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# Public Roads

## A JOURNAL OF HIGHWAY RESEARCH

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

# Public Roads

## A JOURNAL OF HIGHWAY RESEARCH

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Mt. Hood forms the background for this view of the North Fork Iron Creek–Warm Springs Junction section of Oregon's recently completed Mt. Hood Highway, ORE 35 (Photo courtesy of Oregon State Highway Division).

U.S. DEPARTMENT OF TRANSPORTATION
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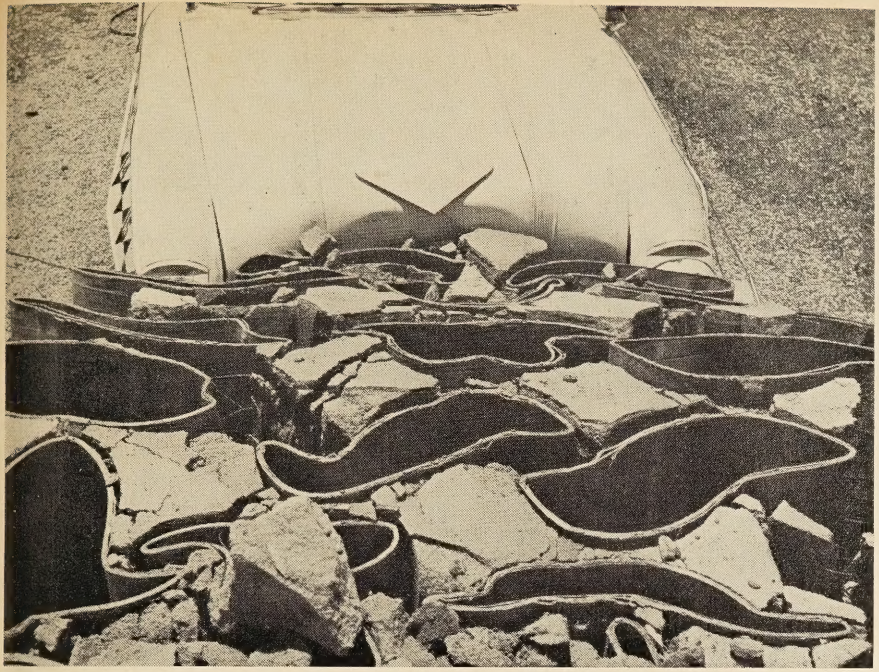

*A cardboard–concrete barrier design—a "safe" vehicle impact.*

# Designing Fail-Safe Structures for Highway Safety

BY THE OFFICE OF RESEARCH

**Reported by [1] F. J. TAMANINI,**
**Chief, Structures and Applied Mechanics Division**

*Highway research has met, and is continuing to meet, the challenge to help stem the enormous accident toll of the Nation's highway system. In addition to numerous innovations on the roadway itself, revisions to the roadside are virtually eliminating lethal targets at which errant vehicles often are directed. Not only are roadside appurtenances being planned-out of probable collision zones, but safe failures are being designed-in for those that cannot be relocated feasibly. These fail-safe structures, which have nearly eliminated fatalities and drastically reduced injury and property damage at locations where they have replaced rigid structures, are being implemented each month by State highway departments.*

*Fail-safe structures must be designed for both strength to perform the tasks for which they were built, and weakness to yield under impact. The author reviews some of the designs that incorporate these seemingly incompatible characteristics, and discusses some of the problems encountered in fail-safe structure design.*

IN the last decade highway planners and design engineers have become increasingly concerned with the responsibility of providing the highway user with safer highways. During the 10-year period, the number of registered vehicles on the highways increased approximately 45 percent—from 74 million to more than 107 million.

Well-engineered geometric designs and modern construction materials and techniques have prevented an untold number of accidents. Statistics indicate that the accident rate on the completed sections of the Interstate Highway System is only 2.99 per 100 million vehicle-miles, compared to the national average accident rate of 5.62 per 100 million vehicle-miles on all other primary and secondary roads (*1*).[2] Without modern features to enhance safety on the Interstate Highway System, the national average accident rate undoubtedly would have been higher.

The effectiveness of new highway construction notwithstanding, the recorded vehicle-accident statistics are unbelievable. On a nationwide basis, these figures, briefly, are as follows:

- Approximately 13 million vehicle accidents annually, or about 35,000 each day.
- More than 56,000 fatalities per year, or about 155 each day. The fatality statistic is increasing at the rate of approximately 2,500 per year.
- Nearly 3,500,000 persons injured annually, or about 10,000 each day. These survivors require about 8 million man-days of hospital care per year to recover.
- About $14 billion of annual economic loss, representing about 12 cents per gallon of gasoline consumed by motor vehicles today.

The engineer has accepted with determination and effectiveness the enormous challenge to reduce drastically this toll of the highway transportation system. Industry, universities,

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[1] Presented at the National Structural Engineering Meeting of the American Society of Civil Engineers, and the 19th Annual Arizona Roads and Streets Conference, April 1970.

[2] Italic numbers in parentheses identify the references listed on p. 132.

private citizens, States, and the Federal Government, all have initiated research programs to enhance accident survivability. Programs also have been launched to develop and produce safer vehicles and to educate drivers to make them more knowledgeable, safer operators.

The highway structural research effort to develop highway structures and appurtenances responsive to the need for safety can be placed in the following four basic categories:

Type I—Structural systems to eliminate rigid supports along the edges of highways.

Type II—Impact attenuation, or energy absorption systems, placed around fixed objects on the roadside or in front of them.

Type III—Fail-safe, frangible structural systems for shoulder-mounted signs, lighting standards, and other highway appurtenances that prevent serious injury in collisions but do not create hazards to other vehicles.

Type IV—Vehicle entrapment or arresting devices and redirectional longitudinal-vehicle barriers.

The researcher's ingenuity and technological freedom, as in the past, are contributing significantly to a more effective and safer highway environment. New highway structures are being designed to virtually eliminate roadside hazards through the use of modern materials and modern construction techniques, longer spans, high geometric standards, and optimum design principles. These are gradually eliminating targets for roadside vehicle collisions. Moreover, something is being done about the present environment, as it is; short-range, quick-payoff programs are producing numerous, higly effective designs—impact-attenuation and redirectional barriers, and frangible roadside structures, to name a few. Some items have proved so effective during development that many States are implementing research results even before research endeavors are completed.

## *Design Considerations*

For the variety of structures required in the highway system—sign supports, guardrail and bridge-rail systems, luminaire supports, protective barriers, bridges, bridge piers, etc.—the designer must not only provide a structure that will withstand normal environmental loadings—dead, live, and wind—but one that will be economical to build as well. In addition to the normal requirements of his discipline, the designer is now called on to integrate safety provisions in his designs. This requires considerable engineering judgment, as the many different interrelated variables are not well defined at present. However, research is providing much needed technical data to reduce the paucity of needed information.

Table 1 is an example of research contribution to highway design engineers' fund of knowledge (*2*). It gives tentative, tolerable limits of deceleration for vehicle occupants in vehicle–structure impact situations in which the duration is about 200 milliseconds or less with an associated onset rate of deceleration less than 500 g's per second.

The following design criteria with minor modifications are currently used by highway departments in many States, by industry, by private research establishments, by the Federal Highway Administration (FHWA) (*3*), and by university researchers:

| | |
|---|---|
| Vehicle weight range. | 2,000–5,000 lbs. |
| Vehicle impact speeds. | 60 m.p.h. |
| Impact angle | As much as 25°—measured from the direction of the roadway. |
| Average permissible vehicle deceleration. | 12 g's maximum while preventing actual impacting or penetration of the roadside hazard. |
| Maximum occupant deceleration onset rate. | 500 g's per second. |
| Maximum duration of impact. | 300 milliseconds or less. |
| Change of momentum. | 1,100 lb.-seconds or less. |

These criteria, intended as guidelines, can provide a high probability of accident-survivability for restrained occupants in most vehicle collisions. At present, the indicated restraint for vehicle occupants is provided by lap or seatbelts or by lap and upper torso straps. Air bags currently under development soon will replace these restraints. Although designing *safety* into roadside appurtenances for the protection of unrestrained vehicle occupants is considered economically infeasible at this time, the FHWA is encouraging safety-oriented structural design, high geometric standards, and roadside-object relocation, using the preceding criteria as guidelines, to incorporate as much safety into the highway network that is possible within the confines of existing technology.

## *Frangible and Breakaway Structur*

The preponderant design requirement f vertical sign and luminaire supports is t provision of bending-moment resistan against loading—dead, live, and wind. She resistance is usually an insignificant facto as the structural section selected to provi the bending moment usually provides mo than enough shear resistance. By reducing, eliminating, this excess shear-resistance c pability, the engineer can provide a safe feature for vehicle collisions and still have structure that satisfies normal loading r quirements. By combining ingenuity with h design ability, the designer can design sacrificeable structure that has that *forgiv ness property* for the errant vehicle and i occupants when the vehicle collides with t structure.

### Frangible wood-post structures

Dimensioned wood posts are used in ma States to support roadside signs with pa areas of 80 to 90 square feet or less. Larg size signs are usually supported by met posts in urban areas and by either met posts or treated timber poles in rural are

Smaller size wood posts, 4 by 6 inches a smaller, have highly desirable frangib properties to minimize personal injury a vehicle damage when impacted. However, t increased fracture energy of larger posts poles for larger signs offers a greater haza when they are impacted.

Several State highway departments ha conducted research programs to study t frangibility attributes of wood sign structur and guardrail posts weakened by drill holes and external-face notches. The mo recently completed programs were those Pennsylvania (*4*) and California (*5*).

In Pennsylvania, researchers concluded th drilled holes are superior to face notches f the desired structural integrity and t *fail-safe* safety property. Accordingly, t Pennsylvania Department of Highways r ommends the following characteristics f drilled holes:

- Two drilled holes having their lon tudinal axes parallel to the sign face at inches and 18 inches above the ground lin

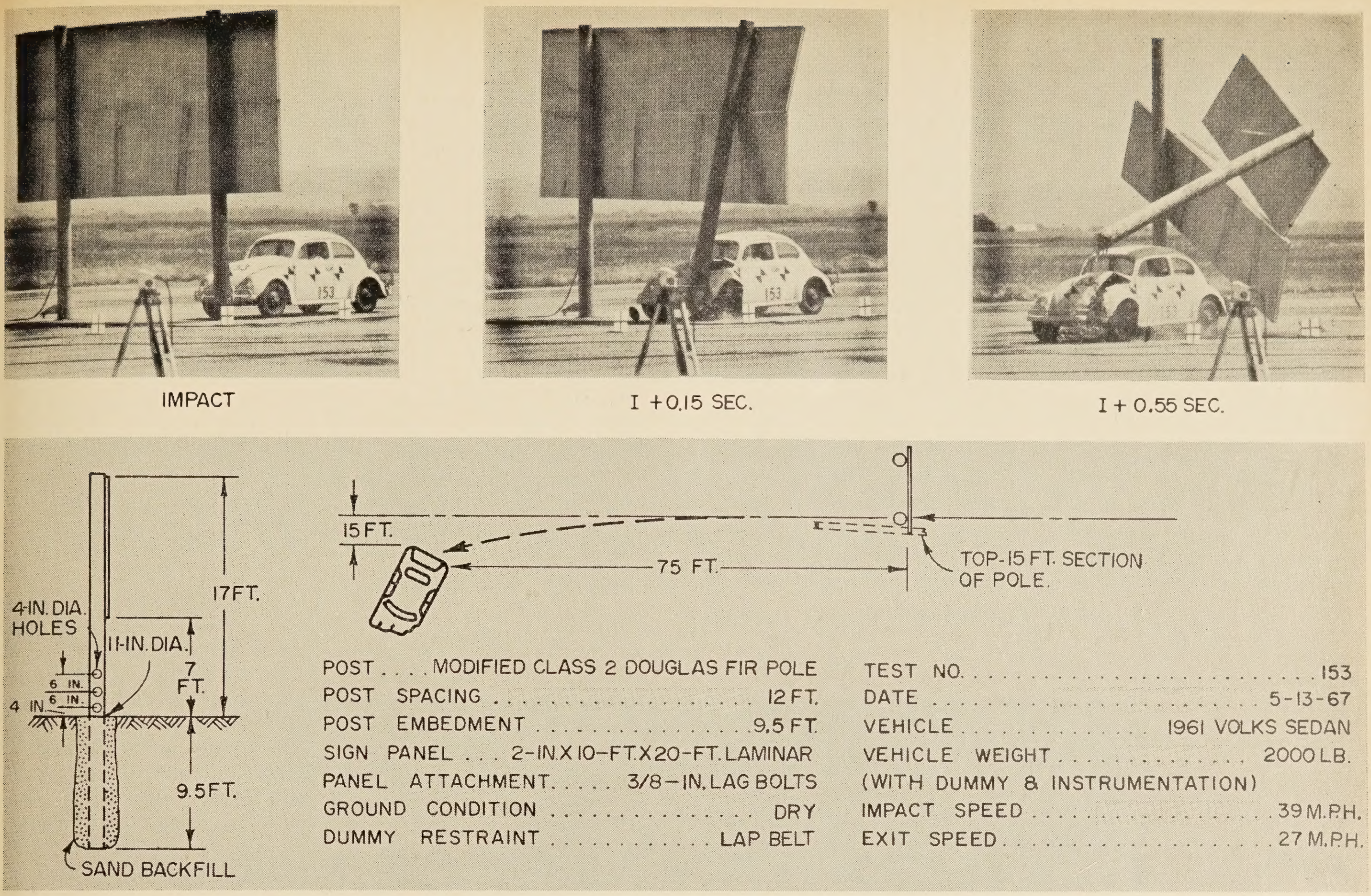
- For 6- by 6-inch wood posts—1½-in diameter holes.

- For 6- by 8-inch wood posts—2½-in diameter holes.

**Table 1.—Tentative tolerable deceleration limits**

| Occupant restraint | Maximum deceleration [1] | | |
|---|---|---|---|
| | Lateral | Longitudinal | Total |
| | g. | g. | g. |
| Unrestrained | 3 | 5 | 6 |
| Lap belt | 5 | 10 | 12 |
| Lap belt and shoulder harness | 15 | 25 | 25 |

[1] From contractor's report (*2*).


IMPACT

I +0.15 SEC.

I + 0.55 SEC.

***Figure 1.—Fail-safe response of a wood sign support.***

In California, researchers tested and evaluated full-size vehicle impacts with dressed dimensioned wood posts and timber poles, with and without drilled holes. Based on the results of this evaluation, the California Division of Highways promulgated the following design requirements:

- Two drilled holes having their longitudinal axes parallel to the sign face at 6 inches and 18 inches above the ground line.
- For 6- by 8-inch dimensioned wood posts—2½-inch diameter holes.
- For timber poles, the hole diameter should conform to those listed in the following tabulation:

| *Pole diameter* | *Hole diameter* |
|---|---|
| Less than 7 inches | No hole. |
| 7 inches to less than 8 inches | 2 inches. |
| 8 inches to less than 9 inches | 2½ inches. |
| 9 inches to less than 10½ inches | 3 inches. |
| 10½ inches to less than 12 inches | 3½ inches. |
| More than 12 inches | 4 inches. |

Drilled holes reduce the bending-moment capacity of structural members about 1 percent and the shear capacity about 45 percent. It is the latter property that influences the damage-limiting capability of the cantilevered support when impacted. The full-size vehicle crash tests in California corroborated this damage-limiting improvement. Figure 1, excerpted from the California report (*5*), shows the impact of an 11-inch-pole sign support by a lightweight vehicle, and lists data associated with the impact. Using these basic data, the change of momentum and the average vehicle deceleration can be readily computed for comparison with the design criteria:

(a) Change of momentum,

$$M=\frac{W}{g}\Delta V \qquad (1)$$

Where,

$W$ is the weight of the vehicle, lbs.

$g$ is the acceleration of gravity, ft./sec.$^2$

$\Delta V$ is the change in vehicle velocity, ft./sec.

Substituting the known data in equation (1),

$$M=\frac{2{,}000}{32.2}\,(12)\,\frac{88}{60}$$
$$M=1{,}090 \text{ lb.-sec.}$$

(b) Average vehicle deceleration, from the impulse-momentum principle,

$$I=M$$
$$I=WG_a\Delta t=M \qquad (2)$$

Where,

$I$ = impulse, lb.-sec.

$\Delta t$ = duration of impact, seconds

$G_a$ = average vehicle deceleration, g's

Substituting the known data in equation (2),

$$2{,}000G_a(0.15)=1{,}090$$
$$G_a=3.6 \text{ g's}$$

The values computed for the change of momentum and average vehicle deceleration do not exceed the proposed maximum design criteria of 1,100 lb.-sec. and 12 g's respectively. They are therefore considered acceptable. Had not the shear resistance of the pole been drastically reduced by the drilled holes, a greater proportion of the kinetic energy would have been needed to shear the member. This would have caused a greater change of velocity and a corresponding increase in change of momentum and average vehicle deceleration, producing an unsafe, high-injury situation.

Wood post or pole highway structures thus are made safer by designing for the specified

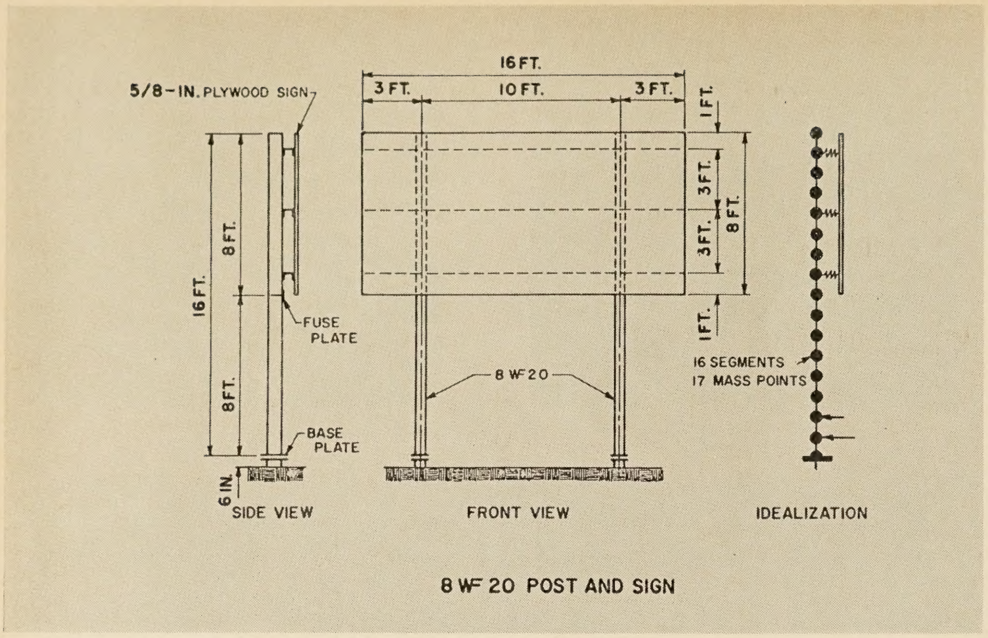


*Figure 2.—Typical breakaway sign structure.*

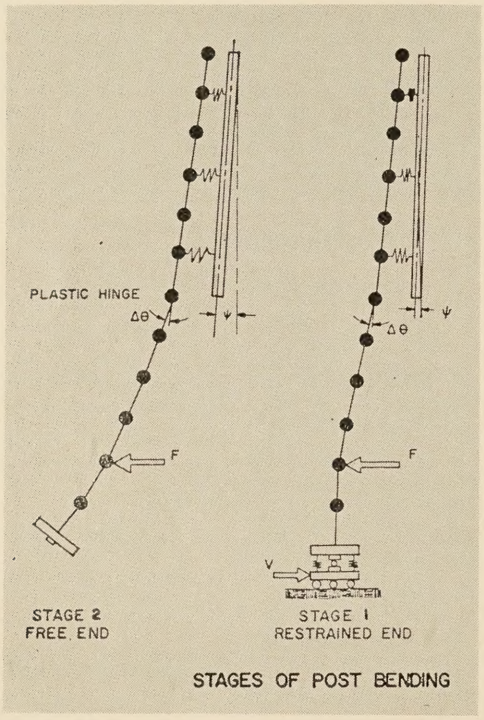


*Figure 3.—Post-bending stages.*

normal-use loads, and then reducing the unneeded shear capacity by drilled holes, as specified in the foregiong table.

### Breakaway metal post sign structures

Fourteen State highway departments in cooperation with FHWA sponsored a 3-year program to study safety criteria for metal sign support structures, extending work initiated by the Texas Highway Department at the Texas Transportation Institute (*6*). A variety of sign-support structures were studied, tested, and evaluated in the program to determine their effectiveness in minimizing personal injury and property damage when impacted by out-of-control vehicles. The stress-raising benefits of notches or slots in timber supports for small signs were studied, and only minor damages to the impacting vehicles were recorded. Several A-frame concepts, including one fabricated from rail-grade, rolled-hat sections and one of tubular aluminum construction with cast aluminum joints, were studied. Although all the structures satisfactorily limited injury and damage, the greatest contribution of this research endeavor was the breakaway roadside sign-support structure (*6*).

A typical 8- by 16-foot sign supported by two breakaway 8WF20 supports is shown in figure 2, together with a schematic indicating the computer idealization of the structure for study. The stages of development of the structure's operation under vehicle impact are shown in figure 3. On impact, the column first bends a very limited amount until the lateral friction resistance of the four preloaded bolts in the *slip base* is overcome, at which point the bolts are dislodged from their slots and the restrained base becomes a free end, moving upward while undergoing energy transfer. As the tendency of the upward-swinging post to peel itself from the sign board proper increases, a damage-limiting *plastic hinge* is activated, preventing further destruction to the sign-post connections. Activation of the mechanical fuse at the plastic hinge to accommodate the bending moment in the *free leg* imposed by the impacting vehicle is shown in figure 4. This action is precipitated as the friction force of the two lower preloaded bolts is overcome. The bolts slip through the slots, preventing structural damage, while the plastic hinge, in opposing the resulting bending moment of the leg, is formed in the opposite flange. From the example of a typical collision with a breakaway structure, shown in figure 5, it is apparent that only minimal damage to the vehicle front end occurs, with no personal injury to occupants, as the sign support performs its intended mission—*to fail* under th impact of the vehicle. This result is opposed t the tragic toll of complete vehicle destructio and five fatalities for the typical collision wit a rigid structure shown in figure 6.

In the breakaway example shown in figure 5 a 3,620-pound vehicle impacted the 8WF2 signpost at a speed of 42.5 miles per hour The change of vehicle velocity and duratio of impact were observed to be 1.2 miles pe hour and 22 milliseconds, respectively. Th change of momentum and the average vehicl deceleration can be computed as follows:

(a) Change of momentum is compute by using equation (1):

$$M=\frac{W}{g}\,\Delta V=\frac{3,620}{32.2}\,1.2\left(\frac{88}{60}\right)$$

$$M=200 \text{ lb.-sec.}$$

(b) Average vehicle deceleration is ol tained from the impulse-momentum princip equation (2):

$$WG_a\times \Delta t=M$$

$$3,620\;G_a\times 0.022=200$$

$$G_a=2.5 \text{ g's}$$

Both of these computed values are less th the proposed maximum design criteria pr viously presented.

With regard to the accident shown figure 6, it was estimated that the vehic weighing approximately 4,500 pounds, inclu ing occupants, impacted the rigid signp

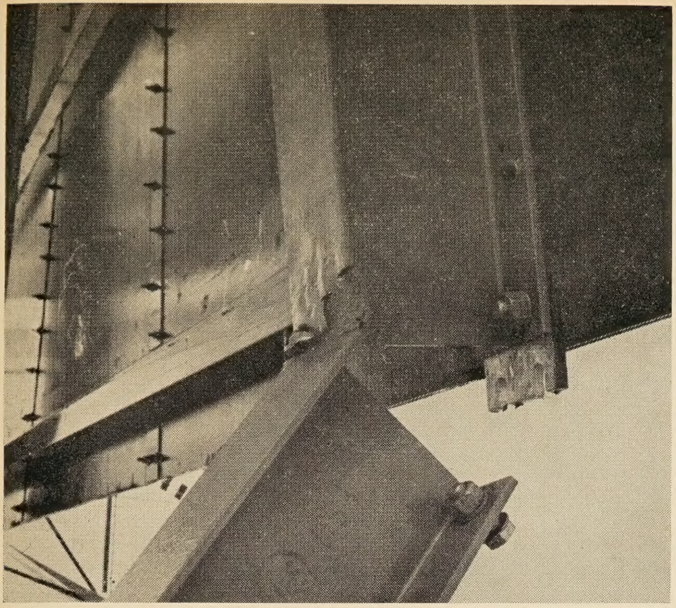


*Figure 4.—Activated plastic hinge of a breakaway sign support.*

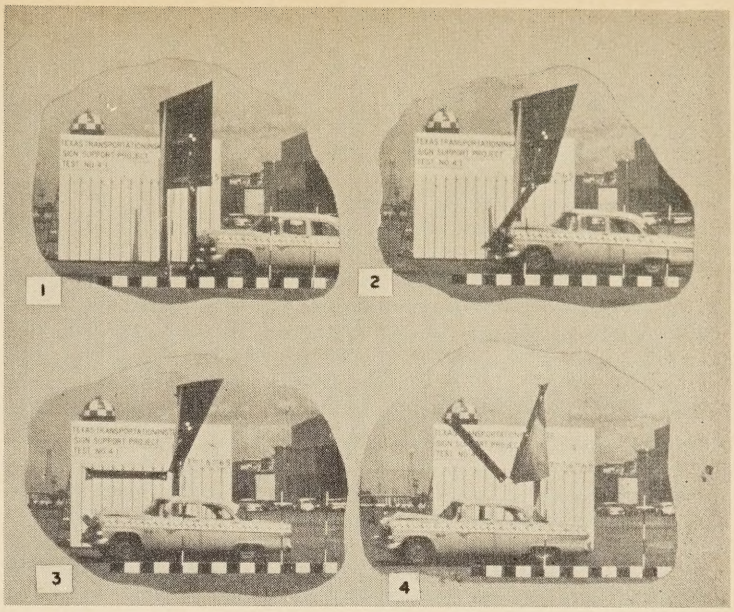


*Figure 5.—Built-in safe failure shown by collision with breakaway sign support.*

*Figure 6.—Collision with a rigid sign post—a fatal accident.*

at approximately 55 miles per hour (determined from the front-end vehicle crush of 3.7 feet). From the energy transfer expression,

$$KE=\frac{1}{2}\frac{W}{g}V^2 \text{------------------------} (3)$$

Where,

$KE$= kinetic energy, ft.-lbs.

$W$= weight of the impacting vehicle, lbs.

$g$= 32.2 ft./sec.

$V$= vehicle velocity, ft./sec.

$$KE=\frac{1}{2}\left(\frac{4,500}{32.2}\right)\left[55\left(\frac{88}{60}\right)\right]^2$$

$$KE=453,000 \text{ ft.-lbs.}$$

From the expression,

$$\text{Work performed}=F_a\times d \text{-------------} (4)$$

Where,

$F_a$= average vehicle impact force, lbs. and

$d$= vehicle deformation, ft.

the average vehicle impact force and the average vehicle deceleration, $G_a$ can be calculated:

$$F_a\times d=KE$$

$$F_a\times 3.7=453,000$$

$$F_a=123,000 \text{ lbs.}$$

$$G_a=\frac{F_a}{W} \text{------------------------} (5)$$

$$G_a=\frac{123,000}{4,500}$$

$$G_a=27 \text{ g's}$$

From equation *I*, the change of momentum can be computed:

$$M=\frac{W}{g}\,\Delta V=\frac{4{,}500}{32.2}\left(55\right)\frac{88}{60}$$

$$M=11{,}300 \text{ lb.-sec.}$$

Medical researchers working in the vehicle crash environment have established a change of velocity of 11 miles per hour as the approximate threshold at which vehicle occupants are likely to incur serious injury by collisions with the vehicle interior. In the second example above, the failure mechanism in the breakaway signpost structure would have made the difference between life and death by reducing the average vehicle deceleration, change of momentum, and change of velocity well below the prescribed maximum safe limits for injury.

Through the development of a comprehensive computer routine resulting from a myriad of mathematical modeling and optimization studies, including laboratory and full-size structural testing, a simplified guide for the design engineer was published (*6*). By use of this design guide (see *Recommendations for Design of Breakaway Supports* at the end of this article), the engineer can design into his wind-resistant structure a failure mechanism that will become operative only when it is impacted by a vehicle. After completing the design of the sign structure to withstand the wind loading, he simply integrates a slip base connection and an upper plastic hinge fuse detail into the post design with the appropriate bolt sizes and preload torques indicated in the *Guide*. For known signboard sizes and wind loads, standard detail sheets can be produced to effect considerable economy.

According to Hosea (*7*), on completed sections of the Interstate Highway System, about 8 percent of the ran-off-the-road, fatal vehicle collisions with roadside obstacles involved sign structures. If this figure is applied to all the roads in the Nation, it can be estimated that perhaps as many as 500 fatal accidents could involve roadside signs annually.

Only one fatality to date has been attributed to a vehicle collision with a breakaway sign. In the several hundred known collisions with breakaway signs, only an insignificant number of minor personal injuries have been reported. In fact, because of the damage-limiting, built-in, *fail-safe* feature, less than 40 percent of the collisions have been reported by drivers.

Actual highway-user cost benefits attributable to the mandatory FHWA policy to use breakaway, or frangible, sign structures on Federal-aid highways can never be accurately determined. However, it is conceded to be a significantly high figure, worthy of the implementation effort.

### Breakaway overhead sign bridge structure

To extend the breakaway sign support concept to overhead sign bridges, 22 State highway departments, in cooperation with the FHWA, are sponsoring a research program at the Texas Transportation Institute in which a full-size, 140-foot-long sign bridge structure with four supports, has been designed, constructed, and instrumented to obtain vehicle–structure interaction data under controlled crash conditions. An experimental breakaway support for this overhead sign bridge structure is shown in figure 7. A close-up of the slip-base detail is shown in figure 8. Posts, 20 feet high, each weighing 1,500 pounds, have functioned very successfully in crash tests under a range of impact velocities and different approach angles. Table 2 presents the vehicle–structure interaction data recorded in two of the tests.

With the completion of this program, a recommended design guide that includes the parameters for safety provisions in breakaway overhead sign bridge structures will be published.

The mathematical model and computer routine for breakaway sign support structures have been modified by Martinez, Hirsh, and Baskurt (*8*) to evaluate the crash–dynamic behavior of a variety of aluminum sign post structures mounted on frangible bases with different fracture energies. In addition to structural input data, the revised routine included input data on vehicles as heavy as 5,000 pounds and on vehicle impact velocities as high as 45 miles per hour. Output information included data on vehicle-velocity change, collision duration, average deceleration, and post-impact structure disposition. These data are presented in tables and charts (*8*) so that, by their use, the designer can readily assess the structural response of his proposed design to varied impact conditions

## *Slip-Base Luminaire Supports*

In many locations, the illumination of high-speed primary and secondary highway routes is considered a necessity for safe, night-time driving. However, the very means

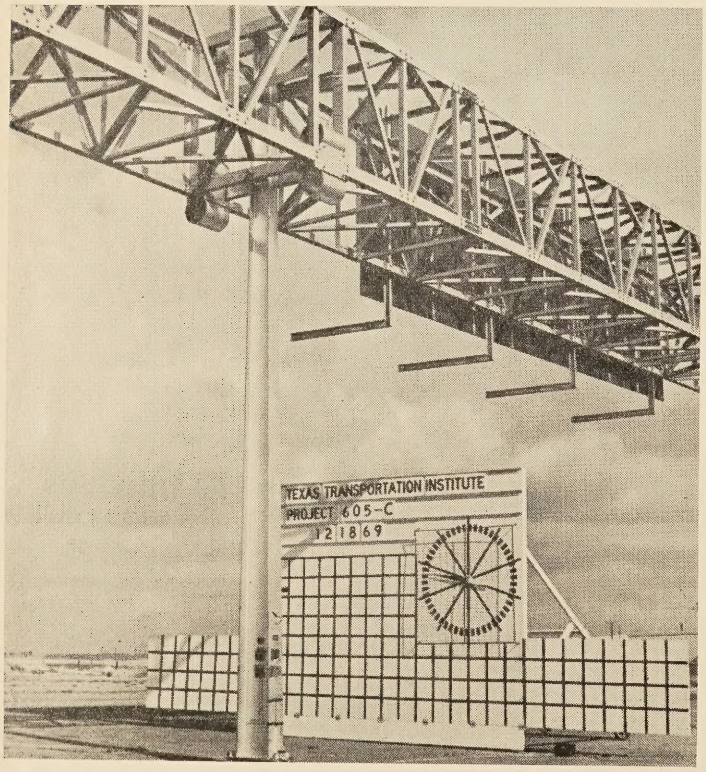


*Figure 7.—Experimental breakaway support for overhead-sign bridge.*

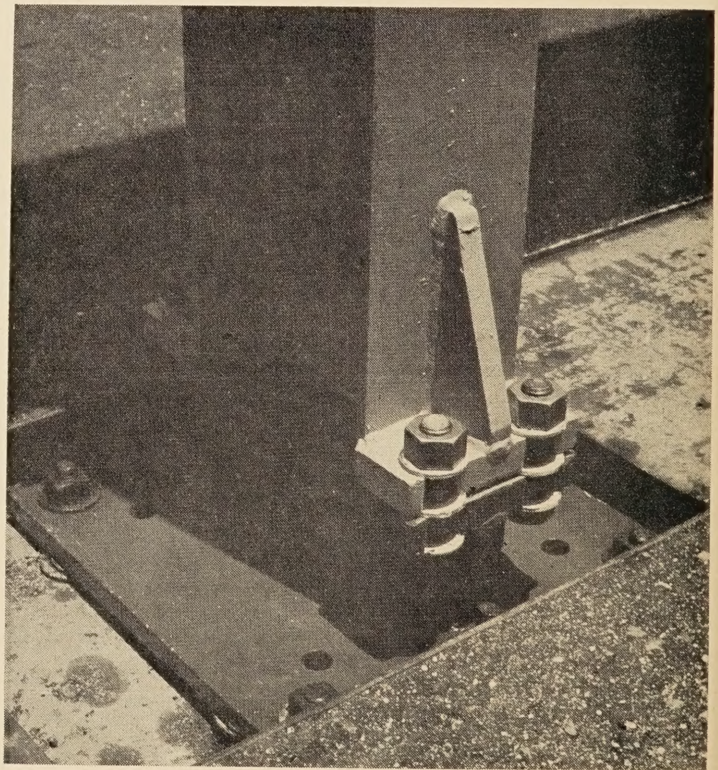


*Figure 8.—Slip base of breakaway support for overhead-sign bridge.*

**Table 2.—Results of vehicle-impact tests on overhead sign bridge support**

| Conditions | Test 1 | Test 2 |
|---|---|---|
| Vehicle weight..........lb.. | 3, 520 | 3, 600 |
| Vehicle impact speed..........m.p.h.. | 20. 9 | 24. 9 |
| Change of speed..........do. | 7. 3 | 5. 1 |
| Maximum vehicle deformation..........ft.. | 1. 1 | 1. 0 |
| Average vehicle deceleration..........g.. | 2. 3 | 2. 9 |
| Duration of impact..........ms.. | 180 | 94 |

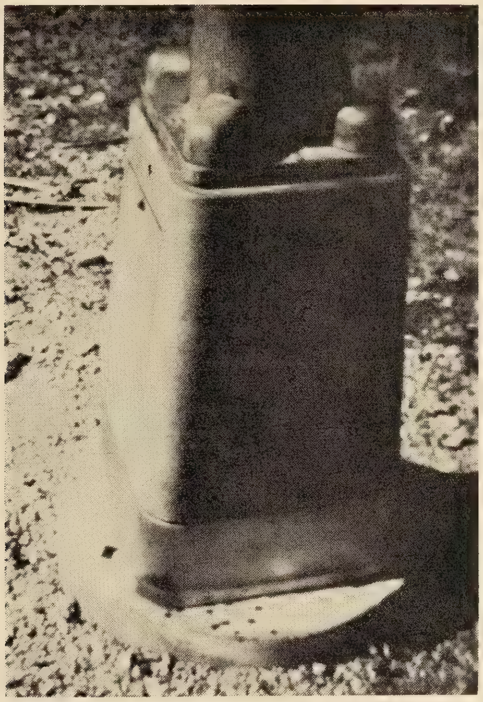


*Figure 9.—Frangible aluminum insert at base of luminaire pole.*

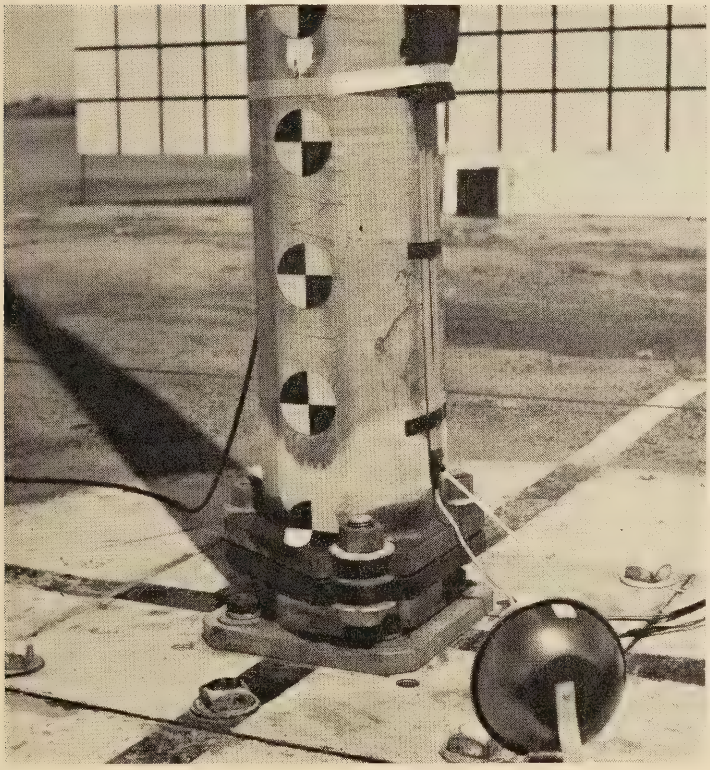


*Figure 10.—Slip base of safe luminaire support.*

of providing this safety has become a roadside hazard. In consonance with improved geometric highway design principles, luminaire structures, as well as roadside signs, are being removed from the 30-foot-wide zone on the side of the roadway wherever relocation of these objects is practical. Studies of single-vehicle, ran-off-the-road accidents indicate that approximately 80–90 percent of the vehicles strike objects that are located within this 30-foot zone. In addition, Federal regulations specify that on all Federal-aid highway systems, luminaire supports must be of the frangible or breakaway type to provide safer impacts when vehicle collisions do occur. The change of moment under impact is required to be less than 1,100 pound-seconds.

Hosea (7) states that about 5 percent of the single-vehicle, off-the-road, fatal accidents on the completed sections of the Interstate System involved luminaire poles. Because of the lower geometric design standards on other roads, this figure can be adjusted to about 8 percent for all roads in the Nation, which represents approximately 500 fatalities per year.

The challenge to reduce the high accident toll of luminaire supports has been accepted by industry, State agencies, and the FHWA, the cooperative efforts of which are producing successful results. Industry has conducted numerous laboratory and full-size crash tests to establish the acceptability of a variety of design combinations of sizes, metals, and metal alloys to meet the specified criteria. Many States are experimenting with high-level lighting structures that are 3 to 5 times higher than the standard 30- to 40-foot high roadside luminaire supports. These are not frangible or breakaway, are usually located at complex interchanges, and are installed at a safe distance from the travelled roadway, obviating all probable vehicular collisions.

To convert the hundreds of thousands of metal luminaire supports not meeting the Federal standards, a simple insert shown in figure 9, was developed at the Texas Transportation Institute under a cooperative research project sponsored by the Texas Highway Department and the FHWA. It is 6 inches or 9 inches high depending on the design and is made of an aluminum alloy that has a low base fracture energy.

A slot-bolted, slip-base for luminaire support was also developed and tested under this research at the Texas Transportation Institute. The details of this structure are shown in figure 10, and a slip-base luminaire installation is shown in figure 11. The high strength bolts in the design are pretensioned and provide friction-shear resistance. The base connection is primarily a bending-resistant joint. When the structure is impacted by a vehicle, the low-base fracture energy, about 750 foot-pounds, is easily overcome, and a safe *failure* ensues. For such structures, the impacting vehicle passes underneath the upward-rotating luminaire support and receives only minor vehicle damage.

Industry has produced a notched-bolt base connection, which under limited tests, has proved to be effective in providing *soft* hits for vehicles. More tests are believed required to determine the life expectancy of these critical devices. Research data on the fatigue characteristics and stress corrosion susceptibility should eventually indicate the true value of this simple system for low base fracture energy.

In research at Texas A&M University, sponsored by a National Cooperative Highway Research Program, the state of the art of luminaire supports was studied. The results of this endeavor are given in the project report (*9*). The predicted response charts from that report, shown in figures 12 and 13, are excellent aids for use by designers to evaluate and select proposed luminaire support designs having different parameter values. From these charts, designers can easily obtain the response of the structure under consideration and the post-crash assessment effects, provided that the base fracture energy is known. Each chart depicts three zones of the post-crash event: (1) The secondary vehicle front-end collision with the post; (2) the secondary impact of the severed post with the roof of the vehicle; and (3) the possible impact of the post with the trunk of the vehicle or with the ground to the rear of the vehicle. The zone of possible minor injuries is also identified. As emphasized in the charts, designs have the lowest possible base fracture energy for vehicle impact in the structure are safest, as low base fracture energies are less sensitive to vehicle impact velocity and result in very low changes of vehicle velocity and low deceleration forces in all impacts (*10, 11*).

Martinez, Hirsch, and Jumper (*12*) have extended these charts to assist the design engineer who is considering mounting heights higher than 40 feet for luminaire supports. Their results for aluminum structures having slip-base energy levels of 750 ft.-lbs. and 3, 000 ft.-lbs., shown in tables 3 and 4, further emphasize the conclusions of the basic study (*9*) that low base fracture energies designed into luminaire supports increase the probability of accident survival because safe changes of vehicle velocity and lower vehicle deceleration are experienced throughout the probable range of impact velocities.

## *Energy Absorption Crash Barriers*

Industrial and academic research organizations and a number of State highway departments, all cooperating with the FHWA, have underway research, development, test, and evaluation programs for impact attenuation devices. These devices, or systems, are basically *pillows*, or *cushions*, placed in front of and alongside roadside hazards such as bridge piers and bridge parapet ends at exit ramps in elevated gore areas. By programed absorption, elasto-plastic absorption, or ultimate collapse, these safety structures act as energy transfer agents for errant, fast-moving vehicles.

In 1967 the FHWA began a short-term, quick-payoff research and development project called the 4S Program—*Structural Systems in Support of Safety* (*3*). The scope of

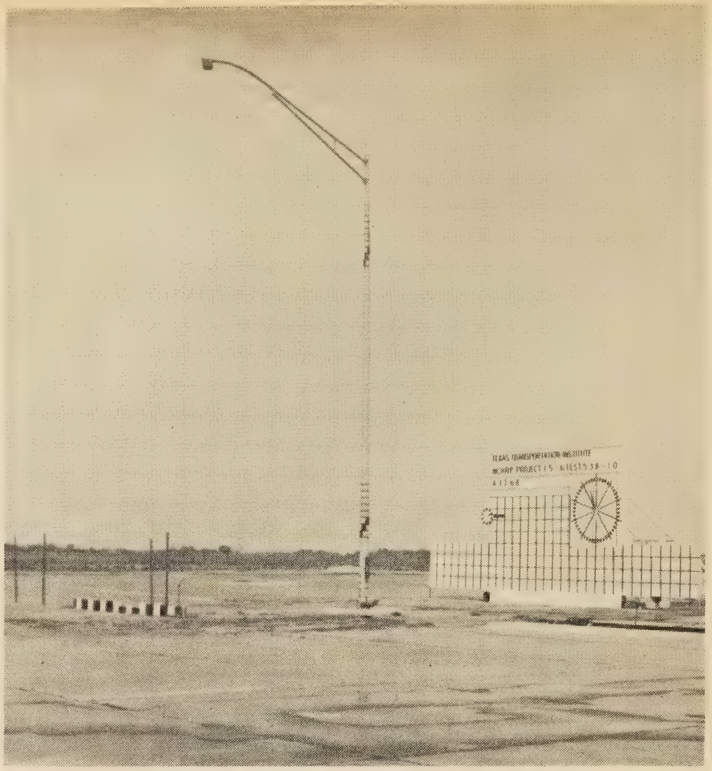


*Figure 11.—Slip-base luminaire installation.*

**Table 3.—Results of collisions with 50-ft. support structures on bases having an energ level of 750 ft.-lb.**

[By computer simulation]

| Vehicle weight | Vehicle impact velocity | Change in vehicle velocity | Average vehicle deceleration | Contact time | Comments |
|---|---|---|---|---|---|
| *pounds* | *m.p.h.* | *m.p.h.* | *g.* | *sec.* | |
| 2, 000 | 15 | 1. 70 | 1. 18 | 0. 065 | Base of support hits in front of vehicle and secondary collision follows. |
| 2, 000 | 30 | 1. 20 | 1. 08 | 0. 049 | Luminaire hits ground. |
| 2, 000 | 45 | 1. 30 | 1. 60 | 0. 036 | Do. |
| 3, 500 | 15 | 0. 72 | 0. 36 | 0. 091 | Base hits ground in front of vehicle and secondary collision follows. |
| 3, 500 | 30 | 0. 55 | 0. 30 | 0. 083 | Top of post hits ground. |
| 3, 500 | 45 | 0. 50 | 0. 70 | 0. 032 | Luminaire hits ground. |
| 5, 000 | 15 | 0. 45 | 0. 46 | 0. 045 | Base of support hits in front of vehicle and secondary collision follows. |
| 5, 000 | 30 | 0. 30 | 0. 30 | 0. 038 | Top of post hits ground. |
| 5, 000 | 45 | 0. 34 | 0. 54 | 0. 029 | Luminaire hits ground. |

**Table 4.—Results of collisions with 50-ft. support structures on bases having an energ level of 3,000 ft.-lb.**

[By computer simulation]

| Vehicle weight | Vehicle impact velocity | Change in vehicle velocity | Average vehicle deceleration | Contact time | Comments |
|---|---|---|---|---|---|
| *pounds* | *m.p.h.* | *m.p.h.* | *g.* | *sec.* | |
| 2, 000 | 15 | 6. 10 | 3. 80 | 0. 072 | Base of support hits in front of vehicle and secondary collision follows. |
| 2, 000 | 30 | 3. 40 | 3. 40 | 0. 046 | Top of post hits ground. |
| 2, 000 | 45 | 2. 60 | 3. 30 | 0. 036 | Luminaire hits ground. |
| 3, 500 | 15 | 4. 56 | 1. 96 | 0. 106 | Base of support hits in front of vehicle and secondary collision follows. |
| 3, 500 | 30 | 2. 40 | 1. 24 | 0. 088 | Luminaire hits ground. |
| 3, 500 | 45 | 1. 70 | 2. 10 | 0. 037 | Top of post hits ground. |
| 5, 000 | 15 | 2. 30 | 1. 50 | 0. 071 | Base of support hits in front of vehicle and secondary collision follows. |
| 5, 000 | 30 | 1. 40 | 1. 25 | 0. 050 | Top of post hits ground. |
| 5, 000 | 45 | 1. 02 | 1. 23 | 0. 038 | Luminaire hits ground. |

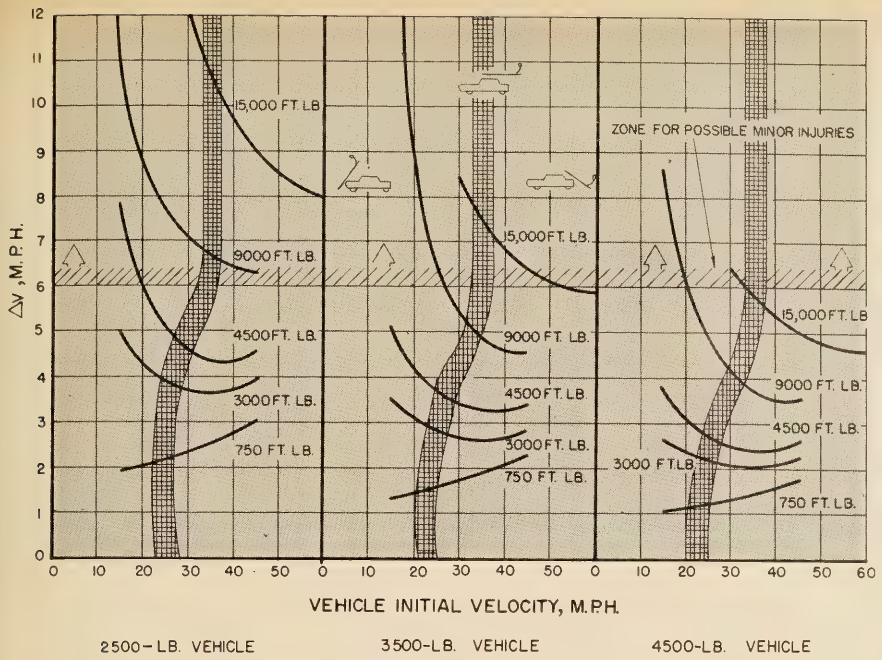


*Figure 12.—Predicted response—collisions with 40-foot steel support.*

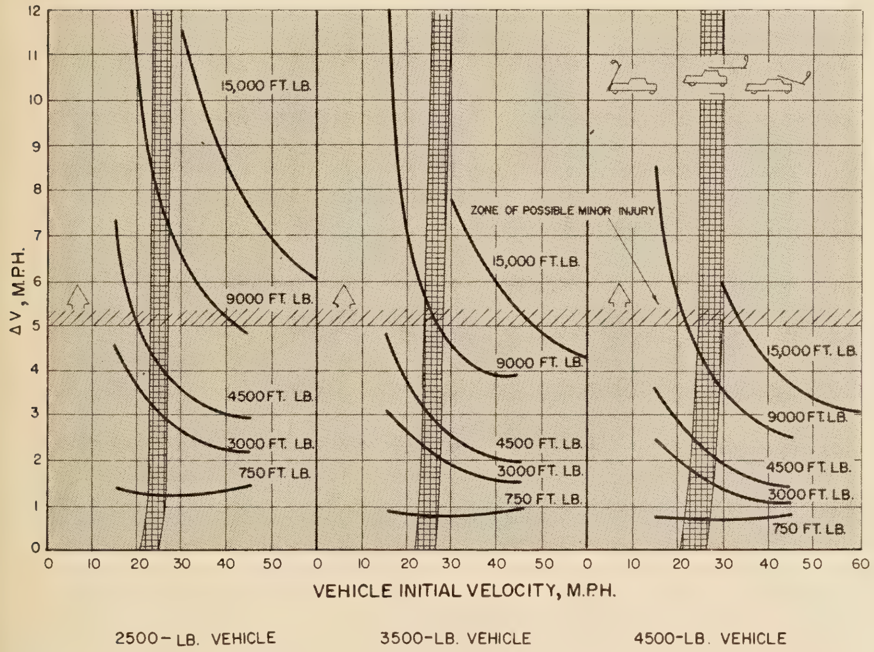


*Figure 13.—Predicted response—collisions with 40-foot aluminum support.*

his research endeavor dealt with the four ypes of research effort listed near the front f this article. Pursuing development of nergy absorption systems of the type II ategory, researchers in this program inestigated energy-transfer capabilities for uch indigenous materials as disposable metal everage containers, empty oil drums, short ood posts, chicken wire fencing, plastic illows, and vermiculite-type concrete. In ddition, industry produced more complicated nd intellectually more appealing type II tructural devices such as the TORSHOK Reusable Highway Barrier, the HI-Dro Cushion Cell Barrier, and the Fitch Inertial Barrier (*13*, *14*, *15*, *16*). These three barriers and one of the expendable variety that uses oil drums as the collapsible fail-safe mechanism are being installed at accident-susceptible highway locations.

The different stages—before, during, and after—of a 70-mile-per-hour vehicle impact with an oil-drum installation at one of these typical locations are shown in figures 14–17. The collision shown in figure 15 was recorded, while the accident was in progress, by the photo-recording instrumentation of an accident data-acquisitioning project of the FHWA. Accidents of this type are occurring at all four types of barriers, and, in all reported incidents, the success of these relatively low-cost *survival kits* has been phenomenal.

The design of an effective bulk-type crash cushion, such as the barrel barriers, incorporates very simple principles of structural behavior. The more complex barrier systems of the reusable variety, previously mentioned, can be designed or analyzed with slightly more sophisticated treatment.

Quantifying the energy absorption capabilities of metal beverage containers and oil drums, Hirsch and Ivey (*17*) determined that dynamic values are 50 percent greater than the static values. Therefore, for general design purposes,

$$e_d = 1.5e_s \qquad (6)$$

Where,

$e_s$ = static energy, ft.-lbs.

$e_d$ = dynamic energy, ft.-lbs., provided by the mechanism.

The kinetic energy of a moving vehicle about to impact an object in its path, such as a solid bridge pier (fig. 18), or a highway cushion barrier, can be computed from the following basic expression:

$$KE = \frac{1}{2}\frac{W}{g}V^2 \qquad (7)$$

Where,

$W$ = weight of vehicle, lbs.

$g$ = acceleration of gravity, ft./sec.$^2$

$V$ = vehicle speed, ft./sec.

Energy transfer takes place upon impact of the vehicle with an object. In an impact with a rigid, immovable object, energy is absorbed by deformation of the vehicle. In an impact with a collapsible, cushion barrier, both barrier collapse and the vehicle deformation account for energy absorption. In either impact, the following expression must be satisfied in the transfer:

$$F_a \times d = KE \qquad (8)$$

Where,

$F_a$ = average vehicle crushing force, lbs.

$d$ = structural deformation, ft.

$KE$ = kinetic energy, ft.-lbs.

Vehicle deceleration can be obtained from the expression:

$$G_a = \frac{F_a}{W} \qquad (9)$$

Where,

$G_a$ = average vehicle deceleration, g's,

### Barrel barrier design example

The example presented here demonstrates a simplified approach to handling energy absorption problems associated with deformable protective highway barriers.

A cushion-type barrel barrier is to be designed for an elevated gore where a triangular area 10 by 34 feet is available for the installation. The barrier is to attenuate, at a safe acceptable deceleration level (see *Design Considerations*), both 2,000-lb. and 4,500-lb. vehicles impacting at 60 m.p.h. Oil drums with static crush strengths of 9,000 lbs. each are to be used, as is a barrel crush efficiency factor, $C_r=0.75$.

The vehicle kinetic energy is calculated to be:

2,000-lb. vehicle—$KE=\frac{1}{2}\frac{W}{g}V^2$

$$=\frac{1}{2}\,\frac{2{,}000}{32.2}\,88^2$$

$KE=240{,}000$ ft.-lb.

4,500-lb. vehicle—$KE=540{,}000$ ft.-lb.

The barrier design for the 2,000-lb. vehicle is as follows:

Number of barrels required,

$$N=\frac{KE}{e_t}=\frac{240{,}000}{9{,}000\times 1.5}$$

N = 17.8 barrels, or 18 barrels

Minimum barrier penetration,

$$L_s=\frac{V^2}{2gG_a}=\frac{(88)^2}{2(32.2)12}=10 \text{ feet}$$

Total barrier length,

$$L=\frac{L_s}{C_r}=\frac{10}{0.75}=13.3 \text{ feet}$$

Using 2-foot diameter barrels, the number of rows required,

$$N_r=\frac{L}{2}=\frac{13.3}{2}=6.7, \text{ or } 7$$

The average number of barrels in each row,

$$N_b=\frac{N}{N_r}=\frac{18}{7}$$

$$N_b=2.56$$

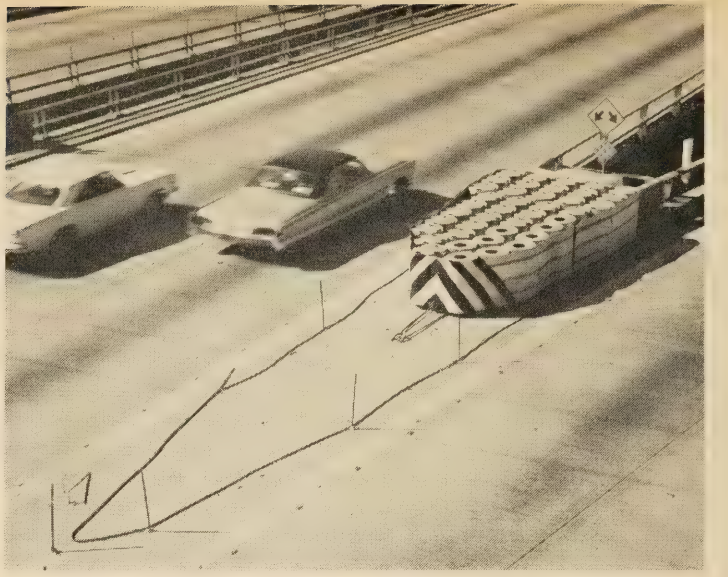


*Figure 14.—Barrel barrier installation at elevated gore.*

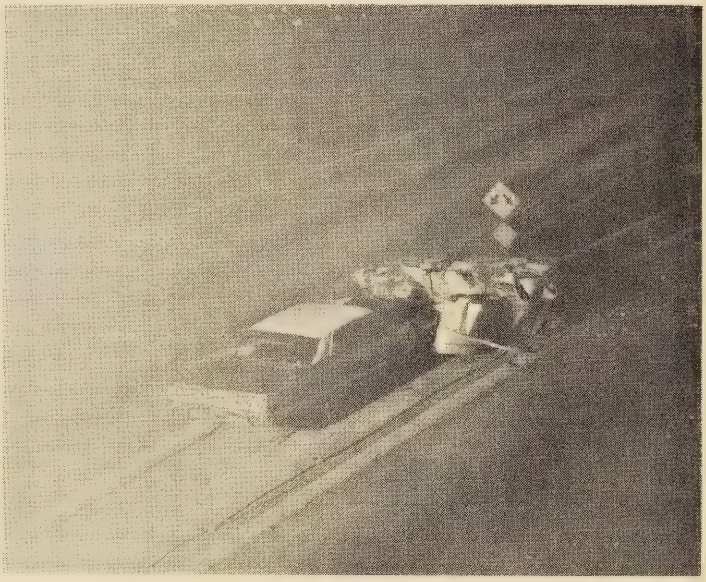


*Figure 15.—Early morning 70-m.p.h. collision with barrel barrier.*

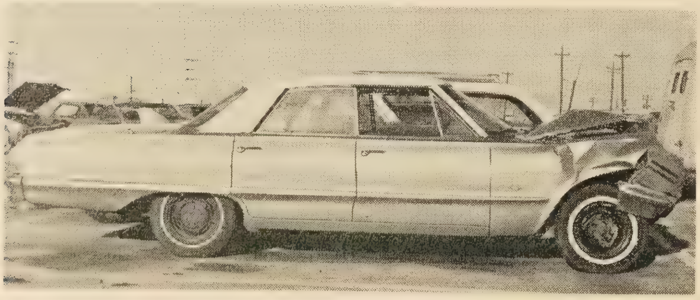


*Figure 16.—Vehicle damage caused by 70-m.p.h. barrier collision.*

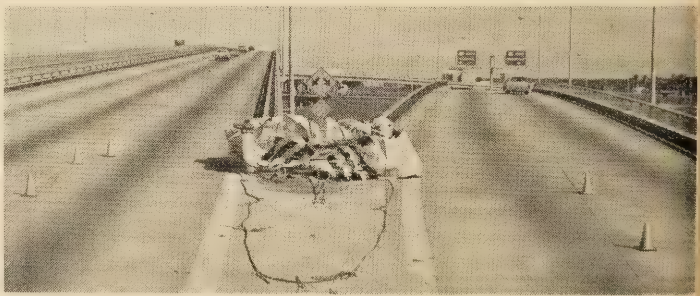


*Figure 17.—Barrel barrier after 70-m.p.h. collision.*

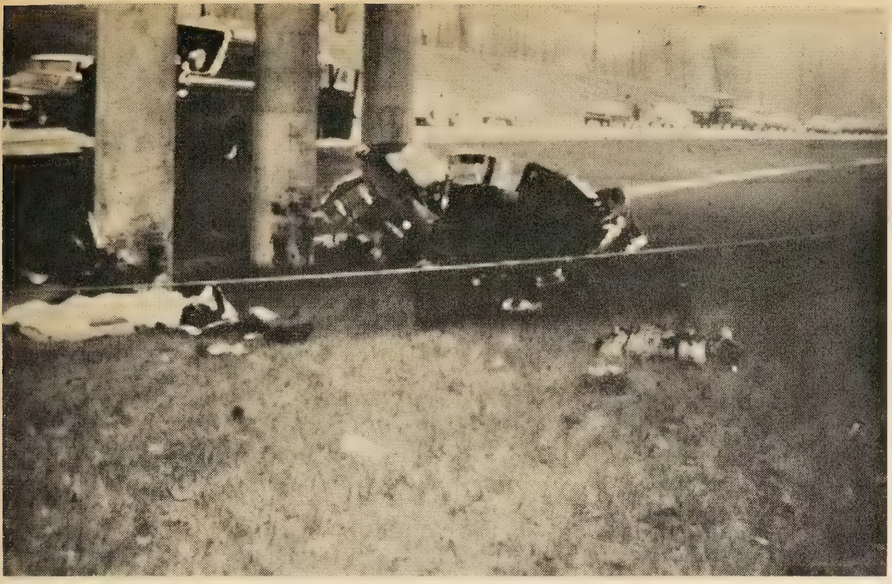
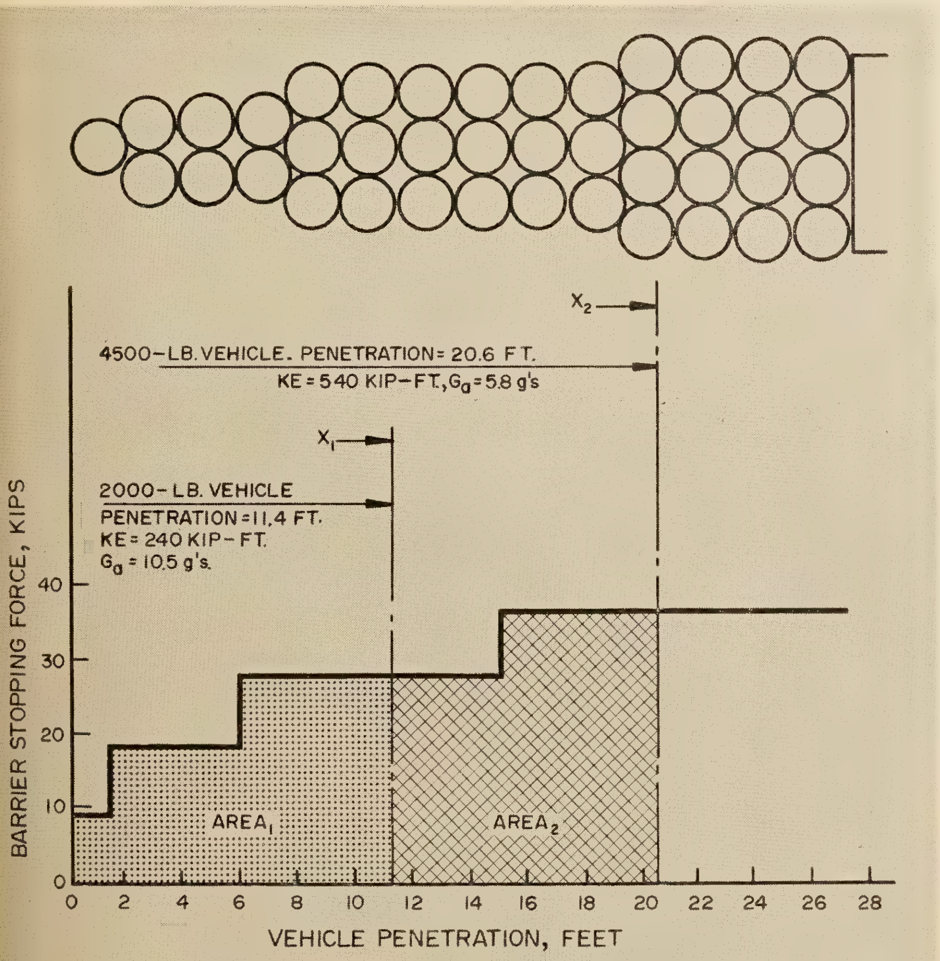


*Figure 18.—Fatal collision with unprotected median bridge pier.*



*gure 19.—Example of barrel-barrier design to accommodate 2,000- and 4,500-pound vehicles.*

The barrier thus delineated will be used also to serve as the nose for the heavier, 4,500-lb. vehicle.

For the 4,500-pound vehicle, the number of barrels required is determined to be,

$$N=\frac{KE}{e_d}=\frac{540{,}000}{9{,}000\times 1.5}=40 \text{ barrels}$$

Using the basic barrier requirements determined necessary to safely attenuate the lighter vehicle, develop an arrangement to also serve as the impact nose for the final barrier. To accommodate the heavier vehicle, add enough barrels to provide the necessary energy absorption capacity as follows (refer to fig. 19):

$\text{Area}_1=240$ kip-ft. = energy to stop a 2,000-lb. vehicle.

$\text{Area}_1+\text{Area}_2=540$ kip-ft. = energy to stop a 4,500-lb. vehicle.

Calculation for penetration by the 2,000-lb. vehicle:

$$\begin{aligned}\text{Area}_1&=240 \text{ kip-ft.}\\&=9\times 1.5+2\times 9(6-1.5)\\&\qquad+3\times 9(X_1-6)\\&=13.5+81+27X_1-162=240\\27X_1&=307.5\\X_1&=11.4 \text{ feet from impact with barrier}\end{aligned}$$

Calculation for penetration by the 4,500-lb. vehicle:

$$\begin{aligned}&\text{Area}_1+\text{Area}_2=540 \text{ kip-ft.}\\&240+3\times 9(15-11.4)\\&\qquad+4\times 9(X_2-15)=540\\&240+97.2+36X_2-540=540\\&36X_2=742.8\\&X_2=20.6 \text{ feet from impact with barrier}\end{aligned}$$

The deceleration levels for each vehicular impact provided by the proposed barrier arrangement are readily calculated to determine compliance:

$$G_a=\frac{V^2}{2gL_s}$$

$$2{,}000\text{-lb vehicle, } G_a=\frac{88^2}{2(32.2)11.4}$$

$$G_a=10.5 \text{ g's}$$

$$4{,}500\text{-lb vehicle, } G_a=\frac{88^2}{2(32.2)20.6}$$

$$G_a=5.8 \text{ g's}$$

Details of construction and installation are not included in this example For an in-depth treatment of the state of the art, refer to the literature (*17, 18*).

## ACKNOWLEDGMENT

The author expresses his appreciation to the numerous researchers and their organizations, some of whom are mentioned herein, for their cooperation in making available technical data and photographs.

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(12) *Impact Response of Fifty-foot Luminaire Support Structures,* by J. E. Martinez T. J. Hirsch, and J. J. Jumper, Texas Transportation Institute, Technical Memo 505–13 December 1969.

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(15) *Guardrails, Median Barriers, Sig and Light Supports,* Highway Research Recor Number 222, 1968.

(16) *Development of Safer Roadside Structures and Protective Systems,* Highway Researc Record Number 259, 1969.

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(18) *The Modular Crash Cushion—Researc Findings and Field Experience,* by T. Hirsch, Don L. Ivey, and Monroe C. Whit HRB Special Report 107, 1970.

## *Recommendations for Design of Breakaway Supports*

(Excerpted from Texas Transportation Institute Report (*6*)).

*Post Sizes*

A standard structural section weighing less than 45 lb./ft. selected to resist the maximum wind load moment.

*Base Plate and Base Connection*

The base plate should be designed for the maximum wind loads and not weigh more than the maximum values shown in the table below. The base bolts should be designed to resist the maximum wind load assuming no pretension. The initial bolt forces in the table below are recommended;

| *Post Size (lb./ft.)* | *Bolt Diam. (in.)* | *Bolt Force (lb.)* | *Torque (A325, galv.)* (lb. in.) | (lb. ft.) | *Base Plate Wt. (lb.)* |
|---|---|---|---|---|---|
| 0–8 | ½ | 920–1380 | 200–300 | 16.7–25.0 | 8.0 |
| 9–20 | ⅝ | 1740–2660 | 460–680 | 37.5–56.5 | 12.0 |
| 21–30 | ¾ | 2400–3600 | 750–1060 | 67.5–88.3 | 21.0 |
| 30+ | ⅞ | 2400–3600 | 850–1280 | 70.8–106.8 | 21.0 |
| 30+ | 1 | 2400–3600 | 450–1470 | 77.1–118.2 | 21.0 |

*Fuse Connection*

The moment capacity for the fuse connection is determined by the maximum wind load moment at the fuse. If slotted plates are used t initial bolt force can be determined by

$$N' = \frac{M}{mnf(s)r}, \text{ where } \begin{array}{l} f(s)_{max} = 0.26 \\ f(s)_{avg} = 0.21 \\ f(s)_{min} = 0.17 \end{array}$$

ASTM turn-of-nut tightening methods are satisfactory if backgroun to-post connections are adequately designed. For torque wren tightening, the bolt force may be calculated using

$$N' = K_T \tau, \text{ where } \tau = \text{bolt torque in lb.–in.}$$

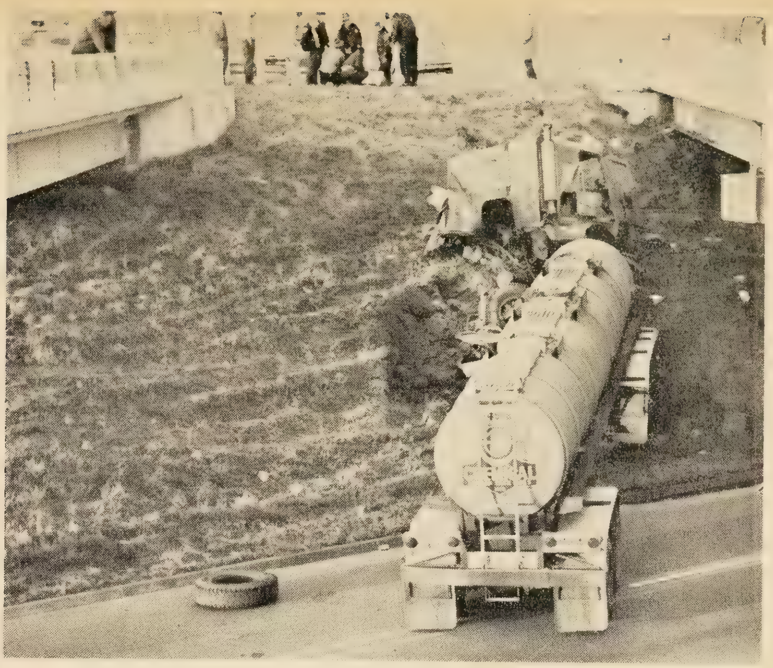
| *Bolt Diameter (ASTM A325 galvanized) (inches)* | *K* |
|---|---|
| ½—13UNC | 4.9 |
| ⅝—11UNC | 3.8 |
| ¾—10UNC | 3.1 |

*Background-to-Post Connection*

The maximum connection force anticipated is 10,000 lb.

*Rotational Stiffness of Sign Background*

A minimum stiffness of 100 ft.-lb./degree (5,730 ft.-lb./radian



# Fatal Accidents on Completed Sections of the Interstate Highway System, 1968–69

THE OFFICE OF
AFFIC OPERATIONS

**Reported by HAROLD R. HOSEA**
**Accident Record Analyst**
**Traffic Performance and Analysis Division**

### *Introduction*

EPORTS of 5,881 fatal accidents that occurred in 1968 and 1969 on sections of Interstate Highway System complying ly with Interstate design standards have n analyzed from police investigation orts obtained from the States. A detailed ort on 2,754 accidents that occurred in 8 appeared in the October 1969 issue of BLIC ROADS.[1] In that article the more ortant characteristics of the accidents—icles, drivers, and environmental factors—re described, and 12 detailed statistical les presenting supporting data were inded. Tables presenting the same type of rmation on 3,127 accidents that occurred 1969 and reprints of the original article available on request.

he purpose of this report is to provide a mary of the experience of the 2 years bined and to note significant changes t occurred between the two periods. As st of the changes from 1968 were relatively minor, details on the 1969 experience are not given here.

### *Number and Characteristics of the Accidents*

A distribution of the 5,881 accidents by accident type, fatalities, injuries, and property damage, is presented in table 1. The totals represent approximately 90 percent of all the fatal accidents that occurred on the Interstate Highway System during the 2-year period.

Two-thirds of all the fatal accidents reported involved only one vehicle in motion, and nearly four-fifths of these crashes—about half the total—resulted from vehicles that ran off the road. A more detailed analysis of these accidents is given in the last paragraph of this report. Between 1968 and 1969, variations in the distribution of accidents by type, as well as changes in the numbers of fatalities and injuries per accident, were insignificant.

The increase of about 3 percent in the average dollar amounts of property damage per accident can probably be attributed principally to generally rising costs. The total economic loss in terms of fatalities, injuries, and property damage resulting from these accidents is estimated at $140 million in 1968, and $164 million in 1969, for a total of $304 million for the 2-year period. The formula devised by the National Safety Council was used for this purpose.[2]

### *Day and Time of Occurrence*[3]

Slightly more than 20 percent of the accidents occurred on Saturday; the lowest percentage was recorded for Tuesday and Wednesday—11 percent for each day; and almost 53 percent occurred on weekends, Friday through Sunday.

The highest percentage of accidents for any hour of the day occurred between 2 and 3 a.m., and more than a fourth happened between midnight and 5 a.m.

Over half of all the accidents occurred at night with relatively small variations for the several types of crashes, except that almost three-fourths of the pedestrian accidents and

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[1] *atal Accidents on Completed Sections of the Interstate way System*, PUBLIC ROADS, vol. 35, No. 10, October .

[2] *How to do a Cost-Benefit Analysis of Motor Vehicle Accident Countermeasures*, by J. L. Recht, National Safety Council, September 1966, p. 20.

[3] In this and following paragraphs of the report, the data referred to are those for the entire 2-year period

**Table 1.—Fatal accidents on completed sections of the Interstate Highway System, 1968–69—accident types, fatalities, injuries, a property damage**

| Type of accident | Accidents |  |  | Fatalities |  | Injuries |  | Property damage |  |
|---|---|---|---|---|---|---|---|---|---|
|  | Number | Percent |  | Total | Per accident | Total | Per accident | Total | Per accident |
|  |  | Total | Subgroup |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  | *Thousands of dollars* | *Dollars* |
| Total accidents, all types | 5,881 | 100.0 | ---------- | 7,124 | 1.21 | 6,701 | 1.14 | 16,873.6 | 2,869 |
| Single vehicle: |  |  |  |  |  |  |  |  |  |
| Ran off road | 3,078 | 52.3 | 78.9 | 3,555 | 1.15 | 2,585 | 0.84 | 7,333.1 | 2,382 |
| Overturn on road | 59 | 1.0 | 1.5 | 65 | 1.10 | 53 | 0.90 | 84.1 | 1,425 |
| Collision with parked vehicle | 213 | 3.6 | 5.5 | 266 | 1.25 | 271 | 1.27 | 839.8 | 3,943 |
| Pedestrian: |  |  |  |  |  |  |  |  |  |
| Persons outside their vehicle | 139 | 2.4 | 3.6 | 147 | 1.06 | 23 | 0.16 | 34.7 | 250 |
| Trespassers | 329 | 5.6 | 8.4 | 335 | 1.02 | 37 | 0.11 | 78.9 | 240 |
| Total pedestrian | 468 | 8.0 | 12.0 | 482 | 1.03 | 60 | 0.13 | 113.6 | 243 |
| Other [1] | 80 | 1.4 | 2.1 | 88 | 1.10 | 43 | 0.54 | 123.9 | 1,549 |
| Total single vehicle | 3,898 | 66.3 | 100.0 | 4,456 | 1.14 | 3,012 | 0.77 | 8,494.5 | 2,179 |
| Multiple vehicle: |  |  |  |  |  |  |  |  |  |
| Rear-end collision | 888 | 15.1 | 44.8 | 1,093 | 1.23 | 1,530 | 1.72 | 4,289.0 | 4,830 |
| Head-on collision: |  |  |  |  |  |  |  |  |  |
| Wrong-way driver | 293 | 4.9 | 14.8 | 484 | 1.65 | 508 | 1.73 | 1,003.1 | 3,424 |
| Vehicle from opposing lanes | 370 | 6.3 | 18.6 | 578 | 1.56 | 934 | 2.52 | 1,694.7 | 4,580 |
| Other | 28 | 0.5 | 1.4 | 37 | 1.32 | 53 | 1.89 | 126.2 | 4,507 |
| Total head-on collision | 691 | 11.7 | 34.8 | 1,099 | 1.59 | 1,495 | 2.16 | 2,824.0 | 4,087 |
| Broadside collision | 154 | 2.6 | 7.8 | 186 | 1.21 | 307 | 1.99 | 516.9 | 3,356 |
| Sideswipe | 250 | 4.3 | 12.6 | 290 | 1.16 | 357 | 1.43 | 749.2 | 2,297 |
| Total multiple vehicle | 1,983 | 33.7 | 100.0 | 2,668 | 1.35 | 3,689 | 1.86 | 8,379.1 | 4,225 |

[1] Primarily vehicles that struck other objects on the road or nonmotor vehicles, and accidents in which occupants fell from vehicles.

head-on collisions caused by wrong-way drivers happened at night. Here again, there were no significant differences between the 2 years in day and time of occurrence.

## *Vehicles*

To assess the importance of different types of vehicles in these accidents, it was necessary to assign the primary responsibility for each accident to an individual vehicle (responsibility does not necessarily imply violations by the drivers involved). Although an element of judgment was involved, significant errors appeared minimal. In two-thirds of the accidents, only one moving vehicle was involved. (See table 1.) Eleven percent of the accidents were head-on collisions resulting from wrong-way drivers or out-of-control vehicles from opposing lanes—accidents in which there is little or no question of responsibility. Rear-end collisions are usually, but not always, the responsibility of the striking vehicle. In these accidents, as well as in broadside collisions and sideswipes, responsibility was assessed on the basis of the details of investigation reports, including the narratives, diagrams, notations of violations, and related data.

Estimates of annual vehicle-miles operated on the Interstate Highway System indicated that passenger vehicles accounted for approximately 80 percent of the travel, and property-carrying vehicles for the remainder. The percentage distribution of these two broad groups of vehicles with respect to primary responsibility of their drivers in all fatal accidents differed very little, with passenger vehicles slightly over-represented. There were, however, significant differences when the different types of accidents and individual types of vehicles were considered. These variations are apparent from the data shown in table 2.

**Table 2.—Fatal accidents on completed sections of the Interstate Highway System 1968–69—accident and vehicle types, and travel distribution.**

| Type of accident | Total accidents | Passenger vehicle | Property-carrying vehicles |  |  |  |
|---|---|---|---|---|---|---|
|  |  |  | Total | Tractor-trailer combinations | Panels and pickups | Single-unit trucks |
| Vehicle miles [1] percent | 100.0 | 79.7 | 20.3 | 10.2 | 6.8 | 3.3 |
| All accidents: |  |  |  |  |  |  |
| Number | 5,881 | 4,767 | 1,114 | 529 | 394 | 191 |
| Percent | 100.0 | 81.1 | 18.9 | 9.0 | 6.7 | 3.2 |
| Single vehicle: |  |  |  |  |  |  |
| Number | 3,898 | 3,243 | 655 | 286 | 250 | 119 |
| Percent | 100.0 | 83.2 | 16.8 | 7.3 | 6.4 | 3.1 |
| Ran off road: |  |  |  |  |  |  |
| Number | 3,078 | 2,647 | 431 | 197 | 181 | 53 |
| Percent | 100.0 | 86.0 | 14.0 | 6.4 | 5.9 | 1.7 |
| Collision with parked vehicle: |  |  |  |  |  |  |
| Number | 213 | 147 | 66 | 33 | 19 | 14 |
| Percent | 100.0 | 69.0 | 31.0 | 15.5 | 8.9 | 6.6 |
| Multiple vehicle: |  |  |  |  |  |  |
| Number | 1,983 | 1,524 | 459 | 243 | 144 | 72 |
| Percent | 100.0 | 76.9 | 23.1 | 12.2 | 7.3 | 3.6 |
| Rear-end collisions: |  |  |  |  |  |  |
| Number | 888 | 605 | 283 | 176 | 62 | 45 |
| Percent | 100.0 | 68.1 | 31.9 | 19.8 | 7.0 | 5.1 |
| Head-on collisions: |  |  |  |  |  |  |
| Number | 691 | 607 | 84 | 22 | 53 | 9 |
| Percent | 100.0 | 87.8 | 12.2 | 3.2 | 7.7 | 1.3 |
| Broadsides: |  |  |  |  |  |  |
| Number | 154 | 123 | 31 | 15 | 10 | 6 |
| Percent | 100.0 | 79.9 | 20.1 | 9.7 | 6.5 | 3.9 |
| Sideswipes: |  |  |  |  |  |  |
| Number | 250 | 189 | 61 | 30 | 19 | 12 |
| Percent | 100.0 | 75.6 | 24.4 | 12.0 | 7.6 | 4.8 |

[1] Estimated by the Federal Highway Administration.

**Table 3.—Characteristics of single-vehicle, off-the-road fatal accidents on compl ed sections of the Interstate Highway System, 1968–69**

| Type of accident | Total |  | Vehicles leaving the road |  |  |  |
|---|---|---|---|---|---|---|
|  | Number | Percent | Left side of road |  | Right side of road |  |
|  |  |  | Number | Percent | Number | Percer |
| Total accidents, all types | 3,078 | 100.0 | 1,439 | 100.0 | 1,639 | 10 |
| Struck fixed object: |  |  |  |  |  |  |
| Total | 2,518 | 81.8 | 1,093 | 76.0 | 1,425 | 8 |
| Overturned | 1,081 | 35.1 | 489 | 34.0 | 592 | 3 |
| Overturned only | 544 | 17.7 | 338 | 23.5 | 206 | 1 |
| All overturns | 1,625 | 52.8 | 827 | 57.5 | 798 | 4 |
| Off the road only | 16 | 0.5 | 8 | 0.5 | 8 |  |

For example, passenger vehicles were i olved in nearly 86 percent of the single-v icle, off-the-road accidents, whereas prop-e y-carrying vehicles were responsible for o y 17 percent of these crashes. Property-c rying vehicles, however, were substan-t ly over-represented in collisions with p ked vehicles, in rear-end collisions, and i sideswipes. These relationships are par-t ularly significant with respect to tractor-t iler combinations and single-unit trucks. I vers of tractor-trailers were primarily r ponsible for 20 percent of the rear-end isions although such vehicles make up y about 10 percent of the traffic on the tem. However, they were involved in y 6.4 percent of the single-vehicle, ran-the-road crashes.

he pattern for light-trucks—panels and kups generally of ¾-ton capacity or less—forms more nearly to that for passenger icles. This is apparent in table 2, which cates that the involvement of these icles in the several types of accidents is sistent with their relative importance in total traffic on the system. This might be ected as these light vehicles closely mble passenger cars and presumably are rated less frequently by the professional ers commonly employed for driving vy commercial vehicles.

## *Vehicle Drivers*

### and sex of drivers

lore than four-fifths of the drivers pri-ily responsible for the accidents were males. A third of the drivers were 25 years of age or under as compared with an estimated 25 percent of all licensed drivers in this age group. Drivers under age 17 were involved in 1.5 percent of the fatal accidents and accounted for about 100 fatalities over the 2-year period.

Substantial differences were found, however, when the different types of accidents were considered. Nearly 40 percent of the drivers involved in ran-off-the-road accidents were 25 years old or younger. Drivers 65 years old or older were responsible for about 5 percent of the total accidents, but they caused nearly three times that proportion of the fatal head-on collisions that resulted from driving the wrong way on divided highways. The data in this category showed but minor differences between the 2 years.

**Table 4.—Fixed objects struck first in single-vehicle, off-the-road fatal accidents on completed sections of the Interstate Highway System, 1968–69**

| First object struck | Number | Percent |
|---|---|---|
| Total, all objects | 2, 518 | 100. 0 |
| Guardrail [1] | 778 | 30. 9 |
| Bridge or overpass | 460 | 18. 3 |
| Sign | 202 | 8. 0 |
| Embankment | 201 | 8. 0 |
| Curb | 146 | 5. 8 |
| Divider [2] | 138 | 5. 5 |
| Pole [3] | 130 | 5. 2 |
| Ditch or drain | 137 | 5. 4 |
| Culvert | 88 | 3. 5 |
| Fence [4] | 51 | 2. 0 |
| Tree | 48 | 1. 9 |
| Other | 139 | 5. 5 |

[1] Includes cable type.

[2] Includes rail, concrete, and chainlink.

[3] Principally light poles.

[4] Principally right-of-way fences.

### Condition of drivers

A fifth of the drivers in ran-off-the-road accidents and a fourth of the drivers who collided with parked vehicles were reported by investigators as being asleep.

Nearly a third of all the drivers whose condition as to sobriety was reported by investigators were listed as having been drinking. This factor, however, was not included in a fourth of the reports. Of the 293 drivers responsible for head-on collisions caused by wrongway driving, reports on the sobriety of 198 were available. Of these, 146, or 74 percent, were reported as having been drinking and 66, or 33 percent, were described as obviously intoxicated.

## *Single-Vehicle, Off-the-Road Accidents*

Fifty-two percent of the accidents studied involved vehicles that ran off the road (table 1). More than four-fifths of these subsequently struck a fixed object (table 3). Overturns occurred in nearly 53 percent of the ran-off-the-road crashes and two-thirds of them involved a fixed object.

Most frequently, guardrails were the first fixed object struck, bridge or overpass elements ranked second (see table 4). About two-fifths of the vehicles struck two or more fixed objects before stopping. When first impacts were guardrails, bridge or overpass elements were the second objects most frequently struck.

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Please direct your comments to the Managing Editor, PUBLIC ROADS Magazine, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C. 20591.

# Travel by Motor Vehicles in 1969

BY THE OFFICE OF HIGHWAY PLANNING

**Reported by W. JOHNSON PA**
**Highway Research Engi**
**Program Management Divi**

MOTOR vehicle travel in the United States in 1969 totaled 1 trillion, 71 billion vehicle-miles. This is equivalent to an average daily traffic (ADT) of 770 vehicles on each mile of the 3. 7 million miles of roads and streets in the Nation. To travel the 1. 071 trillion vehicle-miles, 87 million passenger cars, 2 million motorcycles, 364 thousand buses and 18 million trucks had to travel an average of 9, 969 miles and they had to consume 88 billion gallons of gasoline and diesel fuel at a rate of 821 gallons per vehicle. Total travel for 1970, based on information for the first 6 months of the year, is estimated at 1 trillion, 125 billion, a 5 percent increase over 1969.

National travel by motor vehicle type and related data have been reported in this journal for many years. But because travel estimates were not available by State and highway system—except in certain benchmark years like 1957, 1962, and 1965—the information was for national totals only, categorized for main rural roads, local rural roads, and urban streets. For two of the benchmark years, 1962 and 1965, the available travel estimates by State and highway system were reported respectively in vol. 33, No. 7, April 1965, and vol. 34, No. 12, February 1968. The information was published again for 1967 in vol. 35, No. 8, June 1969, when tabular information on mileage, travel, and accidents in the States—called table TA-1—began to become available annually, and for 1968 in vol. 36, No. 1, April 1970.

### *Definitions*

The term vehicle-miles and other tech terms used in this article are defined in following statements:

*Vehicle-miles.*—The term vehicle-miles fers to the amount of travel by one moto hicle traveling 1 mile and includes trave all highways and streets in the United St

*Trailer combinations.*—A trailer comb tion is a truck or truck tractor pulling o more trailers and/or a semitrailer.

*Vehicles registered.*—Vehicles registere fers to the total number of vehicles regis in a State in a calendar year or in a registr year if the registration year does not from the calendar year by more than 1 m

**Table 1.—Estimated motor-vehicle travel in the United States and related data for calendar year 1969** [1]
**[From table VM-1, Highway Statistics, 1969]**

| Vehicle type | Motor-vehicle travel | | | | | Number of vehicles registered | Average travel per vehicle | Motor-fuel consumption | | Aver trav per gall of fu consu |
|---|---|---|---|---|---|---|---|---|---|---|
| | Main rural roads | Local rural roads | All rural roads | Urban streets | Total | | | Total | Average per vehicle | |
| | *Million vehicle-miles* | *Million vehicle-miles* | *Million vehicle-miles* | *Million vehicle-miles* | *Million vehicle-miles* | *Thousand* | *Miles* | *Million gallons* | *Gallons* | *Mil gall* |
| Personal passenger vehicles: | | | | | | | | | | |
| Passenger cars [2] | | | | | 849, 633 | 86, 861 | 9, 782 | 62, 325 | 718 | 13. |
| Motorcycles [2] | | | | | 9, 225 | 2, 295 | 4, 020 | 123 | 54 | 75. |
| All personal passenger vehicles | 295, 194 | 97, 649 | 392, 843 | 466, 015 | 858, 858 | 89, 156 | 9, 633 | 62, 448 | 700 | 13. |
| Buses: | | | | | | | | | | |
| Commercial | 935 | 193 | 1, 128 | 1, 879 | 3, 007 | 90. 3 | 33, 300 | 657 | 7, 276 | 4. |
| School | 769 | 880 | 1, 649 | 381 | 2, 030 | 274. 0 | 7, 409 | 290 | 1, 058 | 7. |
| All buses | 1, 704 | 1, 073 | 2, 777 | 2, 260 | 5, 037 | 364. 3 | 13. 826 | 947 | 2, 600 | 5. |
| All passenger vehicles | 296, 898 | 98, 722 | 395, 620 | 468, 275 | 863, 895 | 89, 520 | 9, 650 | 63, 395 | 708 | 13. |
| Cargo vehicles: | | | | | | | | | | |
| Single-unit trucks | 74, 142 | 28, 172 | 102, 314 | 64, 927 | 167, 241 | 16, 942 | 9, 871 | 16, 528 | 976 | 10. |
| Trailer combinations | 26, 514 | 1, 580 | 28, 094 | 11, 345 | 39, 439 | 929 | 42, 453 | 8, 199 | 8, 826 | 4. |
| All trucks | 100, 656 | 29, 752 | 130, 408 | 76, 272 | 206, 680 | 17, 871 | 11, 565 | 24, 727 | 1, 384 | 8. |
| All motor vehicles | 397, 554 | 128, 474 | 526, 028 | 544, 547 | 1, 070, 575 | 107, 391 | 9, 969 | 88, 122 | 821 | 12. |

[1] For the 50 States and District of Columbia.
[2] Separate estimates of passenger car and motorcycle travel are not available by highway category.

(Millions)

| DIVISION | STATE | FEDERAL-AID HIGHWAY SYSTEMS | | | | | | | | | | | | | | | | | | NOT ON FEDERAL-AID SYSTEMS | | | | ALL SYSTEMS | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | INTERSTATE | | | | | | | OTHER PRIMARY | | | SECONDARY | | | | | ALL FEDERAL AID | | | OTHER STATE RURAL | OTHER STATE URBAN AND MUNICIPAL | LOCAL RURAL | LOCAL URBAN AND MUNICIPAL | RURAL | URBAN | TOTAL |
| | | RURAL | | | URBAN | | | TOTAL | RURAL | URBAN | TOTAL | STATE | | LOCAL | | TOTAL | RURAL | URBAN | TOTAL | | | | | | | |
| | | FINAL 01 | TRAVELED WAY 1/ 31 | TOTAL | FINAL 02 | TRAVELED WAY 1/ 32 | TOTAL | | 03 | 04 | | RURAL 05 | URBAN 06 | RURAL 07 | URBAN 08 | | | | | 09 | 10 | 11 | 12 | | | |
| New England | Connecticut | 620 | 236 | 856 | 2,057 | 431 | 2,488 | 3,344 | 1,179 | 1,795 | 2,974 | 937 | 813 | 6 | 47 | 1,803 | 2,978 | 5,143 | 8,121 | 243 | 1,806 | 277 | 5,257 | 3,498 | 12,206 | 15,704 |
| | Maine | 572 | 49 | 621 | 69 | 74 | 143 | 764 | 1,437 | 468 | 1,905 | 891 | 147 | | - | 1,038 | 2,949 | 758 | 3,707 | 945 | 323 | 370 | 439 | 4,264 | 1.520 | 5.784 |
| | Massachusetts | 1,478 | 94 | 1,572 | 1,851 | 878 | 2,729 | 4,301 | 2,855 | 4,915 | 7,770 | 687 | 589 | 1,194 | 1,473 | 3,943 | 6,308 | 9,706 | 16,014 | 163 | 989 | 795 | 7.420 | 7,266 | 18.115 | 25.381 |
| | New Hampshire | 485 | 56 | 541 | 75 | 49 | 124 | 665 | 1,139 | 314 | 1,453 | 774 | 145 | 4 | 2 | 925 | 2,458 | 585 | 3,043 | 160 | 205 | 130 | 525 | 2,748 | 1,315 | 4.063 |
| | Rhode Island | 134 | 102 | 236 | 667 | 181 | 848 | 1,084 | 222 | 1,206 | 1,428 | 174 | 416 | 16 | 203 | 809 | 648 | 2,673 | 3,321 | 77 | 115 | 121 | 874 | 846 | 3,662 | 4,508 |
| | Vermont | 308 | 144 | 452 | 41 | 52 | 93 | 545 | 818 | 162 | 980 | 385 | 8 | 142 | 11 | 546 | 1,797 | 274 | 2,071 | 48 | 2 | 207 | 227 | 2,052 | 503 | 2,555 |
| | Total | 3,597 | 681 | 4,278 | 4,760 | 1,665 | 6,425 | 10,703 | 7,650 | 8,860 | 16,510 | 3,848 | 2,118 | 1,362 | 1,736 | 9,064 | 17,138 | 19,139 | 36,277 | 1,636 | 3,440 | 1,900 | 14,742 | 20,674 | 37.321 | 57,995 |
| Middle Atlantic | New Jersey | 352 | 325 | 677 | 1,964 | 1,971 | 3,935 | 4,612 | 2,679 | 5,899 | 8,578 | 39 | 106 | 1,396 | 2,394 | 3,935 | 4,791 | 12,334 | 17,125 | 1,785 | 2,369 | 4,584 | 13,253 | 11,160 | 27,956 | 39,116 |
| | New York | 2,959 | 178 | 3,137 | 7,282 | 1,052 | 8,334 | 11,471 | 8,185 | 14,892 | 23,077 | 1,695 | 1,026 | 2,940 | 1,390 | 7,051 | 15,957 | 25,642 | 41,599 | 23 | 29 | 7,979 | 15,045 | 23,959 | 40,716 | 64,675 |
| | Pennsylvania | 4,903 | 645 | 5,548 | 1,738 | 827 | 2,565 | 8,113 | 8,175 | 6,736 | 14,911 | 5,739 | 3,638 | 48 | 97 | 9,522 | 19,510 | 13,036 | 32,546 | 3,250 | 4,279 | 4.046 | 11,027 | 26.806 | 28.342 | 55.148 |
| | Total | 8,214 | 1,148 | 9,362 | 10,984 | 3,850 | 14,834 | 24,196 | 19,039 | 27,527 | 46,566 | 7,473 | 4,770 | 4,384 | 3,881 | 20,508 | 40,258 | 51,012 | 91,270 | 5,058 | 6,677 | 16,609 | 39,325 | 61,925 | 97,014 | 158.939 |
| South Atlantic (north) | Delaware | 61 | - | 61 | 200 | 75 | 275 | 336 | 975 | 708 | 1,683 | 355 | 214 | - | - | 569 | 1,391 | 1,197 | 2,588 | - | - | 96 | 183 | 1,487 | 1,380 | 2,867 |
| | Dist. of Col. | - | - | - | 213 | 176 | 389 | 389 | - | 1,057 | 1,057 | - | - | - | 506 | 506 | - | 1,952 | 1,952 | - | - | - | 833 | - | 2.785 | 2,785 |
| | Maryland | 1,152 | 44 | 1,196 | 2,003 | 642 | 2,645 | 3,841 | 2,781 | 2,676 | 5,457 | 1,572 | 1,378 | 463 | 444 | 3,857 | 6,012 | 7,143 | 13,155 | 681 | 91 | 3,215 | 2,355 | 9,908 | 9,589 | 19,497 |
| | Virginia | 3,176 | 854 | 4,030 | 973 | 522 | 1,495 | 5,525 | 5,337 | 2,838 | 8,175 | 3,322 | 807 | 2,169 | 523 | 6,821 | 14,858 | 5,663 | 20,521 | 118 | 576 | 2,010 | 3,726 | 16,986 | 9,965 | 26,951 |
| | West Virginia | 548 | 435 | 983 | 105 | 176 | 281 | 1,264 | 2,154 | 801 | 2,955 | 1,868 | 177 | 889 | 32 | 2,966 | 5,894 | 1,291 | 7,185 | 7 | 24 | 307 | 1,190 | 6,208 | 2,505 | 8,713 |
| | Total | 4,937 | 1,333 | 6,270 | 3,494 | 1,591 | 5,085 | 11,355 | 11,247 | 8,080 | 19,327 | 7,117 | 2,576 | 3,521 | 1,505 | 14,719 | 28,155 | 17,246 | 45,401 | 806 | 691 | 5,628 | 8,287 | 34,589 | 26,224 | 60,813 |
| South Atlantic (south) | Florida | 2,063 | 1,132 | 3,195 | 1,608 | 1,178 | 2,786 | 5,981 | 4,913 | 3,740 | 8,653 | 4,723 | 3,097 | 240 | 30 | 8,090 | 13,071 | 9,653 | 22,724 | 1,486 | 1,622 | 2,277 | 9,486 | 16,834 | 20,761 | 37,595 |
| | Georgia | 2,436 | 1,102 | 3,538 | 1,941 | 184 | 2,125 | 5,663 | 6,325 | 2,259 | 8,584 | 2,785 | 547 | 1,366 | 512 | 5,210 | 14,014 | 5,443 | 19,457 | 153 | 334 | 1,976 | 6,390 | 16,143 | 12,167 | 28,310 |
| | North Carolina | 1,593 | 1,256 | 2,849 | 445 | 418 | 863 | 3,712 | 4,684 | 2,140 | 6,824 | 9,541 | 2,526 | 3 | 195 | 12,265 | 17,077 | 5,724 | 22,801 | 1,896 | 588 | 33 | 2,498 | 19,006 | 8,810 | 27,816 |
| | South Carolina | 1,223 | 617 | 1,840 | 134 | 208 | 342 | 2,182 | 5,159 | 1,638 | 6,797 | 3,075 | 720 | 181 | 10 | 3,986 | 10,255 | 2,710 | 12,965 | 369 | 1,241 | 465 | 472 | 11.089 | 4.423 | 15,512 |
| | Total | 7,315 | 4,107 | 11,422 | 4,128 | 1,988 | 6,116 | 17,538 | 21,081 | 9,777 | 30,858 | 20,124 | 6,890 | 1,790 | 747 | 29,551 | 54,417 | 23,530 | 77,947 | 3,904 | 3,785 | 4,751 | 18,846 | 63,072 | 46,161 | 109,233 |
| East North Central | Illinois | 2,786 | 1,362 | 4,148 | 5,133 | 612 | 5,745 | 9,893 | 8,501 | 7,817 | 16,318 | 1,131 | 668 | 2,063 | 544 | 4,406 | 15,843 | 14,774 | 30,617 | 1,540 | 3,696 | 2,828 | 15,192 | 20,211 | 33,662 | 53,873 |
| | Indiana | 2,538 | 1,304 | 3,842 | 1,460 | 355 | 1,815 | 5,657 | 8,231 | 2,375 | 10,606 | 3,491 | 633 | 1,521 | 207 | 5,852 | 17,085 | 5,030 | 22,115 | 190 | 139 | 1,423 | 6,750 | 18,698 | 11,919 | 30,617 |
| | Michigan | 3,411 | 321 | 3,732 | 3,614 | 1,445 | 5,059 | 8,791 | 6,918 | 6,791 | 13,709 | 1,802 | 499 | 7,122 | 1,313 | 10,736 | 19,574 | 13,662 | 33,236 | 20 | 72 | 4,174 | 13,403 | 23,768 | 27,137 | 50,905 |
| | Ohio | 4,852 | 108 | 4,960 | 5,089 | 1,307 | 6,396 | 11,356 | 8,207 | 6,360 | 14,567 | 4,331 | 1,863 | 2,285 | 2,398 | 10,877 | 19,783 | 17,017 | 36,800 | 108 | 426 | 5,112 | 13,375 | 25,003 | 30,818 | 55,821 |
| | Wisconsin | 1,766 | 128 | 1,894 | 797 | 202 | 999 | 2,893 | 5,726 | 2,762 | 8,488 | 1,663 | 554 | 1,692 | 992 | 4,901 | 10,975 | 5,307 | 16,282 | 52 | 71 | 1,574 | 5,906 | 12,601 | 11,284 | 23,885 |
| | Total | 15,353 | 3,223 | 18,576 | 16,093 | 3,921 | 20,014 | 38,590 | 37,583 | 26,105 | 63,688 | 12,418 | 4,217 | 14,683 | 5,454 | 36,772 | 83,260 | 55,790 | 139,050 | 1,910 | 4,404 | 15,111 | 54,626 | 100,281 | 114,820 | 215,101 |
| West North Central | Iowa | 1,659 | 175 | 1,834 | 371 | 35 | 406 | 2,240 | 5,329 | 1,529 | 6,858 | - | - | 1,987 | 280 | 2,267 | 9,150 | 2,215 | 11,365 | 95 | 63 | 972 | 2,931 | 10,217 | 5,209 | 15,426 |
| | Kansas | 1,033 | 169 | 1,202 | 476 | 59 | 535 | 1,737 | 3,729 | 1,149 | 4,878 | 571 | 28 | 1,329 | 435 | 2,363 | 6,831 | 2,147 | 8,978 | 69 | 59 | 1,077 | 2,817 | 7,977 | 5,023 | 13,000 |
| | Minnesota | 568 | 484 | 1,052 | 1,264 | 769 | 2,033 | 3,085 | 5,576 | 2,375 | 7,951 | 1,172 | 37 | 2,921 | 181 | 4,311 | 10,721 | 4,626 | 15,347 | 27 | 117 | 1,252 | 4,050 | 12,000 | 8,793 | 20,793 |
| | Missouri | 2,433 | 747 | 3,180 | 1,813 | 412 | 2,225 | 5,405 | 5,923 | 2,187 | 8,110 | 2,510 | 450 | 20 | 38 | 3,018 | 11,633 | 4,900 | 16,533 | 170 | 717 | 1,850 | 6,190 | 13,653 | 11,807 | 25,460 |
| | Nebraska | 977 | 110 | 1,087 | 102 | 22 | 124 | 1,211 | 3,078 | 646 | 3,724 | 653 | 33 | 640 | 81 | 1,407 | 5,458 | 884 | 6,342 | 4 | - | 994 | 1.860 | 6,456 | 2.744 | 9,200 |
| | North Dakota | 378 | 114 | 492 | 14 | 23 | 37 | 529 | 1,126 | 174 | 1,300 | 213 | 5 | 453 | 14 | 685 | 2,284 | 230 | 2,514 | 1 | 2 | 686 | 451 | 2,971 | 683 | 3,654 |
| | South Dakota | 444 | 298 | 742 | 22 | 13 | 35 | 777 | 1,579 | 238 | 1,817 | 247 | 30 | 447 | 29 | 753 | 3,015 | 332 | 3,347 | 22 | 7 | 587 | 398 | 3,624 | 737 | 4,361 |
| | Total | 7,492 | 2,097 | 9,589 | 4,062 | 1,333 | 5,395 | 14,984 | 26,340 | 8,298 | 34,638 | 5,366 | 583 | 7,797 | 1,058 | 14,804 | 49,092 | 15,334 | 64,426 | 388 | 965 | 7,418 | 18,697 | 56,898 | 34,996 | 91,894 |
| East South Central | Alabama | 657 | 1,173 | 1,830 | 180 | 1,236 | 1,416 | 3,246 | 4,590 | 1,976 | 6,566 | 1,440 | 344 | 941 | 156 | 2,881 | 8,801 | 3,892 | 12,693 | 41 | 53 | 888 | 3.355 | 9,730 | 7,300 | 17,030 |
| | Kentucky | 1,934 | 269 | 2.203 | 718 | 347 | 1,065 | 3,268 | 4.352 | 1,551 | 5.903 | 3,762 | 539 | 230 | 61 | 4,592 | 10,547 | 3,216 | 13,763 | 1,192 | 716 | 1,135 | 2,065 | 12.874 | 5.997 | 18.871 |
| | Mississippi | 928 | 297 | 1,225 | 194 | 425 | 619 | 1,844 | 4,015 | 758 | 4,773 | 915 | 95 | 1,166 | 217 | 2,393 | 7,321 | 1,689 | 9,010 | 16 | 20 | 642 | 1,497 | 7,979 | 3,206 | 11,185 |
| | Tennessee | 1,638 | 751 | 2,389 | 1,257 | 408 | 1,665 | 4,054 | 4,945 | 2,443 | 7,388 | 968 | 235 | 669 | 81 | 1,953 | 8,971 | 4,424 | 13,395 | 50 | 7 | 1,845 | 3,939 | 10,866 | 8,370 | 19,236 |
| | Total | 5,157 | 2,490 | 7,647 | 2,349 | 2,416 | 4,765 | 12,412 | 17,902 | 6,728 | 24,630 | 7,085 | 1,213 | 3,006 | 515 | 11,819 | 35,640 | 13,221 | 48,861 | 1,299 | 796 | 4,510 | 10,856 | 41,449 | 24,873 | 66,322 |
| West South Central | Arkansas | 1,038 | 167 | 1,205 | 345 | 13 | 358 | 1,563 | 2,840 | 1,081 | 3,921 | 2,318 | 379 | 271 | 73 | 3,041 | 6,634 | 1,891 | 8,525 | 49 | 74 | 756 | 1,475 | 7,439 | 3,440 | 10,879 |
| | Louisiana | 811 | 1,068 | 1,879 | 747 | 337 | 1,084 | 2,963 | 2,703 | 1,622 | 4,325 | 3,698 | 608 | 12 | 1 | 4,319 | 8,292 | 3,315 | 11,607 | 762 | 421 | 1,022 | 2,360 | 10,076 | 6,096 | 16,172 |
| | Oklahoma | 1,307 | 328 | 1,635 | 1,002 | 44 | 1,046 | 2,681 | 4,708 | 1,572 | 6,280 | 1,141 | 353 | 778 | 302 | 2,574 | 8,262 | 3,273 | 11,535 | 219 | 94 | 995 | 3,994 | 9,476 | 7,361 | 16,837 |
| | Texas | 3,935 | 1,622 | 5,557 | 7,482 | 1,334 | 8,816 | 14,373 | 12,661 | 8,239 | 20,900 | 8,339 | 2,454 | - | - | 10,793 | 26,557 | 19,509 | 46,066 | 1,502 | 1,111 | 2,495 | 14,901 | 30,554 | 35,521 | 66,075 |
| | Total | 7,091 | 3,185 | 10,276 | 9,576 | 1,728 | 11,304 | 21,580 | 22,912 | 12,514 | 35,426 | 15,496 | 3,794 | 1,061 | 376 | 20,727 | 49,745 | 27,988 | 77,733 | 2,532 | 1,700 | 5,268 | 22,730 | 57,545 | 52,418 | 109,963 |
| Mountain | Arizona | 1,365 | 1,236 | 2,601 | 472 | 186 | 658 | 3,259 | 1,119 | 537 | 1,656 | 583 | 55 | 790 | 2,298 | 3,726 | 5,093 | 3,548 | 8,641 | 223 | 14 | 689 | 1,938 | 6,005 | 5,500 | 11,505 |
| | Colorado | 1,058 | 576 | 1,634 | 747 | 197 | 944 | 2.578 | 2,055 | 1,703 | 3,758 | 1,508 | 206 | - | - | 1,714 | 5,197 | 2,853 | 8,050 | 22 | 33 | 1,489 | 2,898 | 6,708 | 5,784 | 12,492 |
| | Idaho | 559 | 261 | 820 | 49 | 14 | 63 | 883 | 1,240 | 283 | 1,523 | 369 | 25 | 326 | 126 | 846 | 2,755 | 497 | 3,252 | 3 | 3 | 652 | 487 | 3,410 | 987 | 4,397 |
| | Montana | 282 | 546 | 828 | 33 | 14 | 47 | 875 | 1,472 | 262 | 1,734 | 430 | 59 | - | - | 489 | 2,730 | 368 | 3,098 | - | - | 808 | 533 | 3,538 | 901 | 4,439 |
| | Nevada | 491 | 191 | 682 | 29 | 81 | 110 | 792 | 628 | 252 | 880 | 286 | 68 | 95 | 189 | 638 | 1,691 | 619 | 2,310 | 20 | 20 | 100 | 645 | 1,811 | 1,284 | 3,095 |
| | New Mexico | 1,110 | 463 | 1,573 | 223 | 182 | 405 | 1,978 | 1,481 | 630 | 2,111 | 895 | 153 | 7 | 2 | 1,057 | 3,956 | 1,190 | 5,146 | 86 | 497 | 424 | 782 | 4,466 | 2,469 | 6,935 |
| | Utah | 584 | 583 | 1,167 | 655 | 53 | 708 | 1,875 | 883 | 573 | 1,456 | 530 | 442 | 106 | 139 | 1,217 | 2,686 | 1,862 | 4,548 | 36 | 148 | 411 | 659 | 3,133 | 2,669 | 5,802 |
| | Wyoming | 606 | 242 | 848 | 21 | 18 | 39 | 887 | 906 | 129 | 1,035 | 252 | 19 | 17 | 8 | 296 | 2,023 | 195 | 2,218 | 2 | 3 | 341 | 338 | 2,366 | 536 | 2,902 |
| | Total | 6,055 | 4,098 | 10,153 | 2,229 | 745 | 2,974 | 13,127 | 9,784 | 4,369 | 14,153 | 4,853 | 1,027 | 1,341 | 2,762 | 9,983 | 26,131 | 11,132 | 37,263 | 392 | 718 | 4,914 | 8,280 | 31,437 | 20,130 | 51,567 |
| Pacific | California | 4,341 | 4,542 | 8,883 | 12,239 | 4,505 | 16,744 | 25,627 | 10,970 | 15,734 | 26,704 | 2,501 | 968 | 4,650 | 5,200 | 13,319 | 27,004 | 38,646 | 65,650 | 412 | 1,030 | 11,610 | 33,042 | 39,026 | 72,718 | 111,744 |
| | Oregon | 1,476 | 101 | 1,577 | 863 | 35 | 898 | 2,475 | 2,348 | 1,440 | 3,788 | 1,112 | 347 | 815 | 524 | 2,798 | 5,852 | 3,209 | 9,061 | 37 | 27 | 1,502 | 2,072 | 7,391 | 5,308 | 12,699 |
| | Washington | 1,062 | 791 | 1,853 | 1,824 | 398 | 2,222 | 4,075 | 2,496 | 1,572 | 4,068 | 1,061 | 583 | 1,617 | 1,082 | 4,343 | 7,027 | 5,459 | 12,486 | 18 | 151 | 2,865 | 4,469 | 9,910 | 10,079 | 19,989 |
| | Total | 6,879 | 5,434 | 12,313 | 14,926 | 4,938 | 19,864 | 32,177 | 15,814 | 18,746 | 34,560 | 4,674 | 1,898 | 7,082 | 6,806 | 20,460 | 39,883 | 47,314 | 87,197 | 467 | 1,208 | 15,977 | 39,583 | 56,327 | 88,105 | 144,432 |
| Total - All Divisions | | 72,090 | 27,796 | 99,886 | 72,601 | 24,175 | 96,776 | 196,662 | 189,352 | 131,004 | 320,356 | 88,454 | 29,086 | 46,027 | 24,840 | 188,407 | 423,719 | 281,706 | 705,425 | 18,392 | 24,384 | 82,086 | 235,972 | 524,197 | 542,062 | 1,066,259 |
| | Alaska | - | - | - | - | - | - | - | 356 | 110 | 466 | 137 | 49 | - | - | 186 | 493 | 159 | 652 | - | - | 169 | 331 | 662 | 490 | 1,152 |
| | Hawaii | 51 | 124 | 175 | 203 | 227 | 430 | 605 | 643 | 435 | 1,078 | 148 | 49 | 44 | 32 | 273 | 1,010 | 946 | 1,956 | 11 | * | 148 | 1,049 | 1,169 | 1,995 | 3,164 |
| United States Total | | 72,141 | 27,920 | 100,061 | 72,804 | 24,402 | 97,206 | 197,267 | 190,351 | 131,549 | 321,900 | 88,739 | 29,184 | 46,071 | 24,872 | 188,866 | 425,222 | 282,811 | 708,033 | 18,403 | 24,384 | 82,403 | 237,352 | 526,028 | 544,547 | 1,070,575 |

1/ Traveled-way includes travel on highways in the Interstate System status of completion group 2. This group consists of mileage which is adequate for present traffic but will need further construction and improvement to bring it to full Interstate standards. In some instances these are divided highways with full control of access and in others they are two, three or four-lane undivided highways with no access control.

* Less than 0.5 million vehicle-miles.

Note: For this table travel on frontage roads has been placed in systems 11 and 12. The numerical codes which are shown above for all 14 administrative highway systems are used for identification purposes in analyses of travel, mileage, and accident data based on these systems.

*Motor-fuel consumption.*—Motor-fuel consumption is the total consumption of motor fuel by highway vehicles for the year. The total amounts are obtained from State records and adjusted to remove fuel consumed for farm and other nonhighway uses.

*Motor-fuel-consumption rate.*—Motor-fuel-consumption rate is the average rate of motor-fuel usage in miles per gallon (m.p.g.).

*Annual miles per vehicle.*—Annual miles per vehicle is an average figure obtained by dividing the total travel in annual vehicle-miles by the total number of vehicles registered.

*Gallons per vehicle.*—Gallons per vehicle is a figure obtained by dividing the fuel consumed by the vehicles registered.

*Interstate System traveled way.*—The traveled way of the Interstate Highway System consists of completed sections plus those roads and streets now carring traffic that will be served by the Interstate System when it is completed.

### *Travel*

The travel and related data for 1969 are shown in table 1 by road system and vehicle type. Travel estimates by State and highway system, which are the estimates prepared by the State highway departments, are shown in table 2.

In 1969, 37.1 percent of the travel was on main rural roads, which comprise 17 percent of the Nation's total of 3.7 million miles of roads and streets. Urban street travel was 50.9 percent of the total travel and 14 percent of the total mileage. Local rural roads, approximately 69 percent of the total mileage, carried 12.0 percent of the travel.

The Interstate System traveled way accounted for about 1 percent of the total mileage and carried 18.4 percent of the travel. The Federal-aid primary system, including Interstate, represented about 7 percent of the mileage and carried 48.5 percent of the travel. All Federal-aid systems combined, which includes 24 percent of the mileage, carried 66 percent of all travel.

Ten States reported 1969 travel in excess of 30 billion annual vehicle-miles—more than half of all the Nation's travel. California, far exceeding any other State, had 111.7 billion vehicle-miles; Texas, 66.1 billion; New York, 64.7 billion; Ohio, 55.8 billion; Pennsylvania, 55.1 billion; Illinois, 53.9 billion; Michigan, 50.9 billion; New Jersey, 39.1 billion; Florida, 37.6 billion; and Indiana, 30.6 billion. When the travel in seven additional States, which reported travel exceeding 20 billion vehicle-miles, is added to that of these 10 States, approximately 70 percent of the Nation's travel is accounted for.

Passenger cars constituted 81 percent of all vehicles registered in 1969 and accounted for 79 percent of all travel; motorcycles, 2 percent of all vehicles and less than 1 percent of all travel; trucks and truck combinations, 17 percent of all vehicles and 19 percent of all travel; similiar figures for buses were less than 1 percent.

In vehicle performance, annual miles per vehicle rose from 9,847 in 1968 to 9,969 in 1969. Gallons of fuel consumed per vehicle continued the sharp rising trend that began in 19— from 804 in 1968 to 821 in 1969. Miles traveled per gallon of fuel consumed, which began dropping in 1967 after several years of relative stability, dropped again from 12.25 in 1968 to 12.15 in 1969.

The decreases in miles traveled per gallon are attributed primarily to passenger cars as they represent most of the travel. Further decreases in miles per gallon are expected as more and more cars having pollution control devices are introduced into the automobile population, and as stricter pollution control requirements are implemented. The use of low-lead gasolines and the lower compression engines required by these fuels will reduce engine efficiency and thereby reduce miles per gallon. If the American mini cars take a significant part of the market, the higher miles per gallon for these cars may moderate the downward trend. It is too early to determine, however, what effect these vehicles will have.

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

*The following highway research and development reports are available from the National Technical Information Service (formerly the Clearinghouse for Federal Scientific and Technical Information), Sills Building, 5285 Port Royal Road, Springfield, Va. 22151. Paper copies are priced at $3 each and microfiche copies at 95 cents each. To order, send the stock number of each report desired and a check or money order to the National Technical Information Service. Prepayment is required.*

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

| *Stock No.* | |
|---|---|
| PB 194263 | Adaptation of the AASHO Pavement Design Guides to Oklahoma Highways. |
| PB 194279 | Consolidation Characteristics of a Varved Clay. |
| PB 194330 | Experimental Bituminous Concrete Pavement Study, I–95 Groton—Report 2, Analysis of Various Data Obtained During and After Construction. |
| PB 194332 | Asphalt Content Studies by the Nuclear Method. |
| PB 194333 | Evaluation of Bituminous Compaction Procedures Using Nuclear Gauges. |
| PB 194334 | Phase B: Deflection Study Evaluation of Pavement Design in Virginia Based on Layer Deflections, Subgrade and Its Moisture Content. |
| PB 194392 | Tensile Lap Splices Part I: Retaining Wall Type Varying Moment Zone. |
| PB 194393 | A Profile Measuring, Recording, and Processing System. |
| PB 194397 | Statistical Specification for Pug Mill Mix Materials. |
| PB 194475 | Computer Programs for Bridge Deck Analysis. |
| PB 194658 | Traffic Systems Reviews and Abstracts, July issue, 1970. |
| PB 194659 | Passage of Anadromous Fish Through Highway Drainage Structures. |
| PB 194690 | Highway Investment and Regional Economic Effects. |
| PB 194704 | The Properties and Recognition of Deleterious Charts. |
| PB 194706 | Traffic Systems Reviews and Abstracts, August issue, 1970. |
| PB 194707 | Traffic Systems Reviews and Abstracts, September issue, 1970. |
| PB 194709 | Evaluation of a Flexible Pavement in Illinois. |
| PB 194718 | Pavement Deflection Measurement—Dynamic—A Feasibility Study. |
| PB 194719 | Materials Development and Utilization. |
| PB 194720 | Determination of Statistical Parameters for Highway Construction—Continuation II. |
| PB 194721 | Pavement Marking Paints: Two Studies (Replaces PB 186485). |
| PB 194722 | Gap-Graded Versus Continuously-Graded Shrinkage Compensating Concrete. |
| PB 194817 | Hydraulic Investigation of Soil Erosion and Sedimentation in Highway Median and Side Ditches. |
| PB 194884 | In-Service Experience on Installation of Texas Modular Crash Cushions. |
| PB 194885 | Evaluation of Several Types of Curing and Protective Materials for Concrete. |
| PB 194890 | Field Investigation of a continuous composite Prestressed I-Beam Highway Bridge Located in Jefferson County, Ill. |
| PB 194891 | Traffic Systems Reviews and Abstracts Cumulative Indexes. |
| PB 194892 | Trends of Pavement Characteristics During 12 Months of a Designed Experiment. |
| PB 194893 | Sensitivity Analysis of the Evaluation of a Bus Transit System in a Selected Urban Area. |
| PB 194894 | On the Development of a Freeway Driver Information System. |
| PB 194896 | A Comparison Between Selected Traffic Information Devices. |
| PB 194897 | Time Dependent Deformation Characteristics of Compacted Cohesive Soils. |
| PB 194899 | Evaluation and Prediction of the Tensile Properties of Lime-Treated Materials. |
| PB 194908 | The Use of Diagrams in Highway Route Location: An Experiment. |
| PB 194909 | A Thermoviscoelastic Characterization of an Asphaltic Concrete. |
| PB 193910 | Prediction of Moisture Movement in Expansive Clays. |
| PB 194911 | Prediction of Subjective Response to Road Roughness Using the General Motors—Michigan Department of State Highways Rapid Travel Profilometer. |
| PB 194933 | Use of a Rumble Stripe to Reduce Maintenance and Increase Driving Safety. |

# IGEST OF RECENT RESEARCH AND DEVELOPMENT RESULTS

**eported by the Implementation Division, Office of Development**

*The items reported here have been condensed from highway research and evelopment reports, predominately of Federally aided studies. Not neces- rily endorsed or approved by the Federal Highway Administration, the ems have been selected both for their relevancy to highway problems and r their potential for early and effective application.*

*Each item is followed by source or reference information. Reports with an NTIS" reference number are available in microfiche (microfilm) at 95 nts each or in paper facsimile at $3 each from the National Technical formation Service (NTIS), 5285 Port Royal Road, Springfield, Va. 22151.*

## LECTRONIC MOVING LOAD SCALES

A portable electronic scale platform about 2 inches thick by 54 by inches has been developed and shows promise for weighing moving hicles. The field data recorded in analog form on magnetic tape can converted to digital form, yielding speed and length of vehicle, time day, number of axles, axle spacing, wheel weights, and vehicle classi- ation. Indications are that gross weights of many of the vehicles may obtained within 10 percent of the static vehicle weight, provided propriate adjustment factors are applied to the recorded data. Further search is underway to evaluate more definitely the relationship tween dynamic weighing and static weighing.

*A Portable Electronic Scale for Weighing Vehicles in Motion,* 1968, Texas High- y Department, Report No. 54-1F. NTIS No. PB-180364.

## ARTHWORK CROSS SECTIONS BY PHOTOGRAMMETRY

Earthwork cross-section data for cut volumes obtained photogram- etrically has been found to be sufficiently accurate for highway design d for pay quantities. Percent differences in volume between carefully tained ground cross sections and photogrammetrically determined lumes ranged from 1 percent up to 11 percent, depending on whether e topography was rolling to rough or flat, respectively.

*Determination of Accuracies in Earthwork Quantities From Photogrammetrically ade Survey,* May 1968, Texas Highway Department, Report No. 38. NTIS No. -179585.

## KID-RESISTANCE INDEX FOR SEAL COAT SCREENINGS

A simple and satisfactory test method has been devised for determin- g in the laboratory the original coefficent of friction of seal coat screen- gs applied to asphalt concrete pavements. The method measures the gularity and surface roughness of screenings and shows good correla- n with actual service performance which is dependent on resistance reduction in the friction factor as a result of wear and polish by traffic. screening samples experienced a rapid decrease in their initial coeffi- ent of friction and thereafter attained an equilibrium figure for a stained period of service equivalence. Information is for an interim port.

*kid Resistance of Screenings of Seal Coats,* January 1968, California Division Highways, Report No. B-3-1. NTIS No. PB-178085.

## VEMENT SERVICEABILITY INDEXES

omparative tests of the *CHLOE Profilometer* and the *California Pro- graph* show that both instrument systems gave satisfactory results the obtaining of longitudinal profile data for a serviceability index. n sections of pavement were involved, including both asphaltic and tland cement concrete, varying from excellent to poor condition. Both systems were modified electronically to facilitate accumulation of data for evaluation by statistical methods.

*A Comparison of the Chloe Profilometer and the California Profilograph,* November 1967, California Division of Highways, Report No. D-4-17, NTIS No. PB-178086.

## STABILIZED SOIL BASE COURSES

Under the particular circumstances encountered on one study, a savings of about $1 per square yard was indicated from use of chemical soil stabilization in lieu of crushed aggregate base course. Pavement performance and the results of evaluation tests indicate that for the plastic soil encountered, 6 inches of stabilized select soil subbase was equivalent to 8 inches of crushed aggregate. Satisfactory stabilization was obtained with the following chemical additives: (1) Five percent lime, (2) 5 percent of a proprietary material produced by the Product Development Co., or (3) 2½ percent lime plus 2½ percent cement.

*Chemical Soil Subbase Stabilization,* March 1968, West Virginia Department of Highways, Report No. 17.

## EROSION CONTROL FOR HIGHWAY DRAINAGE

A recent study of erosion control criteria for highway drainage channels provides the designer with a comprehensive design method to protect channels from excessive erosion both prior to and after establishment of a vegetative lining. Statistically derived equations and graphs express channel capacity for a variety of liner materials and test soils in relation to velocity, hydraulic radius, and slope. Comprehensive design examples are included.

*Erosion Control Criteria for Drainage Channels (Structures),* February 1968, Mississippi State Highway Department, Report No. 13. NTIS PB-178478.

## HIGH STRENGTH BOLTS FOR SHEAR CONNECTORS

An interim report of a study of composite bridge stringers reveals that tests using high strength bolts as shear connectors has demonstrated their suitability for this purpose. Since they can be installed in predrilled holes, they permit a smooth beam surface before erection where desirable for safety and transportation purposes. The study has also produced a design method for composite beams with haunches which eliminates overly conservative allowances on loads to shear connectors

*Composite Beam Tests Using High-Strength Bolts as Shear Connectors,* January 1968, Missouri State Highway Commission, Report No. 63-2. NTIS No. PB-180196.

## ORTHOTROPIC DECK PLATE BRIDGE-COMPUTER ANALYSIS

A report covering the analytical phase of a research study of an existing orthotropic deck plate bridge presents methods for studying different parts of such structures. Several important features of the structural action of orthotropic deck bridges are highlighted. The report appendix contains a description of the computer program used in the design and analysis of the bridge. A final report will be submitted on the field testing.

*Field Testing of an Orthotropic Steel Deck Plate Bridge,* March 1968, California Division of Highways, Report No. D-4-15. NTIS PB-178398.

## ACCURATE METHODS OF BOX GIRDER DESIGN

More accurate methods of box girder bridge design are presented in a report covering the analytical phase of a bridge design research study.

General computer programs have been developed for three methods of elastic analysis: (1) Folded plate, (2) finite segment, and (3) finite element. Analysis by these methods has been reduced to a simple matter of preparing basic input data on data processing cards. Appropriate comparison of results from the three methods was satisfactory.

*Analysis of Continuous Box Girder Bridges,* November 1967, California Division of Highways, Report No. D-4-31. NTIS No. PB-178355.

## STEEL PLATE PIPE SEAM STRENGTHS

Experimental laboratory tests performed on structural steel plate pipe specimens indicate no significant differences in ultimate seam strength between (1) Specimens coated with asphalt and those with hot-dip galvanized coating, and (2) specimens with bolt torque levels of 50 ft.-lbs. and 20 ft.-lbs.

*Seam Strength of Asphalt Coated Structural Plate Pipe,* 1968, California Division of Highways, Report No. D-4-70.

## RAISED TRAFFIC LANE MARKERS ARE SUPERIOR

A field test was recently completed on various pavement marking materials. Evaluation included relative long-term costs and traffic safety along with numerous other considerations. The site was on new concrete pavement in a snow-free area. The study concluded that in areas free from snowplow operations, raised markers were superior to standard paint in terms of durability, driver preference, and night visibility under wet conditions. This confirms results previously obtained in California.

*Semi-Permanent Traffic Striping Research Study,* 1968, Washington Department of Highways, Report No. HR-178. NTIS No. PB-180704.

## FASTER TEST PROCEDURE

A modified procedure for the sand equivalent test has been found satisfactory and results in considerable savings in testing time. Success of the procedure has resulted in recommendations to ASTM that it include alternate methods, moist or oven dried, in the test procedure. Key to the test time savings is use of moist materials. Also recommended in connection with the modified procedure was use of prescribed temperature limits.

*Sand Equivalent Test Investigation of Procedural Modifications,* 1968, California Division of Highways, Report No. F-4-14. NTIS No. PB-177887.

## IMPROVED CEMENT UNIFORMITY

In a test study of cement treated base mixing it was found that cement was more uniformly distributed in the mixed base course material when mixing was accomplished with an automatically controlled, continuously fed mixing plant rather than in a batch type pugmill. Specifications for cement control limits, based on the titration test, are proposed in accordance with a statistical analysis of variance which takes account of sampling and testing errors as well as process variance.

*Control of Cement Treated Base,* 1968, California Division of Highways, Report No. F-1-14. NTIS No. PB-198202.

## CHLORIDES AS STABILIZING AGENTS

A test road study was recently completed on several experimental sections of base and subbase courses of granular material treated with sodium and calcium chlorides as stabilizing agents. The study indicated that the two chlorides are of little or no benefit as stabilizing agents for aggregate base course materials. The chlorides began to migrate out of the granular layers a few months after construction.

*Investigation 607, Nobles County Base,* 1967, Minnesota Department of Highways, Report No. 303. NTIS No. PB-177744.

## RAPID TEST METHOD FOR HYDROMETER ANALYSIS OF SOILS

Evaluation of a rapid hydrometer analysis technique for the quantitative determination of the distribution of particle sizes in soils indicates good correlation with results from the standard method of test. The rapid test method, with a time savings of 1½ days, will aid greater production efficiency for the contractor, and facilitate economies in field and laboratory testing operations.

*Correlation of Rapid Hydrometer Analysis for Select Material to Existing Procedure,* 1968, Louisiana Department of Highways, Report No. 67-18. NTIS No. [illegible]-179590.

## GREATER SERVICE LIFE FOR GUARDRAIL POSTS

Longitudinal saw cuts or kerfs made in the sides of square-sawed guardrail posts prior to creosote treatment will substantially reduce problems of inservice decay caused by weather checking that penetrates the creosote treatment layer. The saw pattern yielding the greatest benefit used the deepest single cut along the midline of one face.

*Guardrail Post Experiments on Methods of Reducing Post Checking,* October 19[illegible], Oregon State Highway Division, Item No. 16. NTIS PB-183076.

## CONCRETE ANCHORAGE DEVICES

Tests of concrete anchorage devices show that pullout strength of (1) Epoxied-in-place bolts, (2) grouted-in-place threaded bolts, and (3) commercial friction-type anchors, depends on loading rate. However, the strength of cast-in-place bolts was entirely independent of the loading rate. The report on tests impartially evaluates various commercial concrete anchorage devices, and provides technical data on capacity and slipping. The report has been distributed to State highway departments.

*Evaluation of Concrete Anchorage Bolts,* June 1968, California Division of Highways, Report No. D-4-42. NTIS No. PB-183668.

## JOHNSONGRASS ERADICATION

With its vigorous proliferation in some areas, this cropland pest is so tall and luxuriant as often to present a genuine safety hazard. A 3-year study of various herbicides applications has shown two of these, dalapon and DSMA, to be the most effective. DSMA is less expensive and more selective. Details for a systematic control program are given in the report.

*Control and Eradication of Johnsongrass,* 1968, Missouri State Highway Commission, Report No. 61-1. NTIS No. PB-183007.

## SOIL STABILIZATION

Rate of change in length of stabilized soil specimens during laboratory freeze-and-thaw cycles is a good criterion of durability, according to tests used to evaluate the durability and strength of certain North Dakota soils stabilized with lime, flyash, cement, and asphalt. Amounts and best suited types of stabilizers for specific soils in the State can be estimated at the preliminary design stage.

*Soil Stabilization Study,* 1968, North Dakota State Highway Department, Report No. (14)-64.

## LIME STABILIZATION IN NEBRASKA

Hydrated lime was found to be a suitable material to (1) Improve plastic subgrade soils, and (2) use as an admixture to upgrade inferior base course materials. These conclusions were based on 10 years of observations of construction of an experimental project in Nebraska. Details were published earlier in HRB Bulletin 231.

*Investigation of the Effect of the Addition of Hydrated Lime to Plastic Subgrade Soil and the Effect of the Addition of Hydrated Lime and a Pozzolanic Material to a Local Coarse Sand for Base Course,* 1968, Nebraska Department of Roads, Report No. 63-10A.

# PUBLICATIONS of the Federal Highway Administration

*A list of articles in past issues of* Public Roads *and title sheets or volumes 24–35 are available upon request from the Federal ighway Administration, U.S. Department of Transportation, Vashington, D.C. 20591.*

*The following publications are sold by the Superintendent of ocuments, Government Printing Office, Washington, D.C. 20402. rders should be sent direct to the Superintendent of Documents. repayment is required.*

ccidents on Main Rural Highways—Related to Speed, Driver, and Vehicle (1964). 35 cents.
ggregate Gradation for Highways: Simplification, Standardization, and Uniform Application, and A New Graphical Evaluation Chart (1962). 25 cents.
merica's Lifelines—Federal Aid for Highways (1969). 35 cents.
nalysis and Modeling of Relationships between Accidents and the Geometric and Traffic Characteristics of the Interstate System (1969). $1.00.
Book About Space (1968). 75 cents.
ridge Inspector's Training Manual (1970). $2.50.
he Bridge to Your Success (1969). 45 cents.
alibrating & Testing a Gravity Model for Any Size Urban Area (1968). $1.00.
apacity Analysis Techniques for Design of Signalized Intersections (Reprint of August and October 1967 issues of PUBLIC ROADS, a Journal of Highway Research). 45 cents.
onstruction Safety Requirements, Federal Highway Projects (1967). 50 cents.
orrugated Metal Pipe (1970). 35 cents.
reating, Organizing, & Reporting Highway Needs Studies (Highway Planning Technical Report No. 1) (1963). 15 cents.
atal and Injury Accident Rates on Federal-Aid and Other Highway Systems, 1968. 45 cents.
ederal-Aid Highway Map (42x65 inches) (1970). $1.50.
ederal Laws, Regulations, and Other Material Relating to Highways (1970). $2.50.
ederal Role in Highway Safety, House Document No. 93, 86th Cong., 1st sess. (1959). 60 cents.
he Freeway in the City (1968). $3.00.
reeways to Urban Development, A new concept for joint development (1966). 15 cents.
uidelines for Trip Generation Analysis (1967). 65 cents.
andbook on Highway Safety Design and Operating Practices (1968). 40 cents.
  Supplement No. 1 (Nov. 1968). 35 cents.
  Supplement No. 2 (Nov. 1969). 40 cents.
ighway Beautification Program. Senate Document No. 6, 90th Cong., 1st sess. (1967). 25 cents.
ighway Condemnation Law and Litigation in the United States (1968):
  Vol. 1—A Survey and Critique. 70 cents.
  Vol. 2—State by State Statistical Summary of Reported Highway Condemnation Cases from 1946 through 1961. $1.75.
ighway Cost Allocation Study: Supplementary Report, House Document No. 124, 89th Cong., 1st sess. (1965). $1.00.
ighway Finance 1921–62 (a statistical review by the Office of Planning, Highway Statistics Division) (1964). 15 cents.
ighway Planning Map Manual (1963). $1.00.
ighway Research and Development Studies Using Federal-Aid Research and Planning Funds (1969). $1.50.
ighway Statistics (published annually since 1945):
  1966, $1.25; 1967, $1.75; 1968, $1.75.
  (Other years out of print.)
ighway Statistics, Summary to 1965 (1967). $1.25.
ighway Transportation Criteria in Zoning Law *and* Police Power and Planning Controls for Arterial Streets (1960). 35 cents.
Highways and Human Values (Annual Report for Bureau of Public Roads) (1966). 75 cents.
  Supplement (1966). 25 cents.
Highways to Beauty (1966). 20 cents.
Highways and Economic and Social Changes (1964). $1.25.
Hydraulic Engineering Circulars:
  No. 5—Hydraulic Charts for the Selection of Highway Culverts (1965). 55 cents.
  No. 10—Capacity Charts for the Hydraulic Design of Highway Culverts (1965). 65 cents.
  No. 11—Use of Riprap for Bank Protection (1967). 40 cents.
  No. 12—Drainage of Highway Pavements (1969). $1.00.
Hydraulic Design Series:
  No. 1—Hydraulics of Bridge Waterways, 2d ed. (1970). $1.25.
  No. 2—Peak Rates of Runoff From Small Watersheds (1961). 30 cents.
  No. 3—Design Charts for Open-Channel Flow (1961). $1.50.
  No. 4—Design of Roadside Drainage Channels (1965). 65 cents.
Identification of Rock Types (1960). 20 cents.
Increasing the Traffic-Carrying Capability of Urban Arterial Streets: The Wisconsin Avenue Study (1962). Out of print—(Request from Federal Highway Administration).
The 1965 Interstate System Cost Estimate, House Document No. 42, 89th Cong., 1st sess. (1965). 20 cents.
Interstate System Route and Log Finder List (1963). 10 cents.
Joint Development and Multiple Use (1970). $1.50.
Labor Compliance Manual for Direct Federal and Federal-Aid Construction, 3d ed. (1970). $3.75.
Landslide Investigations (1961). 30 cents.
Manual for Highway Severance Damage Studies (1961). $1.00.
Manual on Uniform Traffic Control Devices for Streets and Highways (1961). $2.00.
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