Break-Away Components Produce Safer Roadside Signs

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Studies of the behavior of certain types of roadside sign supports subjected to collisions are described in this paper. The selection of the types of supports considered was predicated on Texas Highway Department design procedures and the development of interim concepts which would minimize hazards. Certain devices were introduced into the sign supports, and full-scale crash tests were conducted to observe the impact behavior of supports containing these devices. These studies have resulted in revised design details which have been included in current construction operations in Texas.

The basic philosophy in the early studies has been termed phenomenological testing. The method employed was to tow a crash vehicle into a controlled collision with a sign support and to record the collision incident on high-speed photographic film, then to study the film and observe the qualitative behavior of the sign support subjected to a collision by an automobile. In later studies attempts were made to obtain displacement-time information from the high-speed film, and still later accelerometers mounted on the frame of the crash vehicle were employed to provide a deceleration-time trace on a recording oscillograph. The simultaneous use of photographic and electronic instrumentation has been the outgrowth of these earlier investigations. A corollary activity was the development of an electronic computer program to simulate the collision incident.

Phenomenological testing has been an important aspect in the testing procedure. Observation of films has produced a clear impression of vehicle and sign behavior. Improvements in camera technique and film data reduction, combined with electronic instrumentation and data reduction have augmented and extended the phenomenological testing. These improvements have produced quantitative analytical information. The mathematical model has been a product of the phenomenological testing and the quantitative testing.

•IN HIGHWAY design, roadside signs have been employed in increasing numbers, mainly because of the increasing mileage of completed Interstate highways. Many factors have been considered in the design of the sign supports for roadside signs. Normally, these supports consist of two vertical cantilever wide-flange beams which are strong and stable when subjected to wind forces. They have aesthetic quality, support a readable sign, are easily maintained, and are located adjacent to the roadway. In short, the sign support is excellent, but lethal. It is this last characteristic

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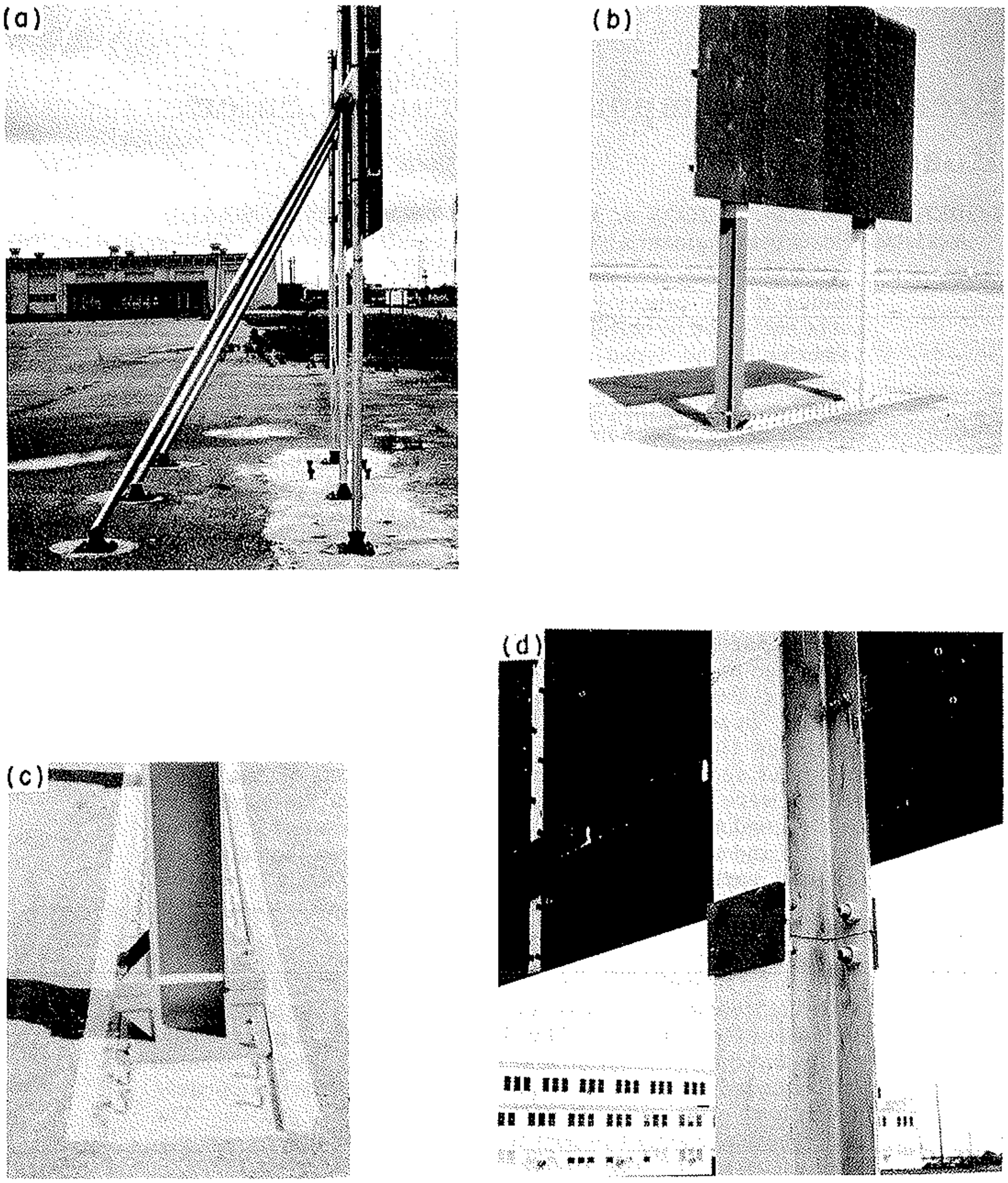

Figure 1. Developmental characteristics of sign supports: (a) braced-leg structure, (b) unbraced post support, (c) slip base, and (d) fracture joint.

which has motivated this study. In 1962 alone, highway sign accidents in Texas resulted in 15 traffic fatalities, and by 1965 the toll had risen to 39.

In 1963, the Texas Transportation Institute (TTI) and the Texas Highway Department, in cooperation with the U. S. Bureau of Public Roads, became actively engaged in studies of the impact behavior of roadside sign supports. From the standpoint of public safety, it was imperative that some means be found to reduce the hazard of collisions involving roadside sign structures. To accomplish this objective, engineers of the Bridge Division of the Texas Highway Department worked in close cooperation

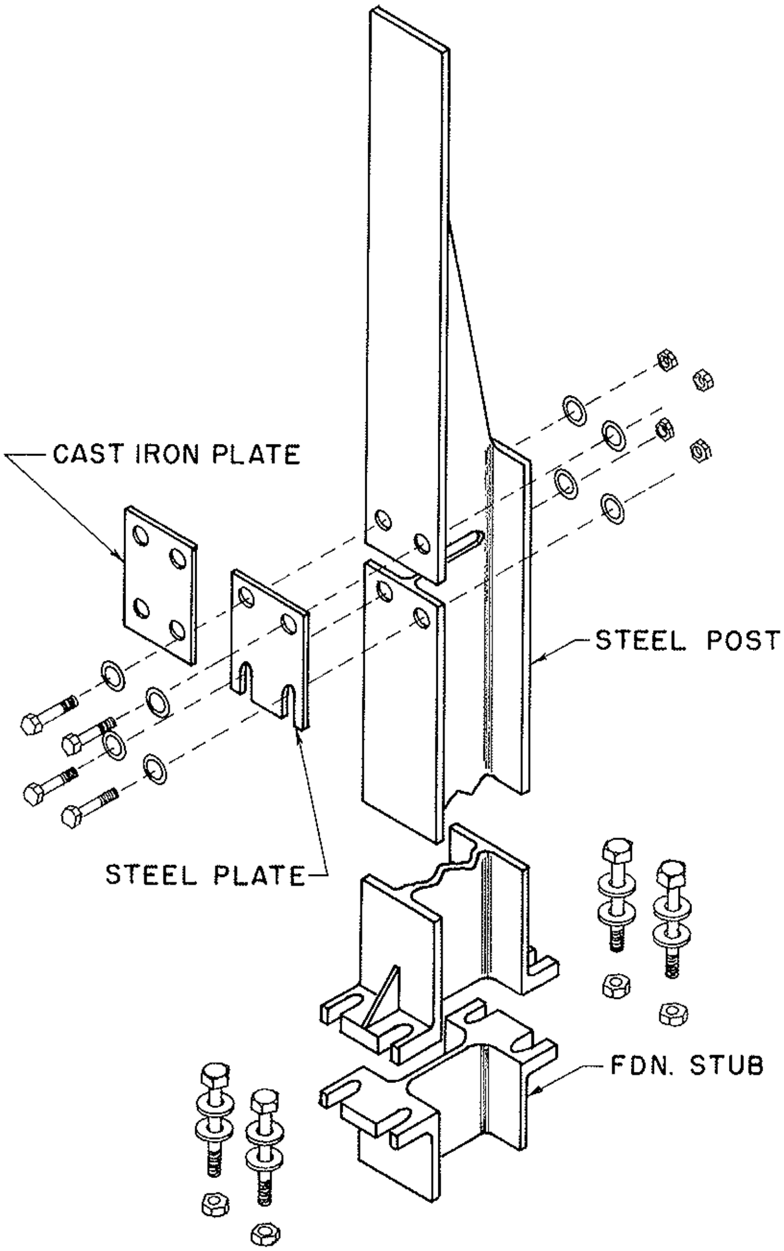

Figure 2. Break-away details.

with the TTI research staff. The project was a team effort in which engineers of the highway department performed the developmental design work, and the research staff of TTI concentrated on development of test facilities, testing, and evaluation.

Most of the earlier research, particularly that reported herein, was devoted to obtaining an immediate solution to a safety problem. Substantial mileage of the Interstate System in the state was under construction or scheduled for construction, and there was an urgent need to develop better design standards for roadside signs. Engineers of the Texas Highway Department proposed basic design concepts, and these were incorporated in experimental designs. These designs were tested, and after each test or series of

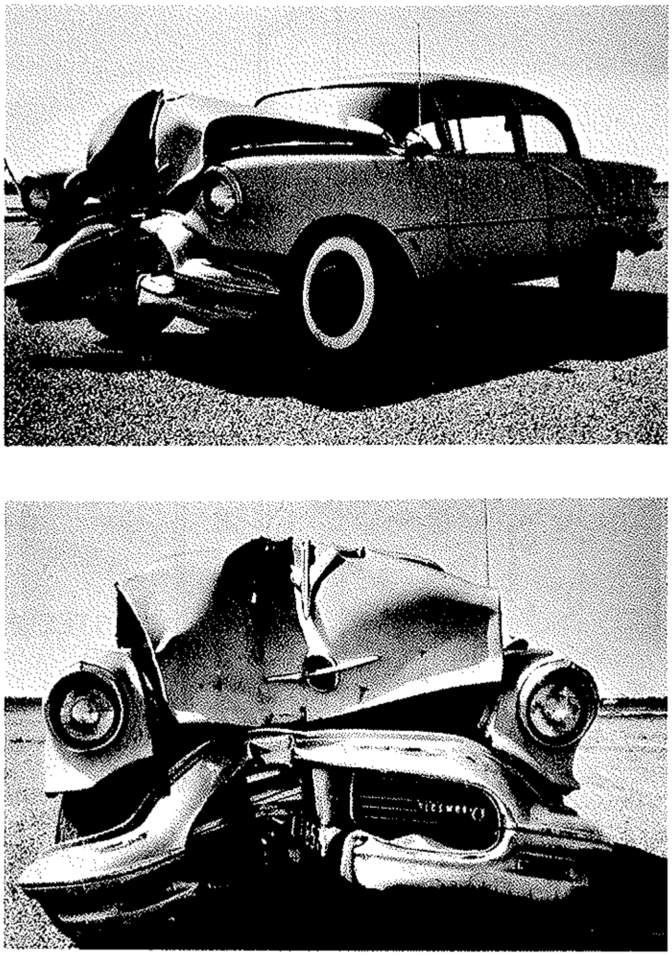

Figure 3. Vehicle damage, slow-speed fixed post test.

tests was conducted, certain design modifications were made to improve the impact behavior of the supports. Because of the extremely close cooperation between the agencies involved, the new design concepts were incorporated in the design standards for the state as soon as they had been proven by test and evaluation by TTI.

Facilities and procedures were developed to create controlled vehicle collisions with sign supports and to obtain time dependent data pertaining to a collision incident. To launch the crash vehicles into sign supports a "reverse tow" procedure was used. Photographic data were obtained at 1000 pictures per second. In later tests, electronic instrumentation, including strain gages and accelerometers, was employed in data acquisition.

A mathematical simulation was developed which expresses quantitatively the dynamic behavior of a sign support subjected to impact by a vehicle. The results from tests were correlated with typical results from the mathematical model.

LARGE SIGNS

The first phase of research was concerned primarily with the development of safer sign supports for large roadside signs. The spacing of support posts in large signs is such that automobile collisions involve only one support. Consideration of accident reports and photographs of damages resulting from collisions with these supports led to a hypothesis that three primary characteristics of the sign support contribute substantially to the severity of a collision: the mass, the structural rigidity or stiffness, and the condition of fixity at the base of the sign support.

In the initial phase of the research special attention was focused on what was referred to as a braced leg structure (Fig. 1a) which constitutes a reduction in mass and structural rigidity. Three tests were conducted on this type of support, two of which employed a safety feature called a fracture joint, which was formed by cutting the tubular supports 6½ ft above the foundation and inserting a cast aluminum core which had high static strength but low impact strength. As verified by high-speed motion pictures of the crash tests, the colliding vehicle ripped out the lower sections of the support structure with little resistance or damage to the vehicle.

From the standpoint of design, construction, and maintenance, the development of the unbraced post support which would slip under impact of collision (Fig. 1b) was chosen for study. To provide satisfactory impact characteristics, it was necessary to develop a base connection which would withstand the overturning moment induced by windloads and at the same time would break away under the force of a collision. The base connection is referred to as a break-away base (Fig. 1c). The lower post stub is bolted to a universal testing foundation at the test site; the stub is normally embedded in a concrete foundation in roadside installations. Both the base of the post and the foundation fitting are slotted to receive bolts which hold the post in an upright position. These slots permit the bolts to slip out, releasing the post when impact occurs.

The earlier tests on this type of support (1) showed that the break-away base functioned satisfactorily, but there was a further need for the post to fold up out of the way, and permit the colliding vehicle to pass under the post. A fracture joint was introduced in the post 7 ft above the foundation (Fig. 1d). This fracture joint was formed by cutting the post and reconnecting it by bolting cast-iron plates to the front and back flanges. It was anticipated that the fracture joint would permit the lower portion of the post to break free. In the full-scale crash test of this concept the break-away base functioned adequately; the fracture joint failed, permitting a portion of the post to bounce on the hood of the vehicle and break the windshield of the automobile. Obviously, this behavior was considered unsatisfactory.

Another modification was needed to allow the post to swing up to clear the colliding vehicle. This was accomplished by replacing the fracture joint with a "hinge joint." The front flange and the web were cut leaving the back flange intact (Fig. 2). The front of the post was then reconnected by a cast-iron plate bolted to the front flange. It was anticipated that the cast-iron plate reconnecting the front flange would fail in tension; then the back flange of the post would serve as a hinge to permit the lower section of the post to fold up out of the way of the colliding vehicle. Three full-scale crash tests were conducted to verify this behavior. In these tests, the design utilizing the hinge joint was struck at speeds of 25 to 50 mph and the lower section of the post folded up, clearing the automobile. Relatively minor damage was incurred by the automobile during impact. The third of these tests was performed to evaluate the impact behavior of the support when struck at an angle to simulate the condition of a vehicle leaving the roadway. The angle of impact, or the angle or incidence for the crash test was established at 15 deg. The selection of this angle was based on previous research which indicated that approximately 95 percent of vehicles leave the roadway at angles of 15 deg or less (2).

Difficulties in casting, handling, bolting and maintaining cast-iron fuses led to the development of an alternate fuse fabricated from steel plate with slots at one pair of bolt holes (Fig. 2). This slotted steel plate is currently specified in Texas Highway Department Standards.

The research and development work described in the foregoing and subsequent discussions was performed at the crash test facility located at the Texas A and M Research Annex. This crash test facility was developed to permit the launching of vehicles into full-scale sign supports under controlled collision conditions. The method employed to launch the vehicles is referred to as the "reverse tow" procedure, since the tow vehicle moves in a direction opposite to the crash vehicle (1, pp. 1-3). The

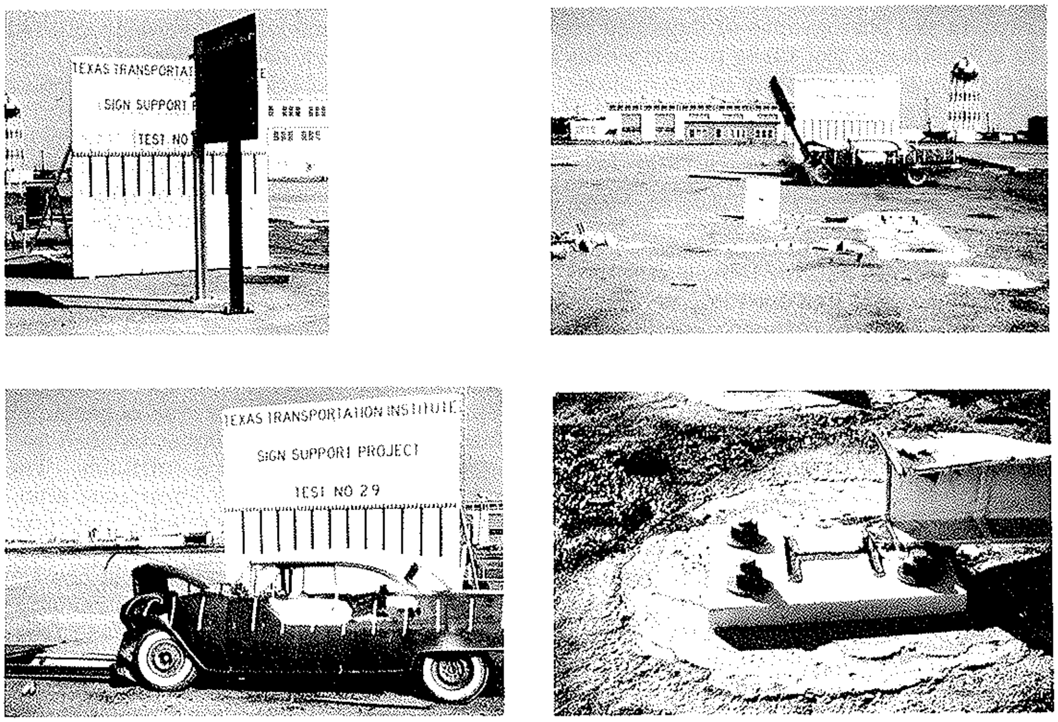

Figure 4. High-speed fixed post test.

two vehicles are connected by a cable and a system of pulleys, the crash vehicle being guided along a rail fastened to concrete pavement. A release mechanism is provided to disengage the cable prior to impact of the crash vehicle with the test element.

SMALL SIGNS

There are numerous signs in use on controlled-access facilities which have small post spacing; thus, a vehicle can collide with both the supports. Such signs constitute a different problem. Improving the safety of this type of sign is important because these signs are employed at points where the probability of being struck is great. A common location of smaller signs is in the gore of an exit ramp, where the sign constitutes the reference point for final action by a driver. Driver indecision contributes to collision with such signs.

Although accident records clearly indicated that conventional gore signs do constitute a hazard, it was desirable to conduct full-scale crash tests of the conventional design to establish a comparison for experimental designs. Full-scale crash tests were conducted using signs fabricated in accordance with the Texas Highway Department Standards for Interstate Signing (SMD-4). The design selected was a 5 by 6-ft plywood sign supported by two posts $3\frac{1}{3}$ ft apart. The posts were 5-in. WF 16# beams of A36 grade structural steel.

A test of this design was scheduled to obtain high-speed motion pictures of the crash. It was planned that the vehicle would strike both legs of the support. A mechanical failure in the automobile transmission impaired the speed and direction, and the vehicle veered to the left after its release from the towing mechanism. As a result, the vehicle struck the left leg of the sign near the center of the hood. The crash speed was later calculated at 22 mph. The damage effects of this collision are shown in Figure 3. The sign installation was not damaged appreciably, and another test was conducted immediately. The vehicle, a 1955 Pontiac, struck both posts simultaneously at a speed of approximately 55 mph. The sign supports failed in the weld at the base plate, but

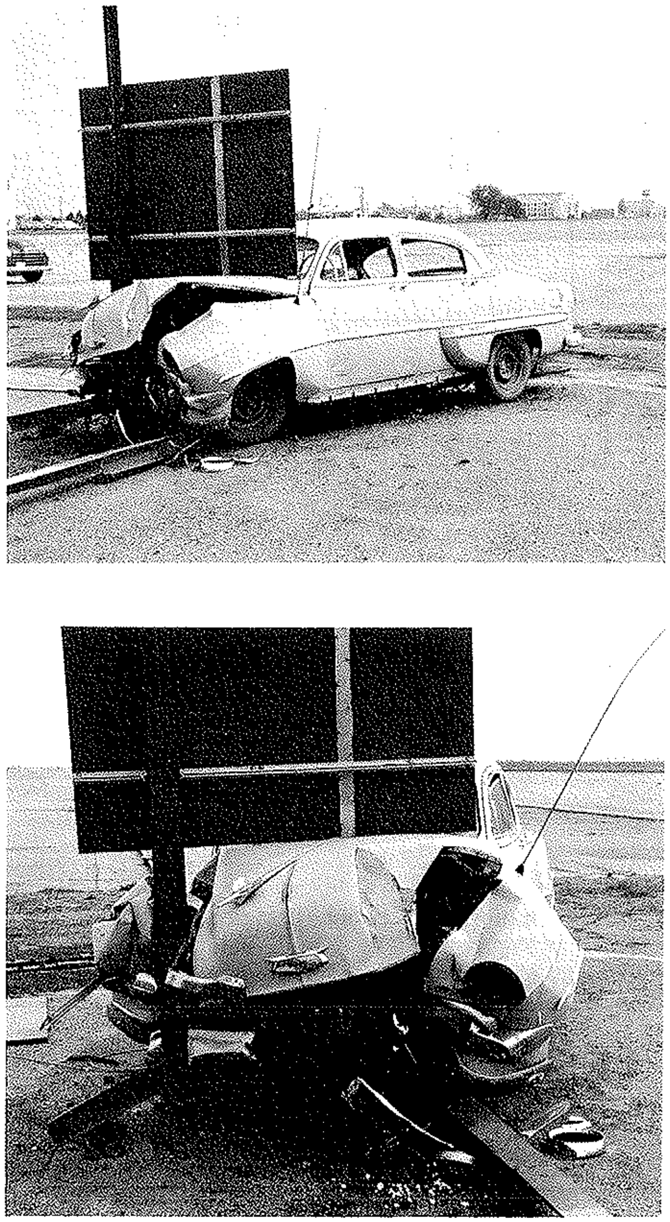

Figure 5. Crash Test No. 32.

failure occurred after much of the impact energy had been dissipated (Fig. 4). A final test on a fixed-base interstate-type sign support was conducted primarily to obtain accelerometer data for comparison with film records. Figure 5 shows the vehicle and sign following the crash.

Experimental Designs

The results of the crash tests involving conventional types of small dual support signs emphasized the need for improved safety aspects. As satisfactory performance had been attained in the large signs using a break-away base and hinge joint, these

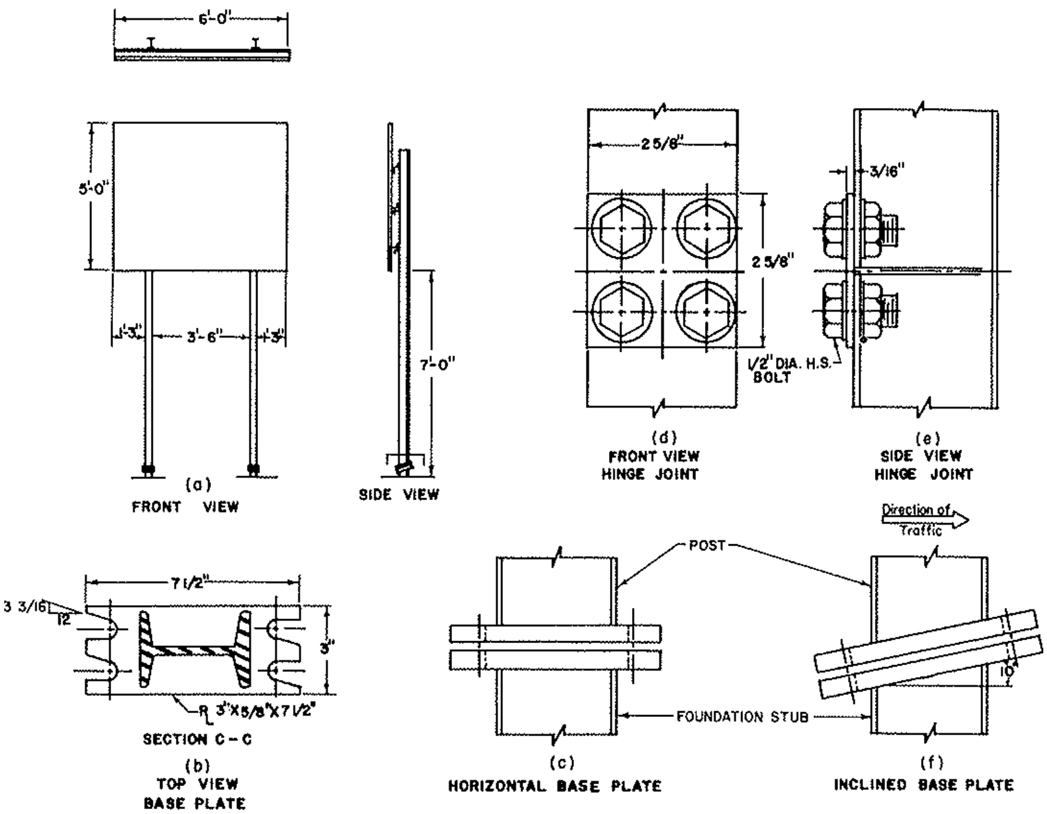

Figure 6. General details of small sign.

same safety devices were employed in the small signs. Details of the experimental sign supports are shown in Figure 6. The 3-in. I-beam supports are capable of withstanding wind velocities up to 70 mph. A 4-in. I-beam would be required to withstand wind velocities to 100 mph.

The break-away base for the small signs is similar to the base used in the large signs. Four bolts were used to hold the sign support in place (Fig. 6b and c). These bolts were torqued to 450 in.-lb. The hinge joint was formed by cutting the front flange and the web of the I-beam 7 ft above the foundation and reconnecting it with a cast-iron plate (Fig. 6d and e).

The experimental design was subjected to full-scale crash tests to determine the effect of various parameters. These conditions were (a) crash speed, 25 and 55 mph (approximately); (b) angle of impact, 0 and 15 deg; and (c) impact condition, one or both legs struck. The effect of these parameters on the impact behavior was determined by observation and study of the high-speed motion picture films.

Speed

At 55 mph, the sign with horizontal base plates struck the trunk of the vehicle. However, at slower speeds (25 mph) the sign struck the top of the automobile face down and caused considerable damage. Sedans having steel tops would provide some protection for occupants of the vehicle. The sign rotated satisfactorily over the top of the automobile at high speeds. The variation in speeds at which the crash vehicle struck the sign support did not materially affect the amount of damage done to the front of the vehicle.

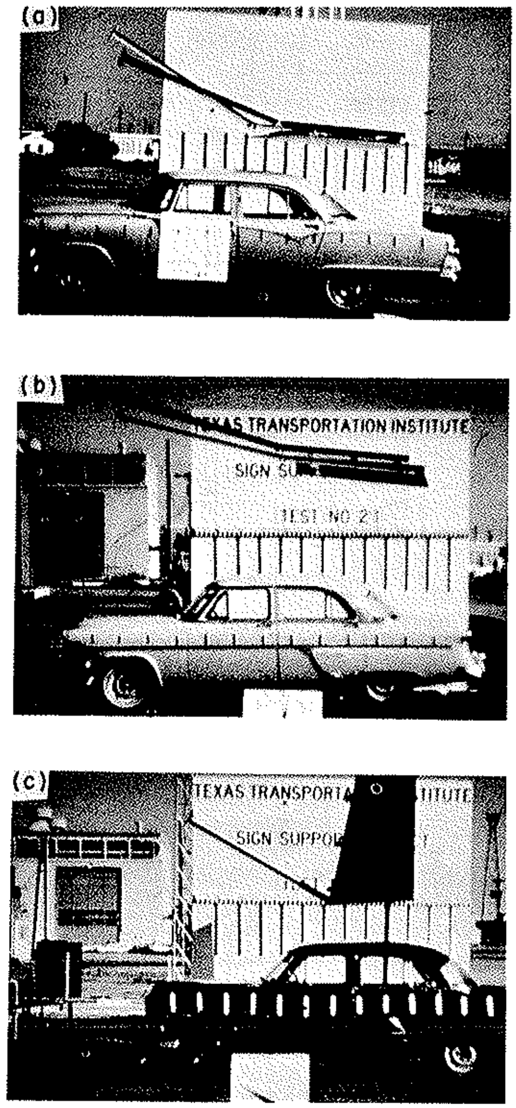

Figure 7. Impact behavior of small signs: (a) 50-mph test, horizontal base plates; (b) 25-mph test, base plates inclined 10 deg; and (c) single leg test.

Films of the slow-speed tests indicated that the slow-moving vehicle did not have time to clear the sign during its rotational passage over the top of the automobile (Fig. 7a). To elevate the sign over the top of the vehicle, the break-away base of each support was inclined 10 deg, as shown in Figure 6f. The inclined base forced the sign upward immediately after the base of both supports was released, and this added lift was sufficient to permit the vehicle to pass under the sign (Fig. 7b). When the sign was tested at a 15-deg angle, the total lift was not as great; however, the lift was sufficient to cause the sign to clear the vehicle at slow speed.

Angles of Impact

The impact behavior of the sign supports was not materially affected by changing the angle of impact from 0 to 15 deg. There was no difference in the damage sustained by the automobile, and there was no appreciable difference in the manner in which the sign rotated above the automobile after slipping free at the base.

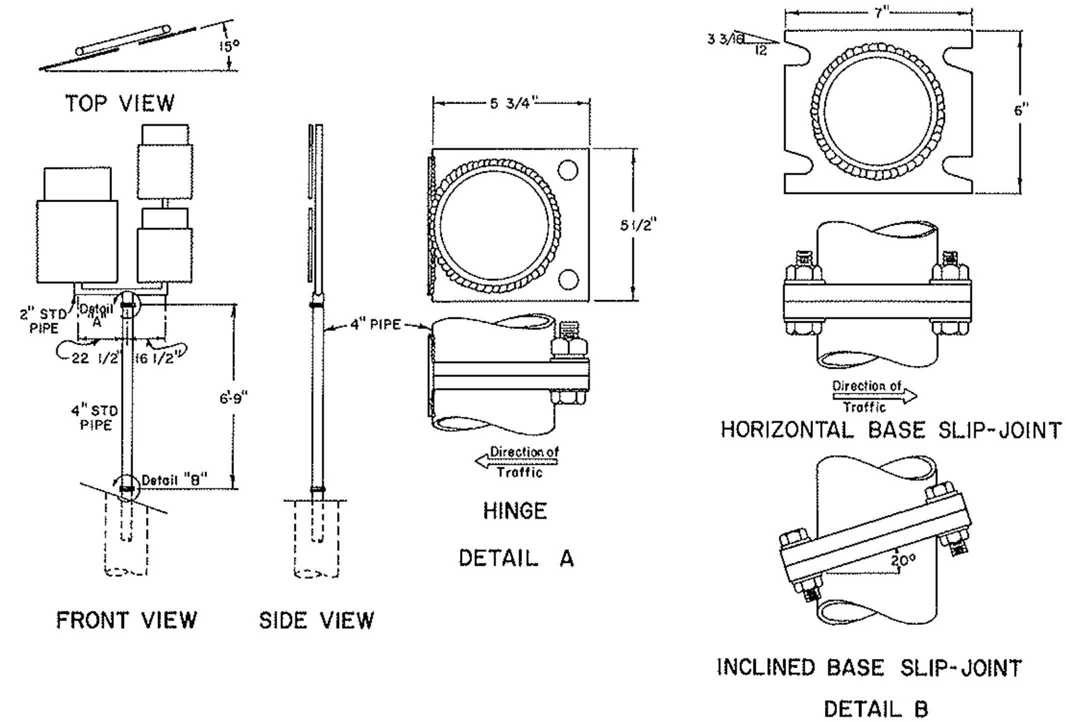

Figure 8. General details of pipe supports.

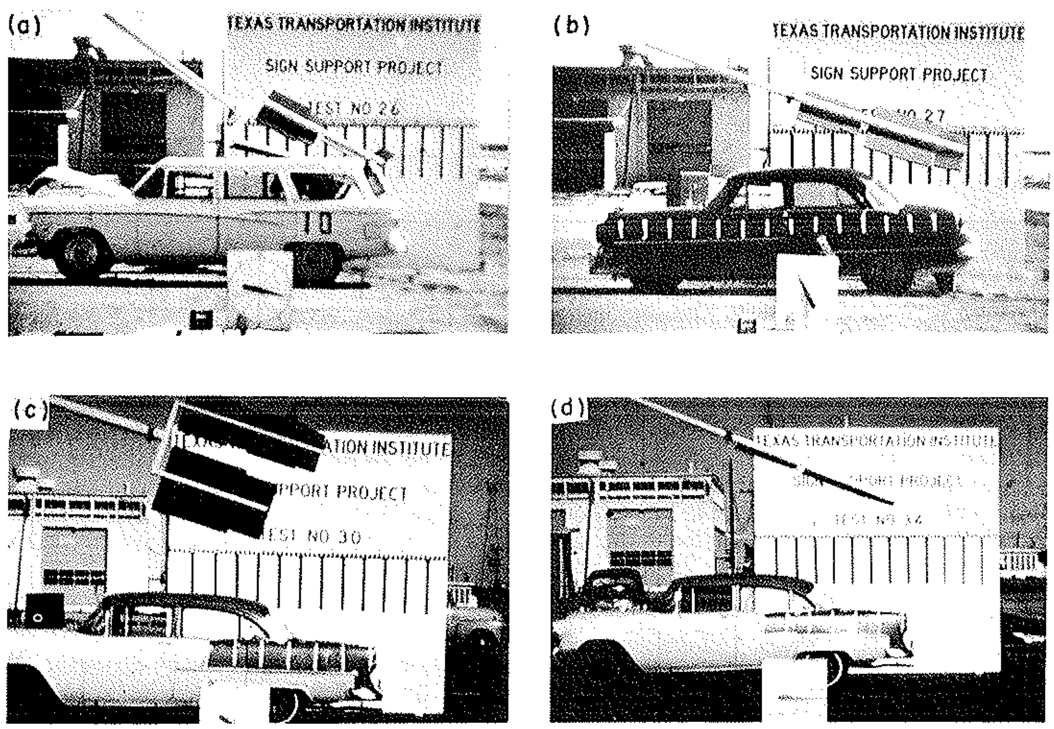

Figure 9. Impact behavior of single pipe supports: (a) 4-in. pipe support, horizontal base; (b) 3-in. pipe, horizontal base; (c) 4-in. pipe, base inclined 20 deg; and (d) 3-in. pipe, base inclined 20 deg.

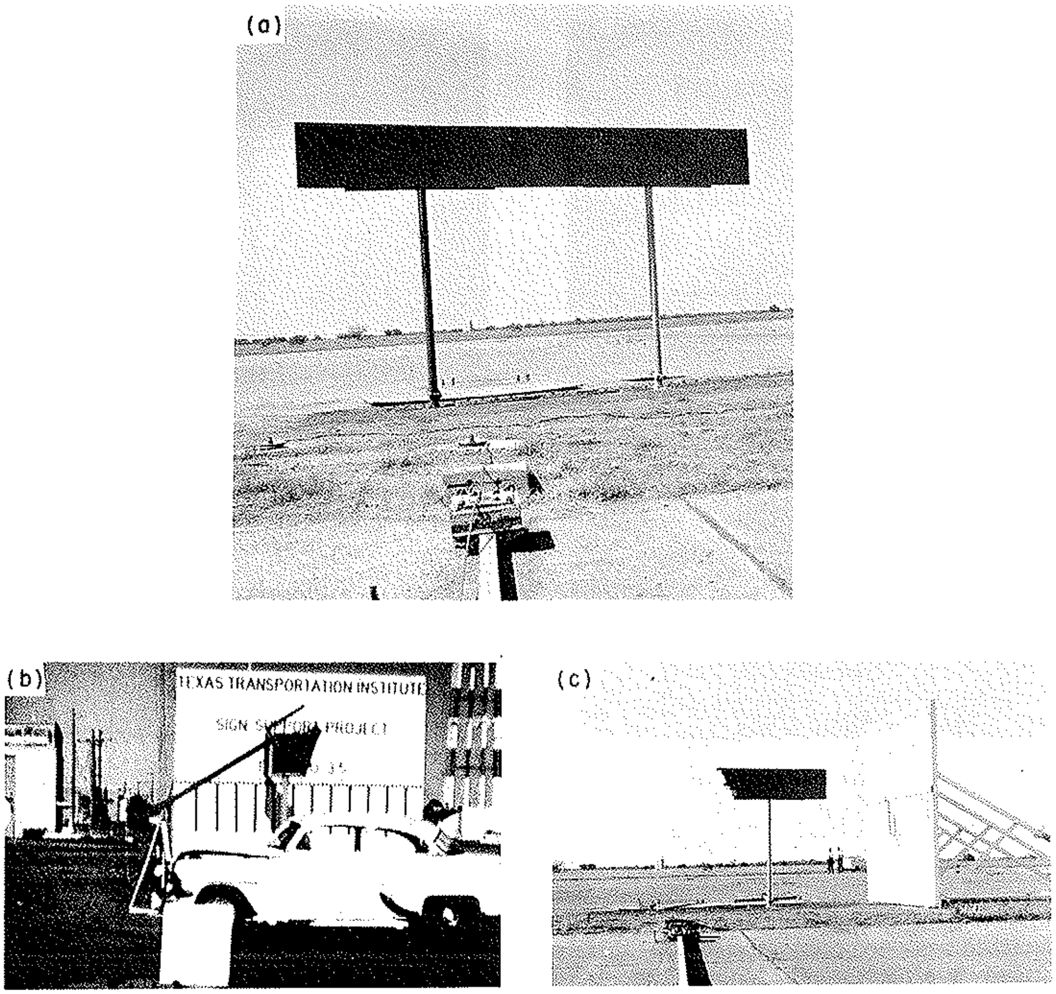

Figure 10. Dual pipe support test: (a) before test, (b) during test, and (c) after test.

In a test in which only the left leg of the sign was struck, the support was easily released at the base and the hinge joint functioned properly to permit the post to hinge up out of the way of the crash vehicle (Fig. 7c). After the vehicle had passed from under the sign, the sign itself rotated horizontally, causing the cast-iron plate on the hinge of the right post to fail, resulting in total sign collapse.

PIPE SUPPORTS FOR WARNING, REGULATORY, AND SMALL GUIDE SIGNS

Standard galvanized steel pipes ranging in diameter from 2 to 5 in. are frequently used for single supports for warning, regulatory and small guide signs. The signs are often located at decision points where the probability of collision is great.

A break-away base similar to that employed in the two-leg supports and a revised hinge joint were designed to fit the circular cross section of the pipe (Fig. 8).

In crash tests on 3-in. and 4-in. pipe supports at a speed of 45 mph, the slip base functioned properly, and the impact caused only minor damage to the front of the automobile. However, the hinge did not function and a secondary collision was experienced when the sign supports struck the roof and trunk of the crash vehicles (Fig. 9a and 9b).

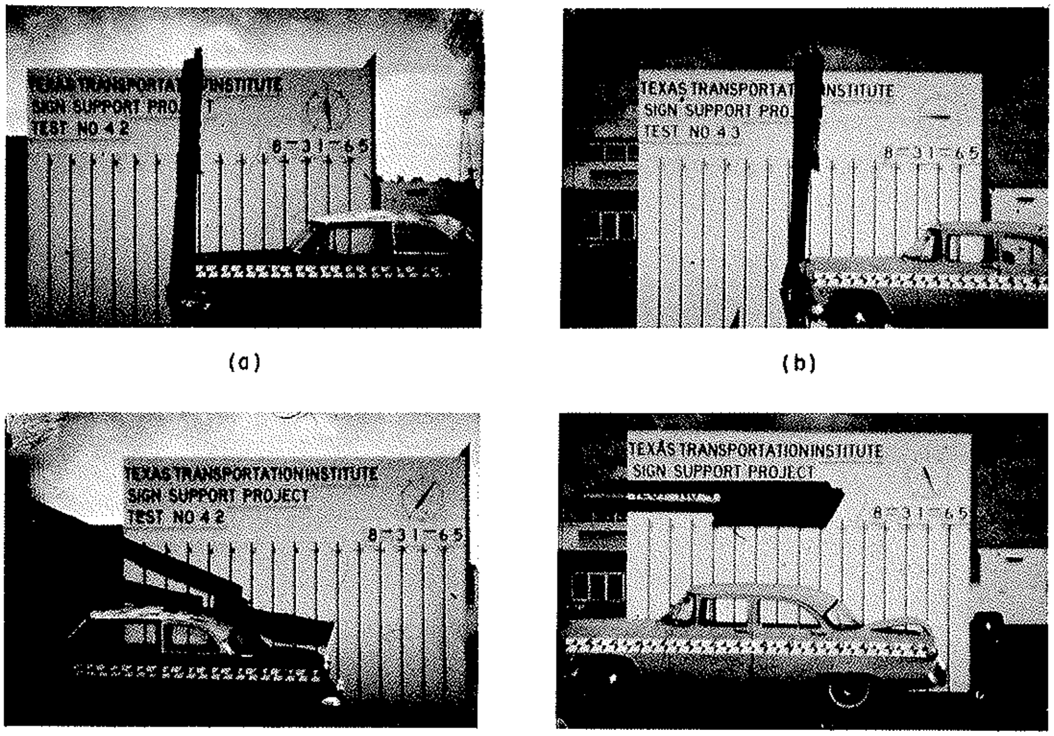

Figure 11. Wood post tests: (a) Pennsylvania design, and (b) TTI design.

Although vehicle damage was not severe, an alternative was sought to avoid the secondary collision. The break-away base was inclined 20 deg as shown in Detail B in Figure 8. Both the 3-in. and the 4-in. pipe supports were modified to incorporate the inclined base and subjected to full-scale crash tests. In both tests at 35 mph, the inclined base functioned properly, and the impact caused only minor damage to the front of the vehicles. Once the base slipped, the sign pitched upward and over the top of the automobile; thus, the secondary collision was avoided.

Dual Pipe Supports

In some instances where direction signs exceed 13 ft in width, dual pipe supports are used (Fig. 10a). A full-scale crash test was conducted using a typical dual pipe design (Fig. 10b). A slip base inclined at a vertical angle of 20 deg was employed. The sign was attached to the sign rack of each post by post clamps bolted to the plywood sign faces.

The sign was oriented at an impact angle of 15 deg. The vehicle struck the left post at a speed of approximately 30 mph. The bumper, the grill, and the hood were deformed approximately 8 in. before slippage occurred at the base of the post. Once the base slipped, the post rotated upward, swinging to the right. This rotation pulled the post partially loose from the sign, its horizontal movement finally caused the sign to break in half (Fig. 10c), and the left portion of the sign and the left support fell to the right of the vehicle. The sign functioned as a hinge in both the horizontal and vertical directions. It was concluded that the dual pipe mounts with a break-away base would perform satisfactorily. It is believed that the inclined base is beneficial because the post is thrust clear of the automobile.

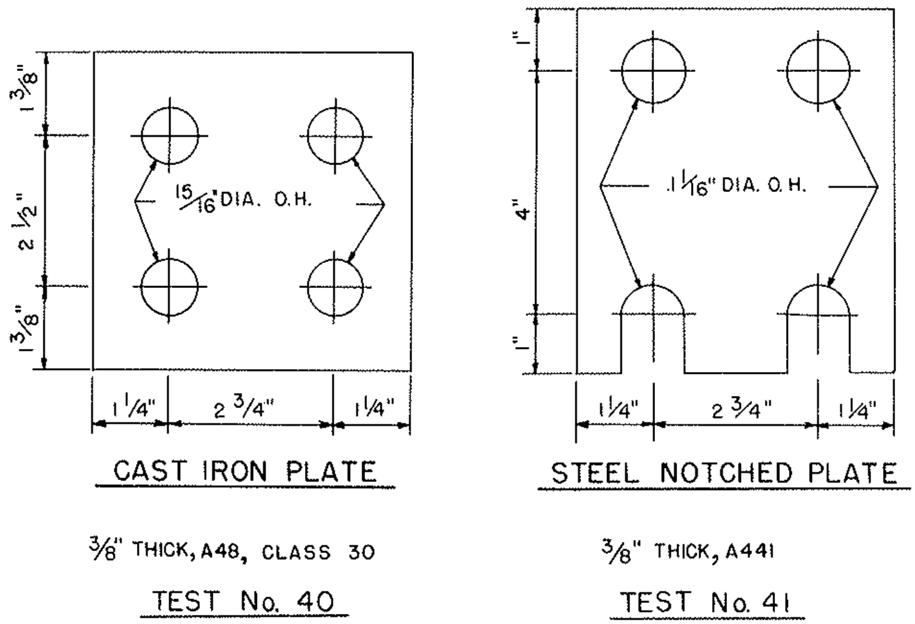

Figure 12. Mechanical fuse details.

WOOD POST SUPPORTS

In an effort to reduce a potential hazard, Pennsylvania is using notched wood posts as sign supports for gore or EXIT signs on some of its Interstate highways. These signs have been erected on an experimental basis on I-90, along Lake Erie. Accident reports have indicated satisfactory impact behavior (4), but these reports yield no information concerning phenomenological behavior. Controlled crash studies were conducted by TTI on the Pennsylvania design and an alternate experimental design, termed the TTI design.

The Pennsylvania design for a 5 by 6-ft EXIT sign normally placed at the nose of the exit ramp was made of extruded aluminum panels, and was supported by two 6 by 8-in. penta-treated pine posts. Wedge shaped notches were cut in the front and rear edges of each post. The posts were trimmed to a 4 by 6-in. rectangular cross section at the base and inserted into sheet metal sleeves embedded in the concrete foundation.

As an alternate to the Pennsylvania design, a design utilizing 4 by 6-in. treated pine posts was developed. To provide a reduction in shear capacity at the base, a ½-in. drill was used to make an oblong hole 2 in. wide through the post below the bumper level. This hole did not materially reduce the capacity of the post to withstand an overturning moment due to windloading because the hole was located at the neutral axis.

Before the crash studies were conducted, limited tests were performed to determine the dead load capacity of the support. Dead load weights were applied to the sign in 50-lb increments; failure occurred when 850 lb had been applied. The load causing failure is comparable to a load of 825 lb that would result from a 100-mph wind according to AASHO specifications.

Both designs were subjected to full-scale crash tests to determine their impact behavior. The signs were erected so that the crash vehicle hit both supports of each design simultaneously at approximately 45 mph.

Pennsylvania Design

When the vehicle collided with both supports (Fig. 11a), the left support broke at the lower notch after the post had deformed the front bumper approximately 4 in. Failure

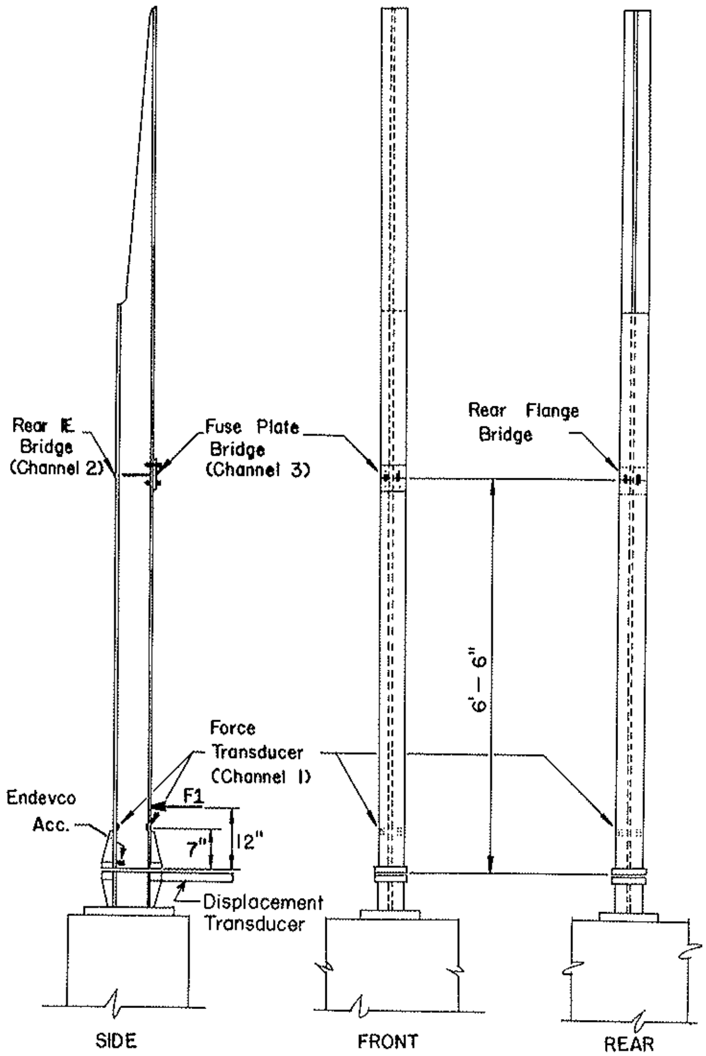

Figure 13. Post instrumentation.

in the right post then followed, beginning at the lower notch on the front, and progressing to its back edge at the foundation.

After the posts sheared at the base, the sign and supports were thrust forward and upward. The sign slipped off the angles to which it was clamped, leaving the posts in rotational motion. The upper end of the right post struck the top of the vehicle over the rear seat, deforming the top approximately 4 to 5 in.

TTI Design

When the vehicle struck both posts simultaneously, the left support broke in two approximately 3 in. above the bumper (Fig. 11b). The break was influenced by a knot in the timber. The post then broke off at the top of the foundation. The section of the post containing the elliptical hole was intact after the test. The right post failed by shearing in front of the hole and splitting from the back of the hole to the top of the foundation. The front bumper was deformed about 3 in. before post failure occurred. After the posts were broken from the foundation, they were thrown clear of the automobile, rotating over its top.

INSTRUMENTED CRASH TESTS

As discussed previously, high-speed motion picture films were made of each of the crash tests. Crash testing and studies led to the conclusion that quantitative data were needed to corroborate developmental design assumptions. A literature search revealed that other investigators had conducted instrumented full-scale crash tests of automobiles with a variety of fixed objects. Severy, et al (5) conducted a series of collisions with fixed barriers. Some of the experiments utilized instrumented vehicles and anthropometric dummies. Beaton and others subjected concrete bridge rails (6) and median barriers (7) to full-scale automobile impacts. Lundstrom and Skeels (8), Henault (9) and Jehu (10) performed research on different types of guardrails subjected to impact. British investigators including Moore (11), Christie (12), and Blamey (13), investigated lighting poles, lamp columns, and telegraph poles subjected to collision by automobiles. The automobile industry in the United States has conducted crash tests for many years. Stonex (14) has reported the development of crash research techniques at the General Motors Proving Ground. Important experiments concerning human exposures to linear deceleration were conducted by Stapp (15) at Muroc Air Force Base, Calif.

Study of these works led to the belief that instrumentation utilizing available equipment could produce quantitative data susceptible of analysis. A series of three tests was conducted in the spring of 1965, in which high-speed motion picture records were supplemented with accelerometers attached to the crash vehicle and strain gages mounted on the break-away posts. These early tests produced encouraging results, and an additional series of tests was proposed for July 1965.

Description of Tests

Tests 32, 33, and 35 were conducted in March and April 1965 and Tests 39, 40 and 41 were conducted in July 1965. Tests 32 and 39 were conducted on two-leg supports, bolted firmly to a concrete drilled footing. The remaining four tests were conducted on break-away type sign supports.

In Test No. 40 the break-away type post was fabricated in accordance with THD Standard SMD-8; and in Test No. 41 certain modifications were made. These are discussed in detail later. Figure 12 shows the type of mechanical fuses used in these tests.

Test No. 39

Construction Details—The sign supports were constructed in accordance with Texas Highway Department Interstate Standard Roadside Plywood Guide Signs (SMD-4, Rev. 1962). Details of the signs are as follows:

Size of sign face:	8 ft by 16 ft by $\frac{5}{8}$-in. plywood
Support posts:	2-8WF 20 (A36 steel, painted)
Windbeams:	3-3Z 2. 33 (6061-T6 aluminum)
Foundation:	24 in. by 8-ft drilled concrete footing
	Four $1\frac{1}{4}$ in. by $2\frac{1}{2}$-ft anchor bolts

Crash Vehicle Description—A 1955 Ford V-8, 4-door sedan weighing 3240 lb was used in this test.

Crash Vehicle Instrumentation—An Endevco Accelerometer, Model 2211C, was mounted on the left main frame member 9 ft behind the most forward bumper point. An amplifier and power source were placed in a wooden box and bolted to the floor of the trunk. The signal generated by the accelerometers was transmitted to a recording oscillograph by means of 1000-ft, 4-conductor, shielded cable (Belden 8404).

Post Instrumentation—A strain gage bridge was installed $6\frac{1}{2}$ ft above base of post on front and rear flanges (Fig. 13).

Test No. 40

Construction Details—The sign support was constructed by a commercial fabricator in accordance with Texas Highway Department Interstate Standard Roadside Plywood

Guide Signs, Break-Away Type Posts (SMD-8, 1965). This standard was modified by the substitution of aluminum Zee sections for windbeams in place of extruded aluminum windbeams specified by the standard drawings. The Zee sections were bolted to the flanges of the support post, thus eliminating the post clamp as specified on the drawings. These modifications were made to insure that the support post would remain fixed to the windbeams, thus permitting the cast-iron fuse to fracture, and the lower portion of the support post to elevate over the crash vehicle.

Construction details of the sign are as follows:

Size of sign face:	8 ft by 16 ft by ⅝-in. plywood
Support posts:	2-8WF 20 (A441 steel, hot-dip galvanized)
Windbeams:	3-3Z 2.33 (6061-T6 aluminum)
Mechanical fuse:	5¼ by 5¼ by ⅜-in. cast-iron plate (A48, Class 30)

Crash Vehicle Description—A 1955 Ford V-8, 4-door sedan, weighing 3240 lb was used.

Crash Vehicle Instrumentation—The vehicle instrumentation was identical to that described for Test No. 39.

Post Instrumentation—Post instrumentation was similar to that shown in Figure 13.

Test No. 41

Construction Details—The sign and sign supports were constructed in accordance with Texas Highway Department Interstate Standard Roadside Plywood Guide Signs, Break-Away Type Post (SMD-8, 1965) with certain modifications. Aluminum Zee sections were used in place of extruded sections for windbeams and these sections were bolted to the support post as described in details for Test No. 40.

A further modification was the substitution of a notched plate in place of the standard cast-iron fuse. The support post was fabricated by TTI personnel from A36 steel. This modification was necessary to meet the testing schedule.

The ungalvanized mechanical fuse was fastened to the support post by using 1-in. diameter A325 high strength bolts. Other details are as follows:

Size of sign face:	8 ft by 16 ft by ⅝-in. plywood
Support posts:	2-8WF 20 (A36 steel, painted)
Windbeams:	3-3Z 2.33 (6061-T6 aluminum)
Mechanical fuse:	5¼ by 5¼ by ⅜-in. notched steel plate (A441)

Crash Vehicle Description—A 1955 Ford V-8, 4-door sedan weighing 3620 lb was used.

Crash Vehicle Instrumentation—The vehicle instrumentation was identical to that described for Test No. 39.

Post Instrumentation—Post instrumentation is shown in Figure 13.

High-Speed Camera Instrumentation

Motion pictures were made of each test. A summary of the equipment used is given in Table 1. Many useful ideas were taken from reports by other investigators. Experience gained from earlier tests led to careful positioning of cameras, addition of stadia markers (reference targets) on the vehicle, and the location of the centi-revolution clock. This latter instrument was mounted on the backboard in Tests 39, 40 and 41. All of the changes were made to produce a better photographic record for analysis.

Philosophy of Instrumentation

The instrumentation employed in Tests 39, 40, and 41 was planned to provide corroborative information. The primary measuring device was the high-speed camera. The camera was operated in accordance with a characteristic curve furnished by the manufacturer so as to produce a nearly constant speed of 1000 frames per second. The centi-revolution clock was calibrated by stroboscopic light technique, which indicated

TABLE 1

PHOTOGRAPHIC INSTRUMENTATION—TESTS 39, 40 AND 41

Device	Description	Location	To Provide
High-speed motion picture camera	Wollensak, Fastax WF-3T 16-mm Kodachrome II daylight KR 449 film 1000 frames/sec	Camera A (see Figs. 2 and 3 of Ref. 3)	Crash vehicle time-displacement data
High-speed motion picture camera	Wollensak, Fastax WF-3 16-mm black and white Tri-X reversal TXR 430 film 1000 frames/sec	Camera B (see Figs. 2 and 3 of Ref. 3)	Crash vehicle time-displacement data (back-up for camera A)
Moderately high-speed motion picture camera	Kodak Cine Special II, 16-mm Kodachrome II, daylight KR 449 film, 64 frames/sec	Random positions	General views of crash test
Standard-speed motion picture camera	Bell and Howell 70 HR, 16-mm Kodachrome II, daylight KR 499 film 24 frames/sec	Random positions	General views of crash test
Stadia reference board	2 in. by 6 in. by 12-ft pine board with black and white spaces in alternate 12-in. increments	Adjacent to impact area	A fixed horizontal length reference
Stadia markers (reference targets)	6 in. by 16-gage sheet metal painted with 3 by 3-in. diamond-shaped black triangles on white background	On side of crash vehicle (see Fig. 24)	Length reference for analysis of high-speed motion pictures
Range poles	¾ in. by 8-ft pipe poles with black and white spaces in alternate 12-in. increments	Adjacent to stadia reference boards (see Fig. 24)	Fixed reference points
Centi-revolution clock	2-ft diameter clock face, divided into 100 intervals, clock hand attached to 1800 rpm synchromous electric motor	Mounted on backboard (see Fig. 24)	Time reference for analysis of high-speed motion picture film
Backboard	16 by 12-ft plyboard mounted on wood truss frame	See Fig. 24 and Ref. (3)	Background for photography and pertinent test information

that the clock hand revolves at 1800 rpm. Analysis of the high-speed film was accomplished by means of a Wollensak Fastax 16-mm motion analysis projector, Model WF 329B. This projector has a frame counter attached to its drive mechanism. The time of various events was thus determined by using the frame count and the centi-revolution clock.

Installation of piezoelectric accelerometers to furnish a record of apparent deceleration of the vehicle and acceleration of the support post was intended to provide data to compare with high-speed film data.

A radar speed meter was installed to provide a determination of speed before impact for comparison with values determined by high-speed motion picture analysis. In current tests, strip switches are employed to provide velocity before and after impact.

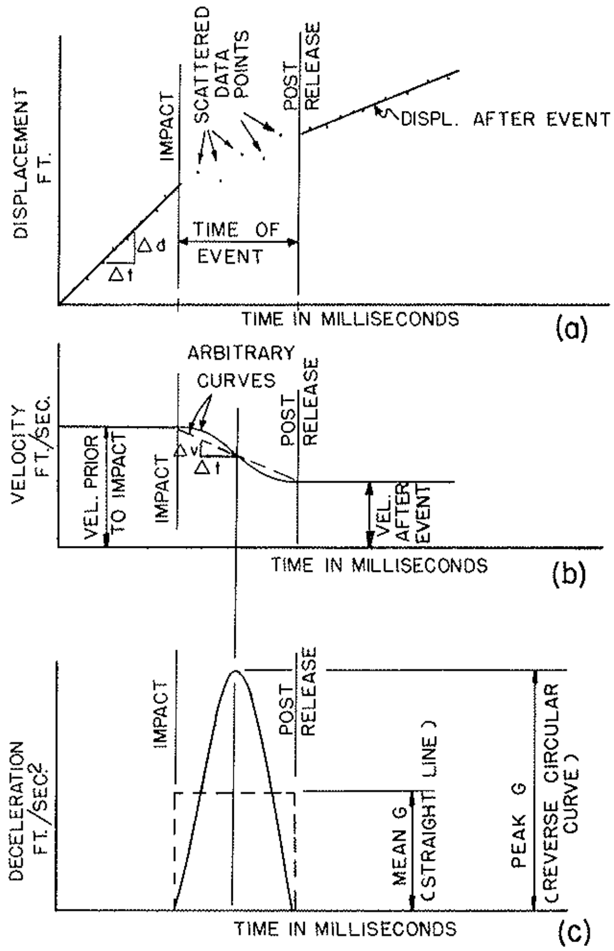

Figure 14. Film analysis by graphical differentiation.

High-Speed Motion Picture Analysis

The motion analysis projector is equipped with a speed control which permits frame by frame analysis. The stadia markers determine linear displacement of the vehicle. The film analysis is accomplished by bringing one of the stadia markers on the crash vehicle into range with a fixed vertical reference; range poles provide a fixed reference point on the film. The time is recorded, and the film is advanced frame by frame until the next stadia marker is brought into range, the time recorded, and the process is repeated. The recorded data are plotted as shown in Figure 14a. The slopes of the fitted curves indicate the vehicle velocity before impact, during the event (i. e., during the time the vehicle is in contact with the post), and following the event.

The slope of the displacement-time curve is plotted and yields the velocity-time curve (Fig. 14b). Similarly, the slope of this curve is the deceleration-time curve shown in Figure 14c.

The film speed used and the 3-in. stadia increment on the vehicle permit a reliable plot of distance-time curves before impact and following the collision. However, the scatter of points during the event permits a variety of curves to be fitted to the data. In Figure 14b two arbitrary curves have been fitted to the data, and as a result the slopes of these curves give a striking difference in the value of decelerations (Fig. 14c). Thus the process of differentiating distance-time curves and velocity-time curves

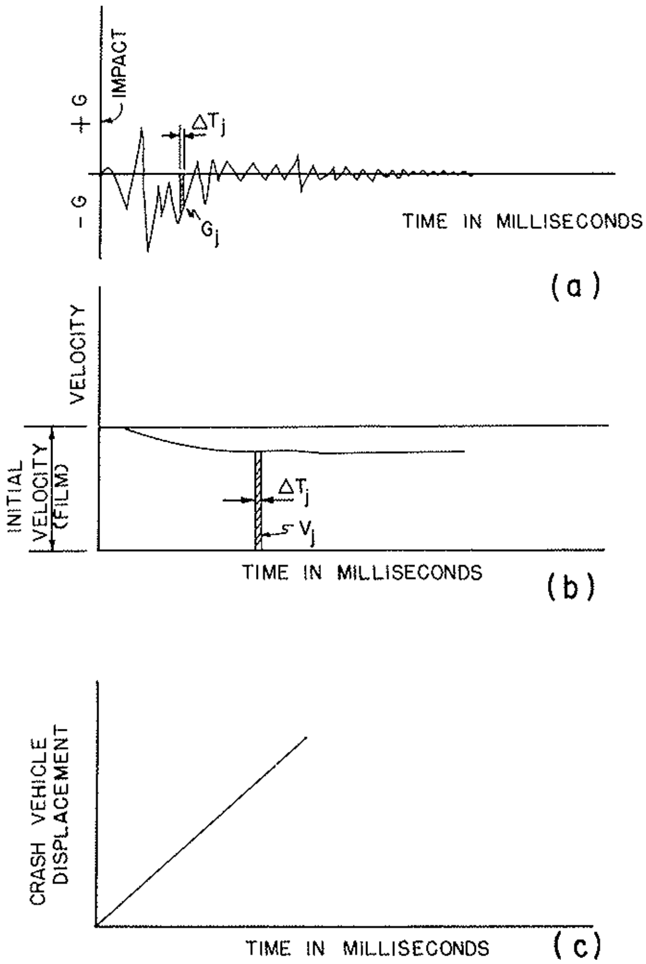

Figure 15. Accelerometer analysis by graphical integration.

produces magnification of minor irregularities. Considerable judgment is required in curve fitting. Even attention to variation of coordinate scales affects the results. The reproducibility of data reduction, therefore, is dependent on the technique employed. Severy and Barbour (16) report: "Application of poor curve fitting techniques may introduce errors as high as 100%, even though correct differentiation is applied to correct basic data."

Vehicle Accelerometer Analysis

A piezoelectric accelerometer was mounted on the frame of the crash vehicle. This accelerometer was located 9 ft behind the bumper impact point. The signal transmitted from this accelerometer was transmitted to a recording oscillograph, and a trace of time dependent deceleration was recorded.

The method of analysis is shown in Figure 15. This process depends on graphical integration. Three methods were employed in this study: (a) tracing the record on graph paper, counting squares, and computing the velocity-time data, (b) using a planimeter, and (c) measuring amplitude values of the acceleration trace for small time increments, then computing velocities and displacements by digital computer. The three methods employed produce results which are in good agreement.

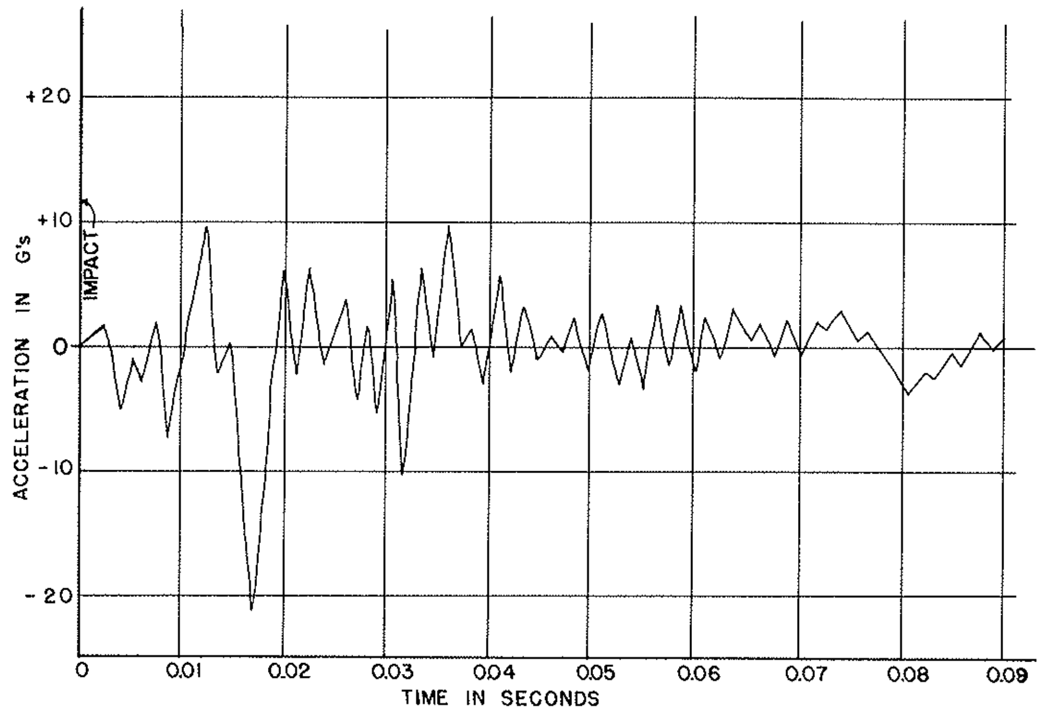

Figure 16. Test No. 41.

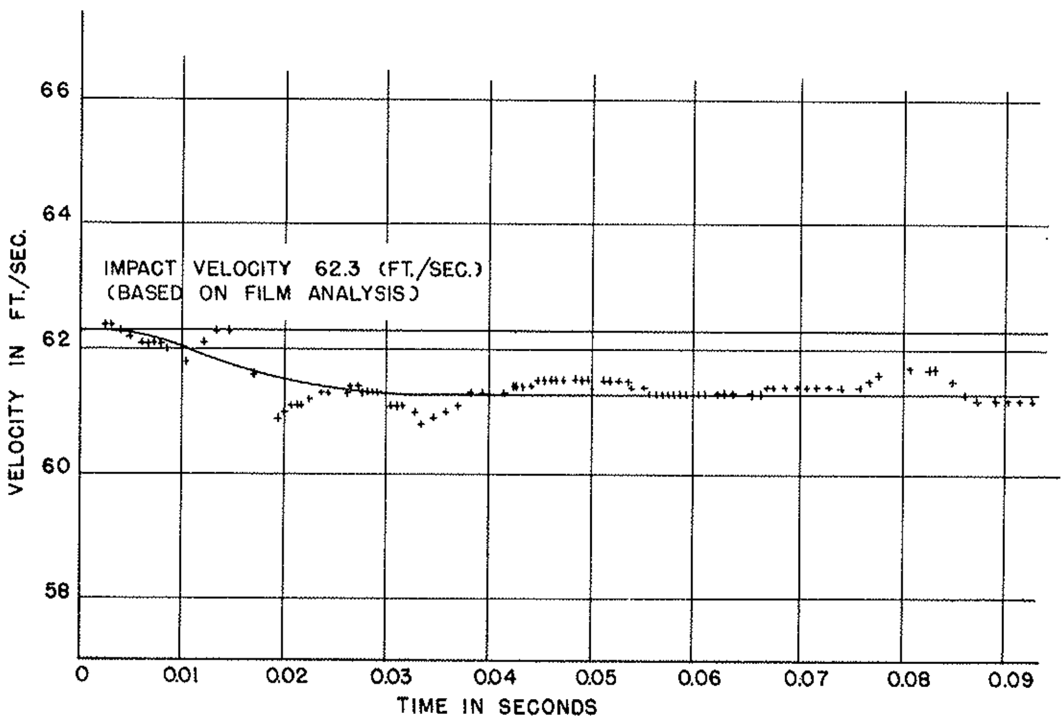

Figure 17. Test No. 41.

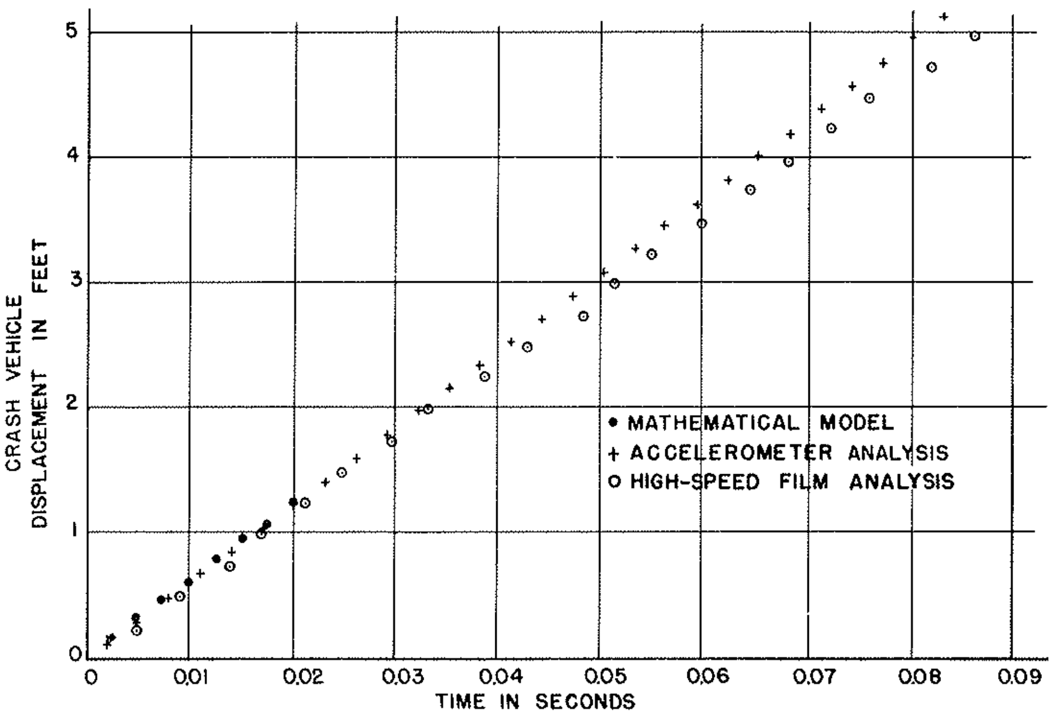

Figure 18. Test No. 41.

Starting with the deceleration-time curve (Fig. 15a) areas are computed, tabulated, and the velocity-time is plotted (Fig. 15b), and the integration process is repeated producing the displacement-time curve in Figure 15c.

This process of graphic integration produces surprisingly good results, as is discussed later. The magnification of minor errors found in the graphical differentiation technique does not occur in the integration process.

A typical set of curves for Test No. 41 is shown in Figures 16, 17, and 18. The displacement-time plot in Figure 18 shows crash vehicle displacement with time as predicted by mathematical simulation, and the actual determinations by accelerometer and high-speed film analysis.

Support Post Instrumentation

Electric resistance strain gages, a piezoelectric accelerometer, a variable resistance linear transducer, and a potentiometric linear transducer were installed (Table 2).

MATHEMATICAL SIMULATION

A dynamic mathematical simulation has been developed which expresses quantitatively the behavior of the sign support subjected to impact by a vehicle. To obtain a working model as quickly as possible, a thorough study was made to determine which variables were most pertinent to the behavior of the actual sign. Detailed observations of high-speed films revealed that the portion of the post above the hinge and the attached sign were rigid against rotation and translation for the initial period of response.

Idealization of the support post and vehicle system shown in Figure 19a consists of a rigid post, connected by a plastic hinge, to a rigid support at the top, and by a slip plane at the base. To simulate the action of the real sign post, the slip base is assumed

TABLE 2

ELECTRONIC INSTRUMENTATION—TESTS 39, 40 AND 41

Device	Description	Location	To Provide
Piezoelectric accelerometer	Endevco Model 2211C with Model 2614B input amplifier	Mounted on left main frame member 9 ft behind most forward point on bumper	Deceleration data (crash vehicle)
Piezoelectric accelerometer	Endevco Model 2211C with Model 2614B input amplifier	Mounted on 150-lb concrete block belted to driver's seat	Deceleration data (crash vehicle)
Piezoelectric accelerometer	Endevco Model 2215 with 2614B input amplifier	Mounted near base of post	Acceleration data (support post)
Recording oscillograph	Honeywell Visicorder oscillograph, Model 1508	Situated in instrumentation trailer 75 ft from target sign	Paper record of accelerometer and strain gage sensing under dynamic loading conditions
Impact force transducer (electric resistance strain gage bridge)*	4 Budd strain gages, metal film type C6-121	Mounted on flanges of post*	Measurement of impact force (time variable)
Electric resistance strain gage bridge*	2 Mirco-measurement strain gages, 90° Rosette, type EP-30	Mounted on rear flange*	Measurement of strain in rear flange (time variable)
Electric resistance strain gage bridge*	2 Micro-measurement strain gages, 90° Rosette, type EP-030 125TF-120	Mounted on mechanical fuse*	Measurement of strain in fuse plate (time variable)
Linear displacement transducer	4-in. potentiometric displacement transducer	Slip-joint release mechanism at base of post	Precise determination of post displacement on impact (time variable)
Linear displacement transducer	19-in. potentiometric displacement transducer	Slip-joint release mechanism at base of post	Precise determination of post displacement on impact (time variable)
Radar speed meter	Electro-matic radar speed meter, Model S2A, with Esterline Angus Graphic Ammeter, Model AW	Near impact area (Ref. 3)	Velocity of crash vehicle before impact

*Tests 40 and 41 only.

to offer a constant resistance to slipping until maximum slip occurs (Fig. 19c). The moment curvature relation is assumed to be as shown in Figure 19b.

Numerical Procedure

The method used in the solution of this problem was developed by Smith (17). It is a modified constant velocity technique which utilizes a forward step integration in time of the finite difference equations of motion.

In the free body diagram for the post and vehicle in Figure 20a and d, the action shown exists at any specified time during the impact event.

The equations of motion for the vehicle can be expressed in the following finite difference relations:

$$X_{1,t+1} = X_{1,t} + \dot{X}_{1,t}\Delta t \qquad (1)$$

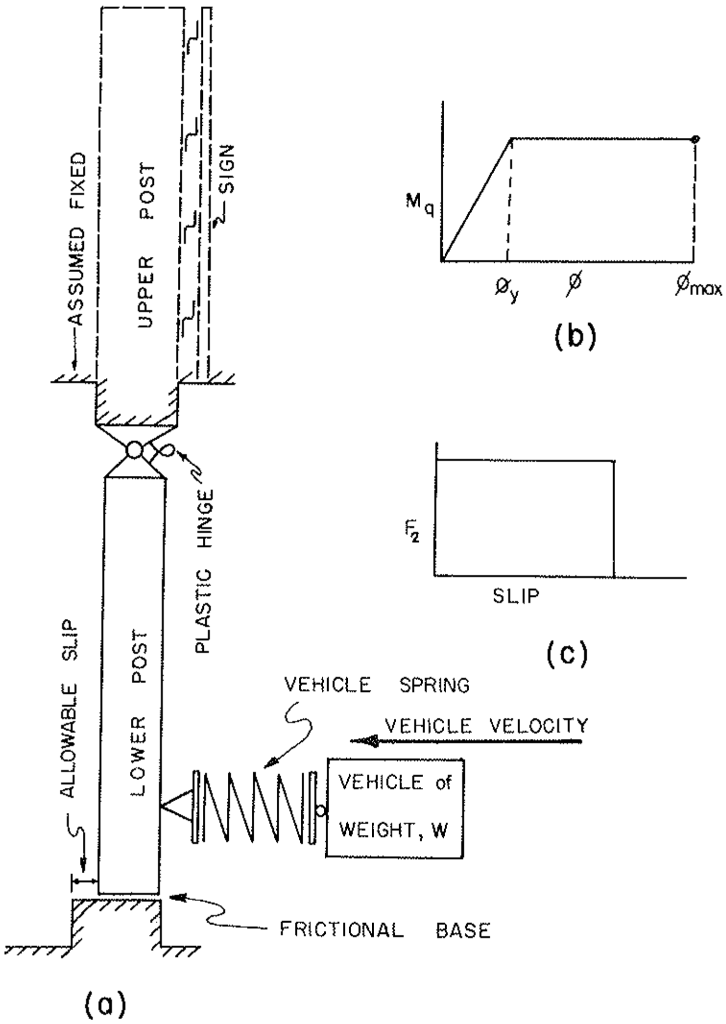

Figure 19. Idealized model of sign support post.

$$F_{1,t+1} = (X_{1,t+1} - X_{2,t+1})K \tag{2}$$

$$\ddot{X}_{1,t+1} = -(F_{1,t+1})/M_1 \tag{3}$$

$$\dot{X}_{1,t+1} = \dot{X}_{1,t} + \ddot{X}_{1,t+1}\Delta t \tag{4}$$

where

X = displacement (ft),
$\dot{X}$ = velocity (ft/sec),
$\ddot{X}$ = acceleration (ft/sec^2),
F_1 = force on vehicle (lb),
M_1 = vehicle mass (lb sec^2/ft), and
K = vehicle spring stiffness (lb/ft).

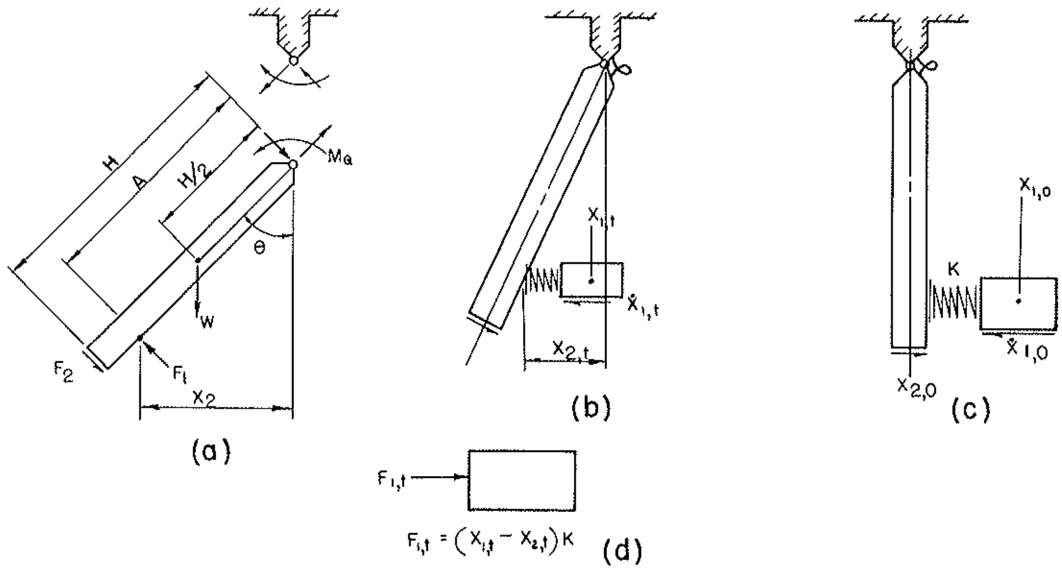

Figure 20. Free body diagrams of idealized post.

For the post, the equations are

$$\Theta_{t+1} = \Theta_t + \dot{\Theta}_t \Delta t \qquad (5,$$

$$M_{F, t+1} = (F_{1, t+1} \cdot A) - \left(F_{2, t+1} \cdot \frac{WH^2}{2} \cdot \sin \Theta_{t+1} \right) \qquad (6)$$

$$M_{Q, t+1} = \theta \cdot \Theta_{t+1}$$

$$\ddot{\Theta}_{t+1} = (M_{F, t+1} - M_{Q, t+1})/J$$

$$\dot{\Theta}_{t+1} = \dot{\Theta}_t + \ddot{\Theta}_{t+1} \Delta t$$

where

Θ = rotation of post (rad),
M_F = accelerating moment (ft-lb),
M_Q = resisting moment of hinge (ft-lb),
θ = slope of moment rotation properties of hinge (ft-lb/rad), and
J = mass moment of inertia about hinge $\left(\frac{\text{ft-lb-sec}}{\text{rad}}\right)$.

The initial starting conditions and order of calculation in the numerical procedure are shown in Figure 21.

Correlation

Figure 22 is a plot of the slip base displacement vs time for the actual sign and the model. The model values fit the actual data very well up to the time of maximum slip (14.8 millisec and 0.073 ft slip). After slip is completed, the model values lag the

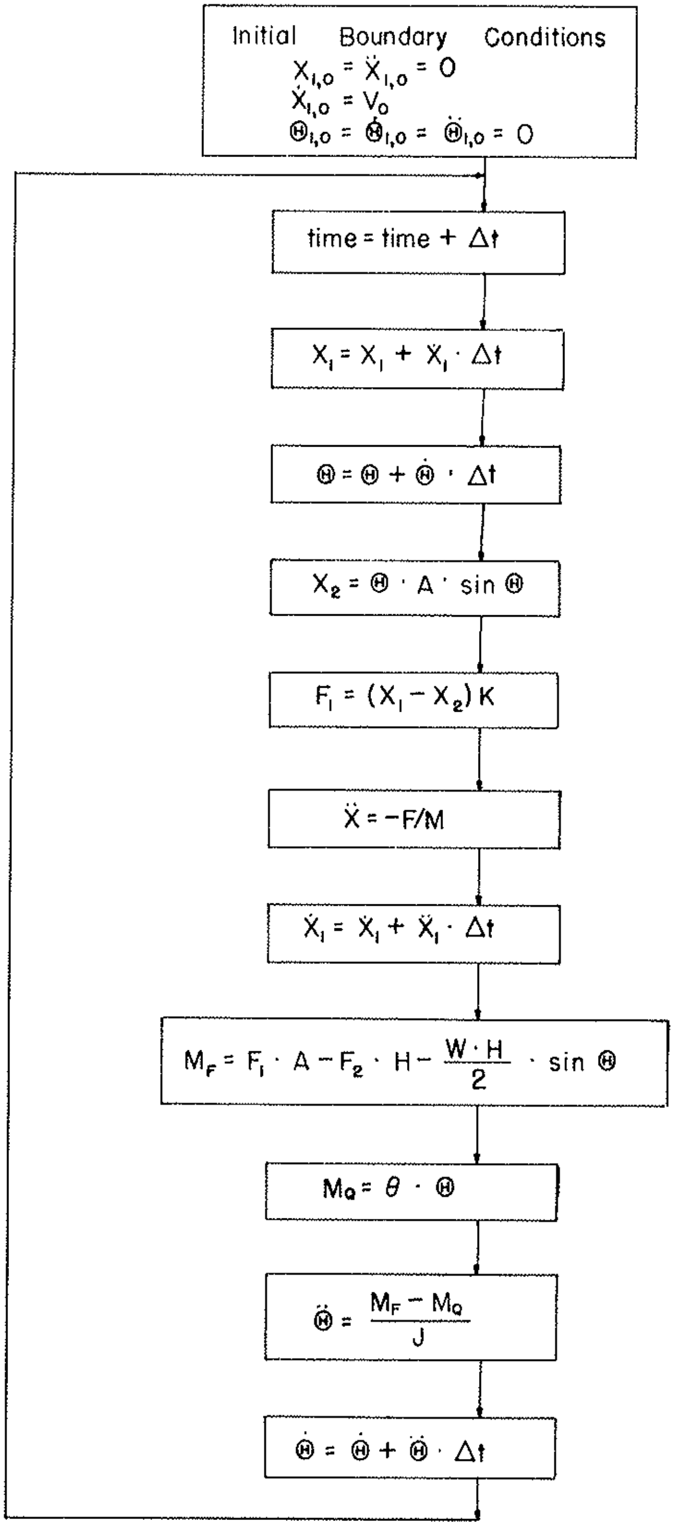

Figure 21. Simplified flow diagram.

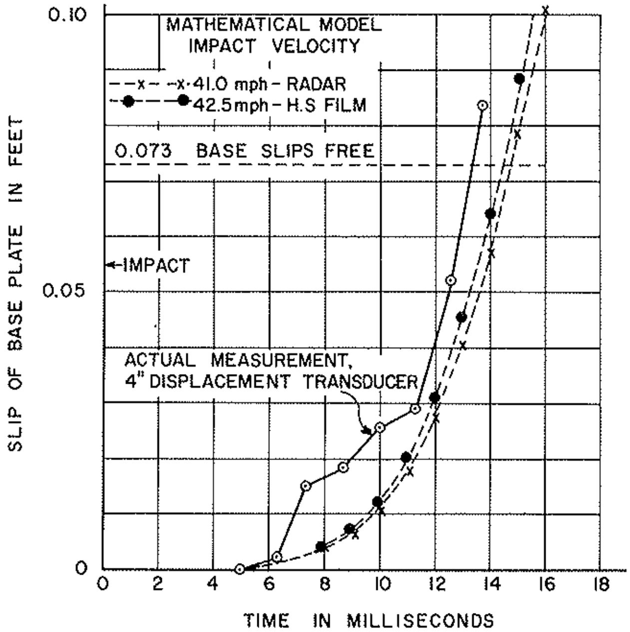

Figure 22. Slip base displacement vs time for sign and model.

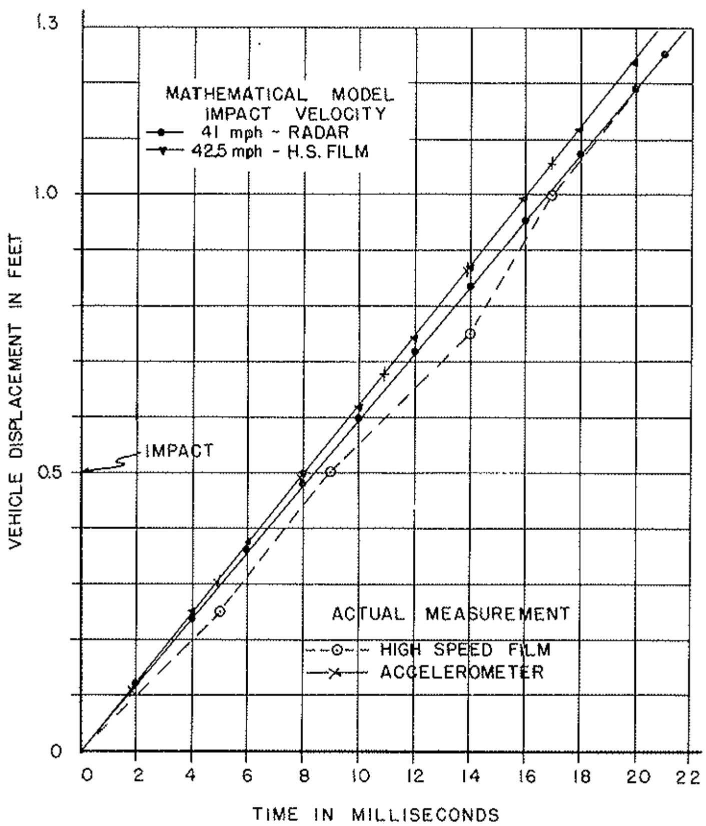

Figure 23. Vehicle displacement vs time.

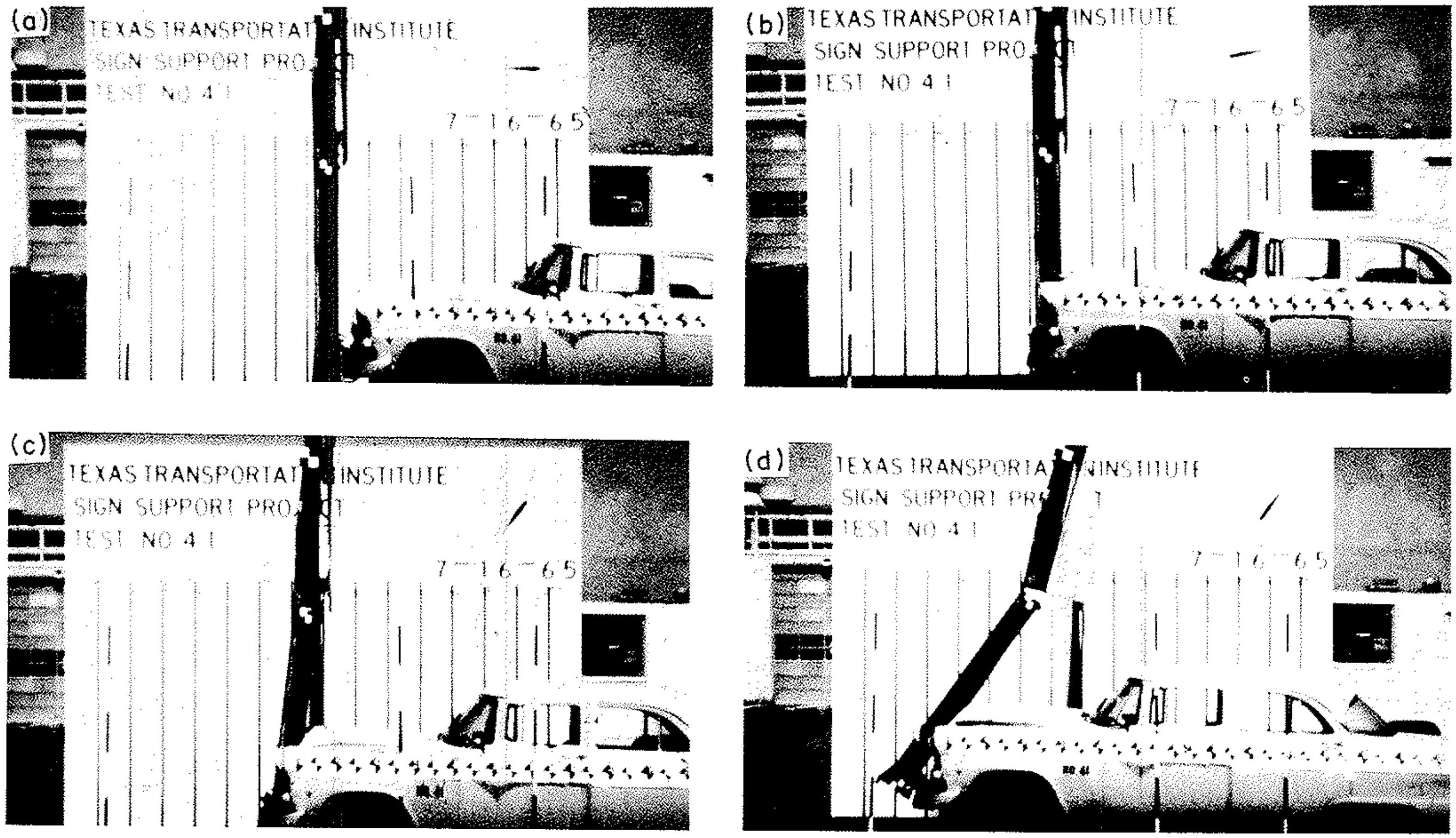

Figure 24. Test No. 41: (a) t = 0; (b) t = 0.015; (c) t = 0.027; and (d) t = 0.070.

actual displacement. This is due to the rigid nature of the top support, i. e., no rotation is allowed in the upper portions of the post above the hinge. Hence, the lower portion will lag behind its true position. There is an excellent correlation between the times when slip is initiated and when the maximum slip occurs.

Figure 23 plots vehicle displacement vs time. The results of the model show close agreement with the test data. These plots appear as straight lines. In reality they are not linear, but curvilinear in nature. This face can be observed by a proper choice of scale. Because the change in velocity is very small, the true nature of the curves is obscured.

Two curves (Figs. 22 and 23) are shown for the mathematical model. One curve represents a solution computed using an impact velocity of 41. 0 mph (from radar record); the other curve represents a solution computed using an impact velocity of 42. 5 mph (high-speed film analysis). Both curves are included because the exact impact velocity is not precisely known.

The data show a very good correlation for the early stages of post response to vehicle impact. The model accurately predicts post response up to the time that the base slips. To use this particular model, one must be very careful to insure that the upper post and sign provide a very high rotational inertia and torsional rigidity. This implies that this model is good only for large rigid posts. Other models are being developed to handle smaller posts.

It is difficult to determine the time of critical events from the high-speed film with any degree of certainty. Attempts have been made to install other instruments which would verify film observations. These attempts have been only partially successful at this writing. Figure 24 shows sequence photographs from the high-speed film of Test No. 41. The critical events observed are listed below:

$t = 0$, bumper touches post,
$t = 0.015$, post base disengages,
$t = 0.027$, mechanical fuse fractures, and
$t = 0.070$, post leaves contact with the vehicle.

Conclusions

The concepts developed through this research have been put into practical application on the Interstate Highway System in various parts of the country. At this writing, there have been 31 accidents in Texas involving break-away roadside signs of various types. There have been no fatalities and no serious injuries. In eight of these accidents the vehicle involved did not remain at the scene. In all but two cases the vehicle was removed under its own power.

The mathematical model has proven valuable for the evaluation of design parameters by providing information that could otherwise only have been obtained through a costly testing program.

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