When this amount of average time savings per vehicle is applied to all right turning vehicles, the overall savings is quite substantial. In a recent study of RTOR in Virginia, the average time savings per RTOR approach per day was found to be 5,647 seconds. (*4*) If RTOR were permitted at 80 percent of the State's intersections (7,792 approaches), the total time saved statewide would be slightly over 4,461,000 hours annually.

The reduced time of idling while waiting for the green light also results in fuel savings and reduced exhaust emissions. Preliminary studies in a portion of the CBD network in Washington, D.C., indicate RTOR could reduce fuel consumption 4 to 8.9 percent for all vehicles.[3] More conclusive results on the effect of RTOR on fuel consumption and vehicle emissions will be included in the final study report.

Pedestrian and Driver Attitudes Toward RTOR

The public's compliance with any traffic control device, either as pedestrians or motorists, is often affected by their attitude toward the device. For example, in a CBD area, there may be a strong negative reaction to permitting RTOR because pedestrians may feel it unnecessarily impedes their movement. For the driver, acceptance of RTOR could be influenced by driving behavior. An aggressive driver would probably find RTOR appealing and would become annoyed at intersections where it was not permitted. Conversely, a hesitant driver might feel that an RTOR maneuver is dangerous, even when acceptable gaps are available, and by habit would not take advantage of the law.

[3] "A New Technique for the Evaluation of Urban Traffic Energy Consumption," by Edward B. Lieberman and Stephen Cohen. Paper presented at the 55th annual meeting of the Transportation Research Board, Jan. 20, 1976.

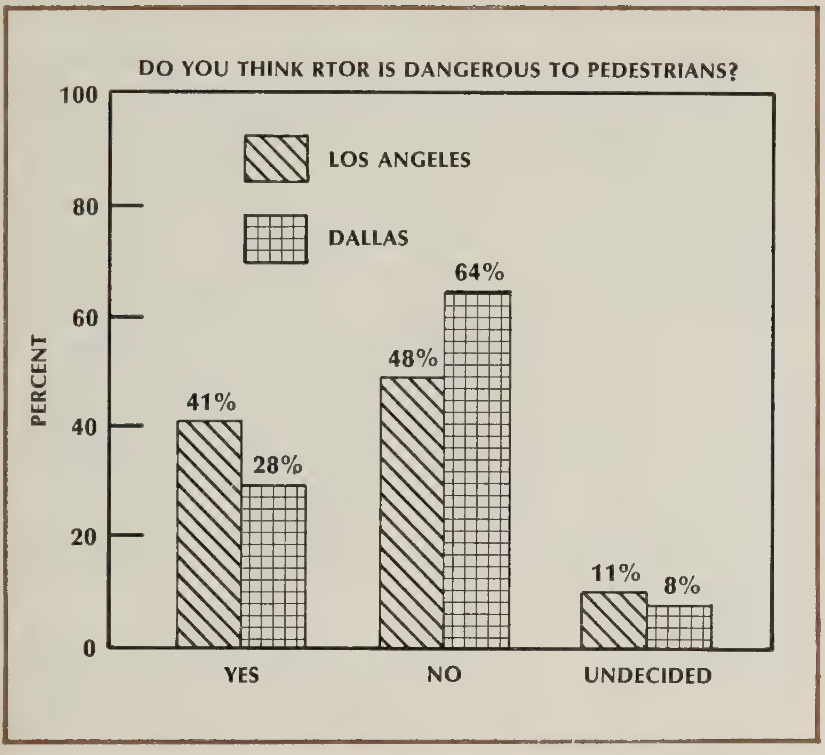


Figure 13.—Pedestrians' attitude toward RTOR.

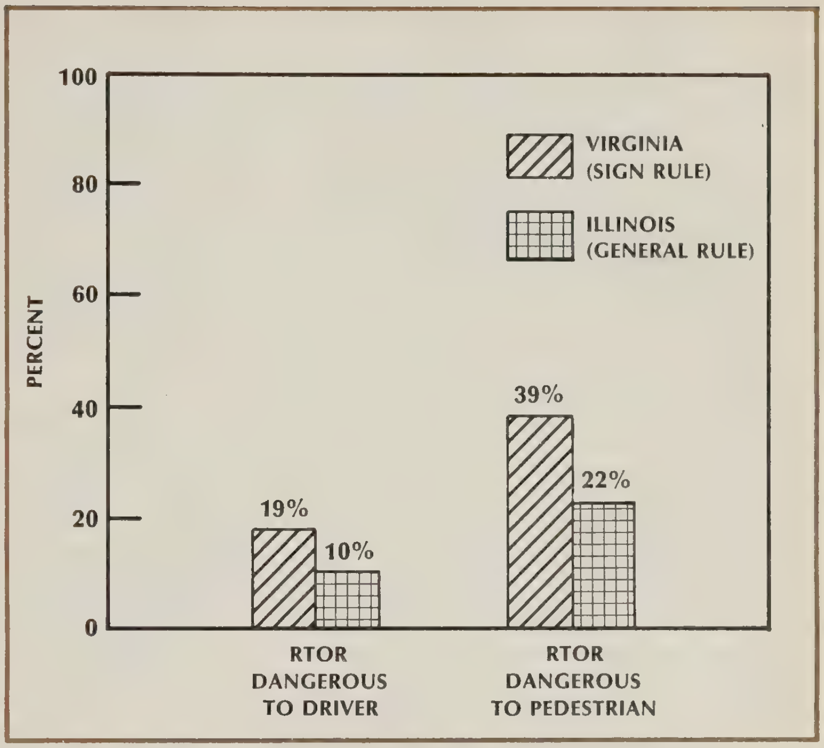


Figure 14.—Driver survey results.

To assess the public acceptance of RTOR, pedestrians were interviewed in four cities, all of which generally permit RTOR; and driver questionnaires were distributed in six States. Reported here are some preliminary results based on pilot studies conducted in the cities of Dallas and Los Angeles for the pedestrian survey and in the States of Illinois and Virginia for the driver survey.

Pedestrian attitudes

The pedestrian survey was conducted in the CBD area near intersections where RTOR was permitted. To keep the interview brief, the pedestrian was asked only five questions, two of which are of particular interest.

Figure 13 shows the results of the question "Do you think RTOR is dangerous to pedestrians?" The majority of the pedestrians interviewed believe that RTOR is not dangerous to pedestrians. However, the positive response was rather high, especially if the undecided are included. It was surprising to find that the Los Angeles respondents felt more endangered by RTOR despite the fact that the pedestrian's right-of-way is respected in California.

The pedestrians were also asked if they had ever been delayed in crossing the street by an RTOR motorist. Sixty-four percent of the pedestrians in Los Angeles and 40 percent of those interviewed in Dallas responded that, on occasion, they had been delayed by an RTOR motorist. The higher positive response in Los Angeles is reflected in the high percentage of pedestrians who have been delayed at some time.

It would appear from the responses to these two questions that many pedestrians feel endangered by RTOR in the CBD areas and are unnecessarily delayed when crossing the street. Some cities, in recognition of this pedestrian problem, have prohibited RTOR at intersections with a large pedestrian traffic or where there are pedestrian signals.

Driver attitudes

The driver attitude survey was conducted through a questionnaire distributed to motorists applying for license renewal. The summary results for the two pilot States—Virginia and Illinois—are shown in figure 14. Virginia permits RTOR where signed, whereas Illinois has been under the generally permissive rule since January 1974.

In answer to the question "Do you feel that RTOR is dangerous to you as a driver?" only a small percentage of motorists interviewed in both States felt that it was. Under the sign rule in Virginia nearly twice as many motorists felt endangered by RTOR than did motorists in Illinois.

The response to the question "Do you feel RTOR is dangerous to you as a pedestrian?" was quite different. For both States, the reply "Yes, it is dangerous" was twice that for the previous question. Apparently, the public feels more endangered by RTOR vehicles as pedestrians than as motorists. The 39 percent response in Virginia probably reflects how the respondents perceive the danger to them as pedestrians rather than based on actual experience because in Virginia RTOR is rarely permitted where pedestrian traffic is heavy.

When asked which RTOR rule they prefer, most of the respondents favor the rule which they now follow. In Virginia 24 percent indicated they should change to the generally permissive rule, while in Illinois only 12 percent felt that the State should change back to the sign permissive rule.

Since these results represent only one State's reply for each rule, it is not possible to draw conclusions about RTOR attitudes in general. The results from four other States—which include Texas and Colorado under the generally permissive rule, and Louisiana and Delaware under the sign permissive rule—should provide a basis for such conclusions.

Law Enforcement of RTOR

Arguments for prohibiting RTOR are that motorists do not comply with the RTOR laws. If RTOR motorists do not make a complete stop or yield to other vehicles or pedestrians, or if they ignore prohibitory signs, RTOR could be a problem. To make sure these law enforcement problems were adequately dealt with, a questionnaire was distributed to city, county, and State police officials in locations with varying RTOR rules.

Preliminary results of the law enforcement survey indicate motorist compliance is quite good. Eighty-two percent of the officials under the generally permissive rule and 62 percent under the sign permissive rule categorized the motorists' obeyance of the full stop requirement as good to excellent. An even higher percentage of officials indicated that the RTOR motorists were good about yielding right-of-way to other vehicles. Again, the officials under the sign permissive rule rated the motorists slightly lower. The apparent higher frequency of violation by motorists following the sign permissive rule may be related to their unfamiliarity with RTOR.

The police officials under both rules were more negative in categorizing the RTOR motorist's respect for pedestrians. More than half of the officials under the sign permissive rule rated the RTOR motorists fair to poor in yielding the right-of-way to pedestrians. Forty-six percent under the generally permissive rule responded "fair/poor." This higher negative response can probably be attributed to the general belief that motorists in most localities show little respect for pedestrian right-of-way laws, especially at intersections, and this lack of respect is carried over to the RTOR situation.

In general, it appears that the police officials do not perceive RTOR under either rule as a major problem, either in enforcement or number of violations. Based on their comments, many feel RTOR is a positive traffic control feature that should be permitted extensively. However, the police officials surveyed did indicate that there is widespread ignorance of the RTOR law, especially under the sign permissive rule. For this reason, some police officials suggested that much more should be done to publicize the RTOR law.

Summary

The information presented here is not intended to settle the controversy of whether or not right turn on red should be permitted, at which locations, or how. It merely documents the current practices with respect to RTOR and presents some of the preliminary research results.

The trend in RTOR is toward the generally permissive rule which permits right turn on red, if the drivers stop and yield the right-of-way, except where prohibited by a sign. When one State adopts the generally permissive rule, the border States usually follow suit to reduce the confusion to motorists traveling from one State to the other.

RTOR can reduce right turn delays, consequently reducing auto emissions and increasing fuel savings. Although the accident analysis is not yet complete, the preliminary data indicate that accidents are occurring because of RTOR. However, compared to all intersection accidents, the frequencies are small. Nevertheless, many pedestrians, though not a majority, feel endangered by the RTOR movement. This could mean that RTOR should be prohibited in areas with significant pedestrian traffic.

As noted earlier, work is still being performed on the effects of RTOR. The safety problem and energy issue are being studied, as well as the legal and signing aspects. More conclusive results of these investigations will be included in the final report and an RTOR policy will be recommended. In addition, guidelines will be presented to assist the traffic engineer in determining whether RTOR should be permitted or prohibited at a particular intersection.

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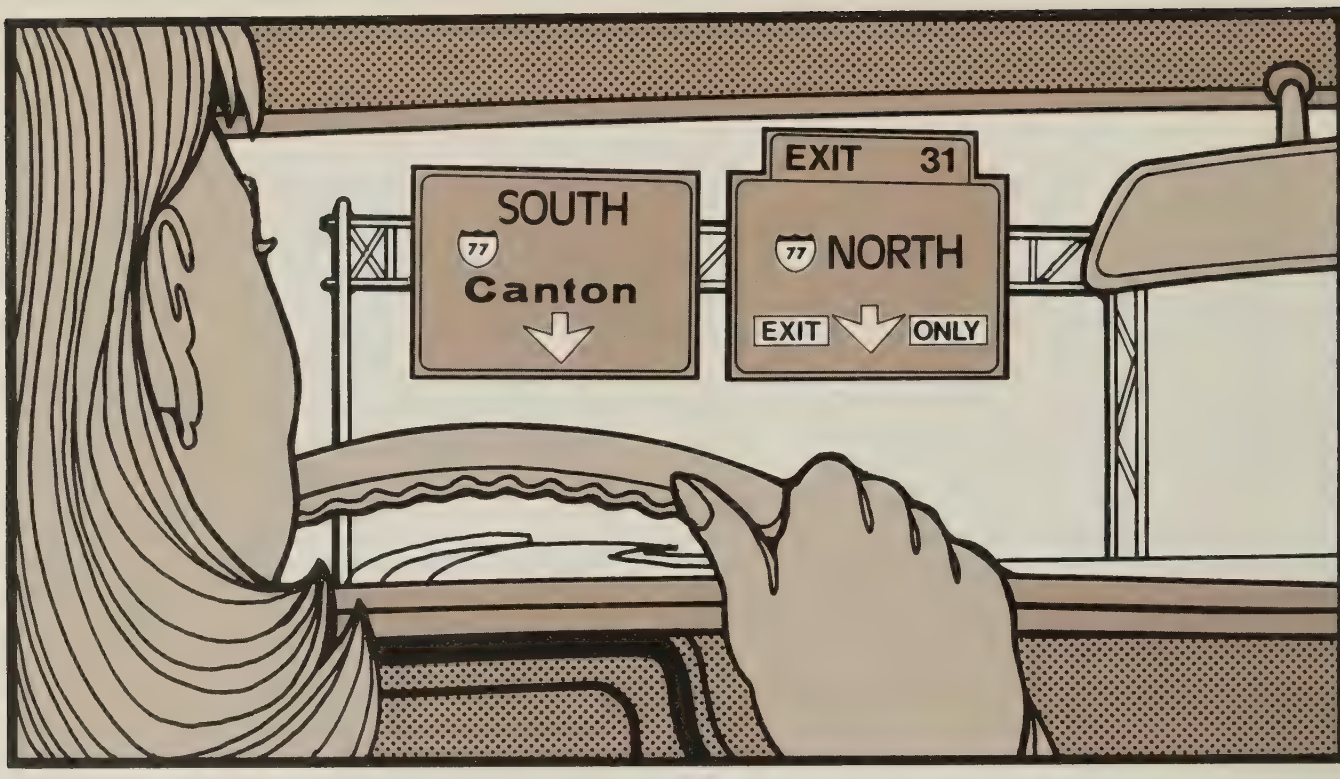

Driver Expectations at Freeway Lane Drops

by King M. Roberts and Alfred G. Klipple

This study was conducted to determine the effects of different sign types and lane drop panel messages on driver expectations at freeway interchange lane drops and major splits. Two laboratory experiments were conducted. The first investigated driver expectations regarding lane drop geometrics and route-and-destination expectations. The second experiment studied expectations regarding geometrics for both lane drop and major split interchanges. In the experiments, subject performance was measured in terms of choice correctness, response latency, and subjective certainty of the accuracy of each choice.

The results indicate that lane drop panels significantly improve the correctness of driver's expectations of freeway interchange geometrics in terms of lane drop configurations. Of the panels tested, the MUST EXIT and EXIT ONLY messages were the most helpful in forming correct expectations. The efficiency of these messages relative to one another is influenced by specific interchange geometrics. Diagrammatic signs, with or without lane drop panels, functioned as well as conventional signs with panels at exits and were superior in all respects to conventional signs at splits.

Introduction

While there is general agreement that unexpected interchange geometrics present problems to both the motorist and the highway engineer, there is little consensus as to what set of highway, route, and human factors constitute the freeway interchange lane drop problem. Further, there are significant questions to be resolved as to the design and application of the most suitable signs and markings to aid the motorist in successfully negotiating the freeway interchange lane drop.

The literature indicates that there is a considerable degree of driver confusion, including violations of expectations, at interchange exits where lane drop or major split configurations exist. Incorrect expectations may occur for at least two basic reasons. First, the driver may expect an option to continue through an interchange when, in fact, remaining in a lane

Figure 1.—Stimulus slide showing the roadway scene and exit direction sign.

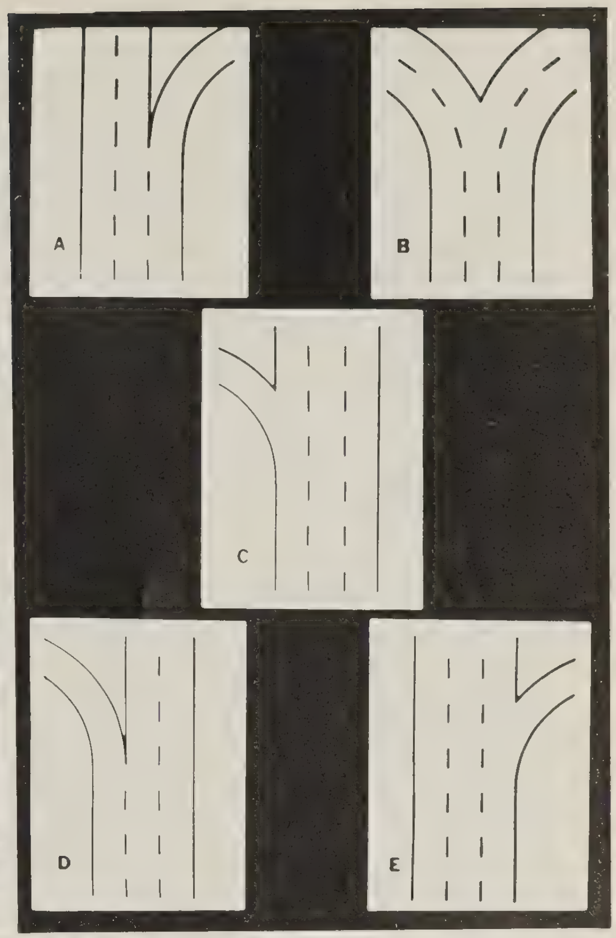

Figure 2.—Response slide showing possible configurations.

forces an exit. Second, the driver may have false expectations regarding the facility and route relationship. That is, he may expect a major route to continue on a facility rather than exit. The degree to which these expectations are held at various interchange configurations is not known. The purpose of these experiments was to determine driver expectations at interchanges with present forms of signing and their variations.

Typically, advance signs for lane drop situations include a route number, a destination name, and some warning (usually in the form of a lane drop panel) of the lane drop. Since expectations could be affected by any or all of these items, Experiment I included a consideration of the extent to which variations in each of these sign characteristics affect driver expectations. Also considered were the effects of sign position—whether the sign was positioned over the right or left lane. Expectations were divided into those regarding interchange geometrics and those relevant to routes and destinations. In Experiment II a further evaluation was made on two lane drop warning messages. Also considered in the second experiment was the effectiveness of using lane drop panels on diagrammatic signs and the expectations which various signing configurations generate at freeway splits.

Experiment I

Purpose

The purpose of this experiment was to specify and quantify expectations as a function of exit direction signs. The signs considered varied along four dimensions: (1) lane drop panel message—EXIT ONLY, MUST EXIT, EXIT LANE, and ONLY; (2) sign position; (3) exit route number; and (4) exit destination name. Driver expectations varied along three dimensions: (1) exit geometrics—right or left exit—and lane drop or non-lane-drop, (2) exit destination, and (3) exit route.

Procedure

Twenty subjects participated in experiment I. Thirty-five mm *stimulus* slides were presented randomly showing a photographed roadway scene and overhead sign bridge on which fictitious signs were superimposed (fig. 1). Immediately after each stimulus slide was shown, a *response* slide was presented (fig. 2). The subject was instructed to choose which configuration he would expect to see at the approaching exit on the basis of the information presented on the stimulus slide, and to make a response by pushing the correct response button as quickly as possible. Response buttons were keyed to the letters on the response slide. The subject then verbally indicated the relative certainty of his response on a 1–5 scale—1 being very uncertain and 5 being very certain. The experimenter recorded the subject's choice, the response latency (time between the presentation of the response slide and the subject's response), and certainty for each trial. He then initiated another trial by presenting the next stimulus slide.

To measure expectations regarding exit *geometrics,* exit destinations and route numbers were held constant while sign position and lane drop panel message were varied. In addition to the eight geometric slides, four control signs were included—two had straight down arrows in lieu of a lane drop panel to indicate an exit lane and two had slanted arrows for this information. One of each type was positioned over the right lane and one over the left.

Each response slide included a right and left lane drop exit, a right and left non-lane-drop exit, and three lanes going into a split with two lanes each.

To measure driver expectations regarding exit *routes and destinations,* route and destination information as well as sign position and message were varied. Variations consisted of four lane drop panel messages, two routes or two destinations, and two sign positions. Interchange geometrics were held constant. This gave a total of 16 signs for testing route and destination expectations.

In this experiment, subjects were also asked to respond to a short questionnaire designed to identify variations of meaning assigned to the four different lane drop panel messages.

Results

There were several significant differences in the accuracy of choices in expected interchange geometrics as a function of lane drop panel message. The MUST EXIT and EXIT ONLY panels were not significantly different from each other; however, with the above exception, MUST EXIT was significantly better than all other panels. All exit message panels were significantly better than the two control signs which had arrows as the only indication of exit geometrics. There was no significant difference in sign position (left or right). It should also be noted that none of the subjects chose the freeway split for any of the signing conditions.

For certainty there were, again, no significant differences in sign position. However, choices on the MUST EXIT panel were more certain than for all other signs, but there were no significant differences in this sign as compared to EXIT ONLY or EXIT LANE.

Sign position did not significantly affect the latency measure, however, MUST EXIT and EXIT ONLY panels produced significantly shorter latency scores than EXIT LANE panels. No other latency comparisons were significant.

The results of the questionnaire indicate that the MUST EXIT and EXIT ONLY panels were most often assumed by the subjects to indicate a lane drop. In addition, the subjects were more certain that their assumptions for these panels were correct than for the other lane drop panels.

There were no significant differences between route accuracy scores for the various signing conditions in the route and destination portion of the data. With respect to sign position, the only significant difference indicates that for MUST EXIT signs higher accuracy scores occurred for the right hand position. The only significant difference in destination accuracy occurred between MUST EXIT and EXIT ONLY, with right and left position combined. Again higher accuracy scores were associated with MUST EXIT.

There were no significant differences in the certainty data.

Experiment II

Purpose

The purpose of this experiment was to specify and quantify driver expectations regarding upcoming interchange geometrics as a function of exit direction signs. Two types of interchange geometrics were studied—lane drop and major split geometrics. In each of these conditions the stimulus materials varied along three dimensions: (1) sign type—conventional or diagrammatic (fig. 3); (2) sign position—sign located over the left or the right lane on the stimulus slide; and (3) lane drop panel message—no message, EXIT ONLY, or MUST EXIT.

Procedure

Thirty subjects participated in this experiment. The procedure was the same as that for experiment I with the exception of the content of the slides. The slides showed the messages MUST EXIT, EXIT ONLY, or no message on both conventional and diagrammatic signs.

Results

Exits. The subjects predicted a lane drop 81 percent of the time when a MUST EXIT panel was present and 75 percent of the time when an EXIT ONLY panel was present. Only 58 percent expected a lane drop when no panel was present. There was no significant difference between dia-

Figure 3.—Stimulus slide showing a diagrammatic exit sign.

grammatic and conventional signs. The analysis indicates that when the position of the stimulus sign was varied from the right lane—the "normal" exit direction—to the left lane, more subjects expected a lane drop to occur. However, this trend was not significant. Also, almost three out of four subjects expected a lane drop when *any* exit was encountered.

The significant results of the certainty measures were the same as those obtained for accuracy. The latency data indicate that faster responses were present when signs were positioned to the left of the roadway. This was true regardless of the type of sign; however, diagrammatic signs were responded to significantly faster than conventional signs. In all situations, latency was shorter for signs which included an exit panel as part of the sign content.

Major splits. The early decision to treat major splits as a separate entity from exit configurations seems, in retrospect, to have been an advantageous one. The data was indeed very different from that obtained from exit variables and seems to generally lend support to previous work reported with diagrammatic signs at roadway split configurations.

The diagrammatic sign in this situation heavily influenced expectancy without regard to the presence or absence of a lane drop panel message. Diagrammatic signs were found to produce a significantly higher expectation of splits than did conventional signs. Subjects were significantly more certain that their responses to diagrammatic signs were correct than for conventional signs.

There was a large and significant difference in time of response for conventional and diagrammatic signs. In addition, there was a significant sign-type-by-panel interaction. This interaction indicates that latencies were shortest for the EXIT ONLY panels when associated with conventional signs, but that latencies for these panels were largest when associated with diagrammatic signs.

Conclusions

In general, the data indicated that the selection of lane drop panels for specific applications should be influenced by the type of sign—diagrammatic or conventional—and the direction that the exit diverges from the roadway—EXIT ONLY panels are superior to MUST EXIT panels at left exits. Based on the research to date, lane drop panel messages significantly improve the correctness of driver expectations of freeway interchange geometrics in terms of lane drop configurations with conventional signs. Diagrammatic signs, however, are equally effective with or without lane drop panels. Of all messages tested, the MUST EXIT and EXIT ONLY panels were the most helpful in correctly influencing expectations. The differences in efficiency of these messages seemed small and probably either one could be adopted.

Tests on roundabout intersection design in the United Kingdom.

Twenty-two Nations Working Together in Highway Research

by Burkhard E. Horn and Walter Diewald

In 1948, the Organization for European Economic Cooperation (OEEC) was established to oversee European reconstruction under the Marshall Plan. In 1960, its objectives achieved, the OEEC was succeeded by the 20-nation Organization for Economic Cooperation and Development (OECD). The expressed purposes of the OECD are far reaching and include a variety of research projects in such areas as economics, world trade, the environment, science, and highway research. This article provides background information on the OECD, its structure and organization, and highlights of its Road Research Program since 1968. The following areas of research are discussed: highway design, construction, and maintenance; highway and traffic safety; highway traffic and transport; and urban traffic systems.

Introduction

In 1948, the United States provided Marshall Plan aid through the Organization for European Economic Cooperation (OEEC) to help in the reconstruction of war-torn European countries. By 1960, Europe was well on the road to economic recovery and Canada, the United States, and 18 European countries formed the Organization for Economic Cooperation and Development (OECD), which succeeded the OEEC. Later Japan, Finland, Australia, and New Zealand became full members, and Yugoslavia decided to participate in certain aspects of OECD activities.

The OECD was formed to (1) foster economic growth of its member countries, (2) help less developed countries both within and outside OECD, and (3) promote trade expansion throughout the world.

OECD is headed by a council consisting of representatives of its member countries. An executive committee prepares the general work of the Council while special committees, working parties, and expert groups conduct detailed work. A Secretariat, headed by the Secretary General, consists of international civil servants. The Secretariat and national delegations, normally headed by a permanent delegate with the rank of Ambassador, are located in Paris at OECD headquarters.

OECD countries represent 20 percent of the world's population and 60 percent of its industrial production. They account for 73 percent of world trade and provide other countries with 80 percent of world development aid.

Among OECD activities are programs relative to economic materials; energy policy; trade, financial, and fiscal affairs; manpower and social affairs; the environment; science and technological policies; agriculture and fisheries; nuclear energy; European intercity transport; the long range transport of air pollution; and road research.

Lane marking tests on a section of autobahn in Germany.

The OECD Road Research Program

Increased economic and political influences on governmental decisions on highway infrastructures, traffic and safety, and their impact on international passenger and freight movement, led to the creation of the OECD Road Research Program in 1968. There was, and is, an evident need to insure the rational use of scarce national highway research resources, to promote and strengthen highway research programs in member countries, and to develop and systemize the exchange of highway research documentation.

The OECD Road Research Program provides a substantive scientific and technical basis for governmental decision-making on urgent highway transportation problems.

The Program, administered by the OECD Steering Committee for Road Research, currently includes 22 of the 24 OECD countries as members: Austria, Belgium, Canada, Denmark, Finland, France, the Federal Republic of Germany, Greece, Iceland, Ireland, Italy, Japan, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States. Australia and New Zealand do not participate in this program.

Steering Committee members are key research administrators in the member countries. Included, for example, are the Director of the United Kingdom's Transport and Road Research Laboratory, the Director of Norway's Road Research Laboratory, and the Associate Administrator for Research and Development of the Federal Highway Administration, U.S. Department of Transportation.

The Steering Committee establishes international expert groups and provides them with policy guidance as they prepare scientific and technological documents needed by OECD member governments. Work of the expert groups helps to avoid duplication in research, encourages technology transfer, stimulates new ideas, and provides direction in research efforts.

The Program operates within a 3-year renewable mandate which permits it to be responsive to continuing development in highway research and practice. Emphasis has been placed on such broadening concerns of member countries as increasing environmental awareness, socio-economic requirements, and the desire for more integrated transportation policies.

The 1974–1976 program of highway research gives priority to applying scientific methodology to improve existing and develop new techniques of analysis, planning, construction, operation, and maintenance of highways; highway transportation; and urban traffic systems. Priority is also given to the continued development of an international documentation scheme in highway transportation research.

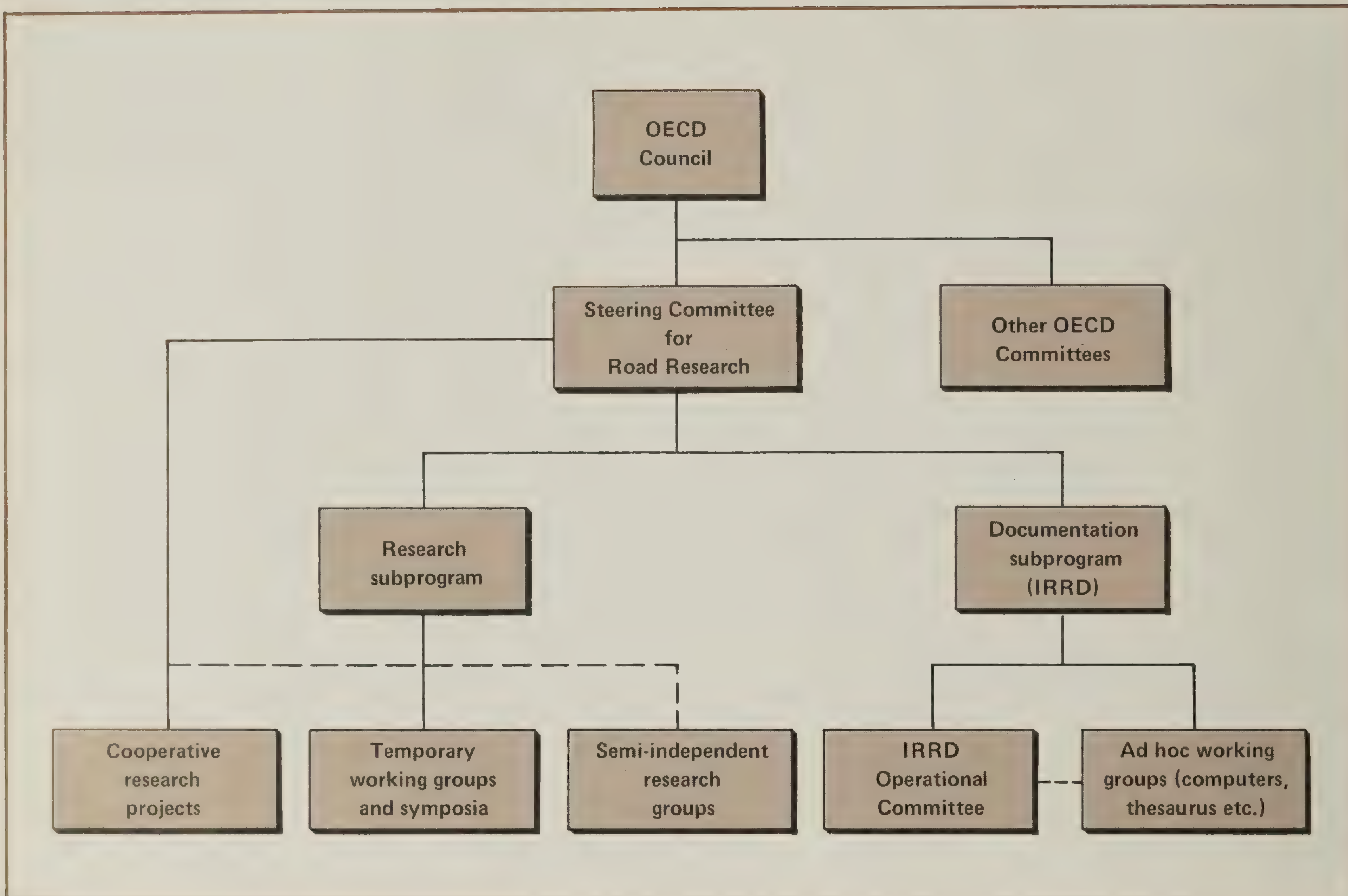

Figure 1.—Organization of OECD road research activities.

Figure 1 shows the organization of OECD road research activities. Each of these efforts involves all or nearly all member countries. Cooperative research projects and semi-independent research groups involve only a few countries—sometimes only two. A recent effort dealing with the comparison between two network signal timing schemes, for example, involved only the United Kingdom and the United States.

Working Method for Developing the Research Subprogram

Since 1968, the Steering Committee has developed a working method for carrying out its mandate. This method forms the basis for operation of the 1974–1976 program and consists of the following procedures:

- Determination of priority research needs. This is made through an analysis of the plans and programs of the national highway research administrations and laboratories, and discussion and examination or comparison of national research plans and programs at special Steering Committee sessions.

- Selection of priority projects for international cooperative study. On the basis of results of the above, this takes into account recommendations arising from earlier OECD Road Research Program activities.

- Establishment of ad hoc groups. These consist of a few top-level experts assigned by the Steering Committee to investigate a particular problem area concerned with research and experiments recently completed or underway. Their goal is to identify systematically the most urgent research needs and priorities in the problem area.

- Creation of temporary road research expert groups. Over an 18-month period, these groups focus on defined

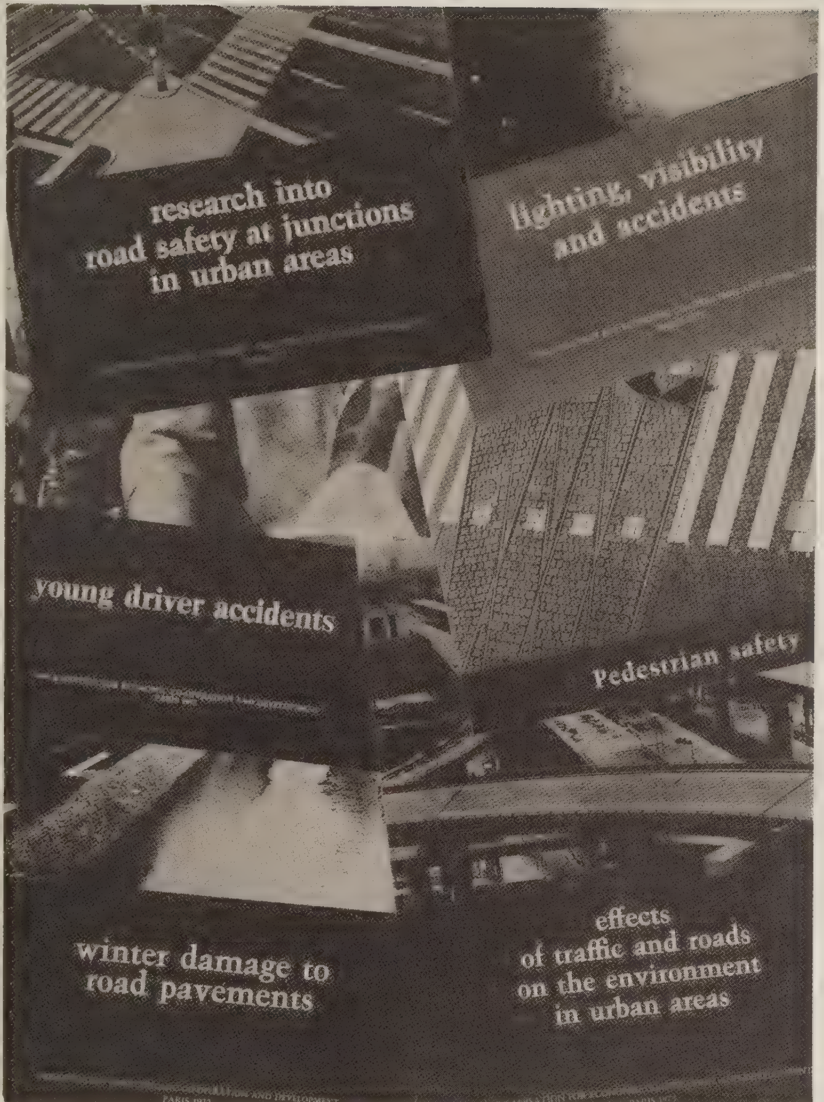

Figure 2.—Some of the publications of the road research program.

priority problems with the aim of preparing a report which includes (1) a review of the state of the art for the topic under consideration, (2) an analysis and interpretation of research results obtained and identification of practices that have proved successful in member countries with a view toward making recommendations for their immediate application, and (3) identification of research needs, and, if needed, detailed proposals and plans for future cooperative research projects. Some 43 groups of experts have produced and published 32 reports, including 6 symposia (fig. 2). (See page 43.) Additional reports are being prepared.

- Organization of an international symposium. Held each year, this centers on a priority research problem and provides a forum for discussion and exchange of ideas and information. The objective is to delineate broad lines of future action and research in the field. Some 11 symposia have been held to date, including five for which the proceedings were published by a member country.

- Initiation of independent groups. Resulting from the reconstitution of temporary road research groups, these coordinate a series of national research projects managed by a national research laboratory. Five reports of these groups have been published.

- Development of international joint research projects. This involves a pooling of national research facilities to be coordinated by a particular member country.

Activities and Results of the Research Subprogram

Through the working method described, it has been possible to study and assess a number of classical and innovative concepts as well as policies, measures, and techniques. Studies have been directed toward the improvement of highways, highway operation and maintenance, the quality of traffic service, the enhancement of traffic safety, and the limitation of undesirable side effects of modern traffic. Following are some of the more important results obtained since 1968.

Highway design, construction, and maintenance

The OECD Road Research Program in highway design, construction, and maintenance includes: development of new concepts and improvements in present highway design techniques, including certain features of bridge design; devising methods to improve the structural design and technology of pavements; further development of highway construction techniques; and development of improved methods, materials, and policies relative to highway maintenance.

The Group on Optimization of Road Alinement by the Use of Computers is an excellent illustration of the potential for international cooperation in research. One important need during highway planning and design is a rapid assessment of the overall consequences, financial and otherwise, of applying various constraints. Computer techniques are available which can determine the optimum vertical highway alinement within the limits imposed, thus minimizing total costs of construction and traffic operations.

The report by the group reviews the background and role of optimization methods in highway location and design with particular attention to cost savings made possible by using these computer techniques. Also in the report, the theory of optimization is outlined and existing national computer programs are discussed.

During the group's research activities, a joint test of four optimization programs was carried out using data derived from the Messina-Catania Autostrada in Italy. Optimization programs from Denmark, France, Germany, and England were tried out on an expressway section 14 km in length. Because the expressway had been open to traffic, it was possible to apply the optimization techniques to a completed design. This enabled the group to make a rapid assessment of the results of optimization.

Although the Italian authorities were unable to reap economic benefits from the tests by modifying the existing design, the report will be useful for future projects in all countries. Theoretical overall savings obtained with regard to earthworks in the existing, difficult terrain were within a range of 8–17 percent and averaged about 10 percent. A second test now underway in Belgium will focus on improving existing optimization programs.

A second example illustrating the direct impact of international work on national practice and highway administration is the Group on Maintenance of Rural Roads. Here, principles were established for an optimum road maintenance management system along with the development of an idealized system for planning and executing highway maintenance.

Details were included relating to preliminary planning, procedures for inspection and assessment of maintenance needs, description of methods for determining priorities and allocating funds, and development of procedures for executing the program, including feedback on costs, standards, and assessments. Also, suggestions were made for having various parts of the program undertaken by central and regional authorities, district offices, and local road teams.

The Symposium on Frost Action in Roads, held in October 1973 at the Norwegian Highway Research Laboratory in Oslo, enabled over 80 experts to share their experience in this field and to contribute to the improvement of frost protection methods.

Significant contributions to the Symposium were provided by the U.S. Federal Highway Administration, the U.S. Army Cold Regions Research and Engineering Laboratory, Norway's Highway Research Laboratory and Institute of Technology, and German and French researchers.

Discussions at the Symposium stressed the need for cooperation between meteorologists and road construction engineers. Topics discussed included the danger of mild winters, physical characteristics with regard to frost penetration, the correlation between laboratory tests and in situ observations, pavement design criteria, traffic load limitations, drainage, and the use of thermal insulation.

Highway and traffic safety

Highway and traffic safety research has been and will remain a high priority area. Nearly all OECD countries now have central agencies or administrations for highway safety action programs, and a number of countries have set up central traffic safety research institutes or departments.

Studies launched by the highway and traffic safety research program include development of measures to improve traffic accident statistics and analyses, concepts and research to influence highway user behavior, policies and techniques to enhance motor vehicle safety, measures and techniques to enhance the degree of safety of certain highway features (fig. 3), planning and programing procedures for highway safety publicity campaigns, and measures to improve the efficiency and effectiveness of legislation and enforcement activities.

A report on roadside obstacles (trees, signposts, luminaires) published in 1975, is a good example of how safety research can be of immediate value to the practicing engineer. The report contains a survey of national guidelines regarding the layout of highways and the roadside and a detailed analysis of experimental research undertaken on various types of obstacles.

Figure 3.—Internally illuminated pedestrian signs frame a marked crosswalk in Bern, Switzerland.

A structured scheme for further research in this field was also developed, directed toward reducing both the frequency and severity of encroachment accidents. To reduce the frequency of such accidents, suggestions were made for research in several areas: improvement of road alinement and skid resistance, development of improved delineators, improvement of highway signing, improvement of vehicle design, investigation of the use of speed limits, and the education of drivers.

To reduce injuries resulting from such accidents, suggestions were made for research involving development of a *safety vehicle,* investigation of passenger restraint systems, biomechanics, development of means for isolating obstacles or making them frangible, and possibilities for removal of certain obstacles.

Highway traffic and transport

Nearly all OECD countries face major traffic and transport problems. The magnitude and complexity of these problems have created substantial research needs and have resulted in a series of long range research programs.

The Steering Committee has focused its attention on policies to reduce urban traffic congestion, measures to improve urban conditions and to protect the urban environment, concepts to promote and optimize public transport, and techniques to improve traffic efficiency.

Noteworthy are those activities concentrating on the use of electronic technology for traffic operations—both in networks and on expressways. The expert group on Area Traffic Control Systems provided a thorough review of existing control modes for computerized traffic regulation of networks and contributed to the structuring of the Urban Traffic Control System/Bus Priority System network traffic control scheme in Washington, D.C.

Activities in the field of electronic aids for freeway operation permitted a complete analysis of existing systems. Most of the recommendations were employed, for example, in planning proposed installations in Germany, France, and Italy.

The International Corridor Experiment (ICE) group brought together European, Japanese, and American experience, expertise, and research with coordinated traffic signal programs, motorist information systems, and ramp metering and merging schemes. Included were the results of research on 10 experimental facilities in member countries. Among these facilities were the North Central Expressway Corridor in Dallas, the Tokyo Expressway Ring Corridor, the Naples Tanganziale Tollway facilities, the French A6/B6/C6 Motorway Complex at Orly, and the German Frankfurt-Mannheim Corridor. Conclusions of the group were coordinated and integrated based on research results obtained from these facilities.

Urban traffic systems

In 1974, the need to consider the many social, economic, and environmental factors that interact with ground transport systems and the far-reaching impact of various modes of surface transport on the span and quality of human life led the Steering Committee to decide to devote attention to research on urban traffic systems. Also to be considered were problems associated with private and public ground transport in the areas of transportation planning, operation, and technology.

As a result of this decision, and in response to a survey conducted within member countries, three new groups were initiated in July 1975. These will have direct impact on this field and will deal with the following topics: transport requirements for urban communities, energy problems and urban and suburban transport, and metropolitan traffic management systems.

The Documentation Subprogram

In the field of documentary cooperation, the Road Research Program has played a promotional role by developing the International Road Research Documentation (IRRD) scheme, launched in 1965 within the framework of the OECD.

The purpose of the IRRD scheme is to collect and distribute information in the form of analytical summaries identified by key words taken from a common trilingual thesaurus. Types of information covered include published documents, serial and nonserial; a continuous survey of ongoing research in member countries; and, by a working agreement with the International Road Federation, similar information in some 50 other countries.

The working model is based on the general principle that IRRD members are responsible for uniformly processing information available in their countries. Processing of information coming from nonmember countries is undertaken by members having facilities for dealing with them.

The sheets (hard copy or magnetic tape) are then sent to one of three language coordinating centers: English (Transport and Road Research Laboratory, Crowthorne); French (Laboratoire Central des Ponts et Chaussées, Paris); and German (Budesanstalt für Strassenwesen, Cologne). These centers coordinate and inspect the sheets before transmitting them to OECD for general distribution. In this way, each member of the IRRD has a complete collection of sheets. The task of the IRRD scheme is to prepare the documentation so that individual countries may make use of it.

One advantage of this method lies not only in the division of labor but also in the certainty that information is processed in each country by specialists. Another advantage is that national experts are able to find unpublished information in their own country. And, national autonomy is preserved because each country is free to use the documentation in a way best suited to its needs.

An Operational Committee consisting of the heads of the documentation services of the three coordinating centers is responsible for supervising the workings of the system, coordinating and harmonizing the efforts of the various participating bodies, dealing with any technical questions related to the functioning of the IRRD, and initiating any studies needed for its further development. The U.S. Transportation Research Board (TRB) and the International Road Federation (IRF) are closely associated with the work of the Operational Committee.

Summary and Conclusions

The preceding description of the activities of the OECD Road Research Program has touched only the highlights of a broad, cooperative research effort involving many countries and hundreds of researchers.

Priority bus lane experiment conducted in Dublin.

The program has resulted in tremendous benefit to the participating countries by avoiding duplication of effort, stimulating technology transfer across borders, and generating new ideas for needed, innovative research efforts. Beyond these direct benefits have come the intangible results of international cooperation in fostering mutual understanding of the problems of others.

Results of a survey conducted in 1972–1973 by the Road Research Steering Committee show a marked tendency toward an extension of the fields of interest of many national road research centers. These centers are gradually having to consider road problems within the more general concept of transport. Environmental, urban, energy, and safety problems which impinge directly on road transport are now getting increasing emphasis.

Clearly, the need for OECD cooperation in road research continues. As today's problems are solved, tomorrow's arise and call for solutions. The OECD Road Research Program will attempt to meet these future challenges as it has in the past, providing member countries with time[ly] and constructive information, ideas, and new knowledge

Publications of the Road Research Program [1]

Road Traffic

Electronic Aids for Freeway Operation (April 1971), $3.

Area Traffic Control Systems (February 1972), $1.50.

Optimization of Bus Operation in Urban Areas (May 1972), $2.

Two-Lane Rural Roads: Road Design and Traffic Flow (July 1972), $3.

Traffic Operation at Sites of Temporary Obstruction (February 1973), $3.25.

Effects of Traffic and Roads on the Environment in Urban Areas (July 1973), $2.50.

Proceedings of the Symposium on Techniques of Improving Urban Conditions by Restraint of Road Traffic (September 1973), $4.

Urban Traffic Models: Possibilities for Simplification (August 1974), $5.

Capacity of At-Grade Junctions (November 1974), $6.

Proceedings of the Symposium on Roads and the Urban Environment (August 1975), $7.

Research on Traffic Corridor Control (November 1975), $4.50.

Road Safety

Alcohol and Drugs (January 1968), $1.20.

Pedestrian Safety (October 1969), $2.25.

Driver Behavior (June 1970), $2.50.

Proceedings of the Symposium on the Use of Statistical Methods in the Analysis of Road Accidents (September 1970), $5.25.

Lighting, Visibility, and Accidents (March 1971), $3.

Research Into Road Safety at Junctions in Urban Areas (October 1971), $1.75.

Road Safety Campaigns: Design and Evaluation (December 1971), $1.75.

Speed Limits Outside Built-Up Areas (August 1972), $2.75.

Research on Traffic Law Enforcement (April 1974), $5.

Young Driver Accidents (March 1975), $6.

Roadside Obstacles (September 1975), $5.

Manual on Road Safety Campaigns (October 1975), $3.

Road Construction

Motor Vehicle Corrosion and Influence of Deicing Chemicals (October 1969), $1.80.

Winter Damage to Road Pavements (May 1972), $2.25.

Accelerated Methods of Life-Testing Pavements (May 1972), $1.50.

Proceedings of the Symposium on the Quality Control of Road Works (July 1972), $4.

Waterproofing of Concrete Bridge Decks (July 1972), $2.75.

Optimization of Road Alinement by the Use of Computers (July 1973), $2.50.

Water in Roads: Prediction of Moisture Content in Road Subgrades (August 1973), $2.

Maintenance of Rural Roads (August 1973), $3.50.

Water in Roads: Methods for Determining Soil Moisture Content and Pore Water Tension (December 1973), $3.50.

Proceedings of the Symposium on Frost Action on Roads (October 1974), $6.50.

Road Marking and Delineation (February 1975), $6.50.

Resistance of Flexible Pavements to Plastic Deformation (May 1975), $4.50.

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[1] In the United States, publications may be obtained from:
OECD Publications Center
1750 Pennsylvania Avenue, NW.
Washington, D.C. 20006
Prices are subject to change.

Our Authors

W. Glenn Smoak is a research civil engineer in the Division of General Research, Bureau of Reclamation. He is the principal investigator of the Surface Impregnation of Concrete Bridge Decks research program being performed by the Bureau for the Federal Highway Administration. Mr. Smoak has been active in concrete polymer materials research at the Bureau for 6 years, during which time he has been instrumental in developing polymer concrete and polymer impregnated concrete process technology, equipment, and facilities.

Allan S. Miller is a special projects engineer in the Office of Federal Highway Projects, Federal Highway Administration's Region 8, Denver, Colo. Before joining Region 8 he was with the FHWA's Implementation Division, Office of Development, in Washington, D.C., where he was responsible for the design, planning, and management of several technology transfer projects in the areas of design, construction, and maintenance.

Hugh W. McGee is a transportation engineer with Alan M. Voorhees & Associates, Inc. Before joining the consultant firm in 1972, Dr. McGee was with the Pennsylvania Transportation and Traffic Center. He is actively involved in highway safety research and has authored several reports on improving traffic operations and safety.

Davey L. Warren is a highway research engineer in the Traffic Systems Division, Office of Research, Federal Highway Administration. Mr. Warren joined FHWA in 1973 and is a recent graduate of the FHWA training program. Since coming to the Traffic Systems Division in 1975, he has been working in the area of traffic safety.

King M. Roberts is an engineering research psychologist in the Analysis and Experimentation Group, Traffic Systems Division, Office of Research, Federal Highway Administration. He is currently involved in the research of sign and delineation treatments to improve route guidance for interstate motorists. Mr. Roberts joined the staff at the Fairbank Highway Research Station in 1963 and, since that time, has worked on a broad spectrum of human engineering problems within the research community.

Alfred G. Klipple is an engineering research psychologist in the Analysis and Experimentation Group, Traffic Systems Division, Office of Research, Federal Highway Administration. He is presently involved in the administration of research in the area of signing and delineation for special usage lanes. Since he came to this organization in 1965, he has been involved in staff and contract research in such areas as perceptual processes, driver decisionmaking, information requirements, and optimal sign characteristics.

Burkhard E. Horn is the administrator responsible for the cooperative research activities within the Road Research Program of the Organization for Economic Cooperation and Development. He has previously held positions of traffic engineer for the City of Wiesbaden, Federal Republic of Germany, and highway engineer for the Highway Administration of the State of Bavaria, Federal Republic of Germany.

Walter Diewald is an administrator in the Road Research Program of the Organization for Economic Cooperation and Development, with responsibilities in the areas of transportation planning, traffic management systems, and highway safety. Dr. Diewald was previously a researcher in transportation systems at Battelle Columbus Laboratories, Columbus, Ohio.

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

The following are brief descriptions of selected items which have been recently completed by State and Federal highway units in cooperation with the Implementation Division, Offices of Research and Development, Federal Highway Administration (FHWA). Some items by others are included when they have a special interest to highway agencies. These items will be available from the Implementation Division unless otherwise indicated. Those placed in the National Technical Information Service (NTIS) will be announced in this department after an NTIS accession number is assigned.

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

Pavement Base Course From Lime Stabilized Incinerator Residue

by FHWA Implementation Division

This 20-minute, 16 mm color film presents new technology developed in an ongoing research study of the construction of a pavement base course using incinerator residue. The film shows the collection and handling of domestic waste, processing the waste through a self-fueling in-

cinerator plant, and preparation of the waste for use as a base course material by mixing it with lime. Standard construction practices and methods can be used to place the base using this material. In this study, the waste product was incorporated in an industrial parking lot. Remaining research related work, including performance data on the material placed in the parking lot, will be finished in about 1 year.

The film is available from FHWA regional offices (see p. 31).

Recycled Asphalt Concrete, Implementation Package 75–5

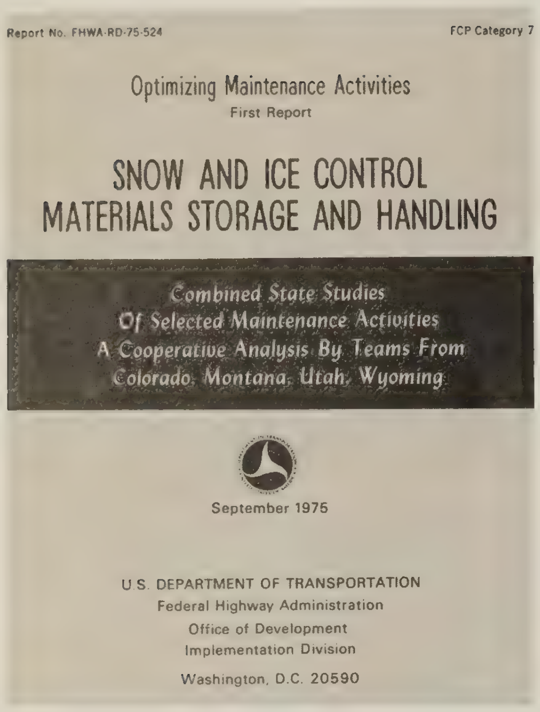
by Nevada Department of Highways and FHWA Implementation Division

The energy crisis has created a serious impact on the highway construction industry because asphalt products have been in short supply and costs have increased dramatically. To alleviate this problem, the Nevada Department of Highways evaluated a new method for reusing deteriorated asphalt pavements on a mile-long section of an interstate highway. A report, movie, and slide-tape presentation were prepared which include a description of the recycling method, production cost data (by FHWA Region 15), and suggested specifications. It was found that several benefits can result from using this recycling method: haul costs are reduced, less new asphalt binder is used, work is performed within the highway right-of-way, base material is exposed to allow corrective measures, original curb elevation is re-

tained, no additional aggregate is required, and emissions are low.

Although this project showed the practicality of the new method, further refinements and simplifications are needed to perfect the techniques and equipment. Also, the long term life of this process is unknown at this time.

The report is available from the Implementation Division, and the film and slide-tape presentation can be obtained from FHWA regional offices (see p. 31).

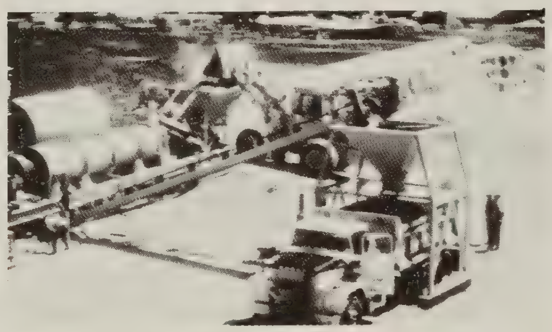


Snow and Ice Control: Materials Storage and Handling, Report No. FHWA–RD–75–524

by Colorado Division of Highways, Montana Department of Highways, Wyoming Highway Department, Utah State Department of Highways, and FHWA Implementation Division

This report, the first in a series on Optimizing Maintenance Techniques, details the results of an in-depth review of the various costs involved with abrasives and chemicals used for snow and ice control. The study was conducted for the purpose of determining, through actual application, how established value engineering techniques can be used in the analysis of highway maintenance activities. It presents discussions of the background, approach, and findings of the study. Also included are recommendations in four areas: (1) Minimum specifications for abrasive materials; (2) procurement practices —materials for snow and ice control should be purchased in large quantities and from centralized sources; (3) processing—chemical additives should be mixed into the abrasives by the supplier; and (4) optimum storage—properly mixed free draining materials do not need to be dried or stored inside. The economic considerations discussed in the report include the findings that the estimated savings among the four States from the implementation of only one of the recommendations (automatic mixing) was $220,000 in 1 year and that the estimated minimum savings to the public would be $5 million annually if the recommendations are implemented nationwide.

The report is available from the Implementation Division.



Portable Drum Dryer-Mixer for Maintenance, Implementation Package 75–3

by Idaho Division of Highways and the FHWA Implementation Division

For patching bituminous pavements, States usually use pre-mixed material from stockpiles or commercially produced hot mix when available. However, it has been difficult to get hot mix materials in isolated areas from either commercial sources or contractor setups at prices the State can afford. Because of this, Idaho invested in a small, portable drum dryer-mixer hot plant in 1973. After some modification, the plant has been performing satisfactorily. It can be easily moved long distances with a minimum of lost time for moving and setting up.

This report outlines the experience Idaho has gained in operating its mini-drum dryer-mixer hot plant. The report covers plant operating characteristics, breakdown of costs, equipment dimensions, labor requirements, and materials used for mix. It is intended for use by contractors and other maintenance organizations to evaluate its potential in their repair activities.

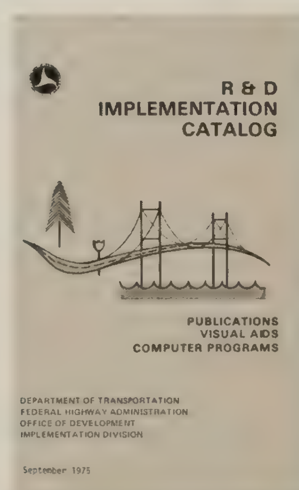
The report is available from the Implementation Division, and a slide-tape presentation can be obtained from FHWA regional offices (see p. 31).

R&D Implementation Catalog

by FHWA Implementation Division

This catalog lists selected publications, visual aids, and computer programs that are available as part of the Federal Highway Administration implementation program. The items are listed in appropriate technical program areas, each under a main title which applies to all the items under the title. Subtitles are shown separately for each item. Items are available directly from the source indicated under the heading "Availability" in each listing. A list of sources and addresses appears at the end of the catalog.

The catalog is available from the Implementation Division.



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 Research)—Performing State Highway Department; National Cooperative Highway Research Program (NCHRP)—Program Director, National Cooperative Highway Research Program, Transportation Research Board, 2101 Constitution Avenue, NW., Washington, D.C. 20418.

FCP Category 1—Improved Highway Design and Operation for Safety

FCP Project 1A: Traffic Engineering Improvements for Safety

Title: Safety Aspects of Vehicle Parking. (FCP No. 31A1613)
Objective: Determine safety and operational characteristics of onstreet parking alternatives; collect and form a data base to compare these various alternatives; and prepare a manual for use by local officials to determine site specific parking arrangements.
Performing Organization: University of Tennessee, Knoxville, Tenn. 37916
Expected Completion Date: November 1977
Estimated Cost: $140,000 (FHWA Administrative Contract)

Title: Motorists' Requirements for Active Grade Crossing Warning Systems. (FCP No. 31A1634)
Objective: Analyze motorists' needs at grade crossings with active warning devices, determine the conspicuity and visibility requirements of such devices, obtain maximum compliance with such devices, and make motorists more aware of grade crossing hazards.
Performing Organization: M. B. Associates, San Ramon, Calif. 94583
Expected Completion Date: December 1976
Estimated Cost: $153,000 (FHWA Administrative Contract)

FCP Project 1F: Energy Absorbing and Frangible Structures

Title: Breakaway Sign Testing. (FCP No. 41F2114)
Objective: Improve the performance of the New Jersey breakaway sign. Full-scale tests will be conducted to verify design improvements in the vertical shock absorber and in sign blank attachments.
Performing Organization: New Jersey Department of Transportation, Trenton, N.J. 08625
Expected Completion Date: December 1977
Estimated Cost: $110,000 (HP&R)

FCP Project 1H: Skid Accident Reduction

Title: Safety Effectiveness of Transverse Grooving. (FCP No. 41H2412)
Objective: Determine transverse grooving's effectiveness in increasing skid resistance, its wear rate, and its ability to reduce wet-weather accidents.
Performing Organization: New York Department of Transportation, Albany, N.Y. 12207
Expected Completion Date: June 1980
Estimated Cost: $118,000 (HP&R)

FCP Project 1L: Improving Traffic Operations During Adverse Environmental Conditions

Title: Driver Visibility Requirements for Roadway Delineation. (FCP No. 31L3022)
Objective: Experimentally determine the optimum and minimum visual roadway delineation treatments and establish the lower saturation limit of yellow-white paint mixture that can still be distinguished from white.
Performing Organization: Systems Technology, Inc., Hawthorne, Calif. 90250
Expected Completion Date: December 1976
Estimated Cost: $322,000 (FHWA Administrative Contract)

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

FCP Project 2C: Requirements for Alternate Routing to Distribute Traffic Between and Around Cities

Title: Color and Shape Coding for Freeway Route Guidance. (FCP No. 32C2102)
Objective: Investigate the underlying principles of color and shape coding and apply these principles in route guidance systems at complex freeway interchanges.
Performing Organization: Institute for Research, State College, Pa. 16801
Expected Completion Date: July 1978
Estimated Cost: $271,000 (FHWA Administrative Contract)

FCP Project 2D: Traffic Control for Coordination of Car Pools and Buses on Urban Freeway Priority Lanes

Title: Evaluation of Alternative Operations Plans for Shirley Highway Bus/Carpool Lanes. (FCP No. 32D1534)
Objective: Evaluate the effects of redefining carpools as three-person, allowing carpool access at "bus only" ramps, and extending the carpool use of the priority lanes into the District of Columbia.
Performing Organization: JHK & Associates, Alexandria, Va. 22304
Expected Completion Date: November 1977
Estimated Cost: $85,000 (FHWA Administrative Contract)

FCP Project 2J: Practicality of Automated Highways

Title: Fundamental Studies in Automatic Longitudinal Control of Vehicles. (FCP No. 32J1021)
Objective: Conduct theoretical and experimental studies to develop one or more practical, efficient, and experimentally validated techniques for automatic longitudinal control of vehicles.
Performing Organization: Ohio State University, Columbus, Ohio 43210
Expected Completion Date: December 1976
Estimated Cost: $153,000 (FHWA Administrative Contract)

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

FCP Project 3F: Pollution Reduction and Visual Enhancement

Title: Low Maintenance Vegetation for Erosion Control. (FCP No. 43F1862)
Objective: Develop a handbook on establishing vegetative covers and develop material for training highway department personnel in erosion control. The study will utilize data collected from previous research projects, the reevaluation of former research plots, and from new research initiated with this study.
Performing Organization: Virginia Polytechnic Institute, Blacksburg, Va. 24061
Funding Agency: Virginia Highway Research Council
Expected Completion Date: January 1979
Estimated Cost: $136,000 (HP&R)

Title: Temporary Erosion Control Methods. (FCP No. 43F1872)
Objective: Develop a laboratory test method for rating temporary erosion control products considered for use in treating slopes; establish a limited number of field test plots and correlate with laboratory tests; adapt the test method developed in this study for various soil types.
Performing Organization: California Department of Transportation, Sacramento, Calif. 95807
Expected Completion Date: June 1979
Estimated Cost: $143,000 (HP&R)

Title: Sound Propagation Over Various Types of Ground Cover. (FCP No. 43F4302)
Objective: Quantify highway noise propagation losses over various types of ground cover.
Performing Organization: University of Washington, Seattle, Wash. 98195
Funding Agency: Washington Department of Highways
Expected Completion Date: January 1977
Estimated Cost: $95,000 (HP&R)

FCP Category 4—Improved Materials Utilization and Durability

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

Title: Internally Sealed Concrete. (FCP No. 24B1422)
Objective: Document the materials properties of internally sealed concrete; develop a low cost, low energy usage heat treatment process; refine the new concrete to attain deep sealing regardless of moisture content; and perform pilot testing on lower cost wax beads and on internally sealed concrete made with low quality aggregates.
Performing Organization: Federal Highway Administration, Washington, D.C. 20590
Expected Completion Date: June 1978
Estimated Cost: $111,000 (FHWA Staff Research)

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

FCP Project 5C: New Methodology for Flexible Pavement Design

Title: Develop a Pavement Maintenance Management System (Computerized) for Rigid and Flexible Pavements. (FCP No. 45C3332)
Objective: Develop tools for managing and coordinating preventive, remedial, and major maintenance, and for resurfacing,

rehabilitating, and reconstructing highways. Determine practical available data inputs for various factors and test the system in a daily operational mode.
Performing Organization: California Department of Transportation, Sacramento, Calif. 95814
Expected Completion Date: November 1977
Estimated Cost: $273,000 (HP&R)

FCP Project 5D: Structural Rehabilitation of Pavement Systems

Title: Pavement Deflections and Foundation Conditions. (FCP No. 45D3051)
Objective: Establish that transitory and permanent moisture are the primary causes of inconsistencies in the performance and structural capacity of flexible pavements. Develop more precise criteria relating pavement design and maintenance to moisture conditions.
Performing Organization: New York Department of Transportation, Albany, N.Y. 12226
Expected Completion Date: July 1978
Estimated Cost: $108,000 (HP&R)

Title: Early Pavement Deterioration in Utah. (FCP No. 45D3062)
Objective: Define each type of problem; investigate methods to identify them; review specifications, procedures, and techniques with early deterioration; and investigate various methods to correct existing pavement failures.
Performing Organization: Utah Department of Highways, Salt Lake City, Utah 84114
Expected Completion Date: June 1978
Estimated Cost: $70,000 (HP&R)

FCP Project 5E: Premium Pavements for "Zero Maintenance"

Title: Prestressed "Zero Maintenance" Pavements (Evaluations, Recommendations, and Documentations)—Study I. (FCP No. 35E3032)
Objective: Update, evaluate, recommend, and document technology for prestressed concrete pavements.
Performing Organization: Portland Cement Association, Skokie, Ill. 60076
Expected Completion Date: January 1978
Estimated Cost: $224,000 (FHWA Administrative Contract)

FCP Project 5F: Structural Integrity and Life Expectancy of Bridges

Title: Crack Control on the Side Faces of Deep Concrete Beams. (FCP No. 45F3142)
Objective: Develop design criteria for control of side face cracking. Conduct a literature survey, collect field data on deep girders which have cracked and which have not, and investigate methods of crack control in the laboratory.
Performing Organization: University of Texas, Austin, Tex. 78712
Funding Agency: Texas Highway Department
Expected Completion Date: August 1977
Estimated Cost: $80,000 (HP&R)

Title: Fatigue Tests of Full-Size Prestressed Girders. (FCP No. 45F3152)
Objective: Determine the effects of the elimination of draped strands in full-size prestressed concrete girders. Draped strands will be eliminated by using straight strands with unbonded lengths at their ends, thus creating "blanketed" strands.
Performing Organization: Portland Cement Association, Skokie, Ill. 60076
Funding Agency: Illinois Division of Highways
Expected Completion Date: July 1978
Estimated Cost: $119,000 (HP&R)

Title: Evaluation of the Bond Behavior of Epoxy Coated Reinforcing Bars. (FCP No. 25F3702)
Objective: Evaluate bond behavior of epoxy coated reinforcing bars relative to that of uncoated reinforcing bars, under static and fatigue loading conditions.
Performing Organization: Federal Highway Administration, Washington, D.C. 20590
Expected Completion Date: June 1978
Estimated Cost: $80,000 (FHWA Staff Research)

Non-FCP Category 0—Other New Studies

Title: Instrumentation for Moisture Measurement—Bases, Subgrades, and Earth Materials (Sensor Evaluation). (FCP No. 50S4603)
Objective: Refine prototype moisture sensors and conduct field evaluations. Recommend applicability to highway practice.
Performing Organization: Southwest Research Institute, San Antonio, Tex. 78228.
Expected Completion Date: December 1976
Estimated Cost: $150,000 (NCHRP)

Highway Research and Development Reports Available from the National Technical Information Service

The following highway research and development reports are for sale by the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161.

Other highway research and development reports available from the National Technical Information Service will be announced in future issues.

STRUCTURES

Stock No.

PB 233711 An Investigation of the Effectiveness of Existing Bridge Design Methodology in Providing Adequate Structural Resistance to Seismic Disturbances. Phase II: Analytical Investigations of the Seismic Response of Long Multiple-Span Highway Bridges.

PB 238954 Slope Stability Analysis: A Computerized Solution of Bishop's Simplified Method of Slices.

PB 242197 The Effect of Varying the Modulus and Thickness of Asphaltic Concrete Surfacing Materials.

PB 246769 Pavement Faulting Study—Final Report.

PB 246801 Pavement Rehabilitation: Proceedings of a Workshop.

PB 246853 Automated Design of Reinforced Concrete Box Girder Bridges.

PB 246854 Girder PC: A Computer Program for Design Checking of Prestressed Concrete Box Girder Bridges.

PB 246855 MSBOX—A Computer Program for Automated Design of Prestressed Concrete Box Girder Bridges.

PB 246893 Bituminous Resurfacings on Flexible Pavements.

PB 247274 Alternate Methods of Avalanche Control (Interim).

PB 247695 Effects of the Clary Screed and Tube Float on Rigid Pavement Construction.

PB 247734 Foundation Design of Embankments Constructed on Connecticut Valley Varved Clays.

PB 247735 Installation of a Sand-Tire Inertial Barrier System in Connecticut.

PB 247739 Ultimate Load Response of a Steel I-Beam Composite Multi-Girder Simple Span Bridge Model.

PB 247757 Vehicle Behavior Under Real Conditions at Impact Attenuation Devices.

PB 247773 Elimination of Draped Strands in Prestressed Concrete Girders.

PB 247774 Epoxy Resins for Jointing Segmentally Constructed Prestressed Concrete Bridges.

PB 247779 Analysis of Characteristic Roughness Patterns in Pavements and the Relationship Between Roughness and Pavement Distress.

PB 247788 Design of an Experimental Post-Tensioned Segmental Concrete Box Girder Bridge.

PB 247794 Strength and Serviceability of Inverted T-Beam Bent Caps Subject to Combined Flexure, Shear, and Torsion.

PB 247802 Computer Design of Glued Laminated Timber Bridge Systems.

PB 247854 End Connections of Pretensioned I-Beam Bridges.

PB 247856 A Guide to the Selection of High-Strength Anchor Bolt Materials.

PB 247910 Time-Dependent Prestress Losses in Pretensioned Concrete Construction.

PB 248033 Wind Loading on Falsework—Phase I.

PB 248034 Automated Design of Continuous Bridges with Precast Prestressed Concrete Beams—Vol. 1: Design Considerations.

PB 248035 Computer Analysis of Segmentally Erected Precast Prestressed Box Girder Bridges.

PB 248036 Static and Buckling Analysis of Highway Bridges by Finite Element Procedures.

PB 248037 Fatigue and Repeated-Load Elastic Characteristics of Inservice Asphalt-Treated Materials.

PB 248059 The Characterization of Road Roughness on Bridge Decks and the Adjoining Pavement.

PB 248105 Compare In Situ Strength of Asphalt Concrete Base (ACB) to Cement Treated Base (CTB).

PB 248107 Calibration of Illinois Roadometers.

PB 248140 Landslides in the Pierre Shale in Central South Dakota: Executive Summary Report.

PB 248143 Determination of Equivalent Axle Loads for Minnesota Flexible Pavements.

PB 248194 The Strength of Anchor Bars: A Reevaluation of Test Data on Development Length and Splices.

PB 248195 Development of a Noncontact Profiling System.

PB 248226 Prestress Losses of In-Service Highway Bridge Members—A Literature Survey.

PB 248289 Feasibility of Measuring Impact Conditions with Traffic Railings.

PB 248295 The Behavior of Multiple Lap Splices in Wide Sections.

PB 248296 Dynamic Response of Bridges to Seismically Induced Ground Vibrations. Phase I: Pilot Field Tests—Strong-Motion Instrument Installation.

PB 248325 Influence of Cognitive Style in a Methodology for Data Base Design.

PB 248403 Analysis of the State of Residual Elastic Strain in Quartzose Rocks by X-Ray Diffraction.

PB 248543 Safety Aspects of Roadside Cross-Section Design.

PB 248565 Results of Special Laboratory Testing Program on Hackensack Valley Varved Clay.

PB 248621 Pavement Evaluation: Phase I—Pavement Evaluation Equipment.
PB 248627 Modification of the BPR-Type Roadometer.
PB 248722 Field Testing of an Orthotropic Bridge.
PB 248836 Performance Study of the Bituminous Concrete Section of the John F. Kennedy Expressway (I-95): Second Interim Report.
PB 249020 Ultimate Load Behavior of Full-Scale Highway Truss Bridges: Phase II—Service Load and Supplementary Tests.
PB 249021 Ultimate Load Behavior of Full-Scale Highway Truss Bridges: Summary Report.

MATERIALS

Stock No.
PB 247287 Grooved Stripes for Plow-Resistant Wet-Night Lane Delineation. Phase 1: Evaluation of Systems.
PB 247378 Corrosion Protection of Reinforcing Steel Provided by Polymer-Impregnated Concrete—Interim.
PB 247414 Lignite Fly Ash as a Partial Replacement for Portland Cement in Concrete—Final Report.
PB 247463 Bridge Deck Deterioration Study—Final.
PB 247464 Field Evaluation of Concrete Polymerization as a Bridge Deck Seal—Final.
PB 247465 Rapid Setting Concrete Patching Study—Final.
PB 247696 Antistripping Additives in Lieu of Mineral Fillers in Asphaltic Concrete Mixtures—Final.
PB 247706 Wet Night Visibility—Final Report.
PB 247723 Technology for Use of Incinerator Residue as Highway Material—Identification of Incinerator Practices and Residue Sources—Interim Report.
PB 248176 Raised Snowplowable Pavement Markers.
PB 248219 Soil Identification by Remote Sensing Techniques in Kansas—Part II.
PB 248604 Evaluation of Structural Steel Coatings in Relation to Industrial Atmospheric Conditions—Final Report.
PB 248629 Field Testing of Two Fast-Drying Traffic Paints.
PB 248916 Improved Performance Criteria for Use in Nuclear Gage Specifications.

TRAFFIC

Stock No.
PB 246094 Investigation of Traffic Dynamics by Aerial Photogrammetry Techniques.
PB 246433 Analysis of Driver Reaction to Warning Devices at a High-Accident Rural Grade Crossing—Executive Summary.

ENVIRONMENT

Stock No.
PB 245863 Control of Large Commercial Vehicle Accidents Caused by Front Tire Failures—Final Report.
PB 246062 Rest Area Wastewater Treatment and Disposal.
PB 247300 Development of Guidelines for the Application of Continuous Two-Way Left-Turn Median Lanes.
PB 247380 Better Grasses for Roadsides—Executive Summary.
PB 247381 Better Grasses for Roadsides—Final Report.
PB 247792 Stabilization of Soils for Erosion Control on Construction Sites.
PB 247839 The Influence of Nitrogen and Maleic Hydrazide (MH–30) on the Growth and Chemical Composition of Bahia grass.

IMPLEMENTATION

Stock No.
PB 246118 The Applicability of High Intensity Sheeting on Overhead Highway Signs.
PB 247125 Highway Maintenance Research Needs.
PB 247179 Nuclear Cement Content Gage Performance Evaluation.
PB 248216 Statistical Specification Evaluation.
PB 248227 Introduction to Concrete Polymer Materials, Supplement 1.
PB 248918 Evaluation of the Use of Salt Brine for Deicing Purposes.
PB 248970 Crash Test Evaluation of Thrie Beam Traffic Barriers.

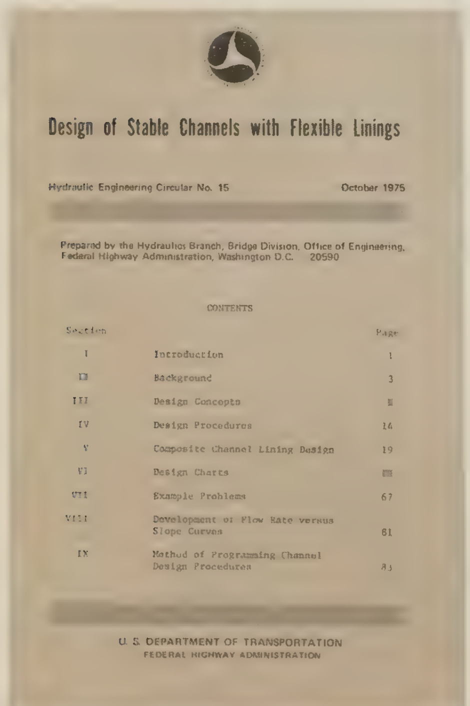
PLANNING

Stock No.
PB 248173 Vehicle Classification Systems Study.
PB 248746 Use of Existing Facilities for Transporting Disadvantaged Residents of Rural Areas: Vol. I—Guide for Transportation Providers.
PB 248747 Use of Existing Facilities for Transporting Disadvantaged Residents of Rural Areas: Vol. II—Research Report.

New Publications

Hydraulic Engineering Circular No. 15, Design of Stable Channels with Flexible Linings, was developed to assist the designer in utilizing various types of flexible channel linings. The combination of results from research completed within the past few years on temporary lining materials and rock riprap and applicable research on vegetative linings provides design information to cover most types of flexible linings presently being used. In addition, the circular contains procedures for two special design considerations: the design of rock riprap for steep side slopes and the design of channel protection for flow in bends.

Hydraulic Engineering Circular No. 15 may be purchased for $2.75 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock No. 050–002–00101–9).


Design of Stable Channels with Flexible Linings

Hydraulic Engineering Circular No. 15 — October 1975

Prepared by the Hydraulics Branch, Bridge Division, Office of Engineering, Federal Highway Administration, Washington D.C. 20590

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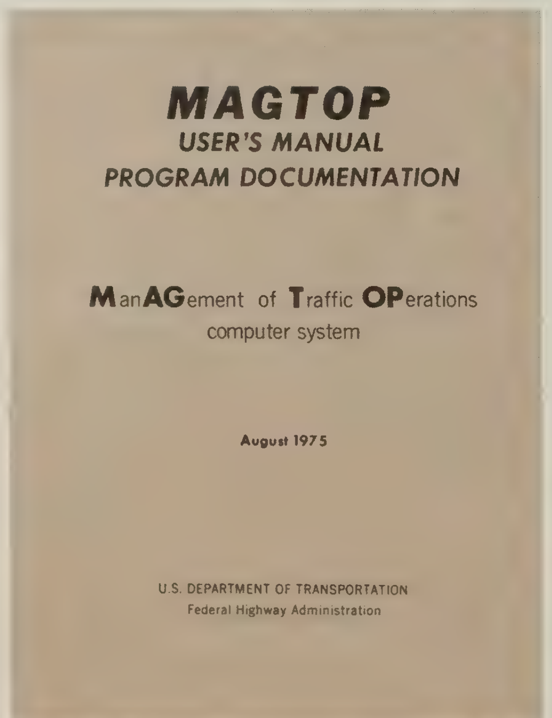
U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

The **MAGTOP User's Manual,** consisting of two volumes, documents the Management of Traffic Operations (MAGTOP) computer system. This system has been designed to assist the traffic engineer in developing traffic operations improvements. It provides a convenient method for storing the large amounts of traffic operations data and provides the integrated facilities to easily summarize, analyze, and display this data.

The **Program Documentation** volume includes an overview of the MAGTOP system as well as chapters on the scope of the system, execution of MAGTOP programs, and run concepts. The chapter on program write-ups forms the bulk of the manual and describes the functions and capabilities of each MAGTOP program. Finally, job submission and system maintenance are outlined; and the file activity report, produced at the end of every MAGTOP run, is described.


MAGTOP
USER'S MANUAL
PROGRAM DOCUMENTATION

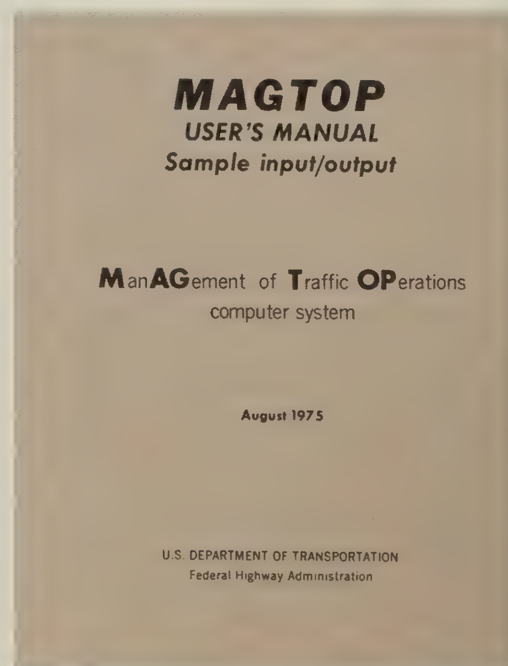
ManAGement of Traffic OPerations
computer system

August 1975

U.S. DEPARTMENT OF TRANSPORTATION
Federal Highway Administration

The **Sample Input/Output** volume provides sample runs for each of the modules contained in the MAGTOP system. An extra sample is included with some programs to further illustrate program operation. The sample outputs also illustrate the kinds of errors which can occur during data collection and coding.

The Program Documentation volume may be purchased for $4.30 (Stock No. 050–001–00104–7) and the Sample Input/Output volume may be purchased for $4.20 (Stock No. 050–001–00105–5). Both are available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.


MAGTOP
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Sample input/output

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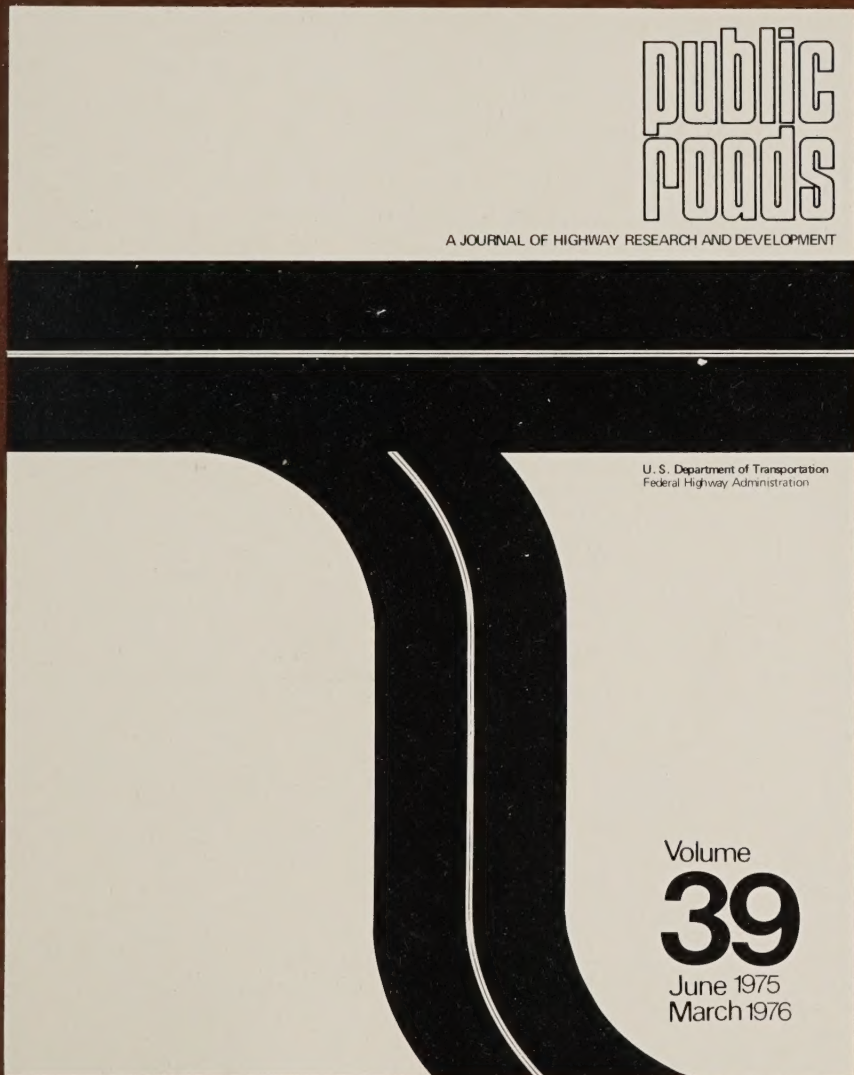
TITLE SHEET, VOLUME 39



The title sheet for volume 39, June 1975–March 1976, 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 managing editor of the magazine, U.S. Department of Transportation, Federal Highway Administration (HDV–10), Washington, D.C. 20590.

Price Increase for PUBLIC ROADS

Effective with the June 1976 issue, the annual domestic subscription rate for **Public Roads** was increased to $7.60 ($1.90 additional for foreign mailing). The price increase is attributed to an increase in postal rates.

The Federal Highway Administration produces the magazine. The Superintendent of Documents, U.S. Government Printing Office, establishes subscription rates and conditions of sale.

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A JOURNAL OF HIGHWAY RESEARCH AND DEVELOPM