

# Effective Fail-Safe Highway Structures

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## INTRODUCTION

This paper considers one most important aspect of highway transportation—the basic job of making streets, roads, and highways safer for the traveling public.

As I see it, there is no greater priority in the Federal Highway Administration's program than saving lives on the highway. From the federal highway administrator down to the project man on the construction site, safety has always been a primary factor since the first Federal-Aid Highway Act passed over 56 years ago, back in 1916. Records have it that 18 years after passage of this first highway act, the highway fatality rate was 16.8 fatalities per 100 million vehicle miles of travel. In 1946 the rate was reduced to 9.18. Then in 1970, the rate was further reduced to 4.9. This continuous decline, reflecting the achievement of greater highway safety, must be ascribed to increasingly more proficient drivers, improved and safer automobiles, and highway designs and construction incorporating higher geometric and safety considerations.

While federal agencies can insist on the integration of safety and geometric features in new federal-aid highway construction programs, the actual accomplishment of these goals can be credited primarily to dedicated state, county, and local officials in segments of the highway system for which they have cognizance. Many are acquainted, in a more or less degree, with what these safety enhancements entail. I will briefly cover by use of pertinent data, experience and examples of that portion of highway safety dealing with, "building in forgiveness." I will draw heavily upon two recent papers on the subject: "Designing Fail-Safe Structures for Highway Safety" (1)\* and "Effective Highway Barriers." (2)

As a background, a few general statistics on the highway transportation system in the United States may be of interest to demonstrate the

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\* Numbers in parentheses pertain to references at the end of this paper.

magnitude of the many challenges facing those engaged in making highway travel safer:

Approximately 3.7 million miles of highways, roads, and streets.

Over 111.5 million registered highway motor vehicles in 1970, a 3.7 percent increase over 1969.

An annual new car production rate of about nine million vehicles.

About 111 million licensed vehicle operators.

One trillion 115 billion miles of vehicle travel annually.

Accident rate—approximately 13 million vehicle accidents each year.

Annually over 55,000 fatalities.

About four million persons injured annually, half of these involving disability beyond the day of the accident.

Economic loss—approximately \$15 billion annually.

The above-cited annual economic loss figure of \$15 billion can be more dramatically portrayed as being about 15 cents for each and every gallon of gasoline used in our automobiles.

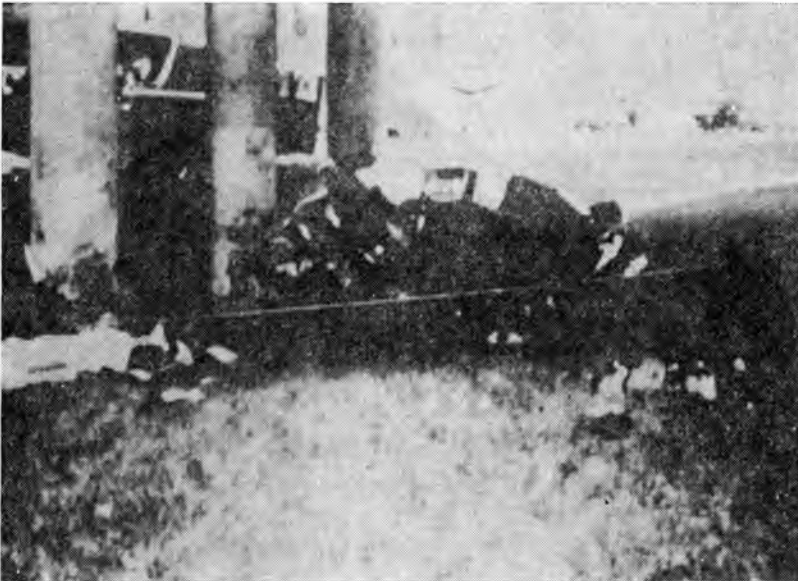
## CONSIDERATIONS FOR A SAFER HIGHWAY ENVIRONMENT

Highway officials and concerned individuals from educational institutions, technical and professional societies, and industry cooperated under various programs and in many committees in the development and use of high geometric standards for our highway system. (3) Concurrently with the development of higher geometric standards for greater highway safety, a number of research studies have been conducted to develop highway structures and appurtenances which would provide for greater highways. (4) Attesting to the successful results to date of these varied endeavors are such highway structural accomplishments as breakaway and frangible roadside sign structures (1, 5), breakaway supports for overhead sign bridge structures (6), slip base and frangible luminaire supports (7), improved guardrails, bridge rails, median barriers, transitional railing systems, and impact attenuators. (5, 8, 9)

In recent years, the highway planners and design engineers have used two general approaches to produce more efficient and safer highways. New highways are designed with the use of higher modern geometric standards, improved construction materials and techniques, longer span structures with a minimum number of supports, and optimum design principles for the highway elements. (3, 4) The opportunities for vehicle collision with roadside obstacles in the resulting clear environment adjacent to the roadway are thus substantially reduced.



**Fig. 1.** No median pier collisions are possible at this Colorado bridge.



**Fig. 2.** A disastrous fatal bridge pier collision.

In Figure 1, for example, the design of the long span, overhead bridge structure eliminates the need of near-shoulder supports and a bridge pier in the median, thereby greatly reducing disastrous collisions such as experienced by the vehicle in Figure 2. By this type of design for roadside safety, the additional benefits of greater driver visibility and aesthetics are evident. Programs are being conducted to implement safety improvement on our existing highways. Roadside obstacles such as culvert walls, signs, luminaire supports, some guardrails, certain terrain features, etc., are being eliminated or removed to a safer distance, usually 30 feet, from the edge of the roadway. Whenever roadside highway appurtenances cannot be relocated, protective systems are being utilized to prevent the actual collision of the vehicle with the obstacle, thereby minimizing personal injury and property damage. Nationwide experience has impressively shown the effectiveness of utilizing break-away and frangible sign and luminaire support, a more careful consideration of warrants and details of guardrails, and experimental installation of impact attenuators.

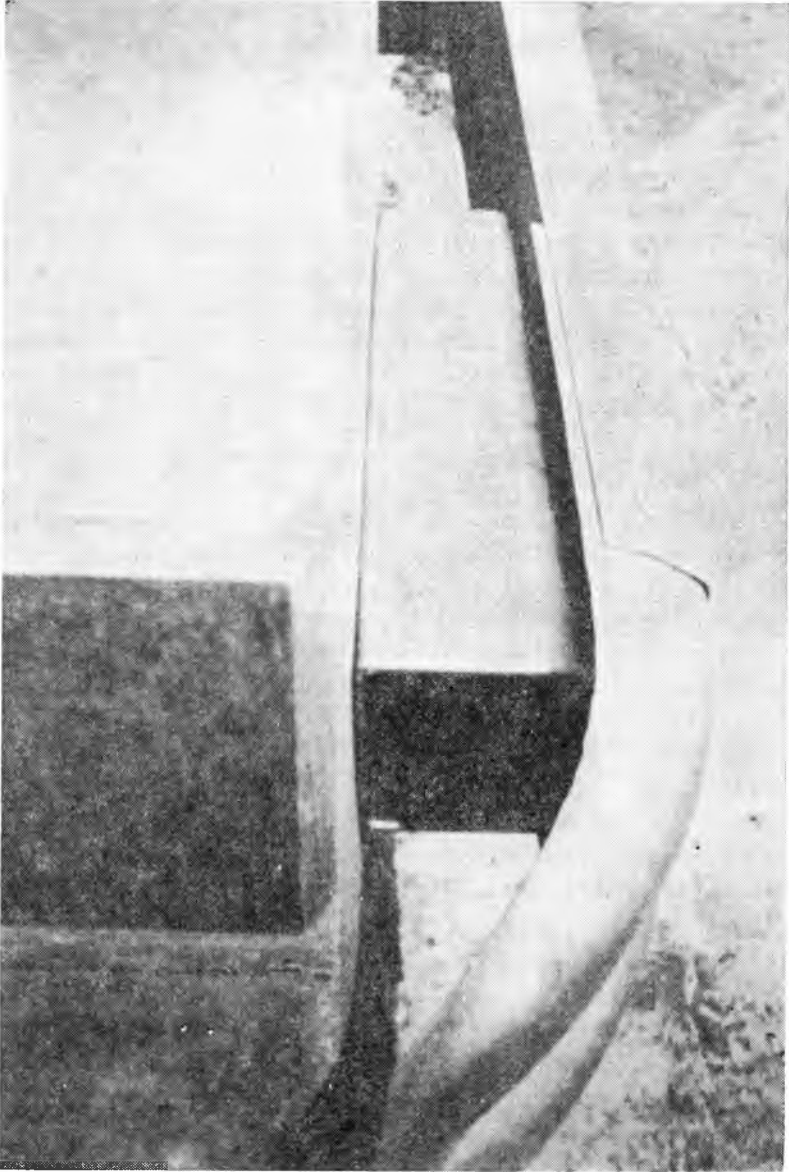
## TRAFFIC RAILINGS

Recent times have seen a steady increase in the average operating speed of vehicles. In 1947 the average speed of main rural highways was about 47 mph, while in 1968 it was about 59 mph, an average increase of about one-half mile per hour per year. Speeds on our interstate system are even higher. The construction of wider roads and full shoulder bridges, while in many respects contributing to safety, permit larger impact angles. Taken together, these changes have increased the severity of the impacts which the traffic railings must resist.

One serious high-injury and fatality area in highway traffic railings has been identified as being in high occurrence collision statistics. It is the transition point, where the normally constructed guardrail or median barrier ends and the bridge rail system begins.

Section 1.1.9 of the 1969 AASHO Specifications (10) demonstrates concern for this transition point by having added a sentence that did not appear in a preceding edition: "A smooth transition by means of a continuation of the bridge barrier, guardrail anchored to the bridge end, or other effective means shall be provided to protect the traffic from direct collision with the bridge ends." This statement is a recognition of what might be called "an integrated traffic barrier" concept. That is, in this case, a recognition that the function of a guardrail is quite similar to that of a bridge rail and a recognition of the necessity of providing effective and safe transitions. Figure 3 shows an attach-

ment detail developed by California (11) to anchor their W-section, strong posts guardrail system to their standard Type 1 bridge rail end post. Figure 4 shows an experimental barrier in which the railing por-



**Fig. 3. Attachment of California W-Section guardrail to bridge rail end post.**

tion of the bridge barrier and the guardrail are the same element. (12, 13) This design was a joint effort between engineers of the Federal Highway Administration and the Southwest Research Institute.

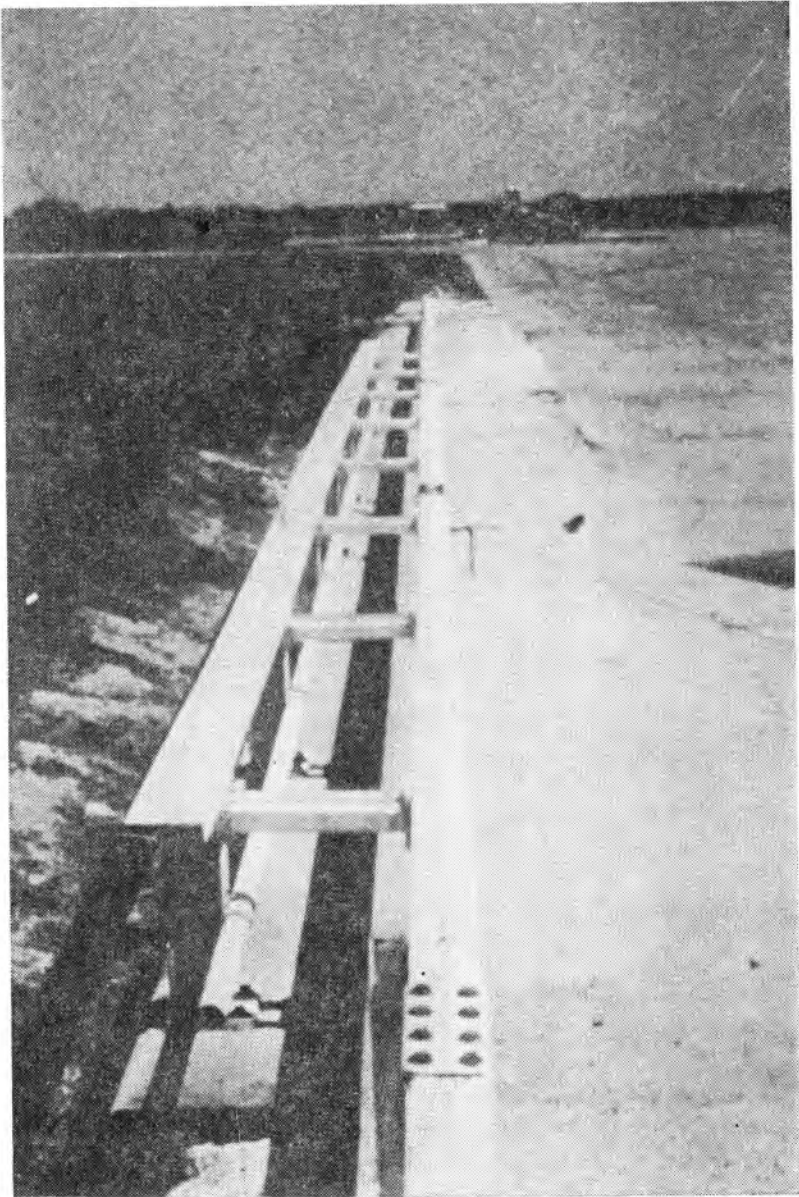


Fig. 4. Guardrail-bridge rail transition of an experimental system.

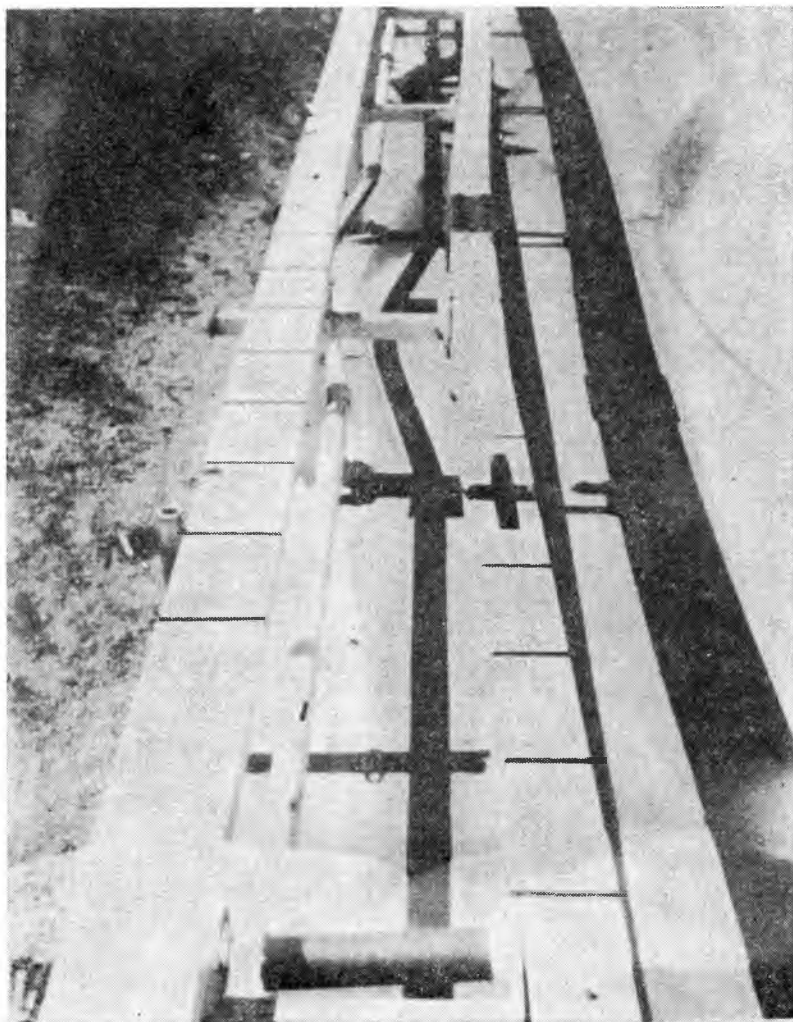


Fig. 5. A 55 mph, 25° impact with a 4,700 lb vehicle of an experimental barrier.

Recent interest has been expressed in the development of high performance railing systems especially for bridge rails and median barriers. For bridge rails, the desirable characteristics for "high performance" systems would include a controlled deflection of the railing system under the majority of the impacts to reduce acceleration experienced by vehicle occupants and a capability to retain trucks and buses on the bridge in severe impacts. If only shallow angle impacts are to be considered, the concept should be expanded to include the redirection characteristics

of some possible version of the shaped concrete barrier of Figure 6. One such experimental system shown in Figures 4 and 5 could be so adopted. One potential difficulty with the tested prototype barrier is illustrated in Figure 7, which depicts a "railing" having the minimum 2 ft. 3 in. bridge rail heights permitted by the AASHO specification. (10) This vaulting problem is widely recognized and most all bridge rails are constructed with substantially higher railings, as would the outer rail of the experimental barrier shown in Figures 4 and 5 in order to prevent penetration at the bridge rail by heavy vehicles in a severe impact situation. Walker and Warner have constructed an energy absorbing block-out of vermiculite concrete and tested it in an otherwise standard W-section, strong posts guardrail systems. (14) This energy absorbing element could conceivably be used in designs along the lines of the design illustrated in Figures 4 and 5.

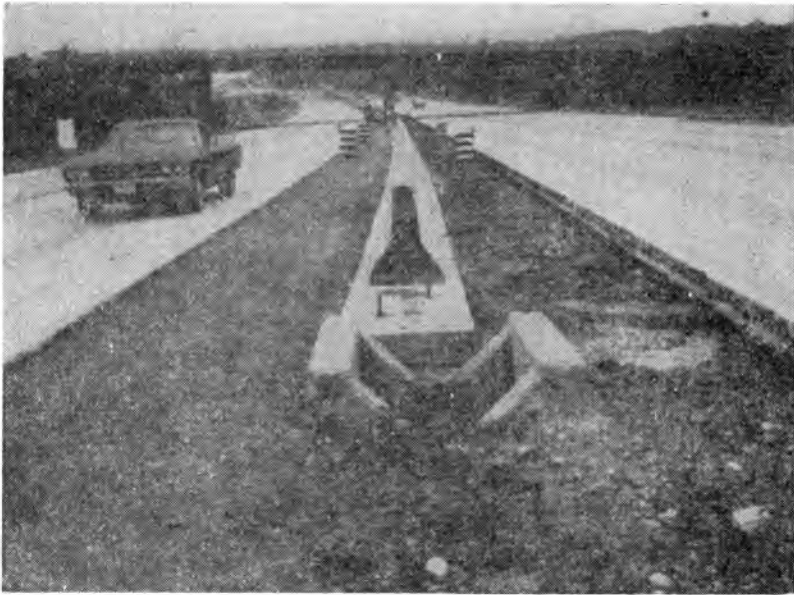
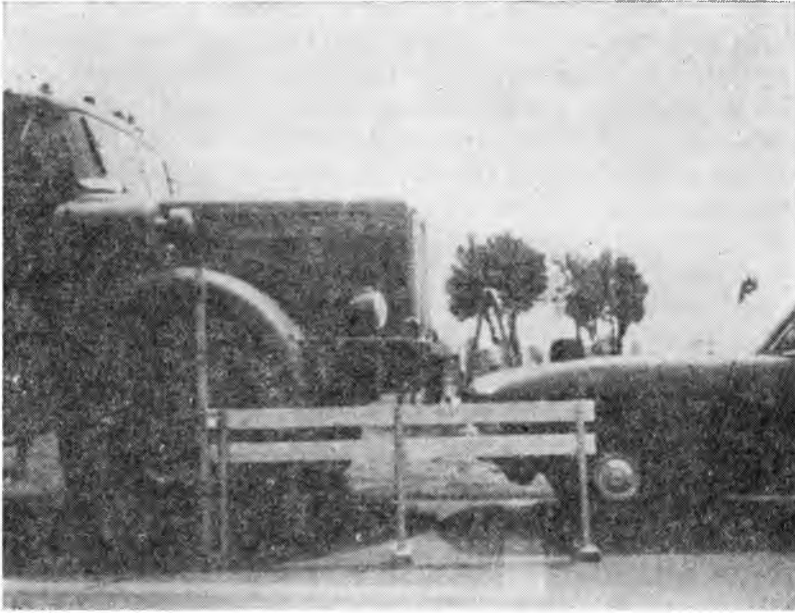


Fig. 6. Typical shaped concrete median barrier.

Shaped concrete barriers as shown in Figure 6 have been proven effective in preventing cross-over, head-on vehicle collisions in narrow medians. Redirectional characteristics of this type barrier are excellent in shallow angle impacts. Approximately 1,300 miles of this barrier have been constructed on highways in the United States. Highway departments are becoming increasingly aware of its low maintenance attributes.





**Fig. 7. Bridge rail height simulation showing minimum 2 ft. 3 in. height permitted by AASHO specifications.**

Figures 8, 9, and 10 show the results of tests of high performance median barrier developed in the Netherlands. (15) The reported favorable test behavior of this system is being studied by Federal Highway Administration for possible installation on U.S. highways. A somewhat similar system has also been developed in West Germany. (16)

The best measure of the performance of barrier systems is well documented accident experience. Unfortunately, very little such information is available at the present time on most barrier systems. It is hoped that a program of the Federal Highway Administration in cooperation with the states (17) to identify accident locations will permit many more such studies to be undertaken in the near future.

## FRANGIBLE AND BREAKAWAY STRUCTURES

The preponderant design requirement for vertical sign-support structures and luminaire supports is to provide adequate bending moment resistance for dead, live, and wind loading. Providing the concomitant shear resistance is usually an insignificant consideration. The structural section selected for the bending moment requirement in most cases provides considerably more shear resistance than is required. It is in the

reduction, or elimination, of this excess shear resistance capability in the structure that the engineer can provide greater safety for vehicle collision, and still have the structure satisfy the normal use requirements. Thus, by combining creativity or ingenuity with his structural capability, the designer can design a sacrificeable structure.

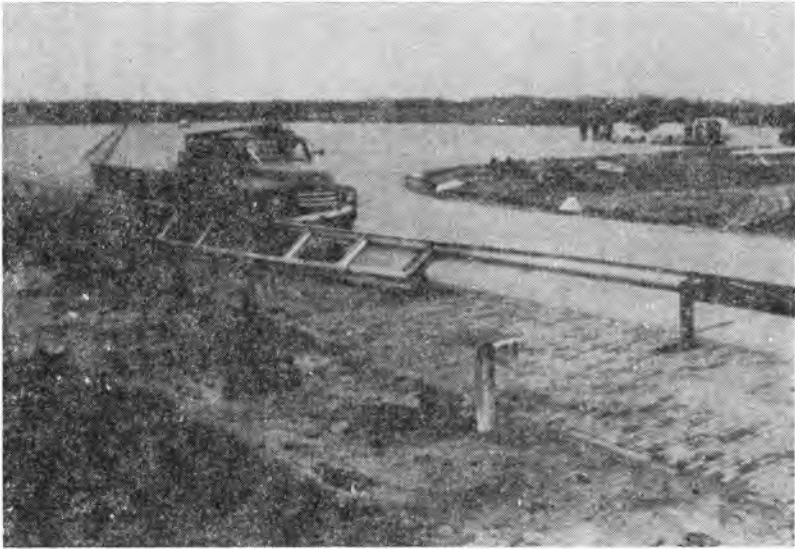


Fig. 8. The SWOV median barrier.

#### *Frangible Wood Post Structures*

The present policy of many states is to use dimensioned wood posts to support roadside signs with panel areas up to about 80 sq. ft—90 sq ft. Larger signs are generally supported by metal posts in urban areas and by either metal posts or treated timber poles in rural areas.

Wood provides highly desirable frangible properties in smaller size posts, 4 in. by 6 in. and smaller, thus minimizing personal injury and vehicle damage upon impact. However, use of larger size supports for larger signs increases the fracture energy of the post or pole and consequently provides a greater hazard upon impact.

Several state highway departments have conducted research studies into the frangibility properties of wood sign structures and guardrail posts weakened by drilled holes and external-face notches. Most recently completed programs were conducted by Pennsylvania (18) and California. (19)

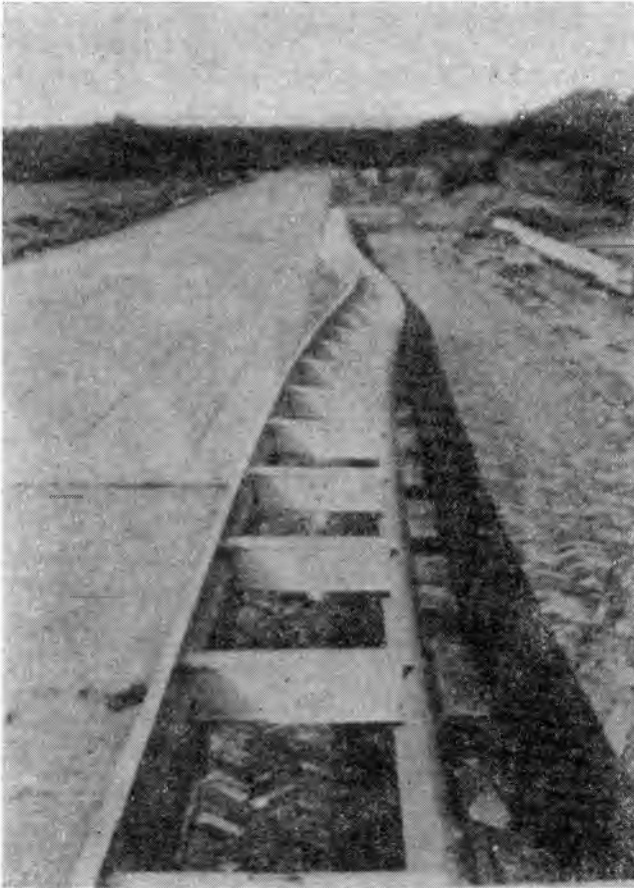


Fig. 9. Elastic deformation of SWOV barrier after impact.

The Pennsylvania research concludes that drilled holes are superior to face notches for providing the desired structural integrity and a fail-safe property. Pennsylvania recommends: (1) two drilled holes having their longitudinal axes parallel to the sign face at 6-in. and 18-in. above the ground line; (2) 1½-in. diameter holes for 6 in. by 6 in. wood posts; and (3) 2½-in. diameter holes for 6-in. by 8-in. wood posts.

The California researchers performed full-size testing and evaluation of vehicle impacts using dressed dimensioned wood posts and timber poles with and without drilled holes. California has promulgated the following design practice: (1) Two drilled holes having their longitudinal axes parallel to the sign face at 6 in. and 18 in. above the ground line; (2) for 6-in. by 8-in. dimensioned wood posts, use 2½-in.

diameter holes; and (3) for timber poles, the hole diameter should conform to the following list.

Pole Diameter	Hole Diameter
< 7 in.	No hole
7 in. to < 8 in.	2 in.
8 in. to < 9 in.	2½ in.
9 in. to < 10½ in.	3 in.
10½ in. to < 12 in.	3½ in.
	4 in.

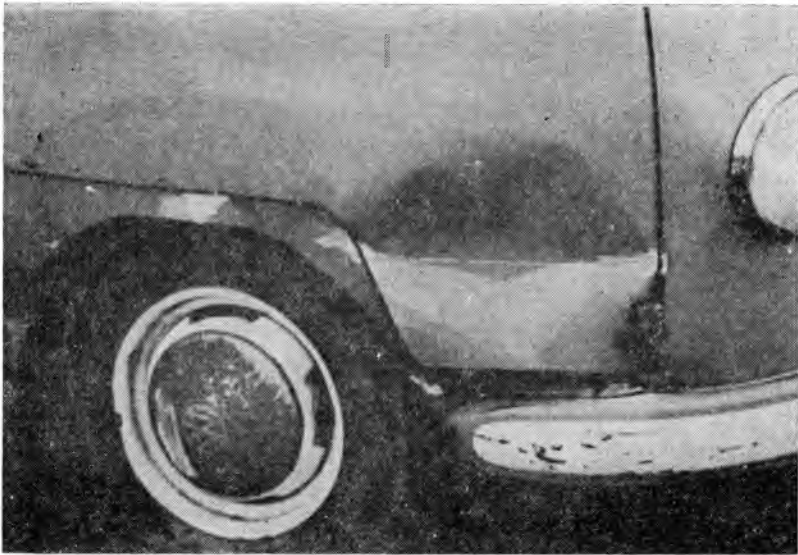
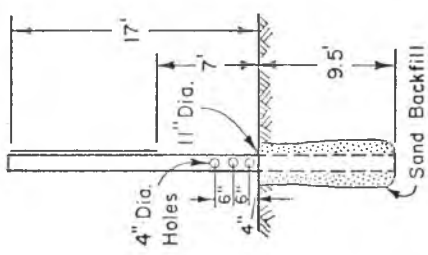
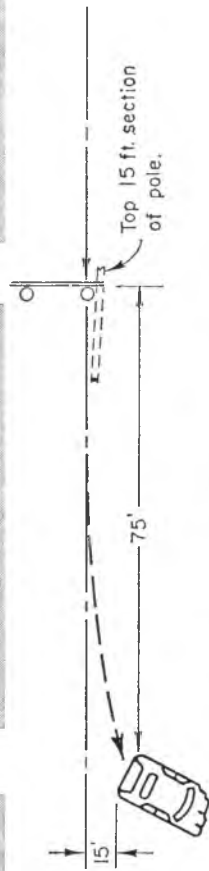
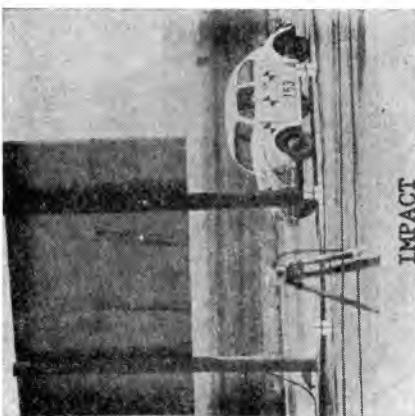
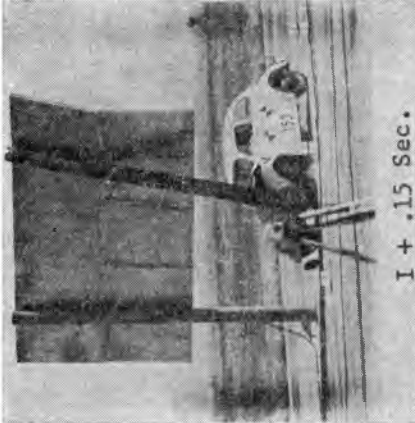
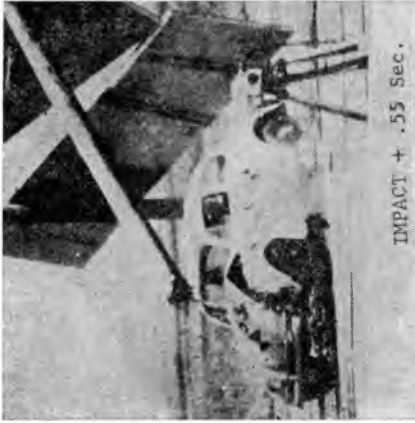


Fig. 10. Damage to VW bus in a 50 mph, 15° collision with an SWOV barrier.

The drilled holes reduce the bending moment capacity of structural members about one percent and the shear capacity by approximately 45 percent. It is this latter property that influences greatly the damage-limiting capability of the cantilevered support upon impact. The full-size vehicle crash test program conducted by the California Division of Highways corroborated this damage-limiting improvement. Figure 11 from the California report (19) shows a lightweight vehicle striking an 11-in. pole sign support. Also, data associated with this impact is presented.

In designing wood post or pole highway structures, greater safety is thus obtained by designing for the specified normal-use loads, then re-



POST . . . . .	Modified Class 2 D. F. Pole	TEST NO. . . . .	.153
POST SPACING . . . . .	.12'	DATE . . . . .	5-13-67
POST EMBEDMENT . . . . .	9.5'	VEHICLE . . . . .	1961 Volks Sedan
SIGN PANEL . . . . .	.2" x 10' x 20' Laminar	VEHICLE WEIGHT . . . . .	.2000 #
PANEL ATTACHMENT . . . . .	.3/8" Lag Bolts	(W/DUMMY & INSTRUMENTATION)	
GROUND CONDITION . . . . .	Dry	IMPACT SPEED . . . . .	.39 mph
DUMMY RESTRAINT . . . . .	Lap Belt	EXIT SPEED . . . . .	.27 mph

Fig. 11. "Fail-safe" response of a wood sign support.

ducing the unneeded shear capacity through the use of drilled holes as specified in the foregoing table.

### *Breakaway Metal Post Sign Structures*

To deal with the safety criteria for metal sign support structures, 14 highway departments in cooperation with the Federal Highway Administration sponsored a three-year (1964-1967) research study extending the work initiated by the Texas Highway Department at the Texas Transportation Institute. (20) The research program studied, tested, and evaluated a variety of sign support structures to determine their effectiveness in minimizing personal injury and property damage when struck by an out-of-control vehicle. What is believed to be the most important contribution resulting from this research endeavor is the breakaway roadside sign support structure. (20)

Figure 12 shows a typical 8-ft by 16-ft sign supported by two breakaway 8 WF 20 supports, together with a schematic diagram of the computer idealization of the structure. Figure 13 presents the stages of development of the structure's operation under vehicle impact. First, the struck column 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. The damage-limiting plastic hinge is activated, preventing further destruction to the sign-post connections. Figure 14 shows the result of the activation of the mechanical fuse at the plastic hinge to accommodate the bending moment in the free leg which was imposed by the impacting vehicle. 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 is formed in the opposite flange in opposing the resulting bending moment of the leg. From the action shown in Figure 15, it is apparent that only minimal front-end damage and no personal injury to occupants are evident as the sign support performed its intended mission—to fail under the impact of a vehicle, as opposed to the tragic toll, i.e., complete vehicle destruction and five fatalities, for the typical collision with a rigid structural system shown in Figure 16.

In the breakaway example shown in Figure 15, a 3,620-lb vehicle struck the 8 WF 20 sign post at a speed of 42.5 mph. The change in vehicle velocity and duration of impact were 1.2 mph and 22 msec, respectively. The average vehicle deceleration was computed to be 2.8 g's.

Fewer than five fatalities have been recorded to date attributable to

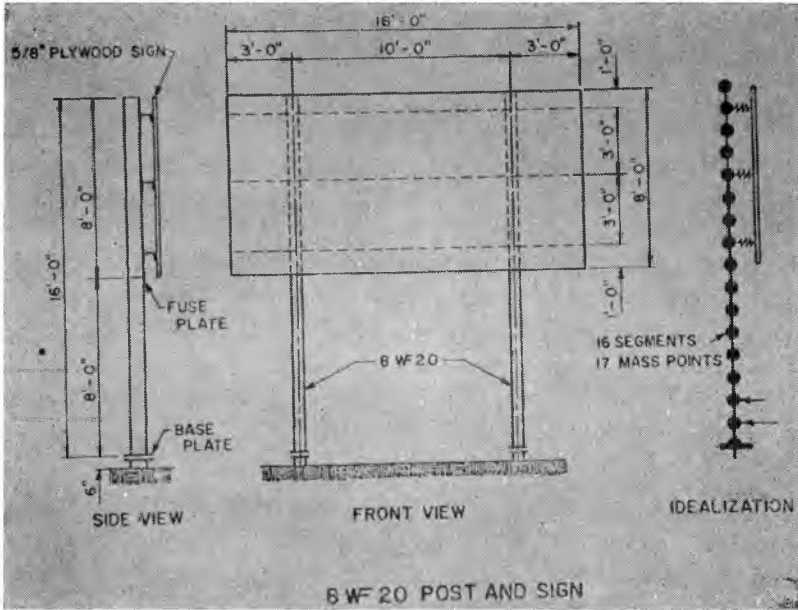


Fig. 12. Typical breakaway sign structure.

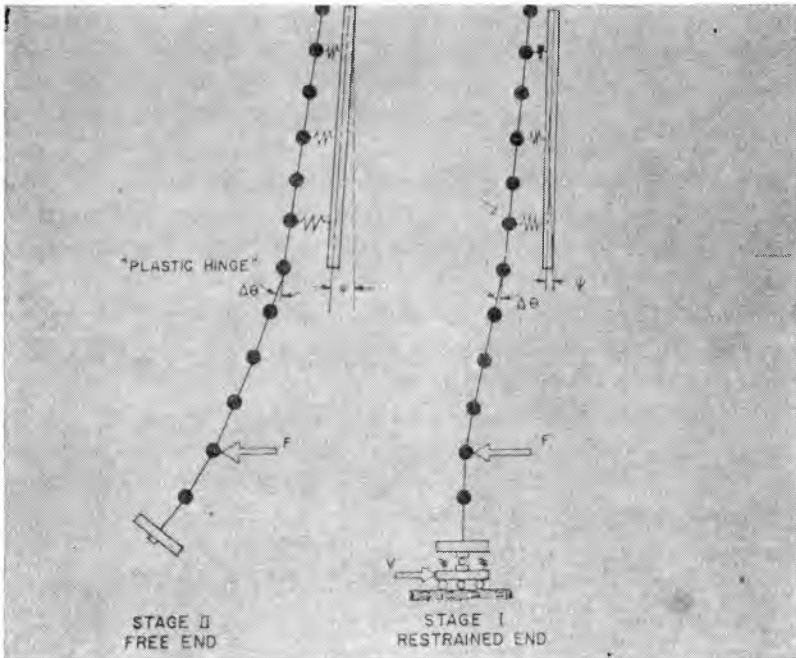
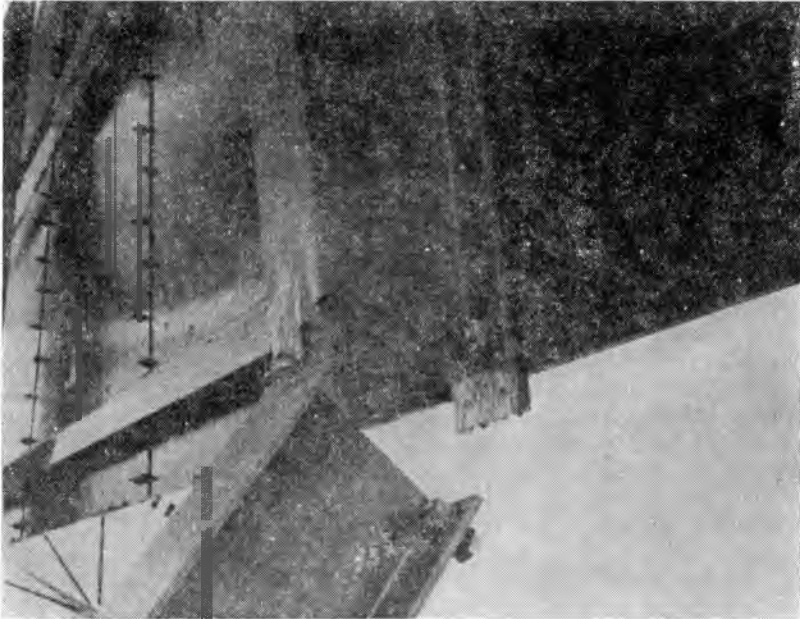


Fig. 13. Stages of post bending.



**Fig. 14. Activated plastic hinge in breakaway sign support.**

a vehicle collision with a breakaway sign. There have been several hundred collisions with breakaway signs with only an insignificant number of minor personal injuries. Because of the damage-limiting, designed-in, fail-safe feature, less than 40 percent of the collisions have been reported by the driver.

The cost benefits actually derived by the highway user through the mandatory policy to use breakaway or frangible sign structures on federal-aid highways can never be accurately determined. It is, however, conceded to be a significantly high figure, worthy of the implementation effort.

#### *Breakaway Overhead Sign Bridge Structures*

To further extend the lifesaving potential of the breakaway sign support concept to the overhead sign bridge, 22 highway departments sponsored a cooperative research program with the Federal Highway Administration at the Texas Transportation Institute. A full-size, 140-ft-long sign bridge structure with four supports was designed and instrumented to obtain vehicle-structure interaction data under controlled crash conditions. Figure 17 shows a typical breakaway support for an overhead sign bridge structure. Figure 18 is a close-up of the slip-base detail. The 20-ft-high posts, each weighing 1,500 lbs, have functioned quite



successfully under a range of impact velocities and various approach angles. Table A presents the vehicle-structure interaction data recorded from such crash tests.

TABLE A—VEHICLE IMPACTS OF OVERHEAD SIGN BRIDGE SUPPORT

Test Data	Test Number			
	1	2	3	4
Vehicle weight, in lbs	3,520	3,950	2,100	4,090
Vehicle impact speed, in mph	20.9	25.7	44.0	46.5
Change of speed, in mph	7.3	5.4	14.8 <sup>a</sup>	8.9
Maximum vehicle deformation, in ft	1.1	1.0	1.8	1.3
Average vehicle deceleration, in units of gravitational acceleration, g	2.8	3.1	9.6	6.7
Duration of impact, in msec	183	91	68 <sup>a</sup>	185

<sup>a</sup> Vehicle snagged onto post—duration during breakaway.

The mathematical model and computer routine for breakaway sign support structures have been modified by Martinez, Hirsch, and Bas-

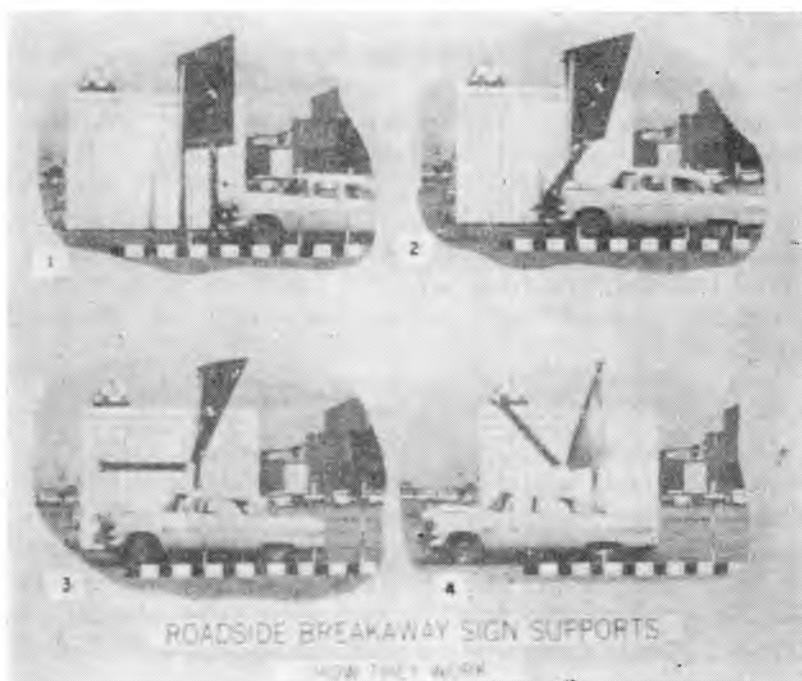


Fig. 15. Impacting vehicle produces safe failure—as designed.

kurt (21) to evaluate the crash-dynamic behavior of a variety of aluminum sign post structures mounted on frangible bases having different base fracture energies.

### SLIP-BASE LUMINAIRE SUPPORTS

The illumination of high speed, primary and secondary, highway routes is considered in many locations to be a necessity for safe, night time driving. However, the means of providing this safety has in itself become a recognizable roadside hazard. In consonance with improved geometric highway design principles, luminaire structures as well as roadside signs are being removed laterally from the 30-ft wide zone adjacent to the edge of the roadway whenever practicable. Studies of single-vehicle, ran-off-the-road accidents indicate that approximately 80 to 90 percent of the vehicles strike objects which are located within this 30-ft 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 for safer vehicle impacts when they do occur. The change of momentum value under impact is required to be less than 1,100 lb-sec.

Hosea (22) states that about five percent of the single vehicle, off-the-road, fatal accidents on the completed sections of the interstate system involved luminaire poles. This figure can be judiciously adjusted because of the lower geometric design standards to about eight percent for nationwide application, representing about 500 fatalities per year.



Fig. 16. Rigid sign post—fatal accident.

The challenge to reduce the high accident toll of luminaire supports has been accepted by industry, state agencies, and the Federal Highway Administration, whose cooperative efforts 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.

To convert the hundreds of thousands of metal luminaire supports not meeting the federal standards along the nation's highways, a very

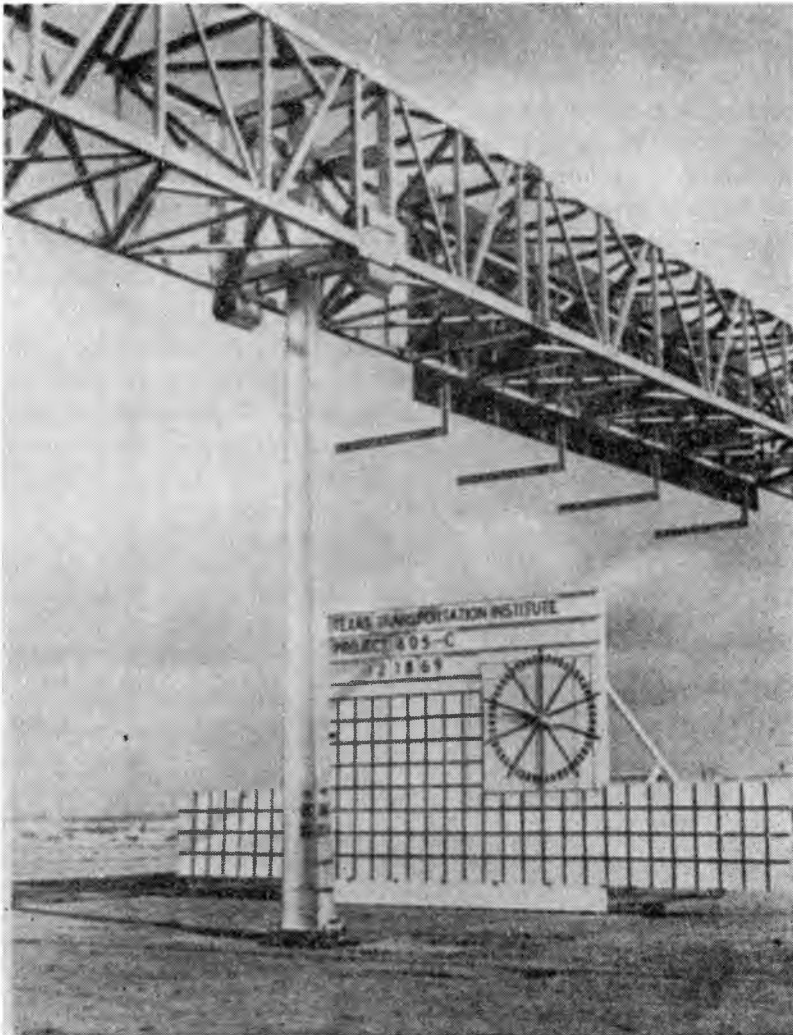
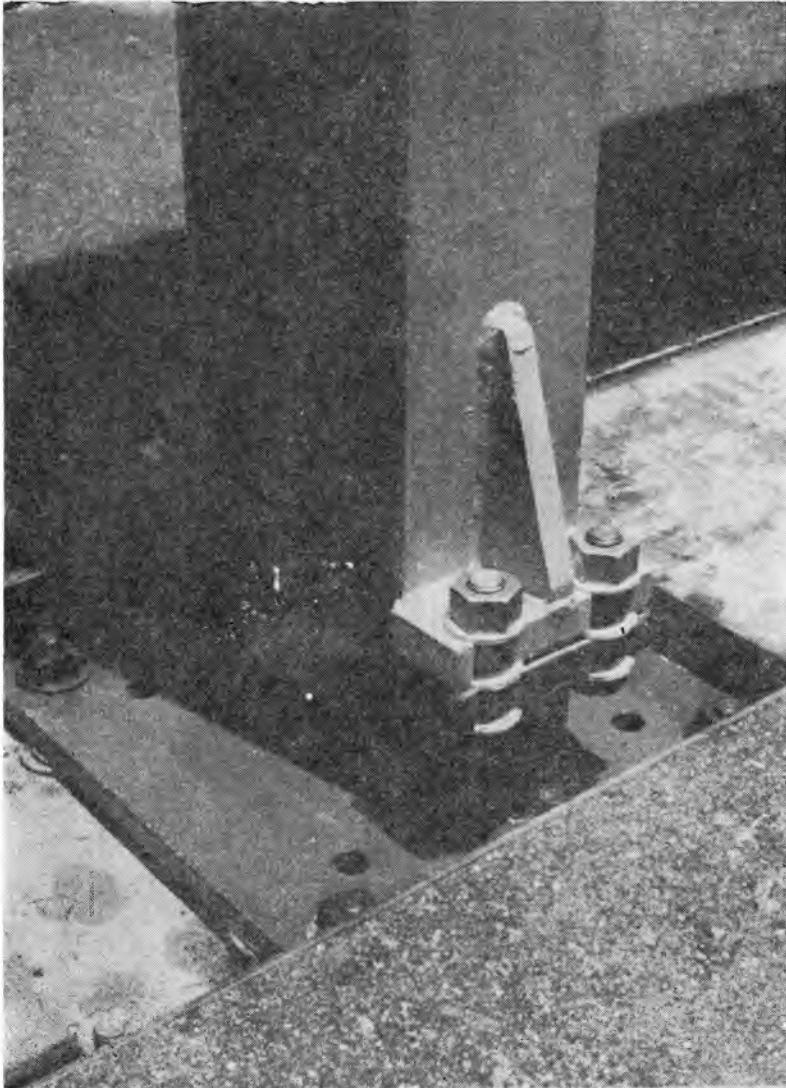


Fig. 17. Experimental breakaway support for overhead sign bridge.

simple, 6-in. to 9-in. high insert shown in Figure 19 was developed. This insert was developed at the Texas Transportation Institute under a cooperative research project sponsored by the Texas Highway Department and the Federal Highway Administration. It is designed of an aluminium alloy having a low base fracture energy.

Also developed and tested under this research was a slot-bolted, slip-



**Fig. 18.** Slip base for breakaway support in overhead sign support bridge.

base for luminaire support. Figures 20 and 21 show the details and installation of this type of structure. The high strength bolts in this design are pretensioned and provide friction-shear resistance. The base connection is primarily a bending-resistant joint. When the structure is struck by a vehicle, the low base fracture energy of about 750-ft-lb is easily overcome and a safe failure ensues. For such structures, the impacting vehicle passes underneath the upward-rotating luminaire support with only minor vehicle damage.



Fig. 19. Use of frangible aluminum insert at base of luminaire pole.

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 the critical notched bolt 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.

Under a National Cooperative Highway Research Program

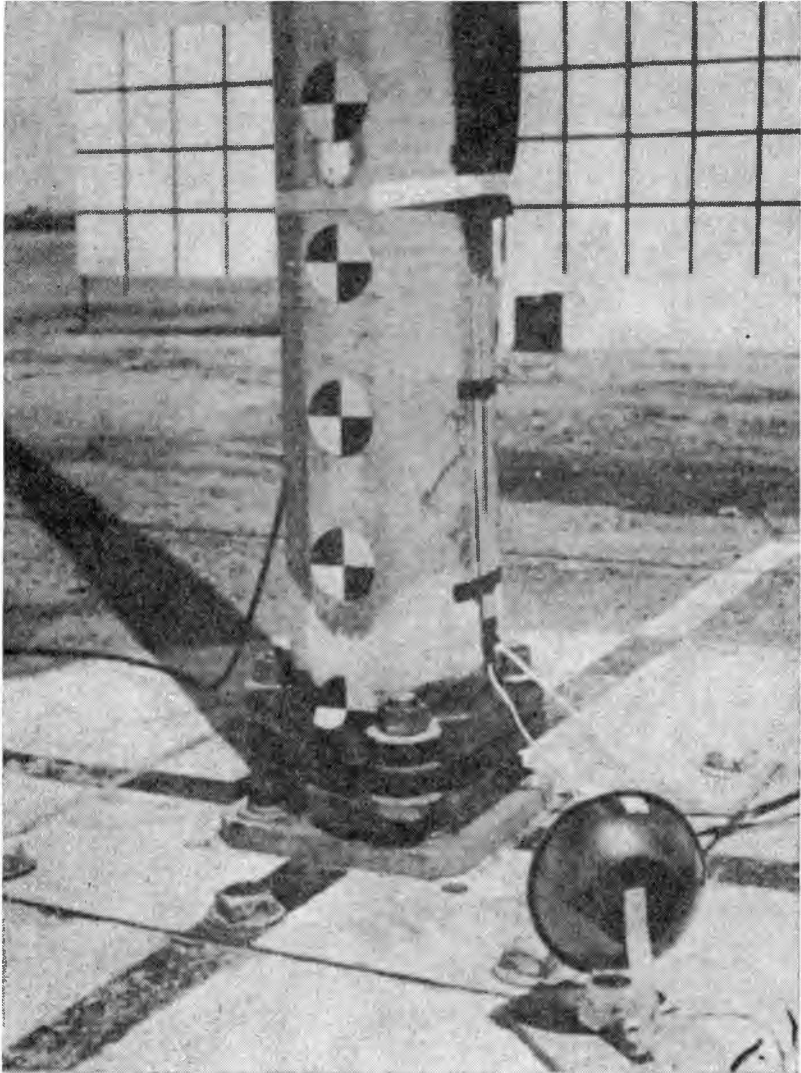


Fig. 20. Slip base for safe luminaire support.

(NCHRP) sponsored at the Texas A & M University, the state-of-the-art of luminaire supports was studied. An NCHRP Report 77 (7) "Development of Design Criteria for Safe Luminaire Supports," presents the results of this endeavor. Figures 22 and 23 are predicted response charts from that report. They are excellent aid to the designer for evaluating and selecting proposed luminaire support designs having different parameter values. By use of these charts, it is easy to obtain

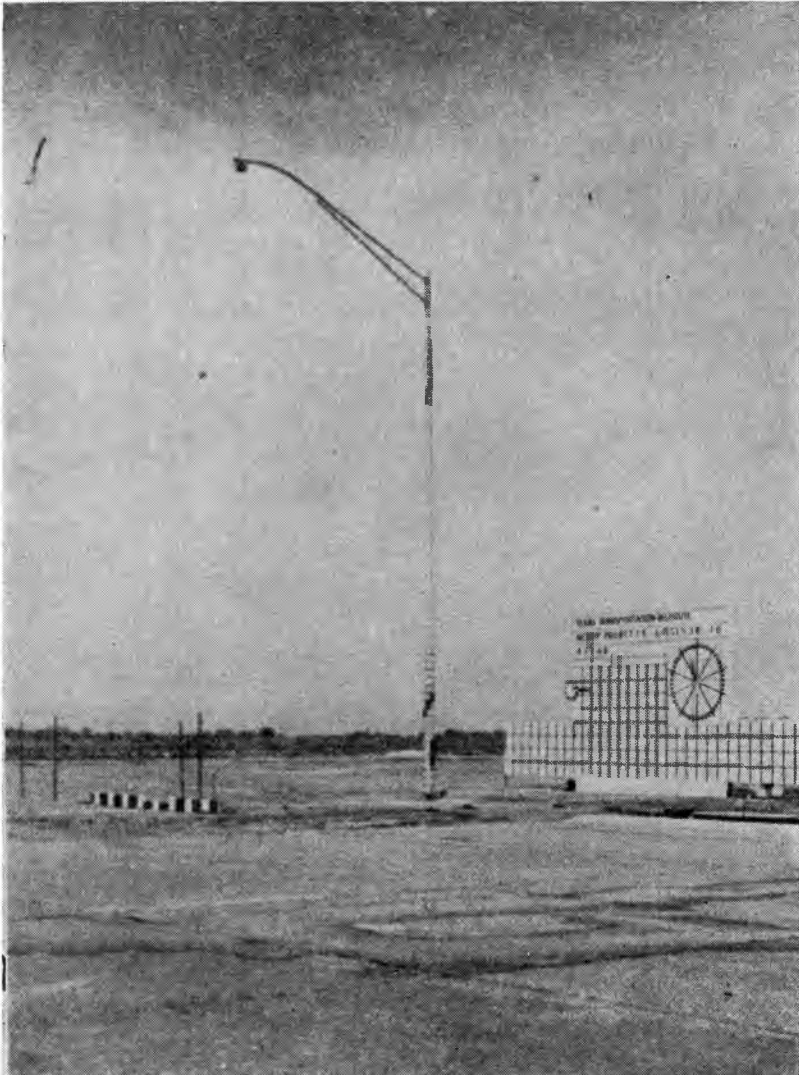


Fig. 21. Installation of slip-base luminaire structure.



the response of the structure under consideration and the post-crash assessment effects provided the base fracture energy is known. Each chart in the figures 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 on the same charts. All charts emphasize to the design engineer the safety aspect for utilizing the lowest possible base fracture energy for vehicle impact in his structure. As a further enhancement to safety, it appears that designs having low base fracture energies are less sensitive to the vehicle impact velocity, thus resulting in very low changes of vehicle velocity and concomitant low deceleration forces for all impacts. (23,24)

Martinez, Hirsch, and Jumper (25) have extended these charts to assist the design engineer who is considering luminaire supports higher than 40 ft. This limited extension further emphasizes the conclusions drawn from the basic study reported in the NCHRP Report 77 (7) that the low base fracture energies designed into luminaire supports provide for greater accident survivability.

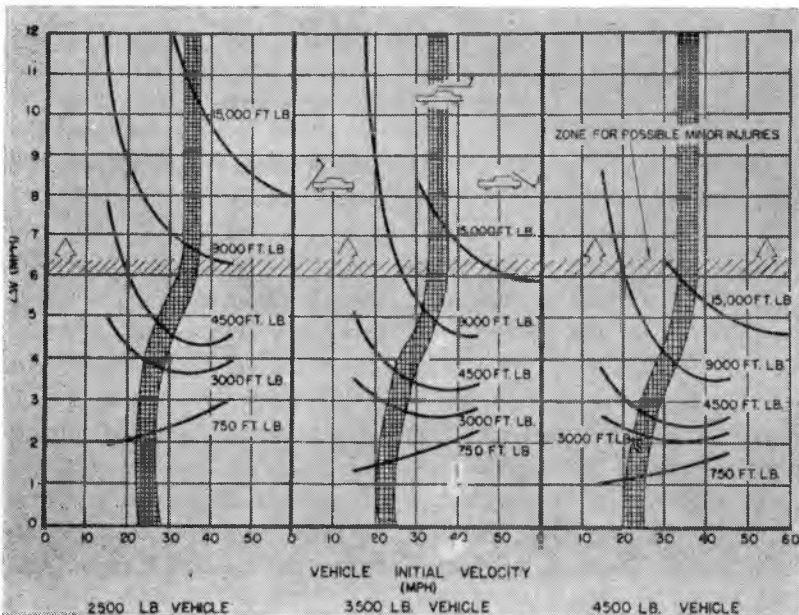


Fig. 22. Predicted response: Vehicles versus 40-ft. steel support.



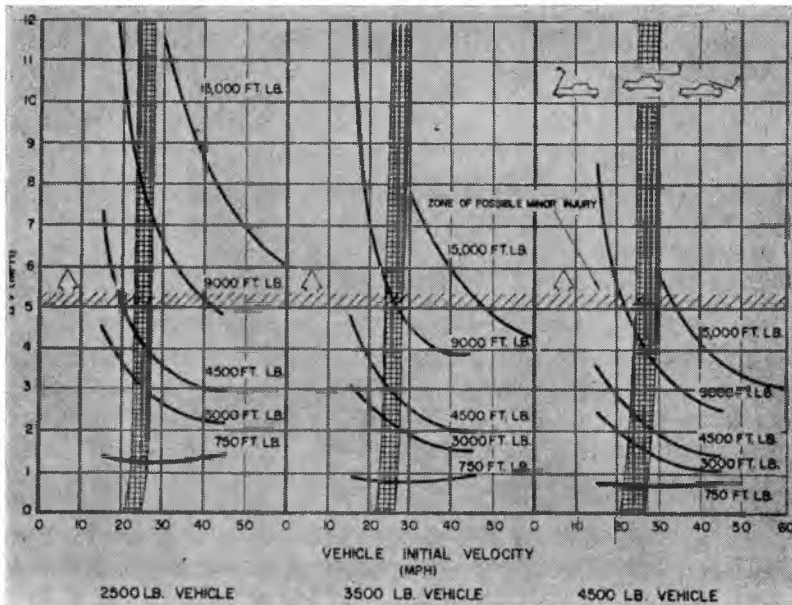


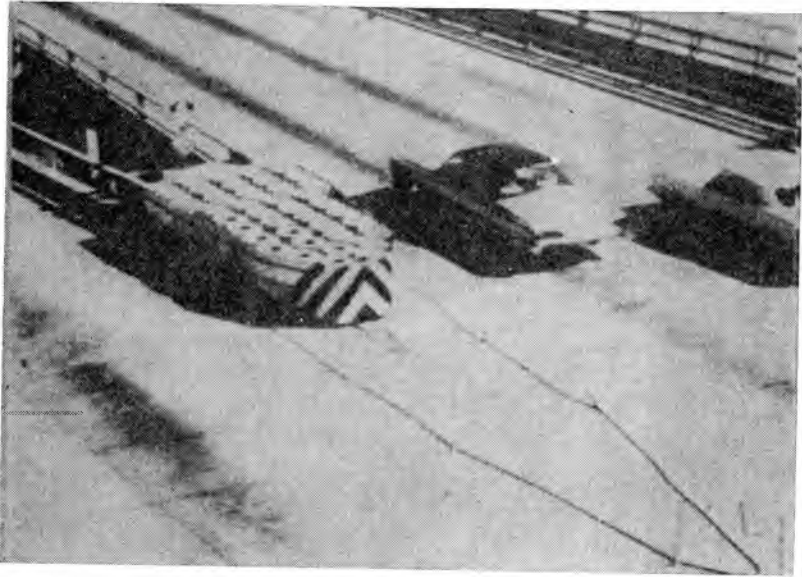
Fig. 23. Predicted response: Vehicles versus 40-ft. aluminum support.

## ENERGY ABSORPTION CRASH BARRIERS

In cooperation with the Federal Highway Administration, industrial and academic research organizations, and a number of state highway departments have under way numerous research, development, test, and evaluation programs for impact attenuation devices. These devices or systems are basically pillows or cushions placed in front and alongside of roadside hazards such as bridge piers and bridge parapet ends at exit ramps in elevated gore areas. The objective of these safety structures is to act as an energy transfer agent for errant, fast-moving vehicles by programmed absorption, elasto-plastic, or ultimate collapse.

In 1967 the Federal Highway Administration (Bureau of Public Roads) initiated the 4S Program, "Structural Systems in Support of Safety," (26) a short-range, quick payoff research and development project. To pursue development of energy absorption systems, energy transfer capabilities were investigated for such indigenous materials as disposable metal beverage containers, empty oil drums, short wood posts, chicken wire fencing, plastic pillows, and vermiculite type concrete. In addition, more complicated structural devices such as the TORSHOK Reusable Highway Barrier, the Hi-Dro Cushion Cell Barrier, and the Fitch Inertial Barrier (27, 28, 29, 5) were developed and produced by industry for the states. The latter three barrier devices

and one of the expendable variety utilizing oil drums as the collapse, fail-safe mechanism are being installed at accident-susceptible locations on the nation's highways.



**Fig. 24.** A modular crash cushion installation at an elevated gore site.



**Fig. 25.** An early morning 70 mph impact in progress.

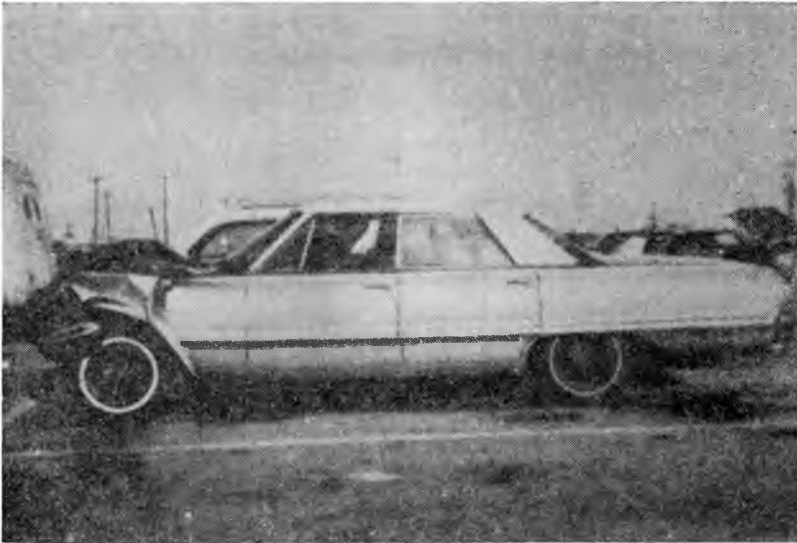


Fig. 26. Vehicle deformation caused by the impact.

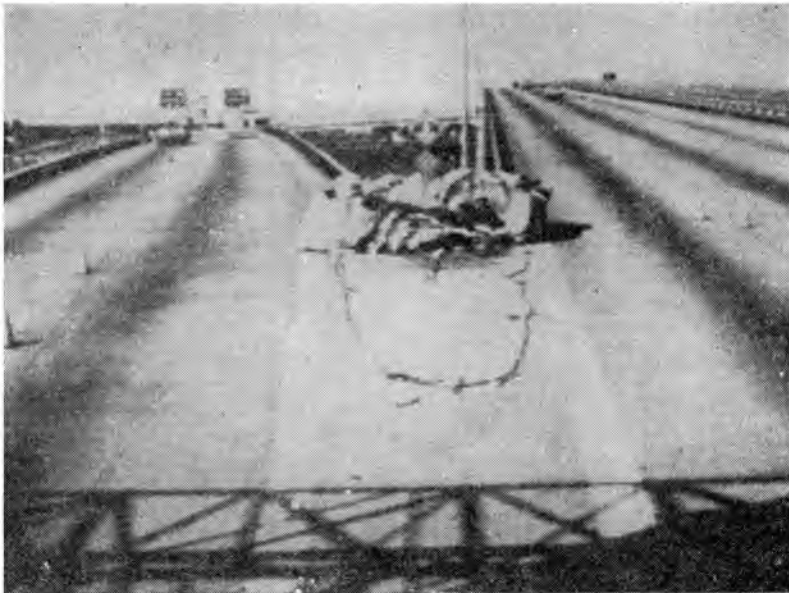


Fig. 27. Barrier damage as a result of attenuating the vehicle impact.

Figures 24-27 show an installation before, during, and after a 70 mph vehicle impact at one of these typical locations. Figure 25, recording a collision in progress, was made available through the photo-recording

instrumentation of an accident data-acquisitioning project of the Federal Highway Administration. Accidents such as the one photographed are occurring with all four types of installed barriers. The success of these relatively low-cost accident survival kits has been phenomenal in all reported incidents.

Very simple principles of structural behavior are involved in the design of an effective bulk-type crash cushion such as the barrel barriers. With slightly greater sophisticated treatment, more complex barrier systems of the reusable variety, previously named, can be designed or analyzed.

Figure 28 is an aerial view of two typical "gores" on an elevated structure having both a left-side and a right-side exit ramp. Each gore has been retrofitted with a Fitch Inertial Barrier. The principle involved in the Fitch Inertial Barrier is that of transfer of momentum from a moving vehicle to the barrier elements which contained a pre-determined weight of sand. The individual containers, 30 or 36 in. in diameter by 36 in. high, are made of highly frangible plastic material and are free-standing, having a false bottom supporting the sand. The sand-filled containers are designed for placement in a precalculated configuration in front of and beside roadside hazards such as gores, massive highway appurtenances, etc., to prevent errant vehicles from



Fig. 28. An aerial view of an elevated interchange.

colliding with the obstacle. The weight of the modules range from 400 to 1,700 lbs. The Fitch concept is adaptable to almost any hazardous fixed object site and no other installation or construction is necessary. Tests with live drivers using conventional lap belts and shoulder harness restraints have been conducted at speeds up to 65 mph with highly satisfactory results. Vehicle decelerations have been observed to range from 2 to 6 g's, depending on vehicle speed and weight, angle of impact, and barrier configuration. Figure 29 shows a typical installation. Accident data on this and other barriers will be given later in the paper.

The TORSHOK barrier (30) was developed by Bernard Mazelsky of Aero-Space Research Associates under a Federal Highway Administration (Bureau of Public Roads) research contract. The barrier is composed of an array of concentric telescopic cylindrical tubes contained by a U-shaped tubular guardrail. The small-size telescopic tube system provides the energy-absorbing capability of the barrier when impacted. A length of stainless steel wire is spirally wound in a force-fit manner in the overlap area between the two concentric cylindrical tubes. Each combination is designed to act at known levels of tension or compression in the barrier. At impact, the spirally wound wire absorbs energy through the relative motion, lengthening or shortening, of the cylinders. This type of barrier can be designed to accommodate a variety of "gore"

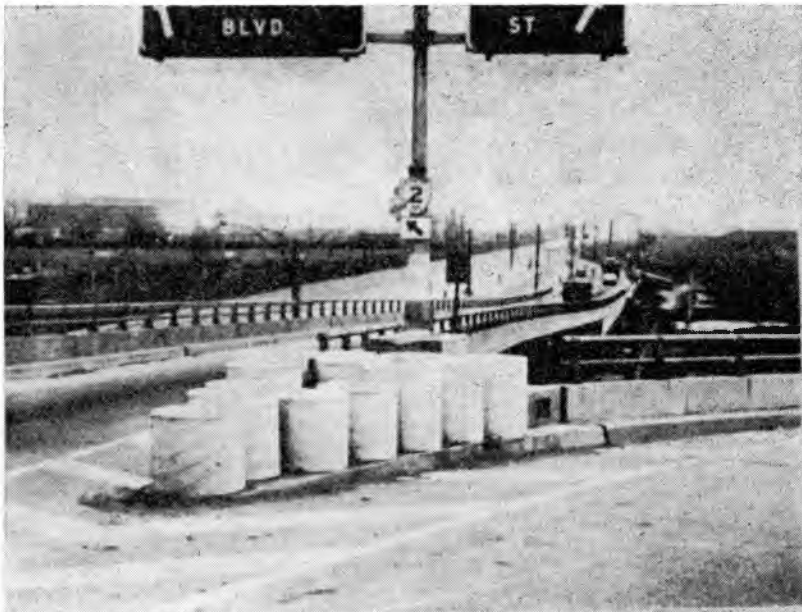
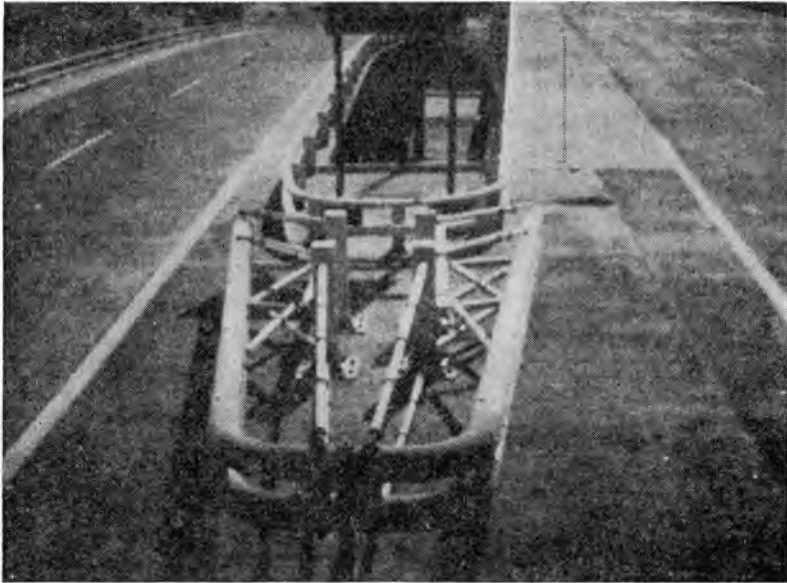


Fig. 29. A fitch barrier protection at an elevated gore.

and bridge-pier-in-the-median situations. Figure 30 is a TORSHOK installation at Albuquerque, New Mexico.

A mechanical jig is available which makes it possible to return the activated tubes to their original lengths after moderate-to-severe impacts, thereby minimizing maintenance effort and restoring the barriers to service as soon as possible. Figures 30c and 30d show results of a 35 mph head-on impact of the Albuquerque TORSHOK barrier by a 3,700 lb pick-up truck. (31) Note the activated TORSHOK tubes in Figure 30c and the front-end damage of the impacting vehicle in Figure 30d.

**Fig. 30. The TORSHOK barrier—an installation at Albuquerque, New Mexico, showing results of a 35 mph impact: (a) Top view, (b) Front view, (c) Activated TORSHOK tubes, (d) Front-end vehicle damage.**



**Figure 30a**

The Hi-Dro Cushion crash barrier is another energy absorption system which has demonstrated protection in vehicle impacts. Figure 31 depicts an installation of the HiDro Cushion barrier at a gore adjacent to an exit ramp in Los Angeles, California. The system is made up of a number of cylindrical vinyl cartridges, 6 in. in diameter and 3 ft long, which are filled with water and suspended between vertical plywood panels. Each cartridge is sealed with a hemispherical cap having a number of simple orifices which allow water expulsion to occur at a fixed rate upon impact. The Hi-Dro Cushion barrier can also be tailored

for a variety of gore installations. In northern climates, inexpensive antifreeze is added to the liquid to prevent freezing. Figure 32 shows an installation in Honolulu, Hawaii, just after an actual impact.

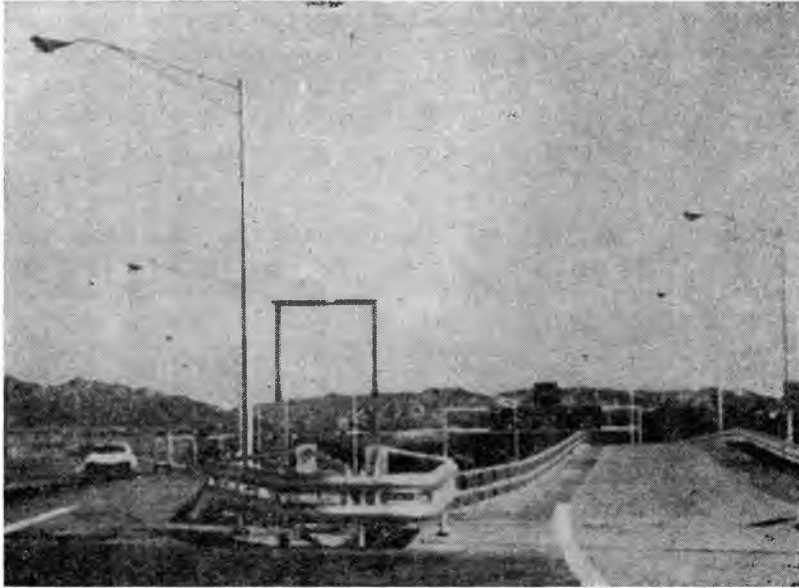


Figure 30b

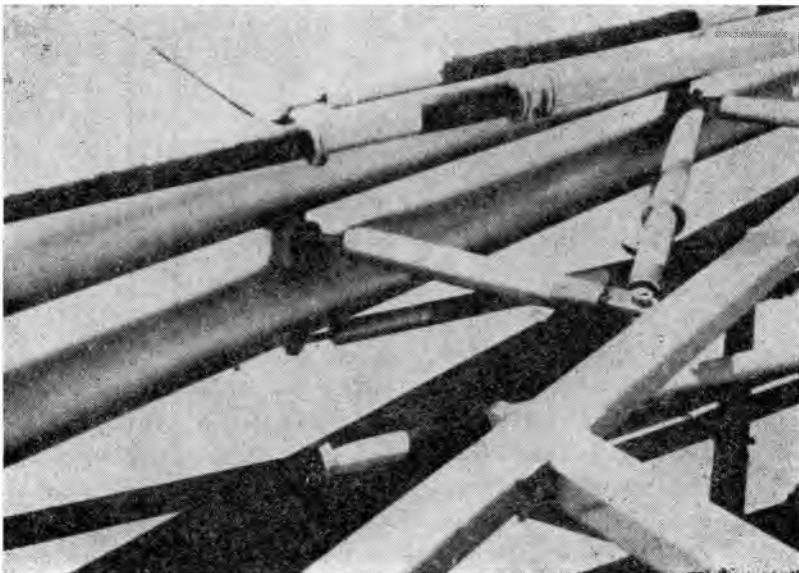


Figure 30c



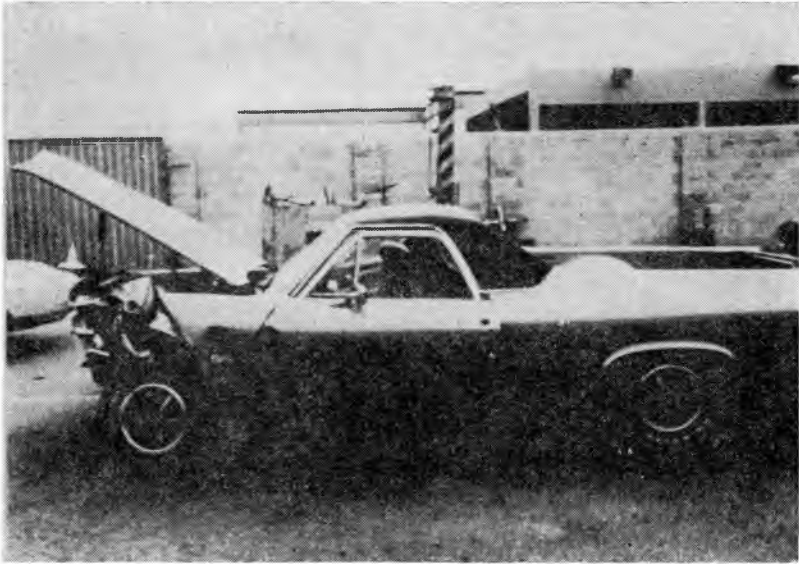


Figure 30d

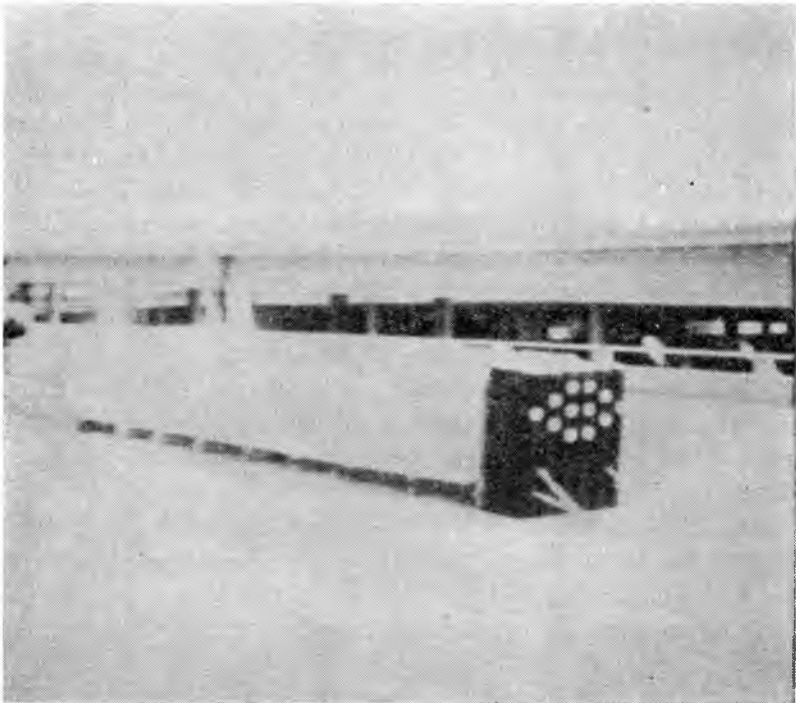
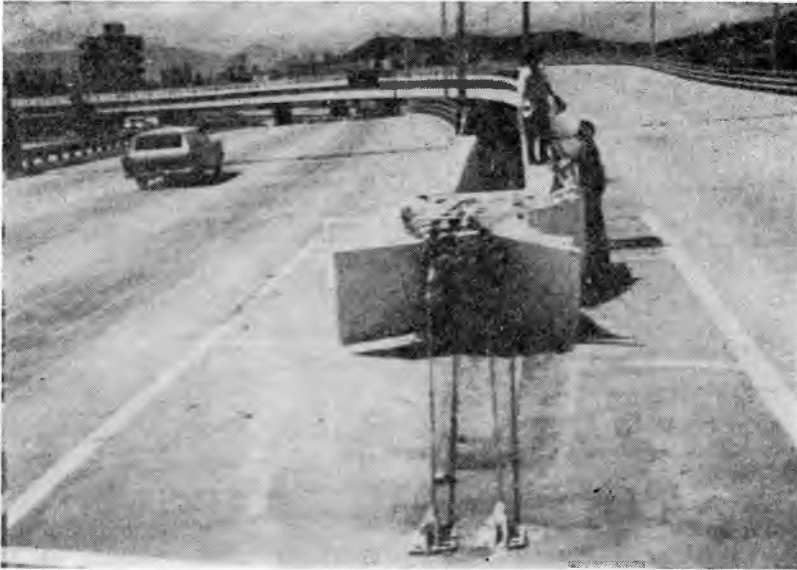


Fig. 31. A Hi-Dro Cushion barrier installation.





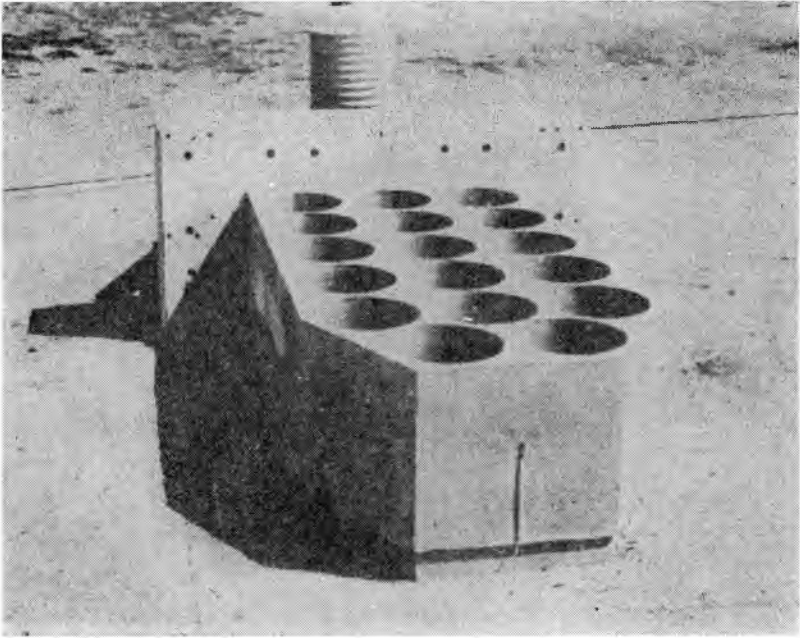
**Fig. 32. The effects of a head-on vehicle impact of a Hi-Dro Cushion barrier.**

## RESEARCH UNDER WAY

Undergoing research at the present time is a promising, lightweight, vermiculite concrete barrier. (32) Figure 33 shows a 7-ft by 12-ft-long barrier which effectively attenuated head-on impact by a 3,650-lb vehicle at 41 mph. The stopping distance was 9 ft, and the average deceleration was about 6 g's, with only minor vehicle damage. Subsequent tests of a 23-ft long barrier impacted at 64 mph by a 4,560 lb vehicle head-on have been similarly successful. Current research is under way to develop desirable angular-impact characteristics, acceptable waterproofing, and an optimum freeze-thaw capability for the barrier.

The Federal Highway Administration conducted research on adapting the Van Zelm Dragnet System to solving the problem of restraining a vehicle from penetrating the median space between twin highway bridges to prevent the possible collision with vehicles at the lower road.

The Dragnet barrier (33) is a fence-type arrangement by which a colliding vehicle is ensnared and stopped at a predetermined distance based on vehicle weight and speed. At each end of the fence-type barrier is an energy-absorbing cartridge which utilizes the principle of cold-working a metal tape as the impacting vehicle draws it forward. Figure 34a shows an experimental impact of the Dragnet barrier by a live driver. The 3,600 lb vehicle traveling at 60 mph was safely arrested



**Fig. 33.** A lightweight vermiculite concrete barrier.

**Fig. 34.** The Van Zelm dragnet. (a) A 60 mph vehicle impact, (b) A dragnet installation at a ferry landing.



**Figure 34a**

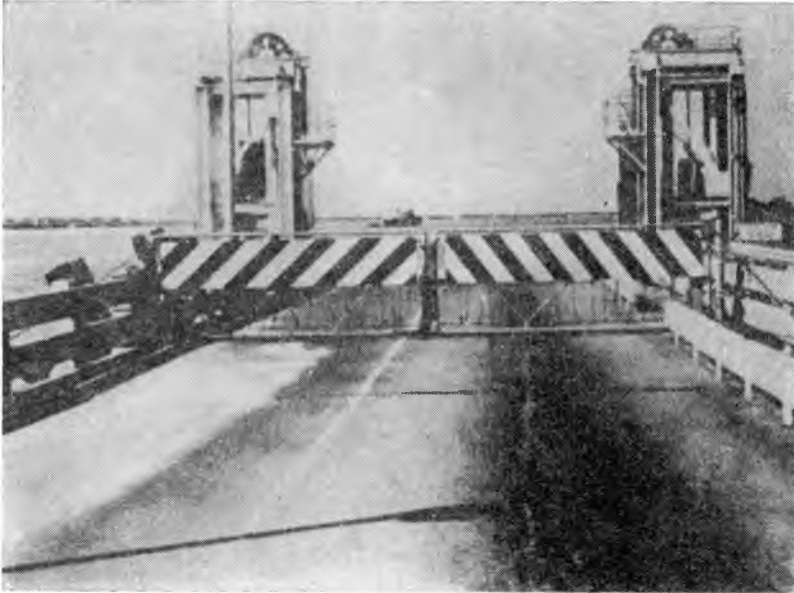


Figure 34b

Fig. 35. A used tire barrier. (a) A 42 mph vehicle impact, (b) Concept for a barrier at a median bridge pier.

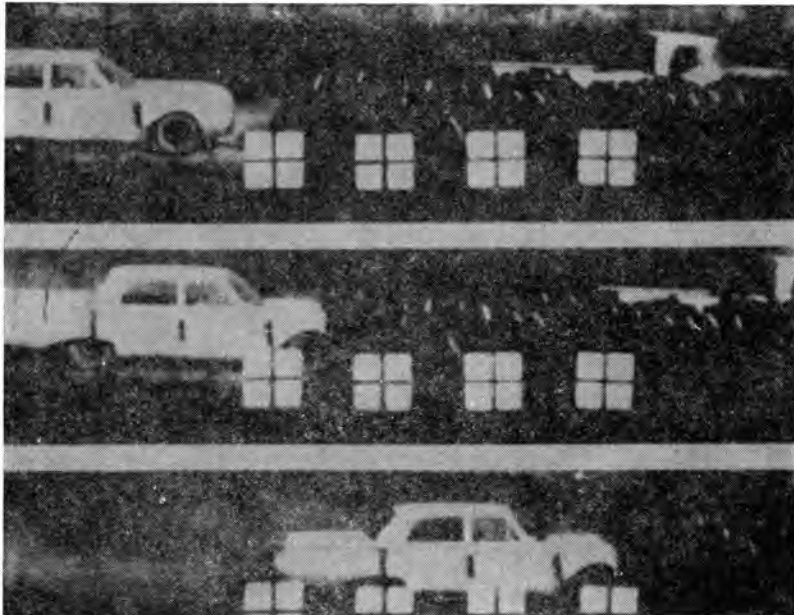
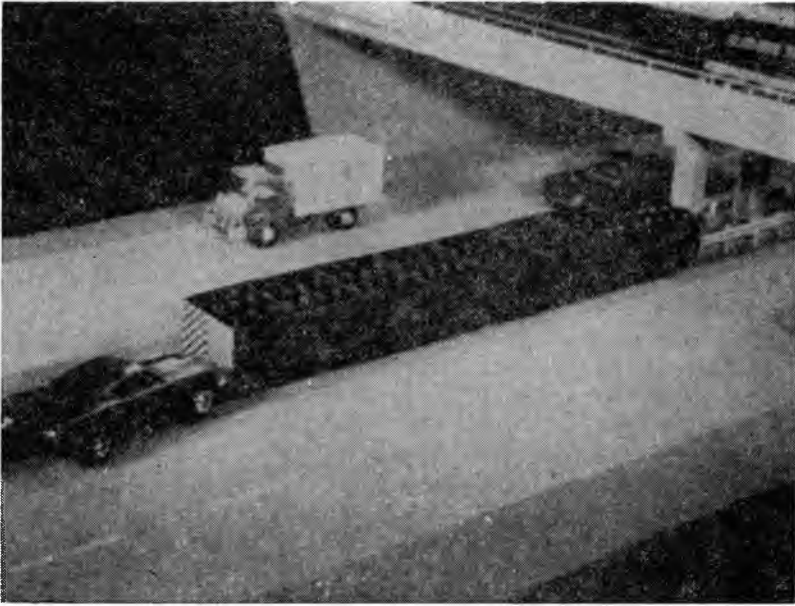


Figure 35a



**Figure 35b**

with no damage within 60 ft, at a deceleration of about 2 g's. Figure 34b shows the only Dragnet installation to date known to us. This device, near Galveston, Texas, performed as designed in the only accident reported to date; a 10 mph collision by a 2½-T truck, whose brakes had failed. Other Dragnet installations are under consideration for sites such as the space between twin bridges and for reversible lane control.

Goodyear Tire and Rubber Company has examined the feasibility of utilizing a long row of discarded automobile tires as a crash cushion. (34)

Figure 35a records the satisfactory progress of a 42 mph impact by a standard-size car. Stopping distance was 12 ft. Figure 35b is a photograph of a yet untested concept for a used-tire barrier in front of a bridge pier in the median. Further development of this concept is under consideration.

## ACCIDENT EXPERIENCE

The following is a summary of the in-service effectiveness of protective highway barriers to date as extracted from a Federal Highway Administration staff study:

"The best measure of the safety performance of barriers is actual documented accident experience. The Federal Highway Administration is currently gathering accident data on impact attenuators under a National Experimental Evaluation Program project. At the present time 38 states are participating in this program. Data on the 129 accidents known to us as of April 15, 1971, on these barriers are given in Table 1. Ninety percent confidence limits on the percent of accidents in which fatalities or injuries may be expected with these barriers are shown in this table. As can be seen, the sample size of our impact attenuator accident data is too small to attach statistical significance to the performance record of each type of device.

"Careful examination of these reports indicated that, had the attenuator not been present, hospitalizing injuries or fatalities would have been expected in 30 accidents as shown in Table 2. The effectiveness of these barriers is shown in that only three hospitalizing injuries and one fatality occurred in these 30 cases.

"The accident data of Tables 1 and 2 do not include Hi-Dro Cell clusters (an array of individual cells without 'fish scales'), which were designed for traffic speeds under 45 mph. Information available to us on these barriers indicates 60 accidents resulting in one fatality, eight injuries, and 51 property damage only collisions. The fatality involved a motorcycle.

TABLE 1—IMPACT ATTENUATOR ACCIDENTS

Attenuator Type	Total	Fatal	Injury	Percent	Fatal Plus
				Injury	Injury Accidents 90% Confidence Limits
Steel Drum	45	1	8	20	11-33%
FIBCO	58	0	5	9	3-20
Tor-Shok	13	0	7	54	28-80
Hi-Dro Cushion	12	0	2	17	3-45
Dragnet	1	0	0	—	—
<b>Total</b>	<b>129</b>	<b>1</b>	<b>22</b>	<b>18</b>	<b>—</b>

"Table 3 shows that 4.4 accidents per year have been experienced at gores where impact attenuators have been installed. Most of the installations to date have been in existing gores rather than in new construction, and in many cases, the attenuator has been installed in front of the existing parapet nose as shown in Figure 28. This, of course, reduces the amount of weaving room available in the gore area and increases the number of accidents that occur. In new construction and in some existing gores, the gore can be designed (or rebuilt as was done for the barrier shown in Figure 24) so that the attenuator occupies essentially the same space as a conventional bridge

parapet nose. No increase in the number of accidents would be expected in this case, and the provision of such space in the design of elevated exit ramps is now required in federal-aid projects." (35)

TABLE 2—IMPACT ATTENUATOR ACCIDENTS JUDGED LIKELY TO HAVE PRODUCED FATALITIES OR HOSPITALIZING INJURIES IF ATTENUATOR NOT PRESENT

Attenuator Type	Total	Fatal	Hospital- izing Injury	Minor Injury	Property Damage Only
Steel Drum	11	1	2	6	2
FIBCO	10	0	0	2	8
Tor-Shok	5	0	0	4	1
Hi-Dro Cushion	4	0	1	1	2
<b>Total</b>	<b>30</b>	<b>1</b>	<b>3</b>	<b>13</b>	<b>13</b>

TABLE 3—FREQUENCY OF OCCURRENCE OF ACCIDENTS WITH IMPACT ATTENUATORS IN GORES

Sites Examined	28
Accidents	95
Total Months of Exposure	260
Accidents/Yr. of Exposure	4.4

## CONCLUSIONS

Bridge rail and guardrail design has evolved over the years in an attempt to meet the needs of the times. The standards to which guardrails and bridge rails must perform have been made more demanding by the slow but steady increase in the average operating speed of vehicles in recent years. Researchers have been and are now responding to the needs for traffic railings with improved performance characteristics, and highway authorities have quickly put to practice the results of this research.

The lifesaving benefits of impact attenuators at roadside hazards have been indeed established through research and experimental construction. In recognition of this, the Federal Highway Administration has issued Instructional Memorandum 40-5-72 dealing with the provision for protective highway barriers. (35) The instructional memorandum directs that adequate impact attenuators shall be provided. To be specific, the memorandum states that:

"Henceforth, on all projects for freeways or high speed or high volume highways that include gores or other highway elements with

hazardous fixed objects the division engineer is not to approve PS&E submissions unless (1) the design provides adequate space for installation of an acceptable crash cushion and (2) there is definite arrangement for the crash cushion installation prior to opening the project to traffic."

Researchers have shown that fatalities, personal injuries, and property damage associated with highway accidents can be effectively reduced. Operational highway officials are accelerating the implementation of protective highway barriers whose effectiveness has been successfully demonstrated. This cooperative effort must be continued.

While emphasis in research, development, test, and evaluation of protective barriers has been concerned with high speed highway systems, the developed engineering technology can be applied to satisfying the needs in and around urban street and road networks. The interest to pursue programs in which this lifesaving technology will be applied to municipal and county road networks is commendable.

#### ACKNOWLEDGMENT

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