IMPACT BEHAVIOR OF SIGN SUPPORTS-II

A STAFF PROGRESS REPORT

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ABSTRACT

Studies involving the impact behavior of certain types of sign supports are described in this progress report. The progress report is presented in two parts. Part A is entitled "Phenomenological Behavior of Sign Supports," and Part B is entitled "An Analytical Study of Break-Away Sign Supports for Roadside Signs." The first part of the report is based on observations of motion picture films of twenty-seven crash tests conducted during the second year of research. Part B presents the results of a series of instrumented crash tests, comprising six in number, conducted to provide data for the development of a mathematical model to predict the impact behavior of sign supports. The development of a mathematical model expressing support post behavior is also described.

The phenomenological behavior of sign supports described in Part A encompasses tests on several different types of sign supports. Following a description of crash test procedures is a section on small signs. These tests were conducted on gore type signs, consisting of two supports with a five-foot by six-foot sign. In the majority of tests described, both legs of the sign support were struck by the colliding vehicle. However, in some tests only one leg of the support structure was impacted by the crash vehicle. A slip base was employed in certain of the tests. The base was either horizontal or inclined at a 10 degree angle to the horizontal. Two types of mechanical fuses were employed in the support posts. These were a cast iron fuse, and a notched plate fuse. In several of the tests neither the break-away slip base nor the mechanical fuse was employed.

All but two of the tests were conducted on steel support posts. The final two tests were conducted on wood post supports. One of these support posts was fabricated in accordance with a Commonwealth of Pennsylvania design, and the other was fabricated in accordance with a design suggested by Texas Transportation Institute personnel.

Some preliminary tests of mechanical fuses were performed and are reported herein. These tests were made in order to determine the feasibility of using a notched plate instead of a cast iron plate for the mechanical fuse.

Another section of the report is devoted to pipe supports for small signs. These pipe mounts contained safety features. Each pipe mount had a slip base. The slip base was either horizontal or inclined at 10 degrees or 20 degrees from the horizontal. Some of the pipe mounts consisted of a one pipe support, others consisted of dual pipe support posts.

Part B of this progress report describes six full-scale crash tests. High-speed motion picture records, accelerometer records, and electric resistance strain gage records were secured for study. A description of the sign supports and of the instrumentation is given. A discussion of data reduction and methods of analysis is presented. The development of a mathematical model expressing the support post behavior is described.

FOREWORD

Studies involving the impact behavior of certain types of supports for highway signs are described in this progress report. The selection of the types of supports considered herein has been predicated upon current design procedures and the development of interim designs which would minimize hazards. Certain devices have been introduced into the sign supports, and full-scale crash tests have been conducted in order 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 method of approach to the research reported herein was dependent upon the successful development of a full-scale crash test facility employing high-speed motion picture cameras to record the behavior of the sign support upon impact when struck by a standard size automobile. Considerable information has been secured on the qualitative nature of support behavior, and as explained in detail in this report, has resulted in observable improvements in impact characteristics. In addition to these qualitative results, the method of procedure just described has been useful in the development of concepts of post behavior under impact.

This progress report consists of two parts. The first part is concerned with phenomenological testing and the second part is concerned with a series of instrumented tests. A mathematical model describing post behavior is also presented in the second part of the report.

The phenomenological testing has been an important aspect in the testing procedure. In tests of this type the high-speed camera has been employed to secure a film record. Observation of these 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.

The phenomenological testing of various sign supports continues. Analysis of the six instrumented tests also continues. Instrumentation, analysis, and evaluation of instrumented tests require much time. For this reason the number of phenomenological tests is far greater than the number of instrumented tests. In addition, certain revisions to existing design standards have been made on the basis of phenomenological tests. It is anticipated that the mathematical model will provide information which will be of benefit in selecting future test prototypes. Thus integration of the two types of tests with a mathematical method of analysis should provide a better approach to the research goal.

This experimentation is the second phase of a research project on sign support structures currently being conducted by the Texas Transportation Institute in cooperation with the Texas Highway Department and the U. S. Bureau of Public Roads. It is not intended that the studies presented herein reflect final research recommendations, but rather that they present a series of tests which have resulted in designs that show promise of providing an economical method for reducing hazards.

ACKNOWLEDGEMENTS

Over twenty-five people were employed in various capacities on this project. Some of them have contributed more than others, but all have contributed to the successful completion of the endeavor.

Particular recognition is made of the efforts of T. J. Hirsch for his advice, counsel, and encouragement.

The fabrication and operations group supervised by T. G. Williams met the specifications for construction and testing within the schedule. Henry Stallings, Buddy Whatley, Columbus Garner, Don Mais and others arrived early and worked late when required to meet testing schedules.

G. H. Clark and T. C. Bennett performed ably in their roles of electronic technicians; and much of the success of completion is due to the untiring efforts of J. C. Mahle, who was always available to expedite the acquisition of materials and supplies.

Several graduate and undergraduate students from the Civil Engineering Department of Texas A&M University served as assistants in performing a variety of tasks.

The authors wish to acknowledge the cooperation and continued interest of engineers of the Bridge Division of the Texas Highway Department.

INTRODUCTION

The purpose of this report is to present the results of the second year of research on the impact behavior of sign supports. The report is presented in two parts. Part A--Phenomenological Behavior of Sign Supports, is based largely on observation of motion picture films of a large number of crash tests of sign supports, and no attempt has been made to describe this behavior in an analytical or mathematical fashion. Part B--An Analytical Study of Break-away Sign Supports for Roadside Signs, presents the results of a series of instrumented crash tests conducted to provide data for the development of a mathematical model to predict the impact behavior.

Most of the research effort on this project has been devoted to obtaining an immediate solution to a problem--that problem being the improvement of the impact behavior of roadside sign supports. Since this was a pioneering effort there was no precedent to follow in a classical theoretical treatment of the problem before experimentation. The dynamic situation of a vehicle striking a post which has freedom to slip is a complex but not an insurmountable problem. However, to analyse the problem theoretically would have taken considerably more time than was permitted. Substantial mileage of the interstate system was under construction or scheduled for construction within the state and there was an urgent need to develop better design standards for the signing of these facilities. To answer this need engineers of the Bridge Division of the Texas Highway Department proposed certain safety features to the unbraced post type support already used and these ideas were incorporated in an experimental design, a systematic testing schedule was established and the necessary tests were conducted.

To evaluate the effect of various parameters such as speed, angle of impact, etc., a large number of tests were required to produce the desired result. Thirty-three tests were conducted during the second year of research, and these tests provided the information needed to develop tentative design standards for the particular type of sign support proposed. With such a large number of tests it was impossible to instrument the vehicle and sign supports to provide analytical data on all tests. Therefore, it was necessary to rely upon the most expedient means of evaluation, high-speed motion picture photography. This permitted the research team to conduct the large number of tests and extract from the motion picture films information needed immediately by the sponsoring agency.

In the summer months of the second year, three fully instrumented crash tests were conducted to obtain data for the development of a basic mathematical model which will be employed in a detailed study of the impact behavior of sign supports. High-speed motion picture photography coordinated with electronic instrumentation including strain gages, peizoelectric accelerometers, and linear displacement transducers were employed. Every effort was made to glean the maximum amount of data from these tests to assist in the development of the model.

In this second year of the project an attempt has been made to first provide an immediate answer to the practical problems at hand; and further, to provide information to establish a sound, systematic approach to a thorough treatment of the problem of impact behavior of sign support structures.

PART A

PHENOMENOLOGICAL BEHAVIOR OF SIGN SUPPORTS

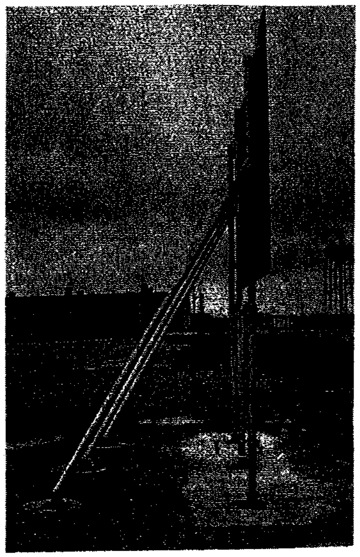
SUPPORTS AND TESTS

The first phase of this project, reported previously,[1] was concerned primarily with the development of safer sign supports for large roadside type signs to reduce the injury and damage effect of motor vehicle accidents involving these signs. Consideration of accident reports and photographs of damage due to collisions with large sign supports led to a hypothesis that three primary characteristics of the sign support contribute substantially to the severity of the collision: (1) the mass, (2) the structural rigidity or stiffness, and (3) the condition of fixity at the base of the sign support.

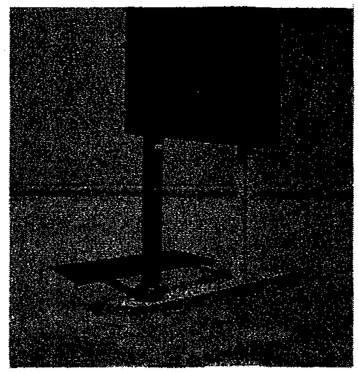
In the initial phase of the research special attention was focused on what was referred to as a braced leg structure, Figure 1 (A), which constituted a reduction in mass and structural rigidity. Three tests were conducted on this type of support, two of which employed a safety feature commonly referred to as a fracture joint. This fracture joint was formed by cutting the tubular supports 6 1/2 feet 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.

The braced leg structure was not readily accepted by the Design Engineers for a number of reasons. Of major concern were the problems that would be encountered in designing and constructing signs to be installed on steep side slopes, and the maintenance of the grass area around the sign supports. Also there was considerable objection to the aesthetic qualities of the sign supports.

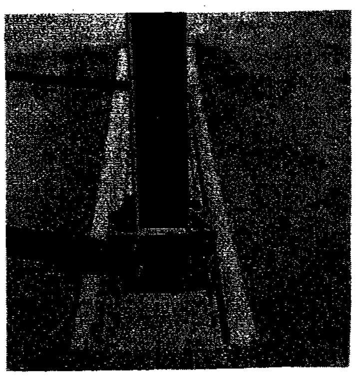
From the standpoint of simplicity in design and ease of maintenance of side slopes and grass areas around the signs, engineers of the Bridge Division of the Texas Highway Department focused their efforts on the development of an unbraced post support similar to conventional designs which would slip under impact of collision, Figure 1 (B). In order to provide such a support with favorable impact characteristics it was necessary to develop a base connection which would withstand the overturning moment induced by windloads and at the same time slip when subjected to the horizontal forces of collision. The base connection is referred to as a slip joint or slip base. An illustration is shown in Figure 1 (C). Although this illustration shows the lower post stub bolted to a universal testing foundation at the test site, it is normally embedded in a concrete foundation in roadside installations. Both the base of the post



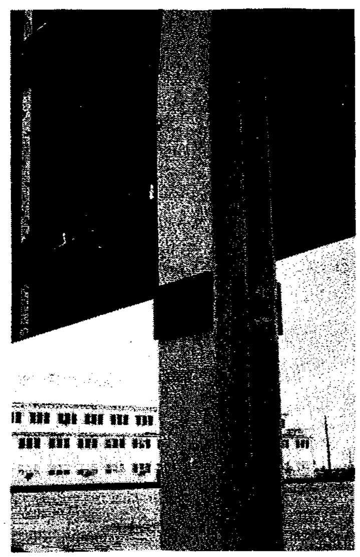
BRACED-LEG
STRUCTURE
(A)



UNBRACED POST
SUPPORT
(B)



CLOSE-UP OF
SLIP BASE
(C)



CLOSE-UP OF
HINGE JOINT
(D)

FIGURE 1 — DEVELOPMENTAL CHARACTERISTICS
OF SIGN SUPPORTS

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 showed that the slip joint at the base functioned satisfactorily but there was a further need for the post to fold up out of the way and thus permit the colliding vehicle to pass on under the post. The initial concept of this safety feature was drawn from the braced leg structure. A fracture joint was introduced in the unbraced post seven feet above the foundation, Figure 1 (D). This fracture joint was formed by cutting the post in two and reconnecting it by bolting cast iron plates to the front and back flanges of the post. It was anticipated that the post would first slip at the base and then the fracture joint would permit the lower portion of the post to break out and thus eliminate the likelihood of the base of the post being dragged through the windshield as observed in earlier tests without the fracture joint. In the full-scale crash test of this particular design slippage occurred at the base as anticipated. The fracture joint failed immediately following this slippage and the high center of gravity of the post section removed by the impact caused it to rotate over the hood of the automobile and the end of the post which had been rejoined to the upper section by cast iron plates pierced the windshield doing considerable damage to the instrument panel and finally vaulted over the top of the automobile. The impact behavior of this particular design was not satisfactory.

The test described above indicated the need to contain the lower section of the post, and allow it to swing up to clear the colliding vehicle. This was accomplished by replacing the fracture joint with a hinge joint. Instead of cutting the post all the way through to form a fracture joint, the front flange and the web were cut leaving the back flange intact. 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 after slippage occurred at the base. Then after this connection failed the back flange of the post would serve as a hinge to permit the lower section of the post to fold up and out of the way of the colliding vehicle. Three full-scale crash tests were conducted to verify this behavior. In these tests reported in greater detail in the earlier report,[1] the design utilizing the hinge joint was struck at speeds of 25 mph 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 test was performed to evaluate the impact behavior of the support when struck at an angle to simulate the conditions of a vehicle leaving the roadway. For the selection of test conditions, reference was made to previous research[2] which indicated that approximately 95% of vehicles leaving the roadway, do so at angles of 15 degrees or less. On this basis the angle of impact, or the angle or incidence for the crash test was established as 15 degrees.

CRASH TEST PROCEDURES

During the first year of the research, facilities were developed for launching vehicles into full-size sign supports under controlled conditions while motion picutre cameras were used to record crash data. A description of these facilities was given in the earlier report. In the second year of research, certain modifications in the launching facilities were made to provide an easier and more realistic means of creating the collision conditions. Also, data collection facilities were improved and expanded.

The procedure used to launch vehicles into sign supports is referred to as the "reverse tow" procedure.[3] In this arrangement the tow vehicle moves in the direction opposite to the crash vehicle. The crash vehicle is guided into the sign support along an I-beam guide rail fastened to concrete pavement. A dolly with rollers to fit the upper flange of the rail is the guide mechanism. The crash vehicle is attached to the dolly by two short lengths of cable. These cables have a hook on one end and a loop on the other; the hooks are placed behind the bumper or convenient frame members of the automobile and the loops are hooked to the dolly by a sliding pin. The long tow cable is also hooked to this pin. The tow cable passes around three pulleys at the end of the rail near the sign, then through a pulley on the tow vehicle, and finally to a point of anchorage back near the sign. To set the crash vehicle in motion the tow vehicle actually pulls the dolly along the rail. When the dolly reaches the end of the rail near the sign a rod in the concrete pavement trips a lever on the dolly which pulls the sliding pin thus releasing the tow cable and the two short cables attached to the automobile. The automobile continues in free motion to collide with the sign support, while the dolly is stopped by a friction block on the rail.

Generally four motion picture cameras were used to record each crash. One of these cameras was a FASTAX WF3T capable of attaining photographic speeds up to 6000 pictures per second. However, the camera was operated at approximately 1000 pictures per second so that normal sunlight would not need to be supplemented with special lighting fixtures. Other motion picture camera equipment included a Bell & Howell 70 HR 16 mm camera with various lenses, and a Kodak Cine Special II 16 mm camera with a 20 mm lens. Normally two of the cameras were operated at 64 pictures per second and the third camera was operated at 24 frames per second. Except in two or three tests conducted on cloudy days Kodachrome II color film was used in all motion picture cameras including the high-speed camera. On the cloudy days, Tri-X black and white film was used in the high speed camera only. Best results were obtained using the color film because the various members of the sign supports were painted different colors and a white backboard was used to provide contrast. A measuring scale was superimposed on the white backboard in black. Thus by knowing the location of the camera and the sign support and the automobile with respect to the backboard, incremental distances traveled by the automobile could be computed.

A high-speed clock was placed in the foreground so that it would appear in the film records. The clock face was graduated in hundredths of a revolution and an 1800 rpm synchronous motor was used to turn the clock hand; thus time could be measured to 1/3000th of a second.

As a check against the motion picture film and other methods of instrumentation, an S-2A Electromatic Radar Speedmeter was used in some of the tests to determine the speed of the crash vehicle at the time of impact. The speed was recorded on an Esterline Angus ink-type chart recorder.

A series of tests were conducted in which electronic data records were compiled for analysis. Details of these tests are found in Part B of this progress report.

SMALL SIGNS

The first phase of this research dealt with roadside signs in which the posts were so widely spaced that it was physically impossible for a vehicle to collide head-on with more than one support. In these large signs the problem of developmental design dealt with the yielding or failure of the single support struck, leaving the sign and the other support or supports intact, or nearly intact. However, there are numerous signs in use on access controlled facilities which are small enough that a vehicle can collide with both of the sign supports. These signs constitute a different problem. The importance of improving the safety of this type of sign is greatly increased by the fact that these signs are normally used at points where the probability of being struck is much greater than in the case of the larger signs. The most common location of this smaller sign is in the gore of an exit ramp where the sign is not only used to exhibit the message "EXIT" but also 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 definite hazard, it was desirable to conduct full-scale crash tests of the conventional design to establish an index for comparison of experimental designs. Also, in order to study developmental designs, it was desirable to have a motion picture film to provide a graphic illustration of the impact characteristics of the conventional design.

On four different occasions full-scale crash tests were conducted using signs fabricated in accordance with the Texas Highway Department Standards for Interstate Signing (SMD-4). The sign selected was a 5' by 6' plywood sign supported by two posts 3 1/2' apart, the posts were 5" WF 16# beams of A36 grade structural steel.

The first of these tests was conducted in conjunction with the Highway Short Course in December, 1964. Scheduling of the test in conjunction with the remainder of the program made it necessary to conduct the test after 5:00 p.m. There was not sufficient light to obtain satisfactory motion picture films of the crash; however, there were approximately 600 people on hand to observe the test.

A second test of the same design was scheduled later in order to obtain high-speed motion pictures of the crash. In this test it was planned that the vehicle would strike both legs of the support head-on at approximately 50 mph. However, while the vehicle, a

1955 Oldsmobile, was being towed along the rail the transmission was inadvertently engaged. The speed of the automobile was reduced and it veered to the left after it was released from the towing mechanism. As a result the vehicle struck the left leg of the sign at the approximate center of the hood. The crash speed was later calculated at 22 mph. The damage effects of this collision are illustrated in Figure 2. The sign installation was not damaged appreciably and the third test was conducted immediately. In this particular test the vehicle, a 1955 Pontiac, struck both posts simultaneously at a speed of approximately 45 mph. In the photographs in Figure 3, it is observed that the sign supports failed in the weld at the base plate, but failure occurred after much of the impact energy had been dissipated and the vehicle had stopped.

A fourth test on a fixed-base interstate type sign support was conducted primarily to obtain accelerometer data for comparison with film records. This test (No. 32) is described more fully in Part B of this report. Views of the vehicle and sign taken following the crash are shown in Figure 4.

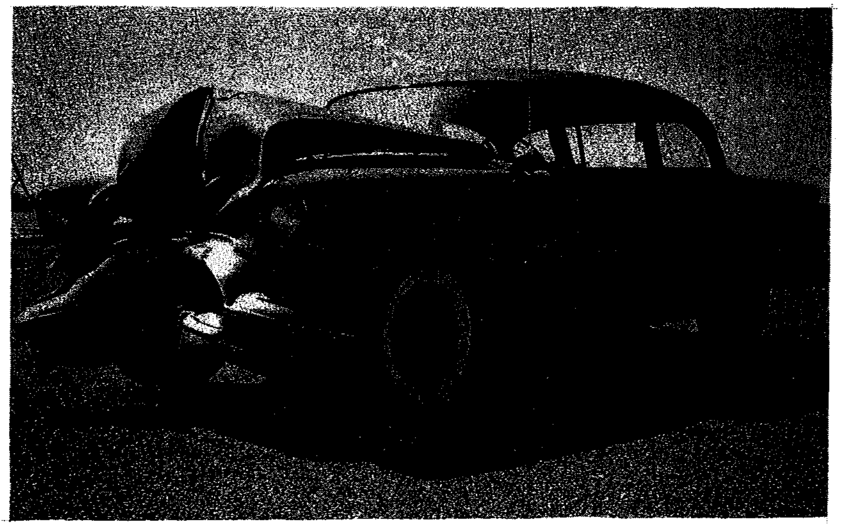
EXPERIMENTAL DESIGNS

The results of the crash tests involving conventional types of small, two-legged signs left little doubt in one's mind regarding the need to improve the impact behavior of these signs. As in the case of the large signs it was desirable to retain the same general configuration in the sign and the sign support from the standpoint of the relative ease of installation and maintenance. Since satisfactory performance had been attained in the large signs using a slip base and hinge joint these same safety features were employed in the small signs. Details of the experimental sign supports are shown in Figure 5. The 3-inch I-beam supports are capable of withstanding wind velocities up to 70 mph. A 4-inch I-beam would be required to withstand wind velocities to 100 mph.

The slip base for the small signs was designed similar to the base used in the large signs. Four bolts were used to hold the sign support in place as shown in Figures 5 (B) and 5 (C). These bolts were torqued to 450 inch-pounds. The hinge joint was formed by cutting the front flange and the web of the I-beam 7 feet above the foundation and reconnecting it with a cast iron plate, Figures 5 (D) and 5 (E).

The experimental design was subjected to full-scale crash tests to determine the effect of various parameter study conditions as follows:

(1) Crash speed - 25 and 50 mph (approximately)



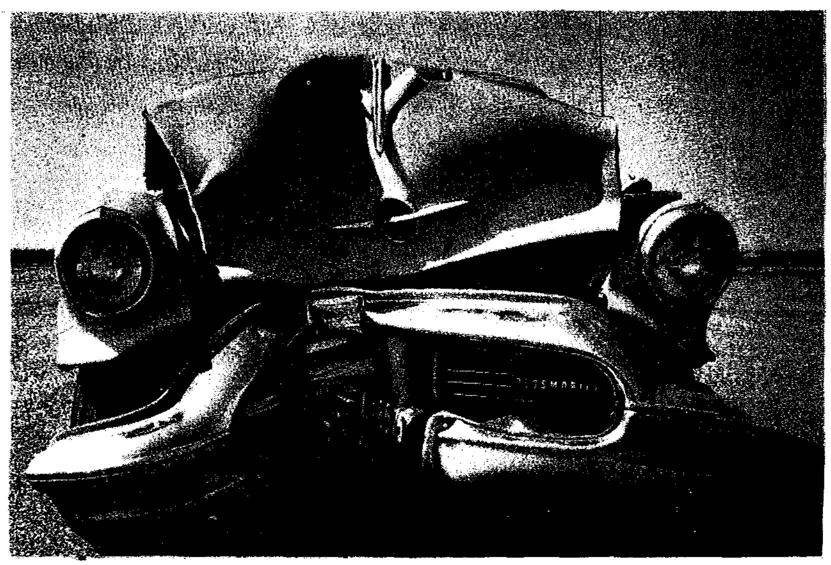


FIGURE 2 — VEHICLE DAMAGE
SLOW-SPEED FIXED POST TEST

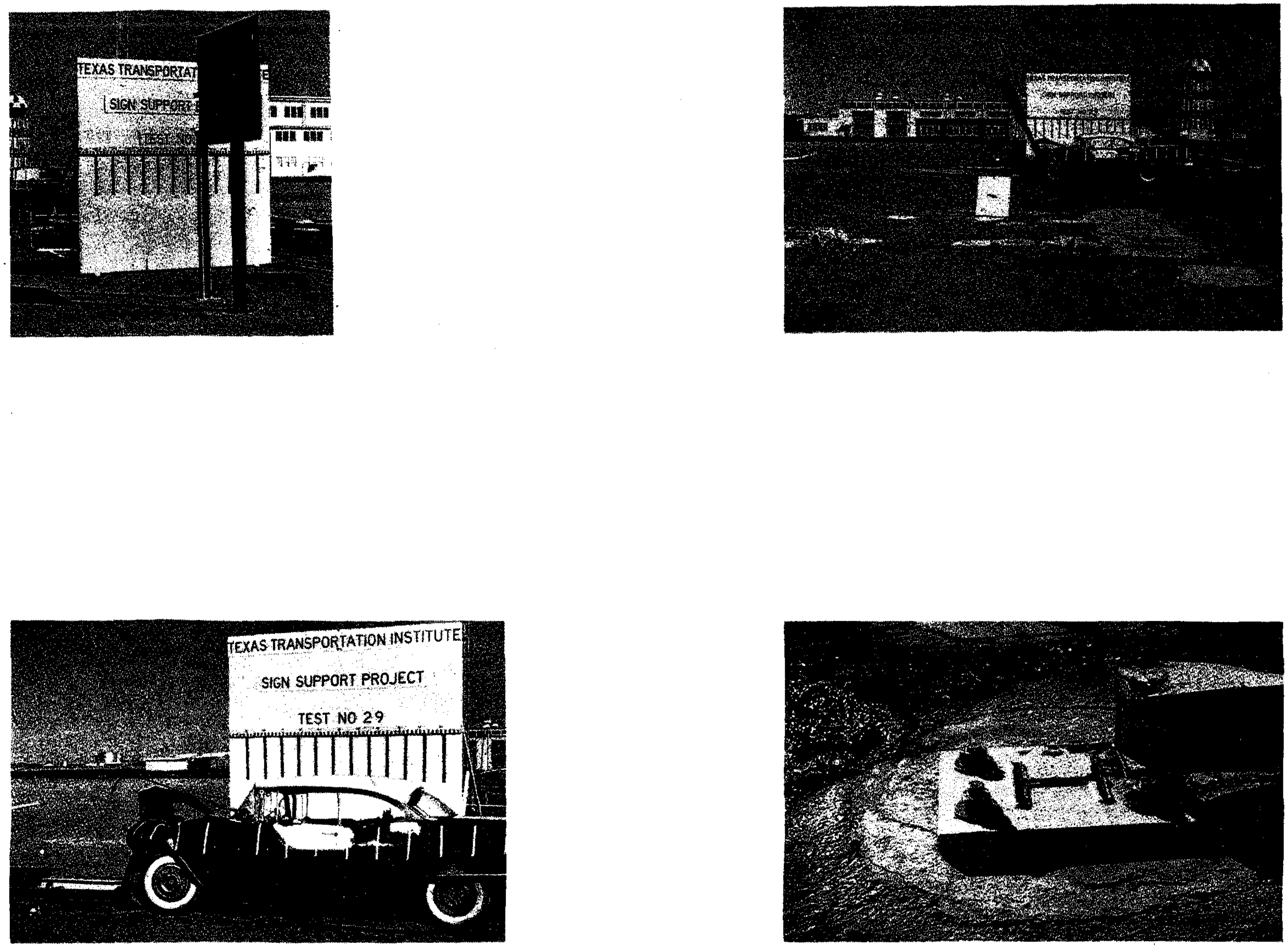
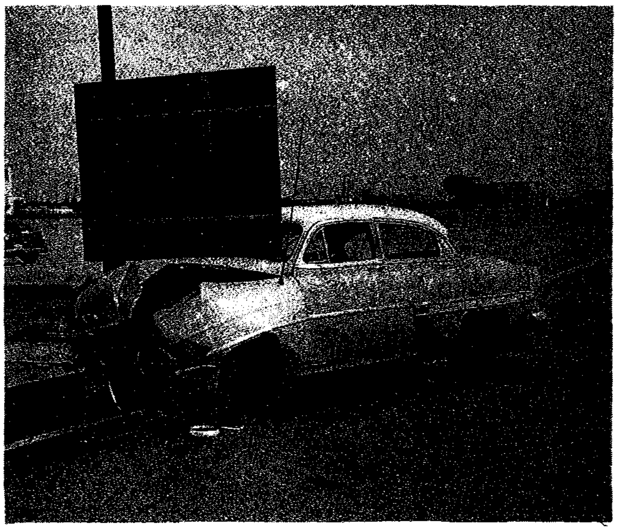


FIGURE 3 — HIGH-SPEED FIXED POST TEST



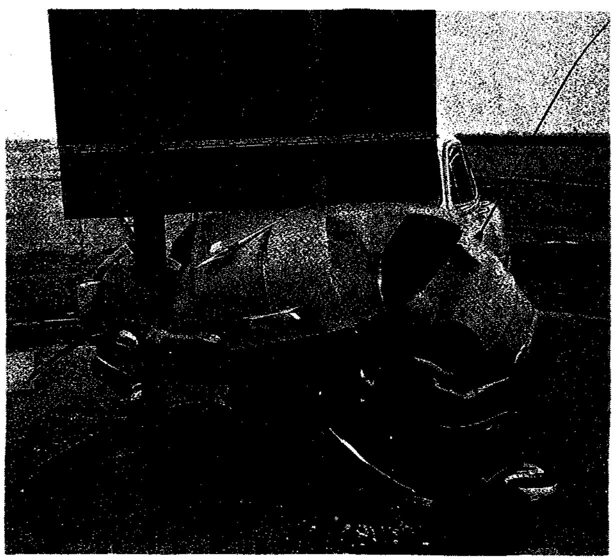


FIGURE 4 - VIEWS OF CRASH TEST NO. 32

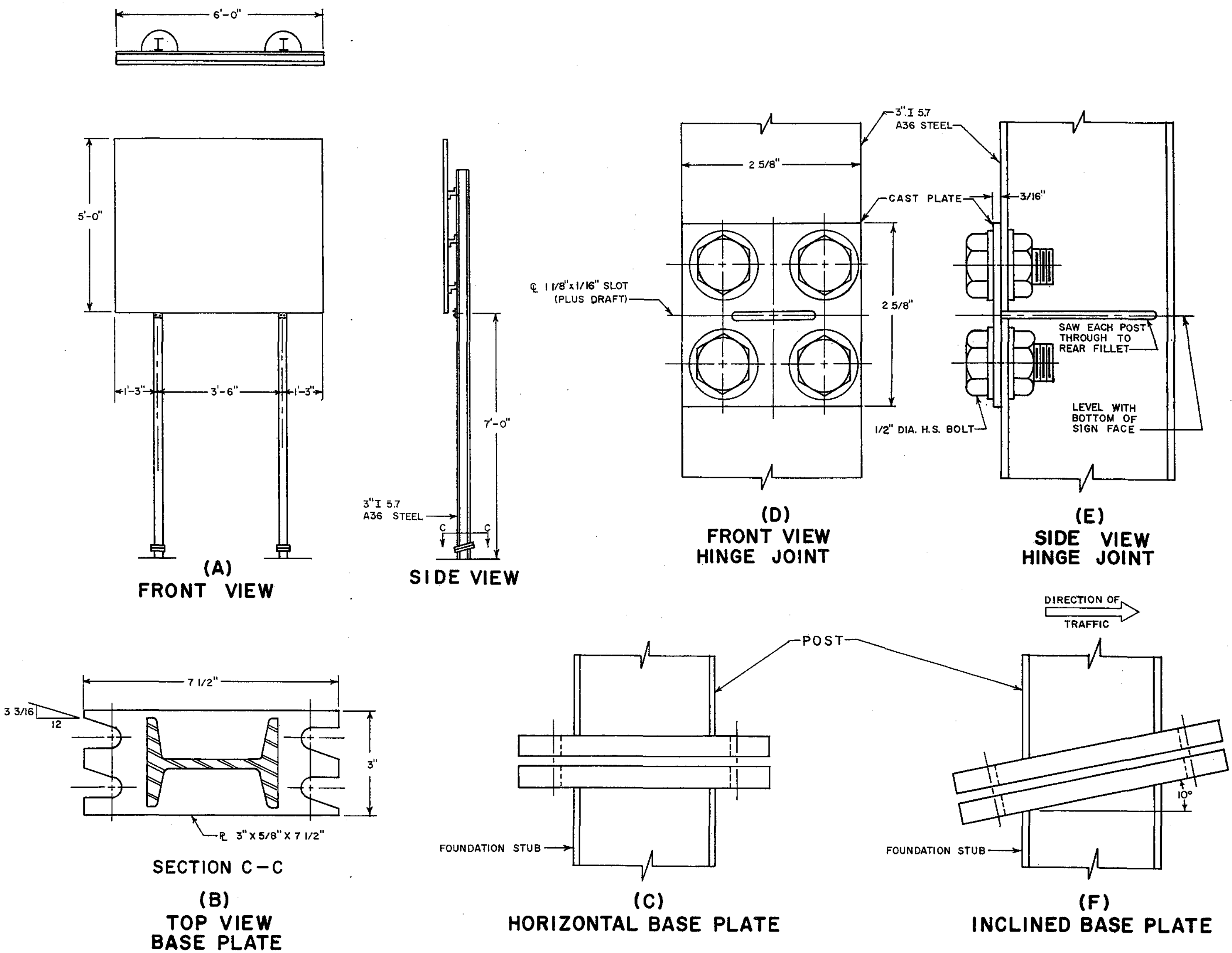


FIGURE 5 - GENERAL DETAILS OF SMALL SIGN

(2) Angle of impact - 0 and 15 degrees

(3) Impact condition - one or both legs struck

A summary of test conditions is given in Table A. The effect of these parameters on the impact behavior was determined by observation and study of the high-speed motion picture films.

Speed

The variation in speed at which the crash vehicle struck the sign support did not materially affect the amount of damage done to the front of the vehicle. However, at slower speeds (25 mph) the sign struck the top of the automobile face down and caused considerable damage to the top of the automobile, Figure 6. Standard sedans were used in these tests and the steel top would have provided protection for occupants of the vehicle in practically every case. However, damage to convertibles would have been rather severe. The sign performed satisfactorily in its rotational movement over the top of the automobile at high speeds. The damage sustained in the slow speed tests however, necessitated some consideration of modifying the design to improve impact behavior at slow speeds.

Observation of the motion picture films of the slow-speed tests indicated that the slow moving vehicle did not have time to clear the sign during its rotational path over the top of the automobile. There appeared to be two alternate solutions; (1) to reduce the angular velocity of the sign in its rotational path, or (2) to increase the height of the path of the sign over the top of the vehicle. The latter result seemed most desirable and this was accomplished by inclining the slip base of each support 10 degrees as shown in Figure 5 (F). 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 on under the sign, (Figure 6). When the sign was tested at a 15 degree angle the total lift was not as great because the left leg was released before the right leg and therefore the right leg restrained the upward movement until it was released by the impact. However, the lift was sufficient to cause the sign to clear the vehicle at slow speed.

Angle of Impact

The impact behavior of the sign supports was not materially affected by changing the angle of attack from 0 to 15 degrees. 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. The 15 degree angle tests were conducted primarily to determine if the supports would buckle be-

TABLE A

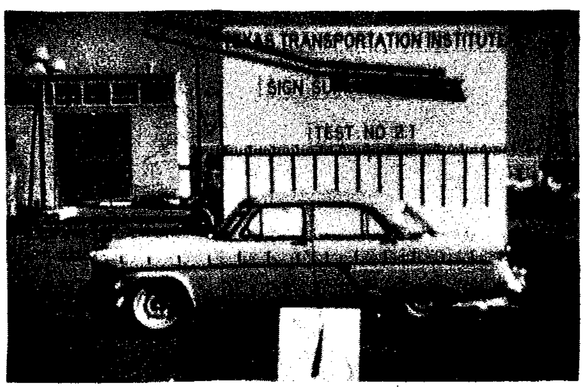
SUMMARY OF CRASH TESTS
OF SMALL SIGNS

"EXIT" or Gore Type - Two Supports - 5' x 6' Sign

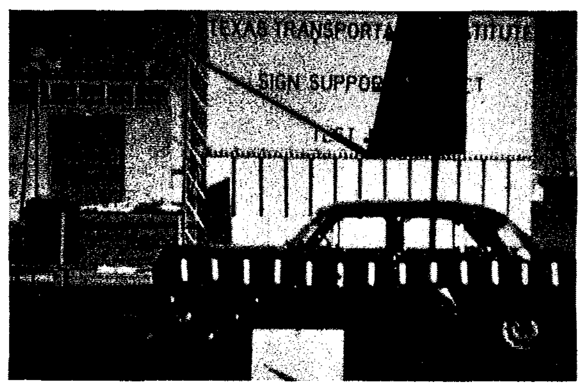
Test Number	Post Description	Safety Features	Approximate Speed Before Impact (mph)	Angle of Impact (Degrees)	Impact Position (Left Leg or Both Legs Struck)	Deformation of Front Bumper and Frontal Area (Inches)	Make & Model Crash Vehicle
1-11,13	Large Sign Tests	(Report 68-1)					
12	3I5.7 A-7 Steel	Horizontal slip base; hinge joint	55	0	Both Legs	3	1955 Dodge
14	3I5.7 A-7 Steel	Horizontal slip base; hinge joint	25	0	Both Legs	5½	1955 Dodge
15	3I5.7 A-7 Steel	Horizontal slip base; hinge joint	35	15	Both Legs	3½	1954 Ford
16	3I5.7 A-7 Steel	Horizontal slip base; hinge joint	25	0	Left Leg	3	1954 Ford
17	3I5.7 A-7 Steel	Horizontal slip base; hinge joint	45	15	Left Leg	3	1954 Ford
18	3I5.7 A-7 Steel	Horizontal slip base; hinge joint	45	0	Both Legs	No Data	1954 Ford
19	5WF16# A-7 Steel	None	45	0	Both Legs	No Data	1955 Dodge
20	5WF16# A-7 Steel	Cast iron inserts below base plate	50	15	Both Legs	11	1954 Ford
21	3I5.7 A-7 Steel	Inclined (10^{o}) slip base plate; hinge joint	25	0	Both Legs	3	1954 Ford
22	3I5.7 A-7 Steel	Inclined (10^{o}) slip base plate; hinge joint	50	0	Both Legs	2	1954 Ford
23	5WF16# A-36 Steel	Cast iron inserts below base plate; hinge joint	45	15	Both Legs	8	1953 Ford
24	3I5.7 A-7 Steel	Inclined (10^{o}) slip base plate; hinge joint	45	15	Both Legs	2	1954 Ford
25	3I5.7 A-7 Steel	Inclined (10^{o}) slip base plate; hinge joint	50	15	Left Leg	4	1954 Ford
28	5WF16# A-7 Steel	None	20	0	Both Legs	24	1955 Olds
29	5WF16# A-7 Steel	None	45	0	Both Legs	36	1955 Pontiac
31	3I5.7 A-7 Steel	Inclined (10^{o}) slip base plate; Friction type hinge joint	30	0	Both Legs	3	1954 Chevrolet
32	5WF16# A-7 Steel	None	45	0	Both Legs	24	1953 Chevrolet
42	6" x 8" wood (Pennsylvania)	Notches (Figure 11)	40	0	Both Legs	4	1954 Ford
43	4" x 6" wood (TTI Design)	Shear slot (Figure 11)	40	0	Both Legs	3	1954 Ford

50 MPH TEST
HORIZONTAL BASE PLATES

25 MPH TEST
HORIZONTAL BASE PLATES



25 MPH TEST
BASE PLATES INCLINED 10°



SINGLE LEG TEST

FIGURE 6—IMPACT BEHAVIOR OF SMALL SIGNS

fore slipping when struck at an angle. There was no tendency for lateral bending in any of the angle tests.

Impact Condition

In the tests 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, (Figure 6). After the vehicle had passed on under the sign, the sign itself rotated horizontally causing the cast iron plate on the hinge of the right post to fail and as a result the sign collapsed.

MODIFICATION OF EXISTING SIGNS

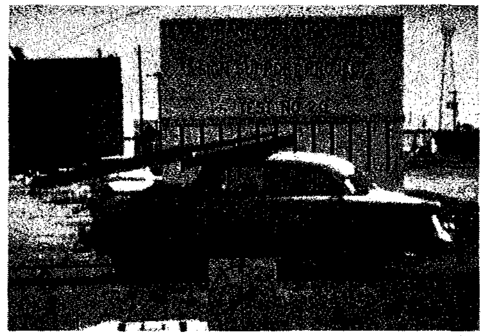
A large number of signs of the conventional design are in place on controlled access facilities in Texas. There is no doubt that these constitute a potential hazard. Therefore, it is necessary to improve their impact behavior. From the standpoint of economy, it is desirable to introduce certain safety features in these signs by field changes with maintenance forces. With this in mind, special cast iron fittings were designed to be bolted to the foundation of the existing signs. The existing signs would then be bolted to the top of these cast iron fittings as shown in Figure 7. The objective in this modification was to permit the sign to break away from the foundation thus eliminating the fixed condition to which a great amount of the resistance of impact could be attributed.

Two full-scale crash tests were conducted to evaluate the impact behavior of conventional sign supports using the cast iron fittings. In the first test the crash vehicle struck both legs of the sign support at approximately 40 mph and the sign was oriented at an angle of 15 degrees.

The test results indicated that the left post deformed the front bumper and other parts approximately 8 to 10 inches before the cast iron fittings fractured. Approximately the same deformation was observed after the right front portion of the vehicle made contact with the right post. Additional deformation was caused by the inertia effects of the sign supports upon release of the base.

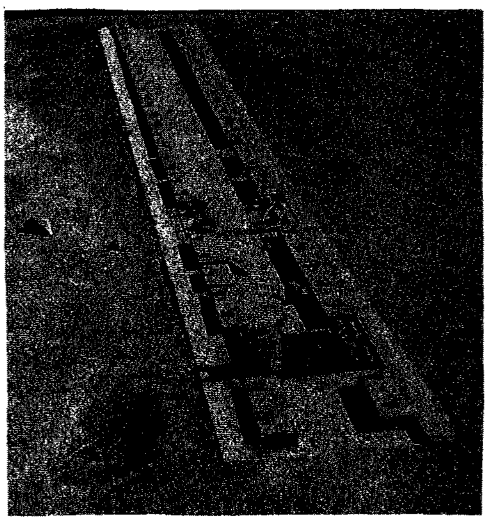
The sign supports rotated about the front of the hood so that the sign face struck the top of the automobile over the driver compartment, Figure 7. The sign produced 3 to 4 inches permanent deformation in the top of the automobile.

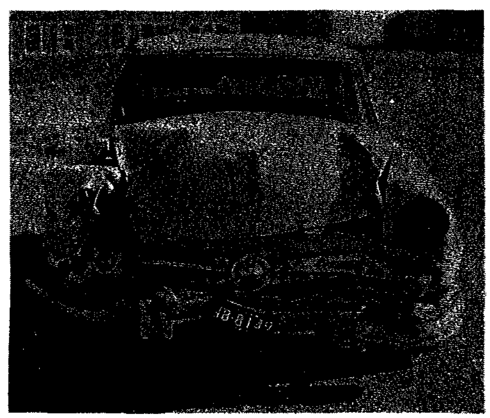
The sign, with supports still attached, struck the ground approximately 75 feet from the foundation and the vehicle again struck both legs of the support causing additional damage to the automobile.



DURING TEST

BEFORE TEST





AFTER TEST

VEHICLE DAMAGE

CAST-IRON INSERTS

FIGURE 7 - MODIFICATION OF EXISTING SIGN SUPPORTS

In the second test of this series, the same fracture mechanism was used below the base plate. In addition, a hinge joint similar to that used in earlier tests on both the large and the small signs was formed in the post at the bottom edge of the sign 7 feet above the base. It was anticipated that the hinge joint would permit the lower portion of the post to fold up out of the way of the colliding vehicle. The modified design was tested at approximately 40 mph with the vehicle again striking both posts. The hinge joints did not function as anticipated. In fact the performance of this design was essentially the same as that of the earlier test.

As a result of these tests it was concluded that this particular method of modifying the existing sign supports was not satisfactory. The major problem encountered was the distribution of the mass of the posts. In order to modify this conventional design it would be necessary to devise some means of separating the post above the base plate in order that the desired rotational effect could be attained to carry the sign with the supports over the top of the automobile. To date there has been no reasonable and practical solution to this problem. However, work will continue in search of a practical method of modifying existing sign supports.

PRELIMINARY TESTING OF MECHANICAL FUSES

This series of tests was devised to produce a numerical or quantitative comparison of certain notched plate mechanical fuses. The design and configurations of these notched plates were suggested by various personnel involved in the project. The notched plate fuse was an alternate device considered as a replacement for the cast iron fracture plate specified by the Texas Highway Department Standard SMD-8, 1965, and used in earlier crash tests to form the "hinge joint" in the support at the bottom edge of the sign.

The apparatus and procedures utilized were predicted partially upon the availability of equipment and costs involved. A 2,128-pound drop hammer was available as was a fork lift tractor. An 8 WF 20 beam was cut into two pieces and a simple hinge was welded in place to join the two beam segments together at one flange (Figure 8). The stub end of the beam was approximately two feet in length and the other part of the beam was about four feet in length. The stub end of the beam was instrumented with four electric resistance strain gages. The purposes of this instrumentation was to furnish a shear force transducer. This transducer was calibrated so as to read directly in pounds. The calibration was accomplished by using dead loads applied slowly to the instrumented beam, the beam being supported as a simple cantilever.

The instrumented and calibrated beam was bolted to the back of the fork lift tractor so as to provide a horizontal cantilever. The drop hammer was elevated and the beam was positioned beneath the hammer by maneuvering the fork lift. The drop hammer was then lowered slowly until it just touched, but did not load the beam. This technique was utilized in order to provide a "suddenly applied" load; the height of fall being zero units of distance. Upon release of the hammer a dynamic load of short time duration was applied.

The strain gages were connected to a Honeywell Model 1508 Visicorder, recording oscillograph. Upon a prearranged signal the recording oscillograph was set into operation and the tripping mechanism on the drop hammer was actuated. The resulting data consisted of a force-time plot of the loading of the several notched plate specimens. The results of the tests are summarized in Table B.

A review of the test results indicates that the notched plate design configuration has a definite effect upon the numerical results. The thicker the plate the higher the observed force, and the greater the torque on the

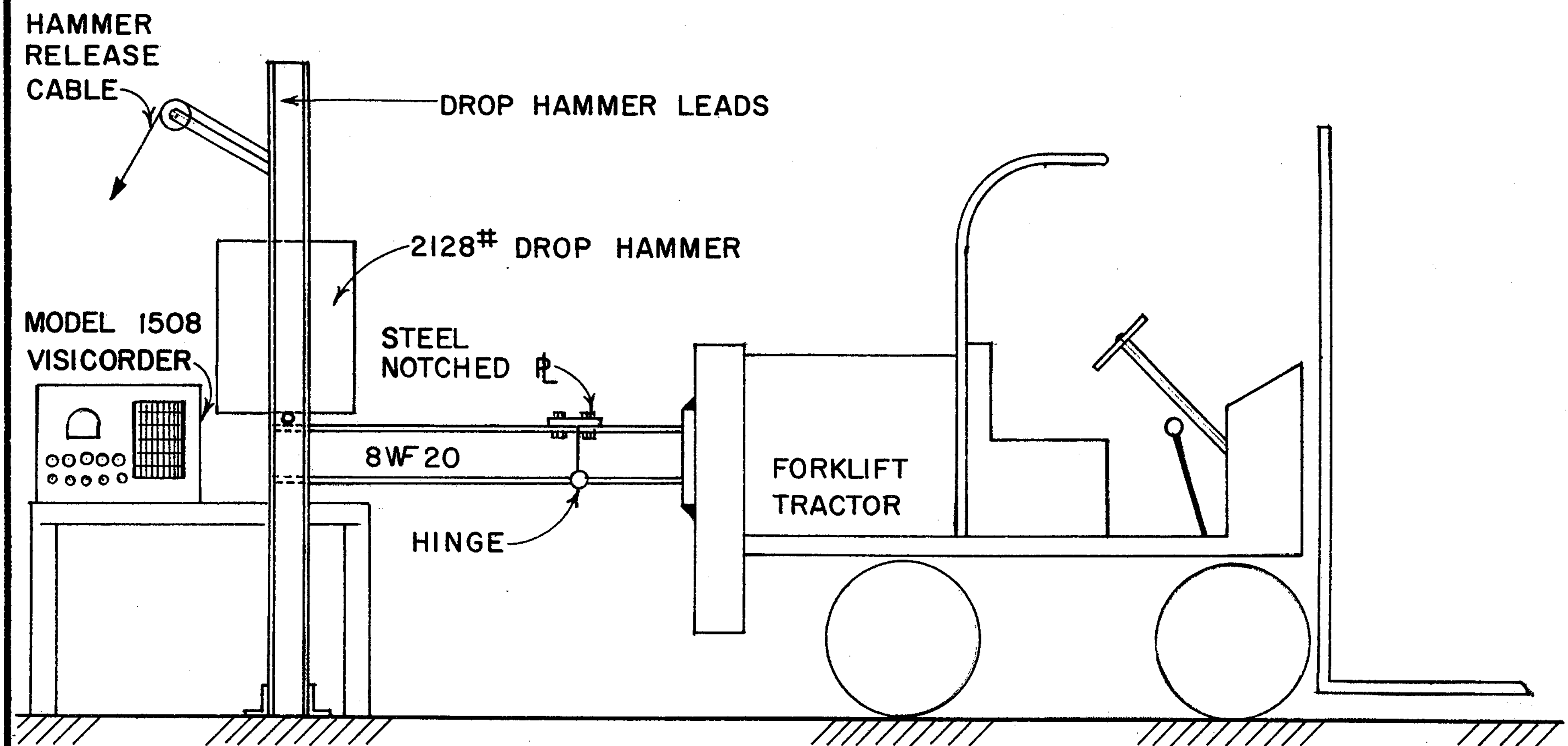
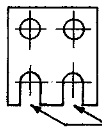
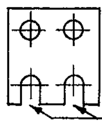
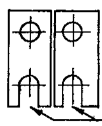
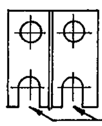
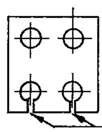
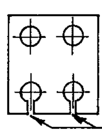
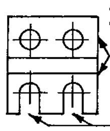
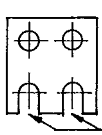
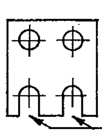


FIGURE 8—DROP HAMMER TEST

TABLE B

SUMMARY OF RESULTS

SPECIMEN NO.	CONFIGURATION	PLATE THICKNESS (IN.)	ASTM SPEC. NO.	BOLT TORQUE (IN. - LB.)	OBSERVED FORCE (LB.)
1	 FULL NOTCH	5/8	A-7	480	1220
2	 FULL NOTCH	3/8	A-441	480	745
3	 FULL NOTCH	5/8	A-7	480	1320
4	 FULL NOTCH	3/8	A-441	480	1120
5	 1/2" NOTCH	3/8	A-7	480	NO SLIP
6	 3/4" NOTCH	3/8	A-7	480	NO SLIP
7	 3/8" PL ON ENDS FULL NOTCH	1/4	A-7	480	1120
8	 FULL NOTCH	5/8	A-7	960	1530
9	 FULL NOTCH	3/8	A-441	960	1070

bolts the greater the observed force. Owing to the preliminary nature of this investigation only a small number of specimens were tested.

It must be emphasized that the testing device was not a standard length post, and since no correlation study was made with a standard length post, and since only a few specimens were tested; therefore the greatest care should be exercised in extrapolating the observed force values to actual crash test forces. To put it more strongly, no attempt should be made at this time to extrapolate the observed values to be representative of those to be expected under full-scale crash test conditions. However, on the basis of these preliminary tests it is recommended that another series of tests be performed with appropriate improvements to the testing device. This recommended series of tests would furnish useful information in designing future full-scale crash tests. Such future tests might well be correlated with slowly applied loads (static testing) with a view to determining theory to substantiate test information.

PIPE SUPPORTS FOR WARNING, REGULATORY AND SMALL GUIDE SIGNS

Standard galvanized steel pipe ranging in diameter from 2 inches to 5 inches is quite frequently used for sign supports for warning, regulatory and small guide signs. Normally these signs require only a single support but in some cases where a direction sign is extremely wide two pipe supports will be used. Although this type of sign may be found at any place along an Interstate or controlled access highway it is commonly used in great numbers at the minor interchanges to direct and regulate interchanging traffic. In such cases these signs are located at decision points where the probability of collision is greater; therefore, it is desirable that these sign supports be provided with safety features to improve impact characteristics.

The slip base and plastic hinge have been used satisfactorily in both the large and small two-legged roadside type signs. Thus these features might well be incorporated in the pipe supports if satisfactory impact performance could be realized. With this thought in mind, D. L. Hawkins of the Bridge Division, Texas Highway Department, selected two typical sign units utilizing pipe supports, one a 4-inch pipe and the other a 3-inch pipe. Modifications were made to the standard design of these units to provide a slip base and hinge joint. The slip base was similar to the design incorporated in the two-legged supports. The hinge joint however, required a completely revised design because the round pipe did not readily lend itself to the fabrication procedure as did the various structural shapes used in the two-legged signs. Instead, the pipe was cut 7 feet above the base and two steel plates were welded to the two cut ends. These two plates were connected at the back with a thin metal strip to provide a hinge and the front sides of the plates were bolted together with two bolts 5/8 inches in diameter with a locally reduced cross section. It was intended that these bolts would fail in tension at the point of reduced cross section when the sign support was subjected to the impact of collision.

Evaluation of Experimental Designs

Since a mathematical model or analytical procedure had not been developed to evaluate the dynamic behavior of these sign supports at the time that an evaluation was urgently needed, it was decided that this evaluation would be obtained through a series of full-scale crash tests. A summary tabulation of these tests is shown in Table C. In the

TABLE C

SUMMARY OF CRASH TESTS

Test No.	Post Description	Safety Features	Approximate Speed Before Impact (mph)	Angle of Impact (Degrees)	Deformation of Front Bumper and Frontal Area (Inches)	Make & Model Crash Vehicle
26	4" Standard Steel Pipe	Horizontal slip base; hinge joint	45	15	6	1955 Ford
27	3" Standard Steel Pipe	Horizontal slip base; hinge joint	45	15	4	1954 Ford
30	4" Standard Steel Pipe	Inclined (20°) slip base	35	15	8	1955 Chevrolet
34	3" Standard Steel Pipe	Inclined (20°) slip base	35	15	6	1955 Chevrolet
36	3" Dual Standard Steel Pipe	Inclined (20°) slip base	30	15	8	1954 Chevrolet
37	2-7/8" Thin-wall tubing (.083")	Inclined (20°) slip base	50	15	5	1956 Ford
38	3" Standard Steel Pipe	Inclined (10°) slip base	35	15	5	1956 Ford

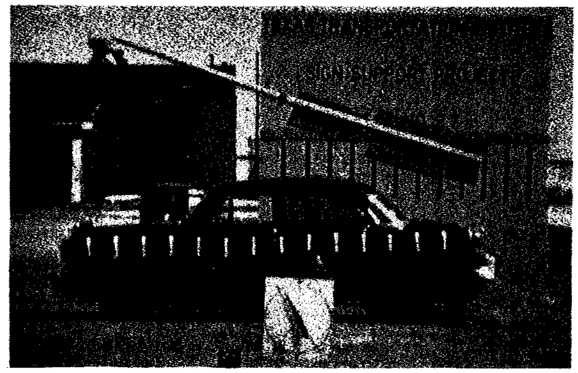
first phase of this series of tests both the 3- and 4-inch pipe supports were tested at a 15-degree-angle of impact and a crash speed of approximately 50 mph.

In the test on the 4-inch pipe support the base slipped after the pipe had penetrated the front bumper of the vehicle approximately 6 inches. The high-speed motion picture film showed that after the base slipped there was considerable deflection (approximately 5 degrees) in the upper members of the support, indicating considerable stress induced in the hinge joint. However, the hinge joint did not function and the entire sign support went into a rotational path over the top of the automobile twisting to one side and striking the top of the automobile (Figure 9). The impact on the top of the automobile caused some 2 to 4 inches permanent deformation.

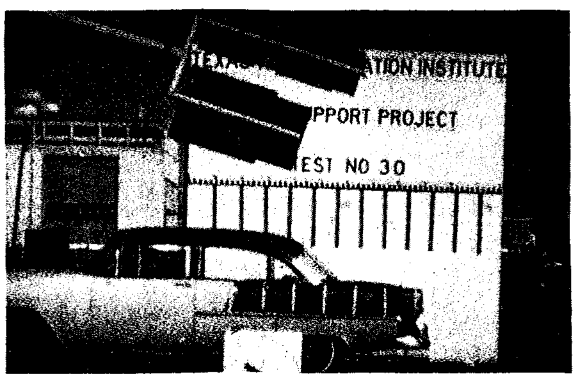
In the crash test on the 3-inch pipe support, the support deformed the front bumper approximately 4 inches before slippage occurred at the base. After the base slipped the ambient air resistance and inertia of the upper portion of the post which was 11 feet in length caused the post to bend through an angle of approximately 5 degrees above the hinge joint. The hinge joint did not fail in this test and the sign support went into a rotational pattern which carried it to a horizontal position approximately 2 1/2 feet directly above the automobile. The support continued in its rotational trajectory and the upper most portion of the post struck the rear of the vehicle (Figure 9).

Although there was not a great amount of damage in either of the two crash tests it was entirely possible that under another set of circumstances considerably greater damage may have resulted. The impact behavior of the sign supports was not considered satisfactory and consideration was given to methods of improving the impact behavior. First consideration was given to the hinge joint; which, had it performed properly, would have permitted the lower portion of the sign support to fold up, stabilizing it somewhat in its rotational trajectory. A rather crudely devised impact test using a drop hammer showed the strength of these bolts to be highly variable, but mainly, not very susceptible to impact loading. Although other bolt designs were considered it was readily evident that the tension type failure of the bolts was not particularly favorable in dynamic action. At the same time, it was realized that bolts having favorable impact characteristics would be a specialty item. The cost of such bolts would probably be prohibitive.

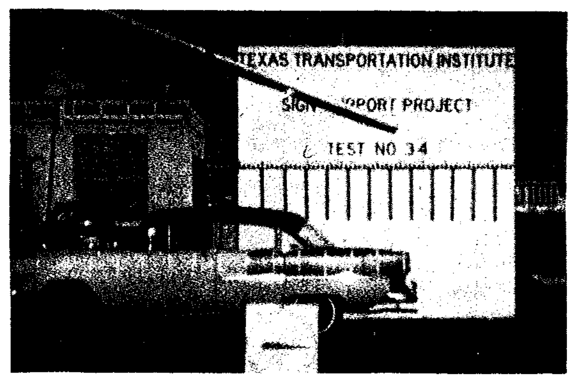
4" PIPE SUPPORT
HORIZONTAL BASE



3" PIPE
HORIZONTAL BASE



4" PIPE
BASE INCLINED 20°



3" PIPE
BASE INCLINED 20°

FIGURE 9 — IMPACT BEHAVIOR OF SINGLE PIPE SUPPORTS

In view of these complexities, an alternative was sought. In earlier work, the rotational pattern of the sign and sign supports was altered appreciably by inclining the slip base. For the single pipe mounts the slip base was inclined 20 degrees as shown in Figure 10 to give the sign a quick vertical lift immediately after slippage occurred at the base. This design and modification would not necessarily reduce the angular velocity of the support as it rotates over the top of the vehicle but it was hoped that the additional lift would be sufficient to keep the sign clear of the automobile until it had passed on under the sign.

Both the 3-inch and the 4-inch pipe supports were modified to incorporate the inclined base and then subjected to full-scale crash tests. In the test on the 4-inch pipe support, the sign support deformed the front bumper of the automobile approximately 6 inches before slippage occurred at the base. Once the base slipped the sign pitched upward and then started rotating over the top of the automobile. Whereas the sign had struck the automobile in the previous test, in this test the sign easily cleared the top of the automobile.

In the test on the 3-inch pipe support, the support deformed the front bumper approximately 6 inches before slippage occurred. After slippage at the base, the support was immediately lifted vertically and then rotated over the top of the automobile. When the vehicle was directly under the support, it was approximately 6 feet above the automobile. As a result of these tests it was concluded that the hinge joint was not necessary in single pipe supports because satisfactory impact behavior could be attained by inclining the base 20 degrees.

In a later test the angle of incline at the base was reduced to 10 degrees. This modification was made on the 3-inch pipe support and other test conditions were the same as in the earlier tests. A study of the films showed that the sign pitched vertically upon release from the foundation and rotated over the top of the automobile. The top of the support struck the extreme rear of the vehicle but caused very little damage.

Earlier design standards for pipe supports permitted the use of thin-wall, high-strength steel tubing in place of standard steel pipe. There was some concern as to whether this material was rigid enough to cause the base to slip as in the case of the standard steel pipe. A single crash test was designed to provide this evaluation. Thin-wall (0.083"), high-strength (52,000 psi yield) steel tubing was used in constructing a single pipe support 11 feet in length. The slip base was inclined at 20 degrees. The angle of impact was 15 degrees and the crash speed was approximately 55 mph.

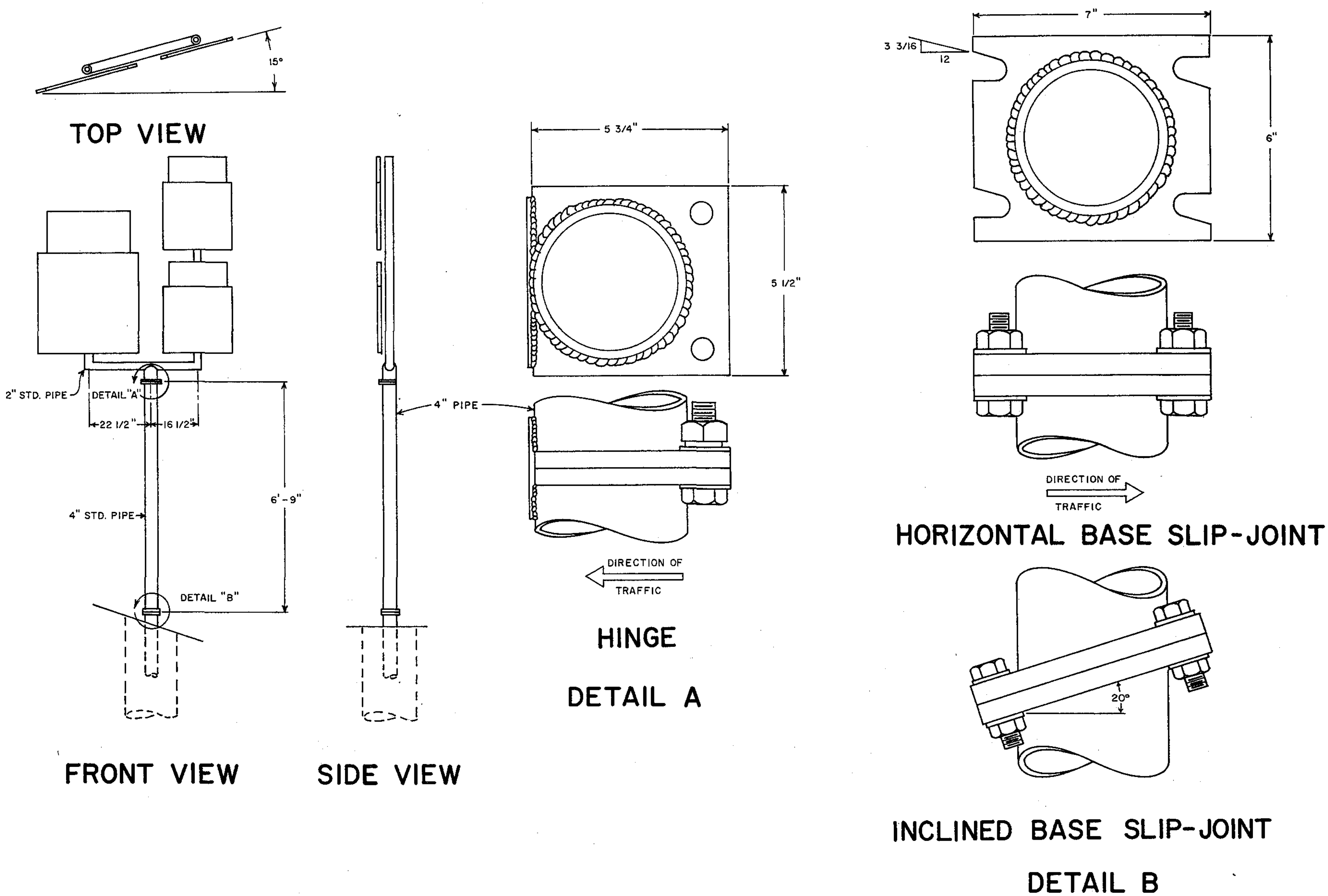


FIGURE 10-GENERAL DETAILS OF PIPE SUPPORTS

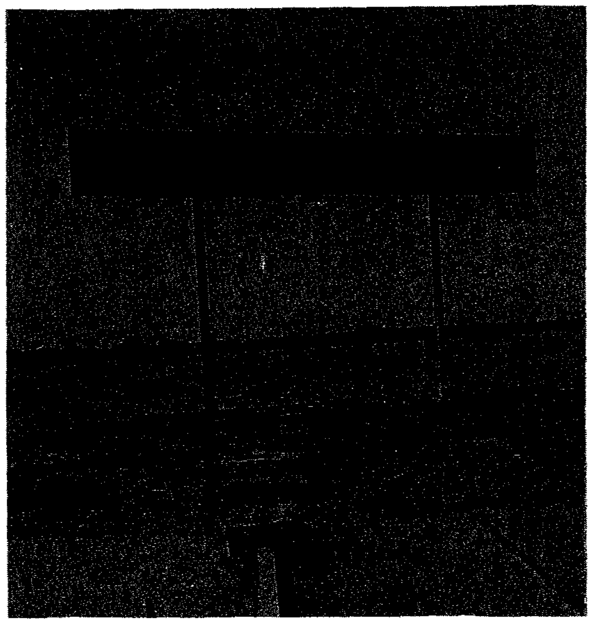
In the crash test the steel tubing was crushed at the point of bumper impact and the release at the base was delayed. The failure in the tube and the delayed release at the base changed the rotational pattern and caused the sign to strike the top of the automobile immediately over the driver compartment. The post then rotated over the top of the automobile.

Dual Pipe Supports

In some instances where direction signs exceed 13 feet in length, a dual pipe support is used. An illustration of this type of installation is shown in Figure 11. As indicated earlier, studies showed that the hinge joint was not a necessary feature to obtain favorable impact characteristics in the single pipe supports. However, there was some doubt as to whether or not it was needed in the dual supports described above. To resolve this question a full-scale crash test was planned using a typical design of the dual pipe support, as illustrated in Figure 11. A standard slip base was employed, inclined at a vertical angle of 20 degrees. The sign was attached to the sign rack of each post by means of standard post clamps which were bolted to the plywood sign faces.

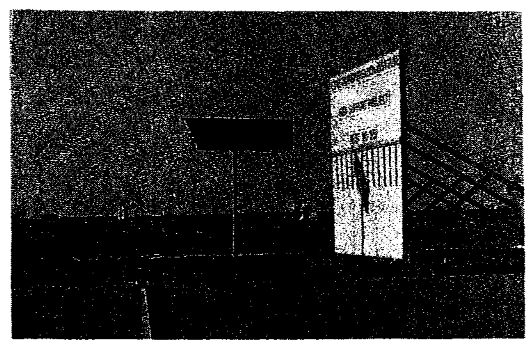
The sign was oriented at an angle of 15 degrees to simulate the most normal conditions of a vehicle leaving the roadway. In the test, the vehicle struck the left post at a speed of approximately 30 mph. Upon impact the bumper of the automobile and the grill and hood were deformed approximately 8 inches before slippage occurred at the base of the post. Once the base slipped the post rotated upward, swinging to the right, attempting to bend the sign around the right support (Figure 11). The upward rotation of the post partially pulled it loose from the sign and its horizontal rotation finally caused the sign to break in half and the left hand portion of the sign including the left hand support fell to the right of the vehicle. Since there was no hinge joint in the support the sign functioned as its own hinge in both the horizontal and the vertical direction.

On the basis of this test it was concluded that the dual pipe mounts would perform satisfactorily provided they employ a slip base. It is believed that the inclined base is beneficial because it aids the post in rotating clear of the automobile. No further tests were conducted on this particular design because experience from tests on two-legged signs



BEFORE TEST

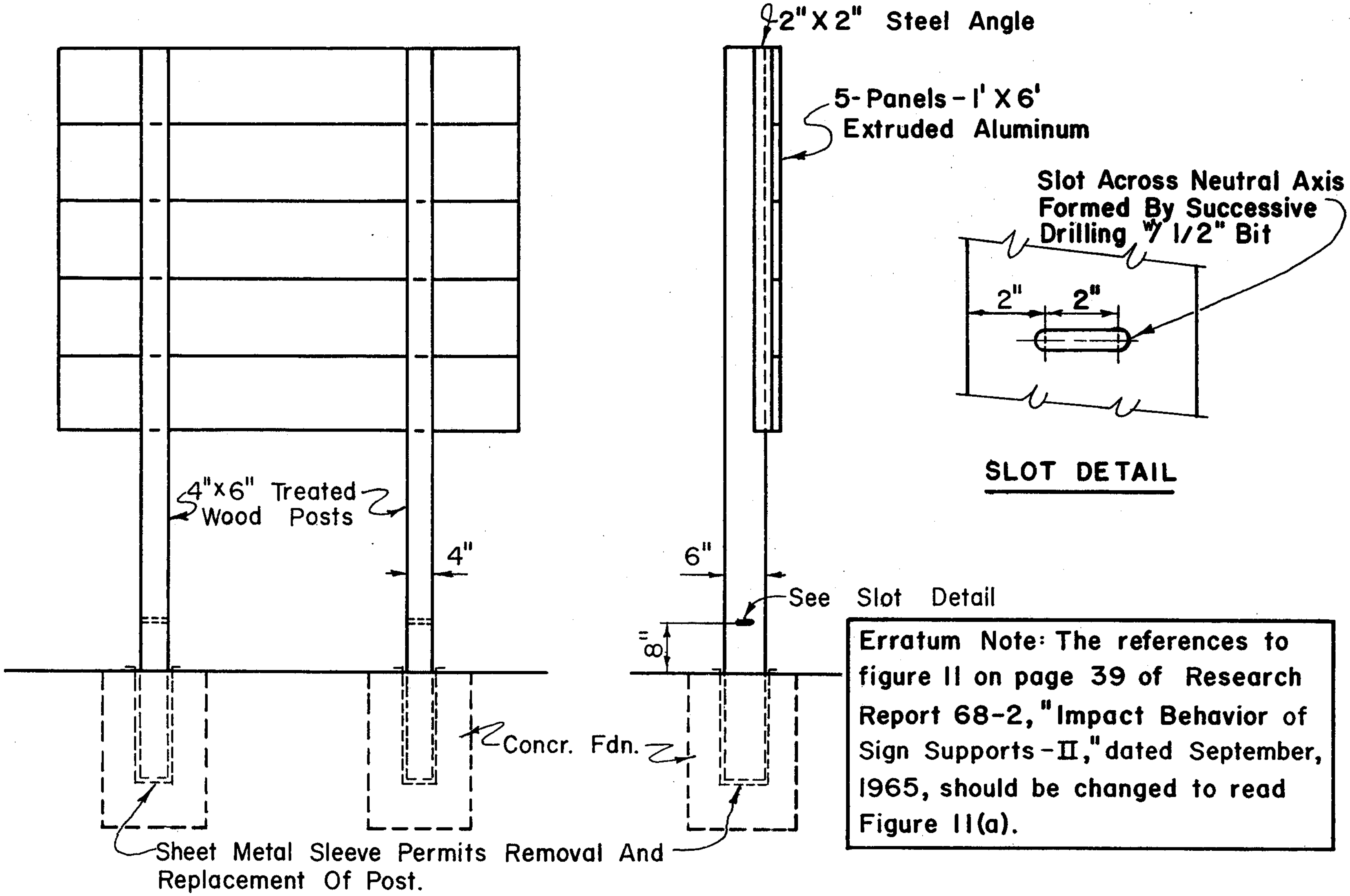
DURING TEST



AFTER TEST

FIGURE 11 — VIEWS OF DUAL PIPE SUPPORT TEST

conducted earlier indicated that the slow speed collision was most critical from the standpoint of the action of the post after it is freed from the foundation. In this particular case, when the post did not contact the automobile after the initial impact, it was assumed that similar satisfactory results would be obtained at high speeds and therefore actual testing was unnecessary.



Erratum Note: The references to figure 11 on page 39 of Research Report 68-2, "Impact Behavior of Sign Supports - II," dated September, 1965, should be changed to read Figure 11(a).

FIGURE 11(a)

WOOD POST SUPPORTS

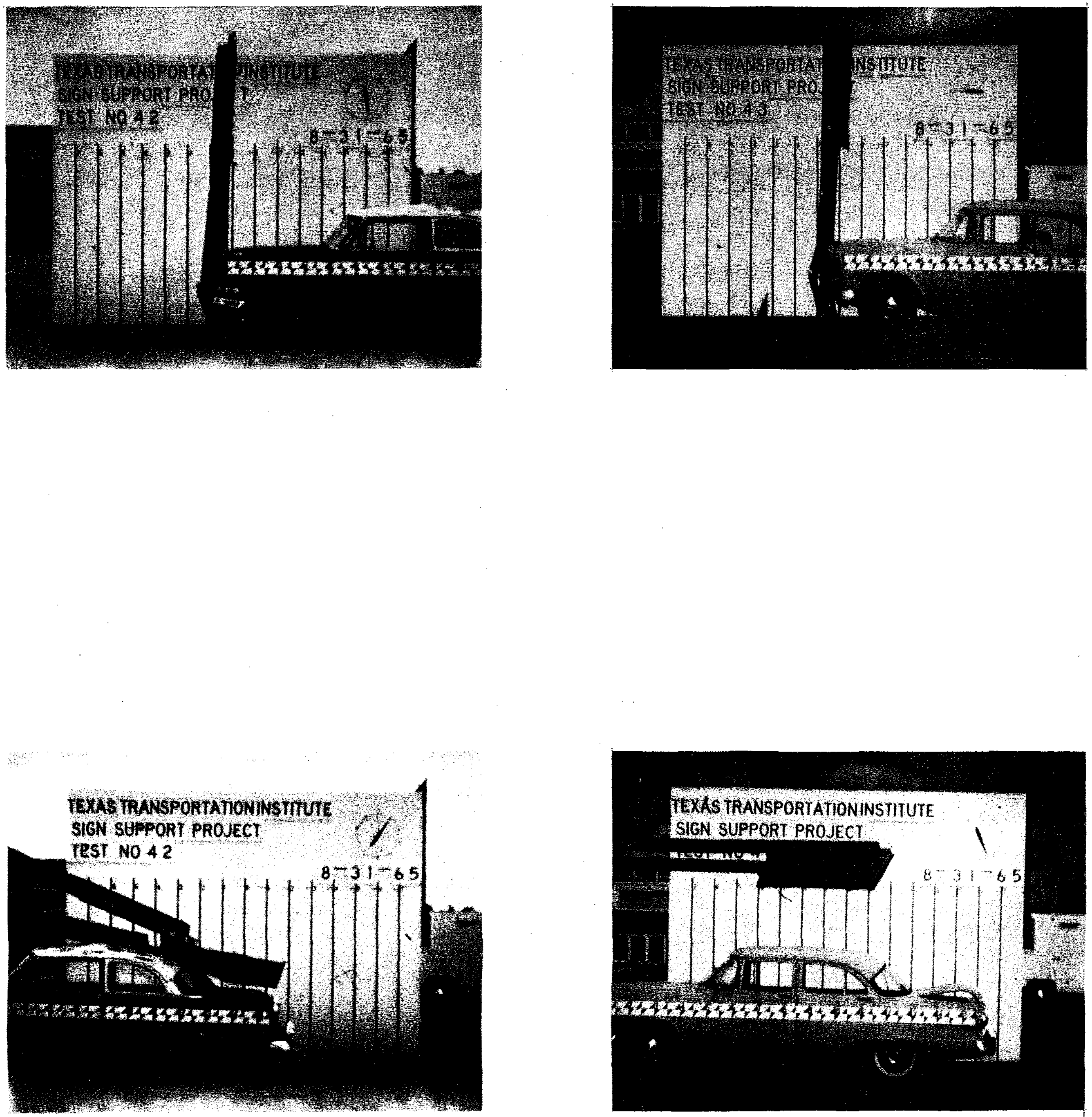
In an effort to reduce the potential hazard, the commonwealth of Pennsylvania is using notched wood posts as sign supports for gore or "EXIT" signs on some of their Interstate Highways. These signs were erected on an experimental basis on Highway I-90 along Lake Erie. Accident reports have indicated satisfactory impact behavior,[4] but these reports yield no information concerning phenomenological behavior.

There has been some interest in determining the impact behavior of the notched wood posts, so controlled crash studies were conducted on the Pennsylvania design and an equivalent experimental design, referred to herein as the TTI Design.

The Pennsylvania design was for the standard 5' by 6' "EXIT" sign normally placed on the nose of the exit ramp. The sign was made up of extruded aluminum panels, and was supported by two 6" by 8" penta-treated pine posts, as shown in Figure 12. The posts were trimmed to a 4" by 6" rectangular cross-section and inserted into sheet metal sleeves embedded in the concrete foundation.

As an alternate to the Pennsylvania design, an experimental design utilizing 4" by 6" treated pine posts was developed. In developing this design, it was of major concern to provide a means for the posts to shear off at the base, functioning in much the same manner as the slip base used on steel posts. To accomplish this, a slot two inches wide was cut through the post just below the bumper level as shown in Figure 11. This slot did not materially reduce the capability of the post to withstand an overturning moment due to windloading because the slot was cut across the neutral axis. Reducing the cross-sectional area, however, substantially reduced the horizontal shear resistance.

Before the crash studies were conducted limited tests were performed to determine the load carrying capability of the support. One of the supports was set in the foundation sleeve (Figure 11) and a cable was fastened to the post 9 1/2 feet above the foundation to approximate the center of a load imposed by the sign. A pulley was held by a fork lift tractor so that a horizontal load would be imposed on the sign support by weights placed on the platform at 50-pound increments until a complement of 850 pounds caused failure. The failure began at a knot in the timber about 18 inches above the horizontal slot in the post, and split to the slot. The load causing failure is comparable to a load of 825 pounds that would result from a 100-mph-wind according to AASHO Specifications.



PENNSYLVANIA DESIGN

TTI DESIGN

FIGURE 12—WOOD POST TESTS

Impact Behavior

Both designs were subjected to full-scale crash tests to determine their impact behavior. The signs were erected so that the crash vehicle, a standard size sedan hit both supports simultaneously at approximately 45 mph.

Pennsylvania Design--When the vehicle collided with both supports, (Figure 12) the left support broke in two at the lower notch after the post had deformed the front bumper approximately 4 inches. The failure in the right post was delayed momentarily and then failed beginning at the lower notch which is on the front of the post and progressing to the back edge of the post at the foundation. The remaining lower portion of the post was broken off at the foundation.

After the posts were broken loose at the base, the supports were thrown clear of the front of the automobile, and the sign and supports started to rotate over the top of the automobile. During this rotation the sign slipped off the angles to which it was clamped, slipping upward and leaving the posts in free 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". The left post barely missed the rear bumper of the automobile as it continued to rotate over the top of the automobile.

Analysis of the high-speed film of the crash showed that the vehicle was traveling at approximately 39.8 mph before impact and 38.6 mph after impact, a reduction in speed of 1.2 mph.

TTI Design--When the vehicle struck both posts simultaneously, the left support broke in two approximately 3" above the bumper, see Figure 12. The break was influenced somewhat by a knot in the timber. The post then broke off at the top of the foundation. The section of the post containing the slot was still intact after the test. The right post failed at the slot, shearing in front of the slot and splitting down from the back of the slot to the top of the foundation. The posts deformed the front bumper only about 3" before failure occurred. After the posts were broken loose from the foundation, they were thrown clear of the automobile and the sign and sign supports rotated through three-fourths of a revolution over the top of the automobile (Figure 12). The performance of the wood posts after impact was very similar to the 3" I-beam supports with a horizontal slip base tested earlier.

An analysis of the high-speed films showed that the speed before impact was 39.8 mph before impact and 38.6 after impact, a reduction in speed of approximately 1.2 mph. By coincidence, the measured speeds were identical to the test on the Pennsylvania design.

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2. Stonex, K. A., "Roadside Design for Safety," <u>Proceedings, Highway Research Board</u>, Volume 39, 1960, pp. 120-156.

3. Samson, C. H., Jr., Rowan, N. J., Olson, R. M., and Tidwell, D. R., "Impact Behavior of Sign Supports," Report 68-1, Texas Transportation Institute, College Station, Texas, 1965, pp. 1-3.

4. Anonymous, "Wood Break-away Sign Posts Provide Additional Safety for Motorists," <u>Wood Preserving News</u>, Volume 43, No. 2, February, 1965, pp. 13-15.

PART B

AN ANALYTICAL STUDY OF BREAK-AWAY SIGN SUPPORTS FOR ROADSIDE SIGNS

BREAK-AWAY SIGN SUPPORTS

INTRODUCTION

A series of six full-scale crash tests is described in this progress report. This series of tests was planned as a result of earlier studies involving the impact behavior of certain post supports. (1)* The Texas Transportation Institute has conducted over forty full-scale crash tests in which an automobile is towed into a variety of one and two-post highway sign structures. These tests sponsored by the Texas Highway Department in cooperation with the Bureau of Public Roads have defined the phenomenological behavior of certain developmental designs for support posts which break away under impact by an automobile.

High-speed motion picture films were made of each of the crash tests. Detailed study of these films suggested certain modifications in the developmental designs of sign posts with break-away devices. As the testing and studies continued it became apparent that some quantitative data were needed to aid interim evaluation and to corroborate developmental design assumptions. A search of the available literature revealed that other investigators had conducted instrumented full-scale crash tests of automobiles with a variety of fixed objects. Severy, et al. (2) conducted a series of collisions with fixed barriers. Some of the experiments utilized highly instrumented vehicles and anthropometric dummies. Beaton and others subjected concrete bridge rails (3) and median barriers (4) to full-scale automobile impacts. Lundstrom and Skeels (5), Henault (6) and Jehu (7) performed researches on different types of guard rails subjected to impact. British investigators including Moore (8), Christie (9), and Blamey (10) investigated lighting poles, lamp columns, and telegraph poles subjected to impact by automobiles. The automobile industry in the United States has conducted crash tests for many years. Stonex (11) has reported the development of crash research techniques at the General Motors Proving Ground. A Ford Motor Company report (12) discusses a new approach to the design of safer structures for highways. Important experiments concerning human exposures to linear deceleration were conducted by Stapp (13) at Muroc Air Force Base, California. This is not an exhuastive list, but it indicates the wide variety of investigations which have been conducted.

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*Numbers in parenthesis refer to references listed in Appendix A to this report.

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

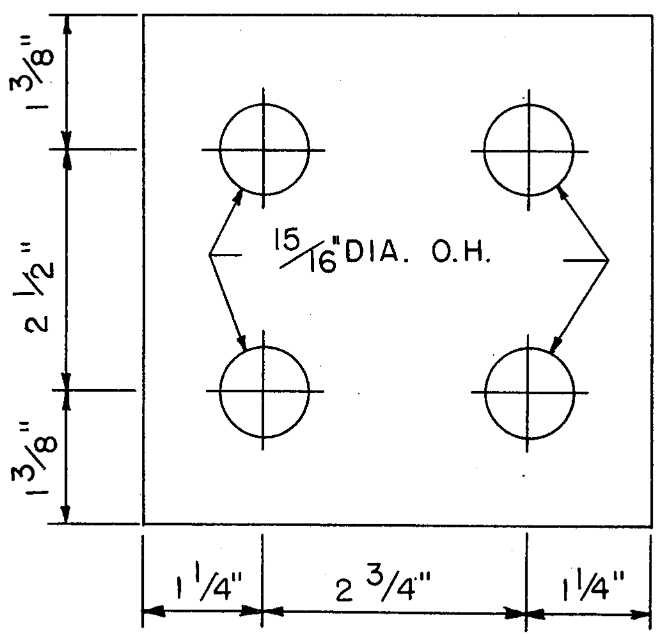
It became apparent to the investigators that a mathematical model of the post behavior should be developed. This model would serve to express in mathematical terms the behavior of the post support under dynamic loading. The model should be based upon analytical theory and should be correlated with the test data. The model could then be useful in predicting the effect of modification of various parameters and as a guide in designing future experiments.

DESCRIPTION OF TESTS

Tests 32, 33, and 35 were conducted in March and April of 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 all six tests only one of the two support posts was struck by the crash vehicle.

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 in this report. Attention is called to Figure 1 which illustrates the type of mechanical fuses used in these two tests.

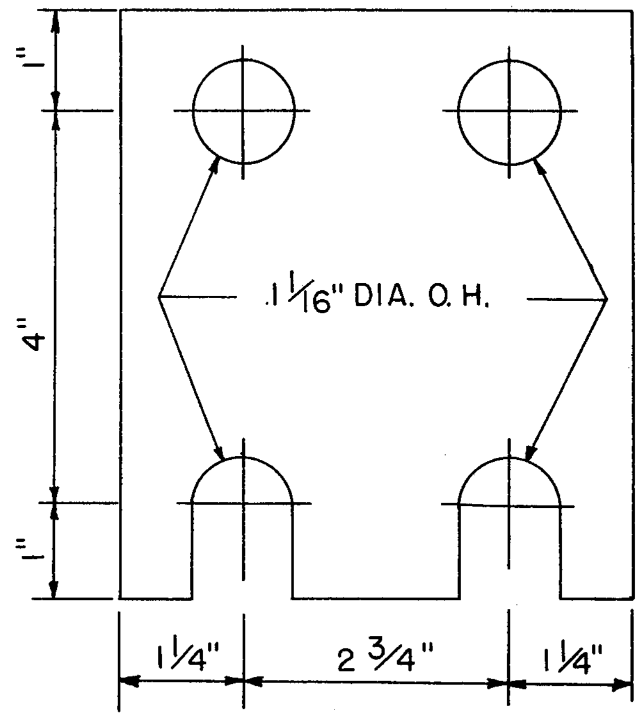
A description of the several tests conducted follows.



CAST IRON PLATE

3/8" THICK, A48, CLASS 30

TEST No. 40



STEEL NOTCHED PLATE

3/8" THICK, A441

TEST No. 41

FIGURE 1 — MECHANICAL FUSE DETAILS

TEST NUMBER 32

Construction Details

Size of Sign Face:	5' x 6' x 5/8" Plywood
Support Posts:	2-5WF16 (A36 Steel, painted)
Windbeams:	Extruded Aluminum (6061-T6)
Foundation:	24" ϕ x 3'-0" Drilled Concrete Footing

The sign and sign support were fabricated using available materials in order to determine general information for future instrumented tests. At the time this test was conducted definite information was not available concerning the behavior of an accelerometer and its amplifier when subjected to a sudden impact with a relatively fixed object.

Crash Vehicle Description

A 1954 Chevrolet 4-door sedan, weighing 3230 pounds was employed in this test.

Crash Vehicle Instrumentation

An Endevco Accelerometer, Model 2211C was mounted on the left main frame member 9'-0" behind the most forward bumper point. Another Endevco Accelerometer, Model 2211C was mounted on a 150# concrete block located on the driver's seat of the crash vehicle. This block was secured in place with a commercial seat belt fastened to the rear floor of the vehicle. An amplifier and power source were placed in a wooden box bolted to the floor of the trunk. The signal generated by the accelerometers was transmitted to a recording oscillograph by means of a 1000-foot, 4-conductor, shielded cable (Belden 8404).

Post Instrumentation

None.

TEST NUMBER 33

Construction Details

Size of Sign Face: 8' x 16' x 5/8" plywood

Support Posts: 2-8WF 20 (A441 Steel, painted)

Windbeams: Extruded Aluminum (6061-T6)

Mechanical Fuse: 5-1/4" x 5-1/4" x 3/8" Cast-Iron plate (A48, Class 30)

The sign and sign support were constructed in accordance with Texas Highway Department Interstate Standard Roadside Plywood Guide Signs, Break-Away Type Posts (SMD-8, 1965). A modification to the standard was the substitute of Alcoa clamps (SC 100, A1) for the THD standard windbeam clamp. This test was run to furnish additional information on instrumentation techniques.

Crash Vehicle Information

A 1952 Chevrolet 4-door sedan weighing 3130# was employed in this test.

Crash Vehicle Instrumentation

The vehicle instrumentation was identical to that described in Test No. 32.

Post Instrumentation

Electric resistance strain gages were mounted on the flanges of the support post struck by the vehicle. Three bridges were employed. The first bridge consisted of four strain gages mounted on the flanges at 10-inch spacing. This system produced a shear force transducer. The theory employed was simply

$$dV = \frac{dM}{dx}$$

since the support post is subjected to a constant shear force between the impact point and the break-away base plate. Other strain gages were installed in order to ascertain approximate values of strain at various locations on the support post.

TEST NUMBER 35

Construction Details

Size of Sign Face: 8' x 16' x 5/8" plywood

Support Posts: 2-8WF 20 (A441 Steel, painted)

Windbeams: Extruded Aluminum (6061-T6)

Mechanical Fuse: 5-1/4" x 5-1/4" x 3/8" Cast-Iron Plate (A48, Class 30)

The sign and sign support were constructed in accordance with Texas Highway Department Interstate Standard Roadside Plywood Guide Signs, Break-Away Type Posts (SMD-8, 1965). This sign was fabricated and a test run to furnish additional information on instrumentation techniques.

Crash Vehicle Description

A 1953 Chevrolet 2-door sedan weighting 3215 lbs. was employed in this test.

Crash Vehicle Instrumentation

The vehicle instrumentation was identical to that described in Test No. 32.

Post Instrumentation

The post instrumentation was similar to that described for Test No. 33.

TEST NUMBER 39

Construction Details

Size of Sign Face:	8' x 16'
Support Posts:	2-8WF 20 (A36 Steel, painted)
Windbeams:	3-3Z 2.33 (6061-T6 Aluminum)
Foundation:	24"ϕ x 8'-0" Drilled Concrete Footing 4-1 1/4" x 2'-6" Anchor Bolts

The sign supports were constructed in accordance with Texas Highway Department Interstate Standard Roadside Plywood Guide Signs (SMD-4, Rev. 1962). This standard was modified by the substitution of 5/16" ϕ x 1 1/2" flat head elevator type steel bolts, and by the use of the z-sections for the windbeams. These bolts are used in current highway sign construction.

Crash Vehicle Description

A 1955 Ford V-8, 4-door sedan weighting 3240# was employed in this test.

Crash Vehicle Instrumentation

An Endevco Accelerometer, Model 2211C was mounted on the left main frame member 9'-0" behind the most forward bumper point.

Post Instrumentation

A strain gage bridge was installed 6'-6" above base of post on front and rear flanges.

TEST NUMBER 40

Construction Details

Size of Sign Face: 8' x 16' x 5/8" plywood

Support Posts: 2-8WF 20 (A441 Steel, Hot-dip Galvanized)

Windbeams: 3-3Z 2.33 (6061-T6 Aluminum)

Mechanical Fuse: 5-1/4" x 5-1/4" x 3/8" Cast-Iron Plate (A48, Class 30)

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 in order to insure that the support post would remain fixed to the wind beam; thus permitting the cast-iron fuse to fracture, and the lower portion of the support post to elevate over the crash vehicle.

The mechanical fuse was cast and galvanized in accordance with the THD standard drawing.

Crash Vehicle Description

A 1955 Ford V-8, 4-door sedan, weighing 3240 lbs. was employed in this test.

Crash Vehicle Description

The vehicle instrumentation was identical to that described for Test No. 32.

Post Instrumentation

Post instrumentation is described on pages 67 through 71 of this report.

TEST NUMBER 41

Construction Details

Size of Sign Face: 8' x 16' x 5/8" plywood

Support Posts: 2-8WF 20 (A36 Steel, painted)

Windbeams: 3-3Z 2.33 (6061-T6 Aluminum)

Mechanical Fuse: 5-1/4" x 5-1/4" x 3/8" Notched Steel Plate (A441)

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 Number 40.

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

The ungalvanized mechanical fuse was fastened to the support post by using 1-inch diameter A325 high strength bolts.

Crash Vehicle Description

A 1955 Ford V-8, 4-door sedan weighing 3620 lbs. was employed in this test.

Crash Vehicle Instrumentation

The vehicle instrumentation was identical to that described for Test No. 32.

Post Instrumentation

Post instrumentation is described on pages 67 through 71 of this report.

High-Speed Camera Instrumentation

Motion pictures were made of each test conducted. A summary of the equipment used is contained in Tables I and II, Appendix B. A comparison of these two tables will indicate that the later tests were more carefully planned and instrumented than were the earlier tests. Observation and critical review of the early films led to changes and improvements in the equipment and techniques. Many useful ideas were taken from reports by other investigators. The location of the high-speed cameras is shown in Figure 2 (Test Number 39) and Figure 3 (Tests Number 40 and 41). Experience gained from earlier tests led to careful positioning of the cameras, the addition of stadia markers (reference targets) on the vehicle, the addition of the stadia reference board, the location of the centi-revolution clock. This latter instrument was mounted on the backboard in Tests 39, 40, and 41, see Figure 17. All of the changes were made in order to produce a better photographic record for eventual analysis.

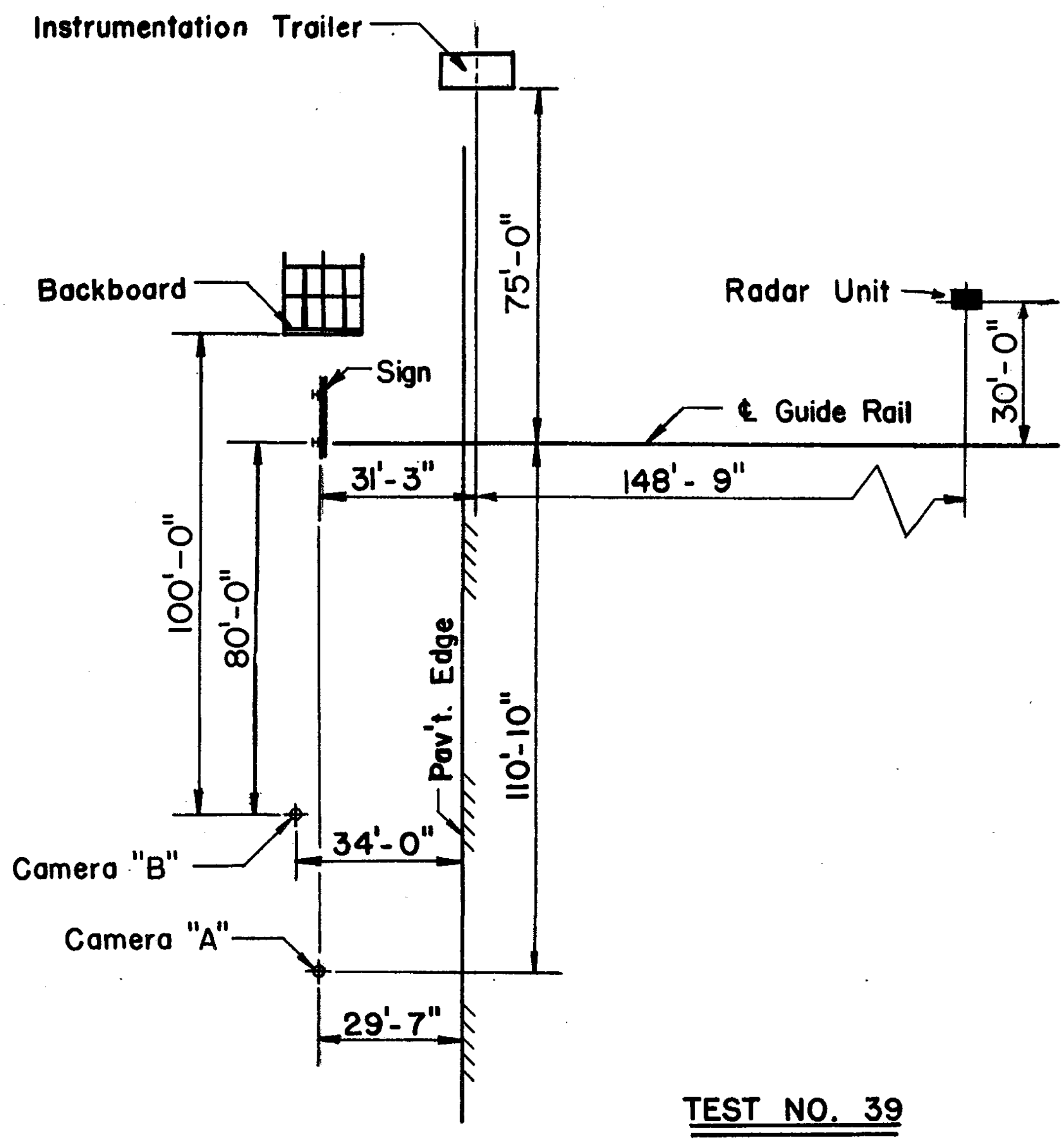
Philosophy of Instrumentation

The instrumentation employed in Tests 39, 40, and 41 was planned to produce corroborative information. The primary measuring device is the high-speed camera record. 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. This calibration indicated that the clock hand revolves at 1800 rpm. Analysis of the high-speed film was accomplished by means of a Wollensak Fastax 16mm 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 by using the centi-revolution clock. It was found that the difference between times recorded by the two methods was less than two per cent.

The installation of the linear displacement transducer was intended to provide an electronic record of the time of various events. The observed time of critical events is contained in Table V, Appendix B. It should be noted that exact agreement is not found; the results are encouraging, however.

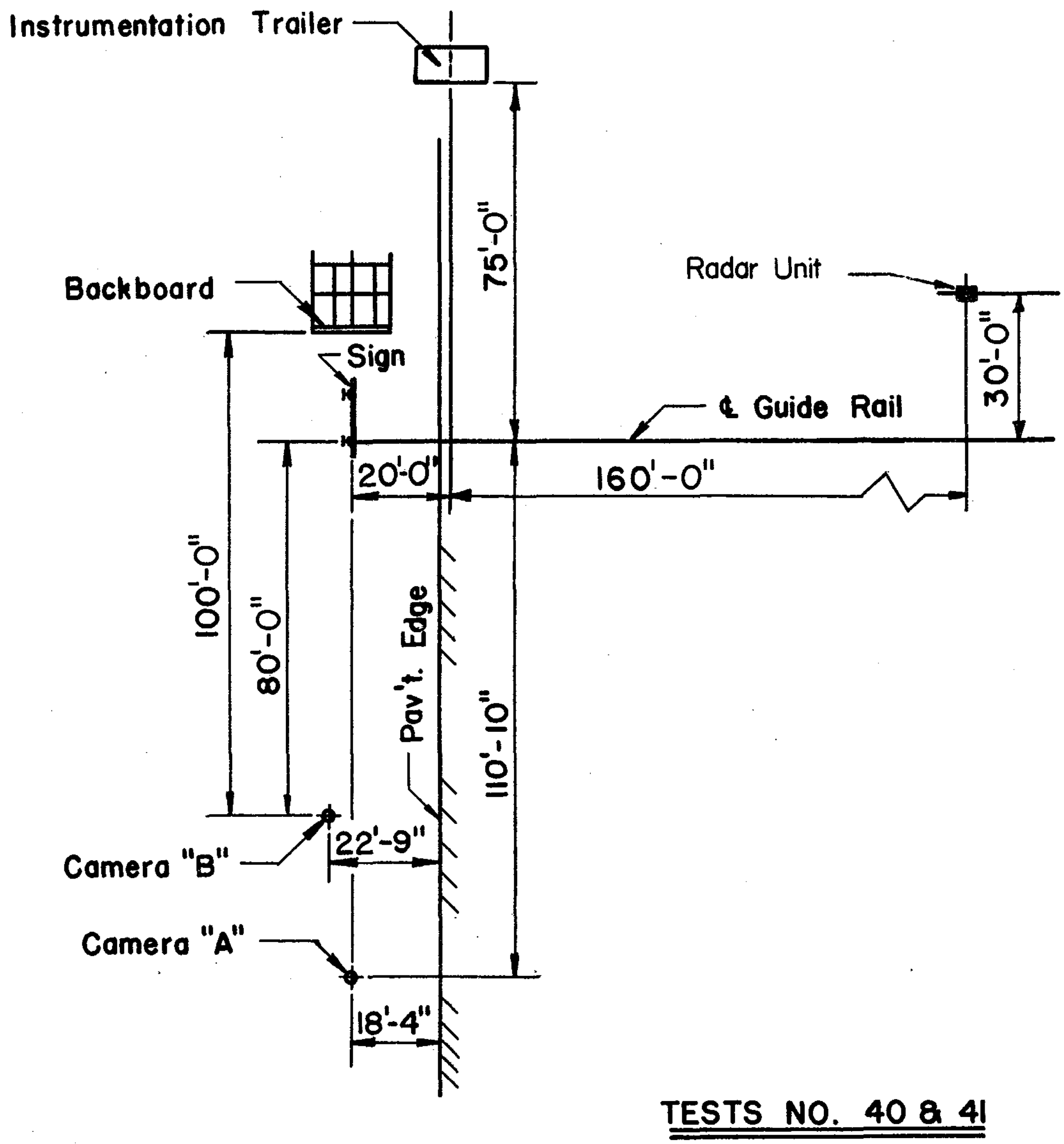
The installation of piezoelectric accelerometers to furnish a record of deceleration of the vehicle and acceleration of the support post was intended to provide data to compare with the high-speed film data.

The radar speed meter was installed to provide a determination of speed prior to impact for comparison with values determined by high-speed motion picture analysis. Values of speed prior to impact are shown in the following tabulation:



Camera A: WF 3T Fastax – KODACHROME II, Daylight, KR 449
Camera B: WF 3 Fastax – Tri-X Reversal Film, TXR 430

FIGURE 2 – PLAN OF TEST AREA



Camera A: WF 3T Fastax– KODACHROME II, Daylight, KR 449
Camera B: WF 3 Fastax– Tri-X Reversal Film, TXR 430

FIGURE 3 – PLAN OF TEST AREA

VEHICLE SPEED PRIOR TO IMPACT

Test No.	32	33	35	39	40	41	Method
(MPH)	39.2	52.0	51.8	44.0	44.6	42.5	Film
(MPH)	*	*	*	46.0	42.0	41.0	Radar
(FPS)	57.5	76.3	76.0	64.5	65.4	62.3	Film
(FPS)	*	*	*	67.5	61.6	60.1	Radar

*No Radar Installation

This table illustrates the philosophy of instrumentation employed. In this case, for example, crash vehicle velocity from film analysis is compared with crash vehicle velocity from the radar record.

High-Speed Motion Picture Analysis

The motion analysis projector described previously is equipped with a speed control which permits frame by frame analysis. The stadia markers (triangular targets in tests 39, 40, and 41) are employed to 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. In earlier tests this was done by using vertical lines drawn on the viewing screen. The range poles in the last three tests provided 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 4(a). The slopes of the fitted curves indicate the vehicle velocity prior to 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 shown in Figure 4(b). Similarly the slope of this curve is the deceleration-time curve shown in Figure 4(c).

The film speed used and the three-inch stadia increment on the vehicle permit a reliable plot of distance-time curves prior to impact and following the collision event. However, the scatter of points during the event permit a variety of curves to be fitted to the data. In Figure 4(b) two arbitrary curves have been fitted to the data and as a result the slopes of these curves give a striking difference in value of decelerations as illustrated in Figure 4(c).

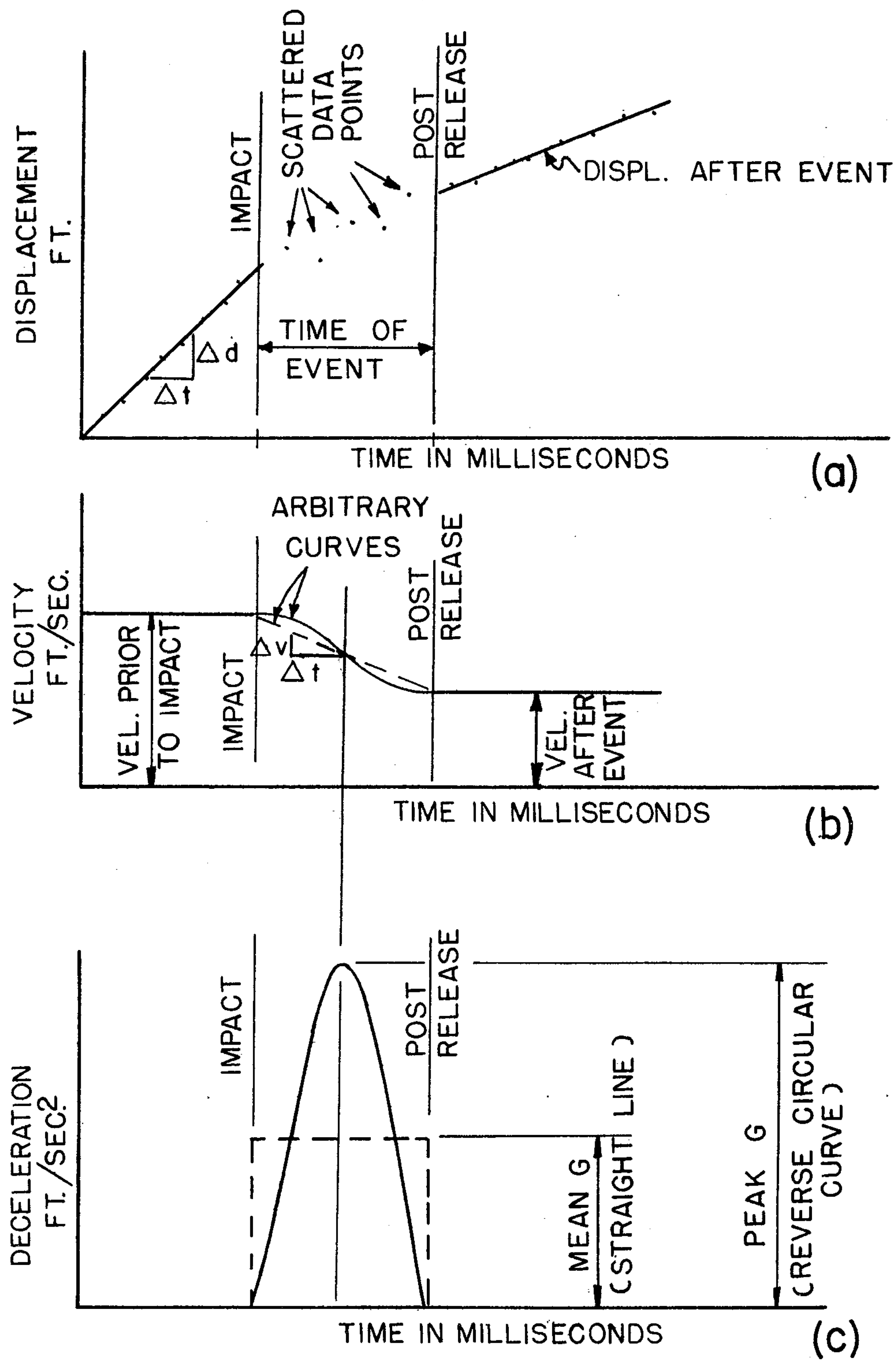


FIGURE 4 — FILM ANALYSIS

BY GRAPHICAL DIFFERENTIATION

Thus the process of differentiating distance-time curves and velocity-time curves produces magnification of minor irregularities. Considerable judgment is required in curve fitting. Even attention to variation of coordinate scales affects the results. Therefore, the reproducibility of data reduction is dependent upon technique employed. Severy and Barbour (14) report that

> "Application of poor curve fitting techniques may introduce errors as high as 100%, even though correct differentiation is applied to correct basic data."

The authors believe that the technique of graphical differentiation shows promise. Examples of data reduction by this method have not been included in this progress report because of the difficulties described.

Vehicle Accelerometer Analysis

A piezoelectric accelerometer was mounted on the frame of the crash vehicle. This accelerometer was located 9'-0" behind the bumper impact point. The signal transmitted from this accelerometer was transmitted to a recording oscillograph and a trace of the time variable deceleration was produced. A copy of the oscillograph record is shown in Appendix C.

The method of analysis is illustrated in Figure 5. This process depends upon graphical integration. Three methods have been employed in this study: (1) tracing on 20 x 20 graph paper, counting squares, recording the squares and time increment and computing the velocity-time data, (2) using a planimeter, and (3) recording amplitude values of acceleration for small time increments, then computing velocities and displacements by electronic digital computer. The three methods employed produce results which are in satisfactory agreement.

Starting with the deceleration-time curve, Figure 5(a) the areas are computed, tabulated and the velocity-time curve is plotted, Figure 5(b), and finally the integration process is repeated producing the displacement-time curve Figure 5(c).

This process of graphical integration produces surprisingly good results, as will be discussed later. The magnification of minor errors found in the graphical differentiation technique does not occur in the integration process. Although curve fitting is employed no great difficulties are encountered.

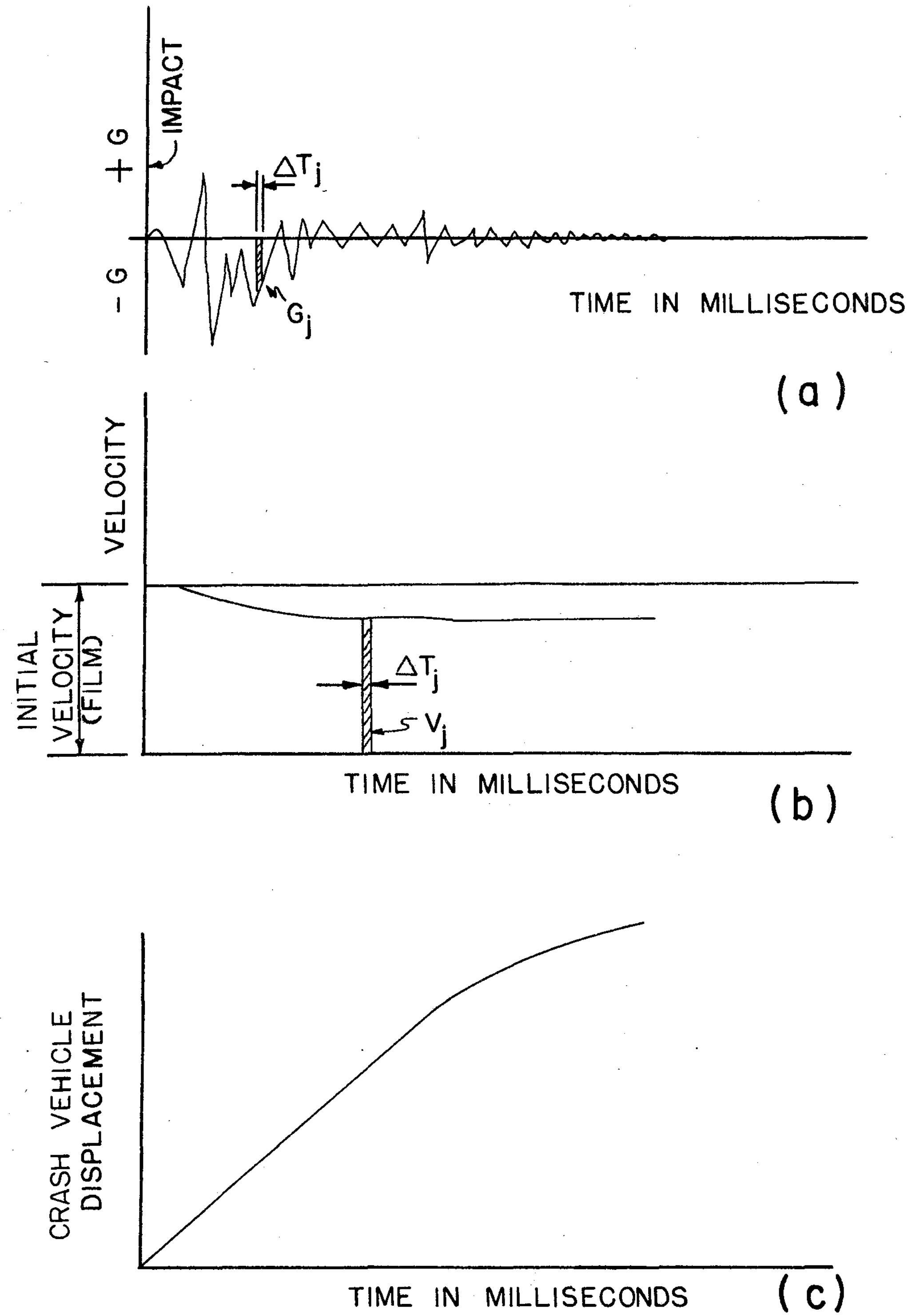


FIGURE 5 – ACCELEROMETER ANALYSIS BY GRAPHICAL INTEGRATION

A typical set of curves for Test No. 41 is presented in Figures 6, 7, and 8. The displacement-time plot shown in Figure 8 indicates the crash vehicle displacement with time as predicted by the mathematical model, and the actual determinations by accelerometer and high-speed film analysis.

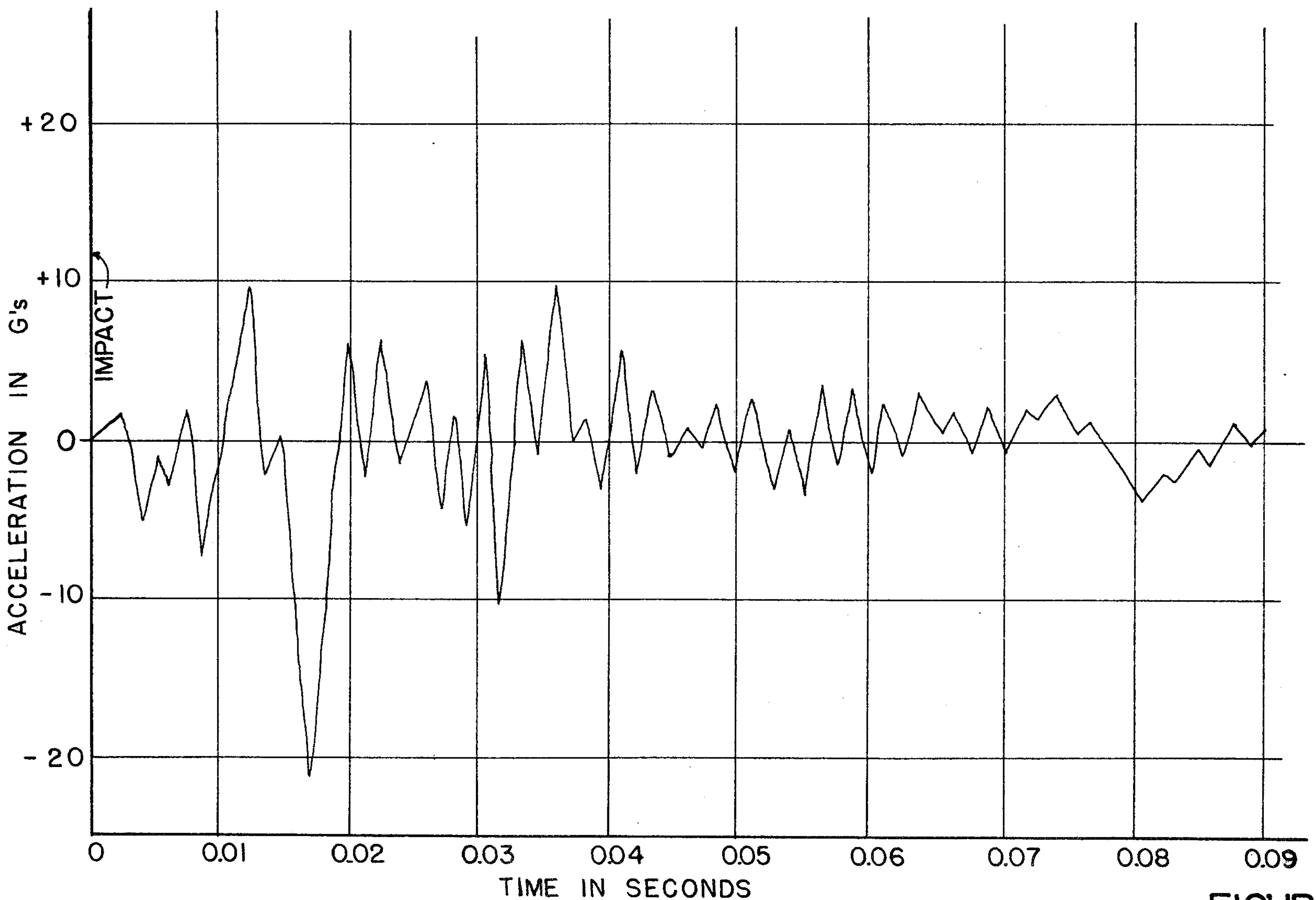
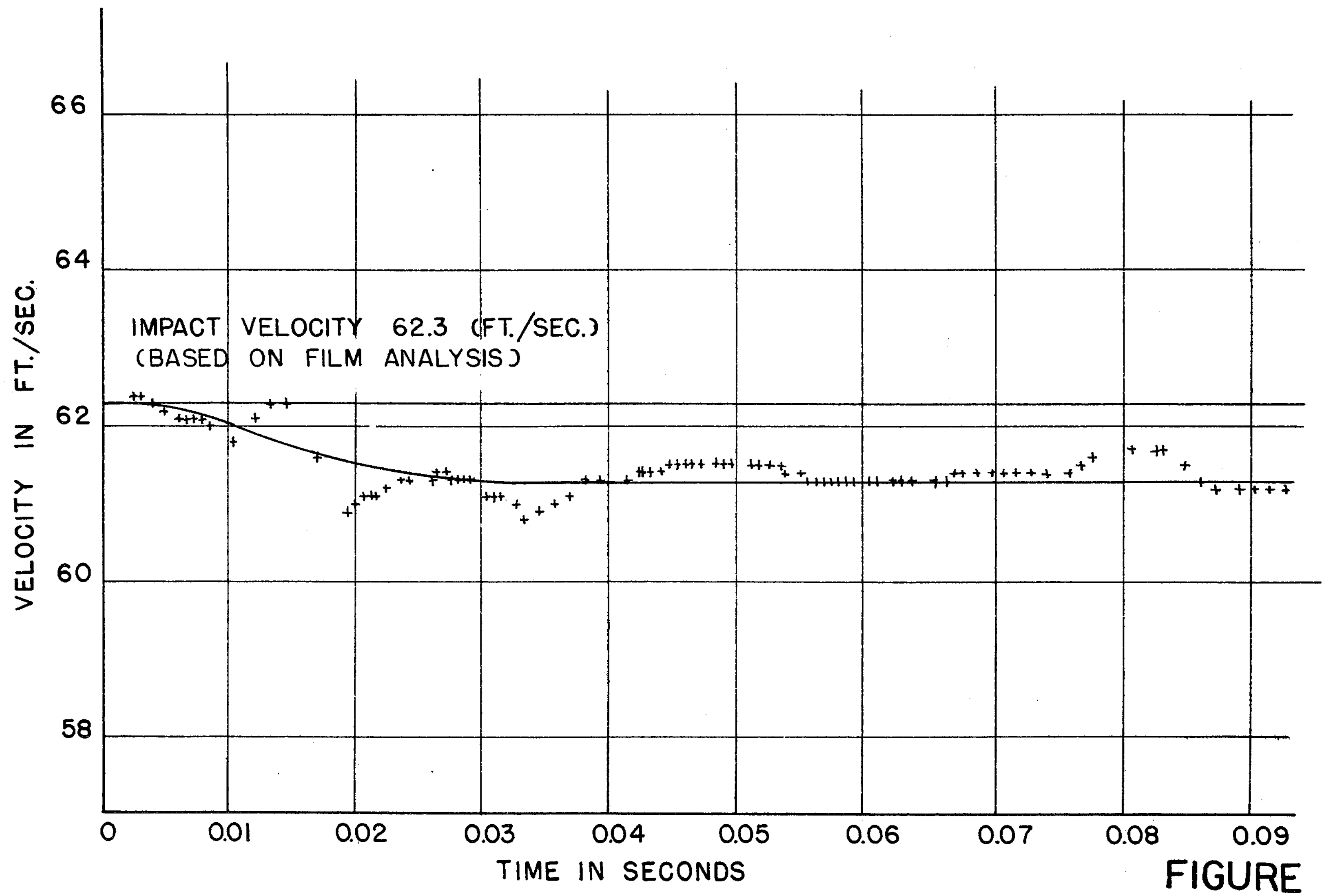

+20
+10
0
-10
-20
ACCELERATION IN G's
IMPACT
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
TIME IN SECONDS

FIGURE 6



66
64
62
60
58
VELOCITY IN FT./SEC.
IMPACT VELOCITY 62.3 (FT./SEC.)
(BASED ON FILM ANALYSIS)
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
TIME IN SECONDS

FIGURE 7

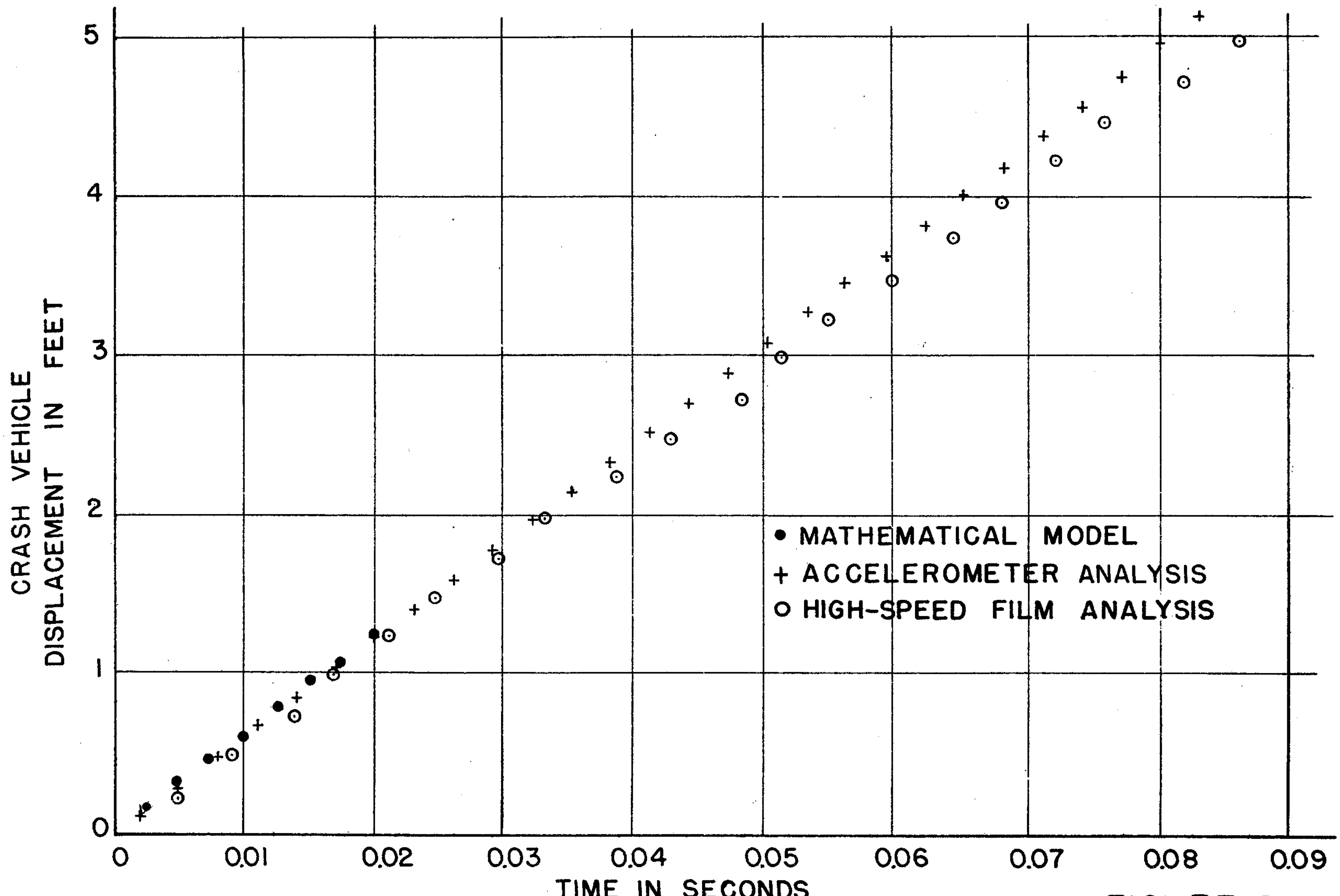

CRASH VEHICLE
DISPLACEMENT IN FEET
0
1
2
3
4
5
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
TIME IN SECONDS
● MATHEMATICAL MODEL
+ ACCELEROMETER ANALYSIS
○ HIGH-SPEED FILM ANALYSIS

FIGURE 8

Support Post Instrumentation

Electronic instrumentation was employed on the sign post. Electric resistance strain gages, a piezoelectric accelerometer, a variable resistance linear transducer, and a potentiometric linear transducer were installed. Views of the post instrumentation are found in Figure 9. The instrumentation of the post in tests 32, 33, and 35 was exploratory in nature and no description is presented herein. The summary in Table III, Appendix B gives the equipment used. The following detailed discussion of electronic instrumentation applies to tests 40 and 41. A summary of equipment used in the later tests is found in Table IV, Appendix B.

Mechanical Fuse Instrumentation

A full bridge composed of two electric resistance strain gages (Micro-Measurements, Inc., Type EP-03-125TF-120) was installed on the mechanical fuse. The full bridge was used for temperature compensation, the gage type was used because of its post-yield qualities. A suitable cement (W.T. Bean type RTC) was used. The gages were cured in an oven at a temperature of 200°F. for three hours, thus making the bond compatible with the post-yield gages. The equivalent strain caused by shunting a balanced, unloaded, Wheatstone Bridge with a calibrating resistor, Rc is:

$$\epsilon = \frac{R}{C\ Ne\ (R + Rc)} \quad \text{, where}$$

$$R_1 = R_2 = R_3 = R_4 = R = 120\ \Omega$$

$$C = \text{Gage factor furnished by the Manufacturer} = \frac{\frac{\Delta R}{R}}{\frac{\Delta L}{L}} \approx 2.03$$

N_e = Number of effective arms in the bridge

$$N_e = 2(1 + \mu - b)$$

μ = Poisson's Ration = 0.285 steel, cast iron

b = Transverse sensitivity of gage (b=0, almost)

$$N_e = 2(1 + 0.285) = 2.57 \text{ effective arms.}$$

$Rc = 50{,}000\Omega$ = calibrating resistor

$$\epsilon = \frac{120}{(2.03)\ (2.57)\ (120+50{,}000)} = \frac{120}{(5.278) \qquad (50{,}120)}$$

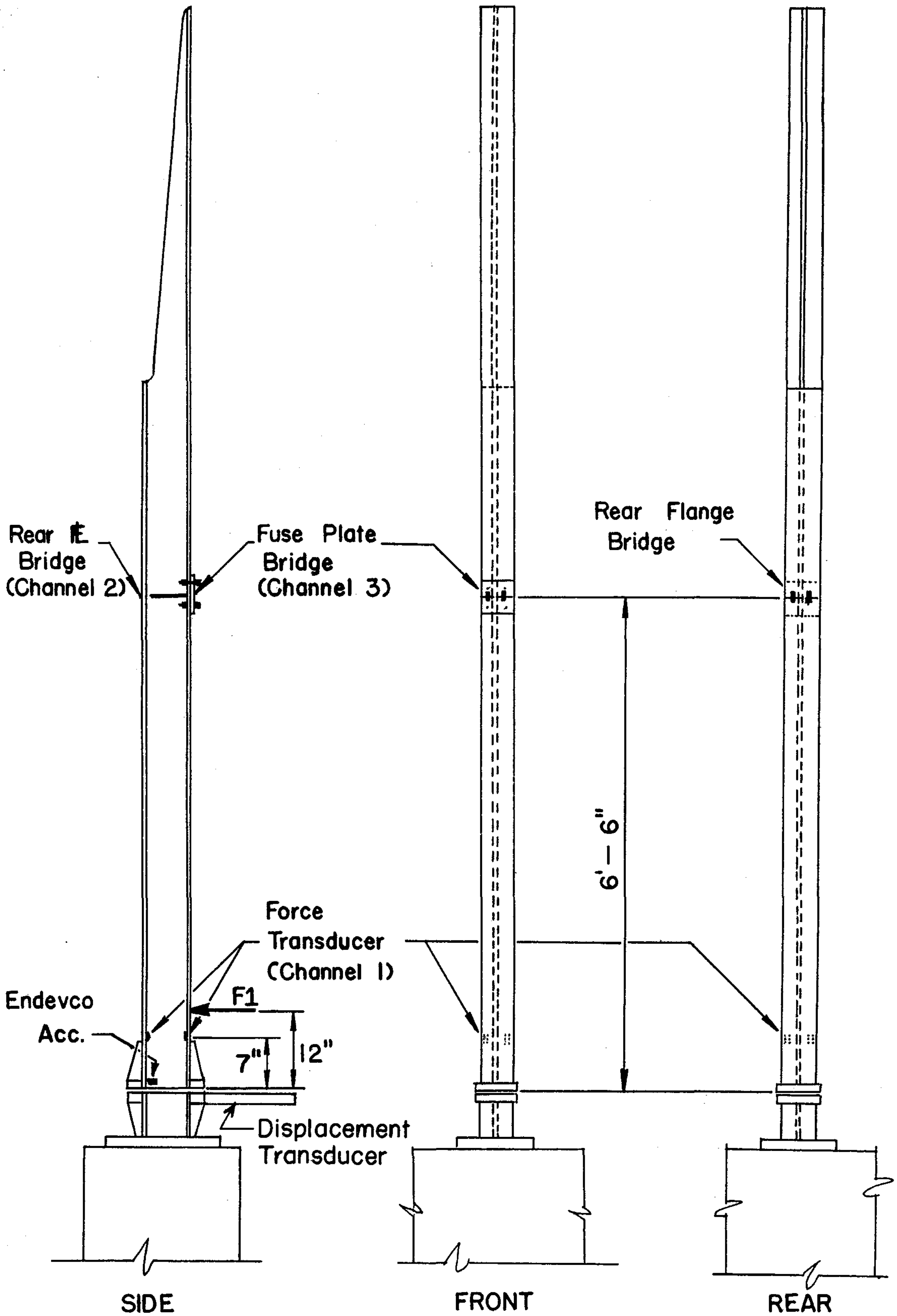
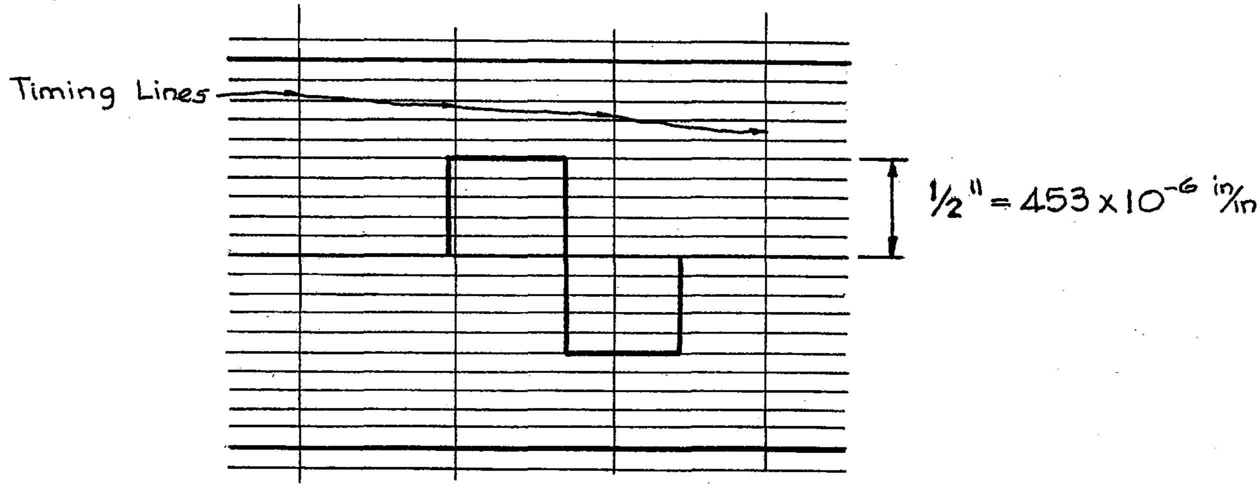


FIGURE 9 — POST INSTRUMENTATION

$\epsilon = 453 \times 10^{-6}$ in/in

The galvanometer on the visicorder is adjusted for a desired deflection of the beam of light on the record paper. The amount of deflection is dependent upon the available paper width. In test No. 41 the deflection, or b-step, was set at 1/2" = 453×10^{-6} in/in as seen in the sketch below.



Deflection of Galvanometer (b-step)
on Visicorder Record

Support Post Strain Gages

The bridge mounted on the rear flange of the beam consisted of the same type gages described for the fuse plate, the only difference being that the gages were mounted with Eastman 910 contact cement.

The gages were of the same type and batch as used on the mechanical fuse (same resistance, gage factor, and configuration). The bridge was calibrated in the same manner as the mechanical fuse.

Impact Force Transducers

Strain gages were mounted on the beam to measure the force of impact between the support post and the crash vehicle. A full bridge with $N_e = 4$ (all arms are effective) was employed to produce high gain and temperature compensation. The four gages were Budd Metalfilm type C6-121. They were attached to the beam with Eastman 910 contact cement. The post was bolted to a fixed support in a horizontal position and calibrated as a simple cantilever beam. A convenient 60 inches from the center of the bridge was used as the point of application of the variable load (moment arm). The load was applied in 100# increments, and the increase in strain was recorded with a Baldwin SR-4 strain indicator. This force was later reduced to an equivalent force at the impact center.

After the beam had been calibrated it was mounted in the vertical position with the sign attached. The same SR-4 strain indicator used in calibration was used to read zero strain. The purpose of this calibration was to determine if the bridge was balanced, and to compare the strain reading of the SR-4 strain indicator to the calculated strain caused by the calibrating resistor.

Displacement Transducers

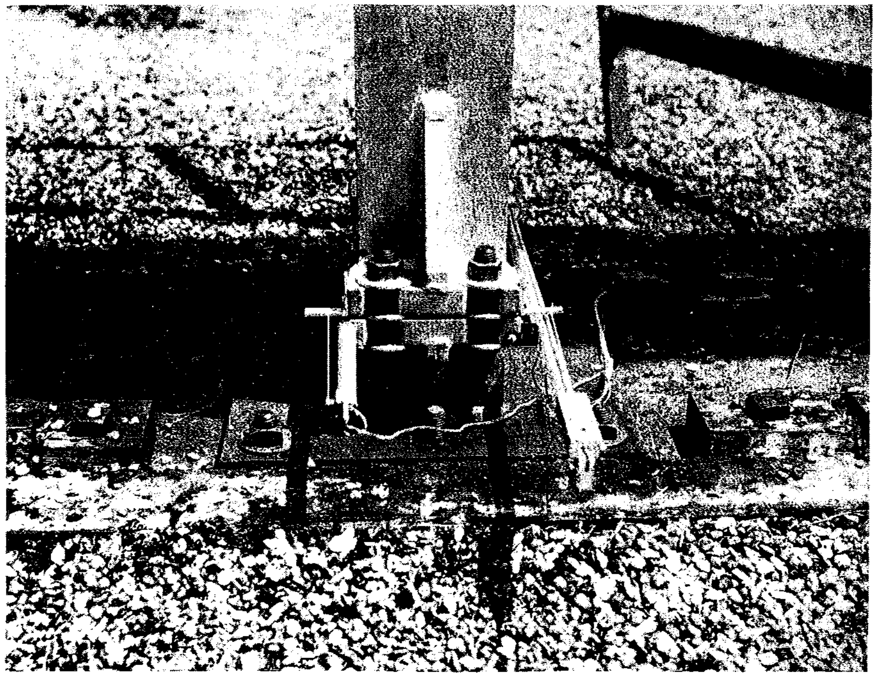
Two displacement transducers were mounted at the base of the beam as shown in Figure 10. Both were designed and constructed for this project. They were of the potentiometer type: one had a 4-inch travel, the other had a 19-inch travel. Electrical and mechanical properties (mass, resistance, linearity, proper choice of galvanometers) were given consideration during the construction but not enough attention to the environment. The 19-inch potentiometer, was impeded by oily particles of soil and other foreign matter which struck the transducer at the time of impact. The longer transducer having greater exposure was more difficult to protect; and it failed to give a reading during either Test 40 or 41. It is realized that more expensive transducers are available but none were on hand, and the hazardous position in which they were to be mounted led to the decision to use the potentiometric transducers. Both transducers are of the same type, they differ only in construction.

The outputs of the potentiometers were attached to a properly dampened galvanometer of compatible frequency response. Both were calibrated previously and found to be linear.

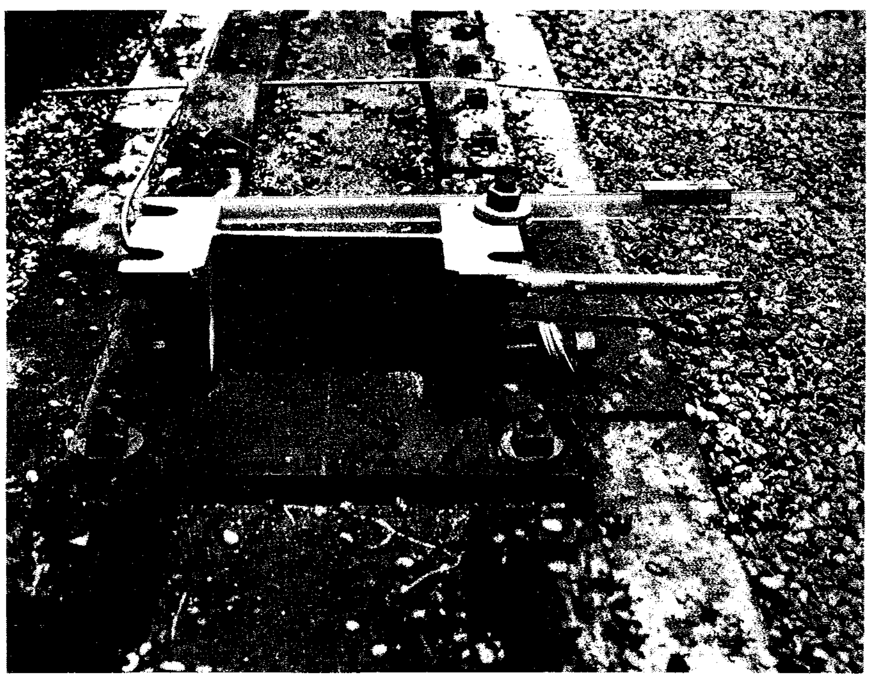
Support Post Accelerometer

An accelerometer was mounted on the support post near the base as shown in Figure 9. It was an Endevco Model 2215, with amplifier 2614B. The system was calibrated and adjusted to give one inch galvanometer deflection equivalent to 33.3G's for Test 40, and one inch deflection equal to 100G's for Test 41.

The post support accelerometer data has not been analyzed.



BEFORE IMPACT



AFTER IMPACT

FIGURE 10 — DISPLACEMENT TRANSDUCERS

THE MATHEMATICAL MODEL

A dynamic model has been developed which expresses quantitatively the dynamic behavior of a sign support subjected to impact by a vehicle. In order to obtain a working model in as short a time as possible a thorough study was made to determine what 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.

This observation led to the assumptions made in determining the mathematical model used in the study. This model is shown in Figure 11. It 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. In order to simulate the action of the real sign post the slip base is assumed to offer a constant resistance to slipping until maximum slip occurs.

The plastic hinge is assumed to behave in an elastic perfectly plastic manner until the cast-iron fuse plate ruptures. Provisions have been made in the mathematical model to express the quantitative behavior of the notched-plate mechanical fuse.

Numerical Procedure

The method used in the solution of this problem is that developed by E.A.L. Smith. This method (15) is a modified constant velocity technique which utilizes a forward step integration in time of the finite difference equations of motion.

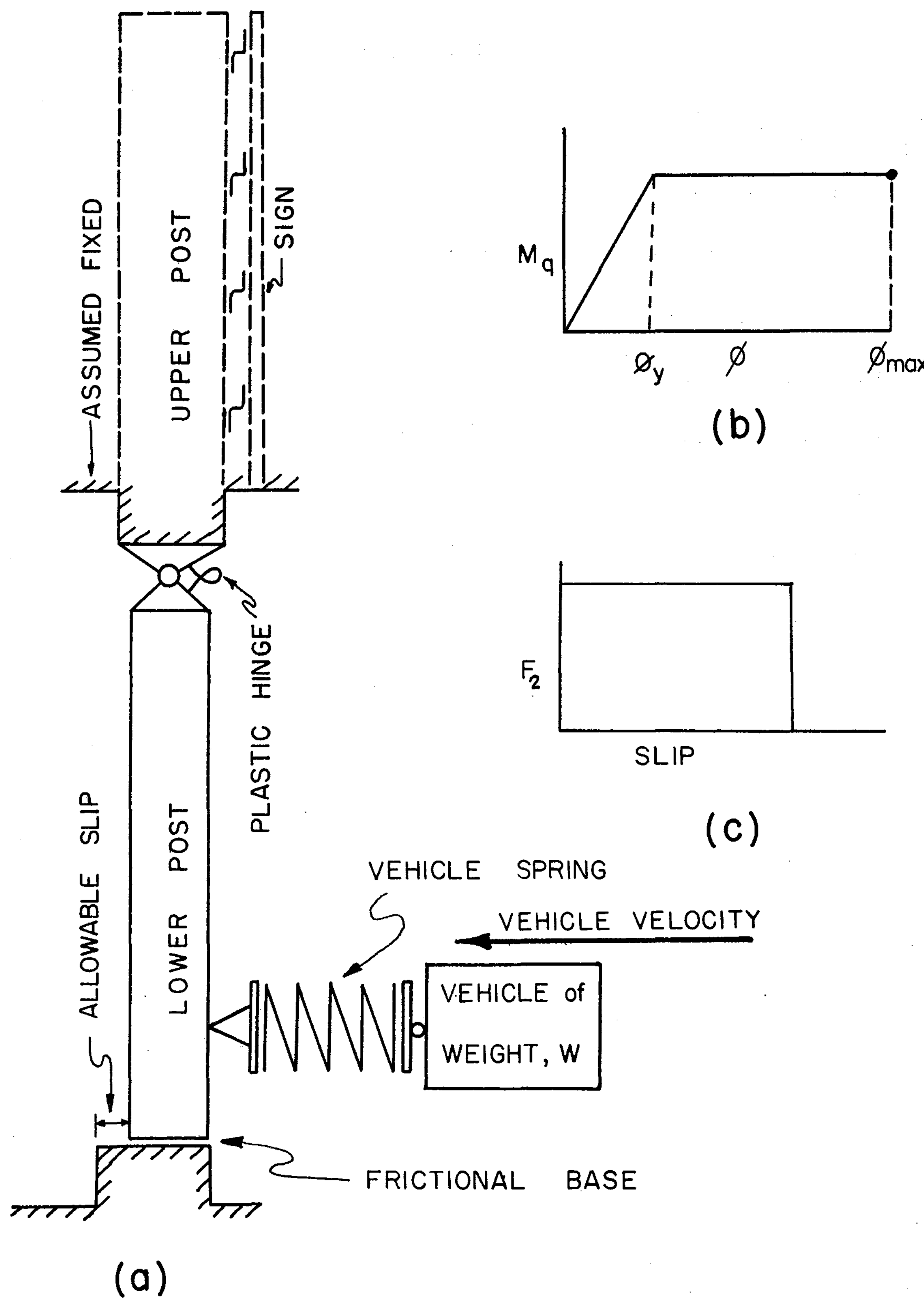


FIGURE 11 — IDEALIZED MODEL OF SIGN SUPPORT POST

NOMENCLATURE

M_Q = moment, foot-pounds.

ϕ = rotation of lower post, radians.

ϕ_y = rotation of lower post @ yield of fuse plate.

ϕmax = rotation of lower post ultimate of fuse plate.

F_2 = base plate force, pounds.

Slip = Distance plate moves before bolts disengage, inches.

F_1 = vehicle force, pounds.

X = generalized displacement, feet.

$\dot{X}$ = generalized velocity, feet/second.

$\ddot{X}$ = generalized acceleration, feet/second/second.

θ = generalized angle, radians.

$\dot{\theta}$ = generalized angular velocity, radians/second.

$\ddot{\theta}$ = generalized angular acceleration, radians/second/second.

K = spring constant of vehicle, pounds/foot.

Δt = time increment, seconds.

A = distance from hinge to point of application of vehicle force, feet.

H = length of lower post, feet.

W = vehicle weight, pounds.

[illegible] = rotational spring constant for plastic hinge.

M_F = accelerating moment on post, foot-pounds.

M_Q = inertial moment on post, foot-pounds.

M_1 = mass of vehicle = W/g, pound-second^2/foot.

σ_y = yield stress in plastic hinge, psi.

ϵ_y = yield strain in plastic hinge, in/in.

ϵ_u = ultimate strain in plastic hinge, in/in.

d = beam depth, inches.

f = plate stress in plastic hinge, psi.

b = fuse plate width, inches.

e = distance between bolt in fuse, inches.

Vo = initial velocity of vehicle, mph.

g = acceleration due to gravity, feet/second/second.

Consider Figure 12, which is a free body diagram of the forces acting on the post and vehicle at any time.

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

$$x_{1,t+1} = x_{1,t} + \dot{x}_{1,t}\Delta t \qquad .....(1)$$

$$F_{1,t+1} = (x_{1,t+1} - x_{2,t+1})k \qquad .....(2)$$

$$x_{1,t+1} = -F_{1,t+1} / M_1 \qquad .....(3)$$

$$\dot{x}_{1,t+1} = \dot{x}_{1,t} + \ddot{x}_{1,t+1}\Delta t \qquad .....(4)$$

For the post the equations are:

$$\theta_{t+1} = \theta_t + \dot{\theta}_t\Delta t \qquad .....(5)$$

$$M_{F,t+1} = F_{1,t+1}\cdot A - F_{2,t+1}\cdot H - (WH/2)\cdot \sin\theta_{t+1} \qquad .....(6)$$

$M_{Q,t+1} =$ [illegible] θ_{t+1} .....(7)

$$\ddot{\theta}_{t+1} = \frac{(M_{F,t+1} - M_{Q,t+1})}{J} \qquad .....(8)$$

$$\dot{\theta}_{t+1} = \dot{\theta}_t + \ddot{\theta}_{t+1}\Delta t \qquad .....(9)$$

The sequence of calculations is started with the following boundary conditions:

<u>For the vehicle;</u>

1) $x_{1,0} = x_{1,0} = 0.$

2) $\dot{x}_{1,0} = V_0$

<u>for the post;</u>

1) $\theta_{1,0} = \dot{\theta}_{1,0} = \ddot{\theta}_{1,0} = 0.$

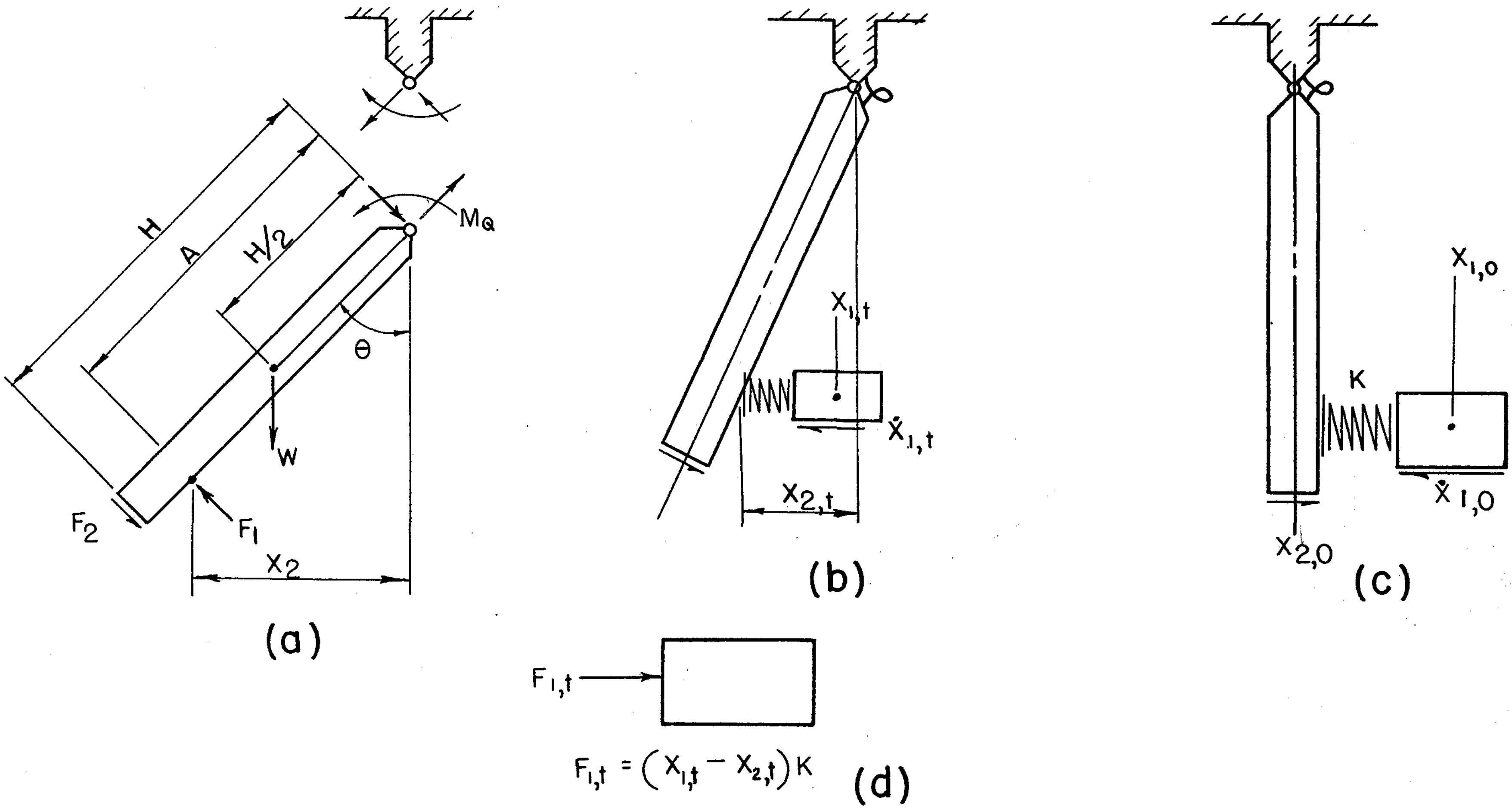
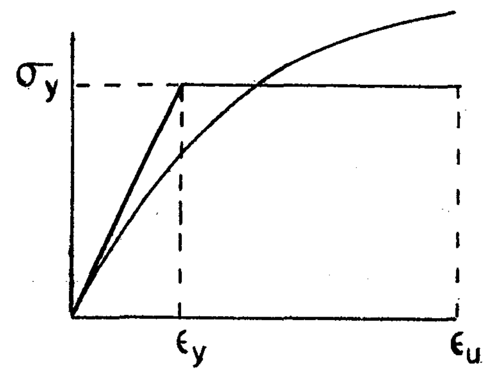


FIGURE 12 – FREE BODY DIAGRAMS OF IDEALIZED POST

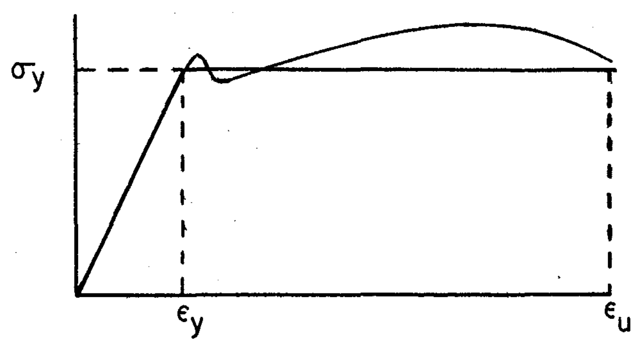
The simplified flow diagram of Figure 13 illustrates the calculation sequence.

Mechanical Fuse

Two types of mechanical fuses have been considered in this study: (1) a cast-iron plate, and (2) a steel notched Plate. The stress-strain characteristics of the materials used are idealized in the following manner:



For A48, Class 30 Cast-Iron



For A441 Steel

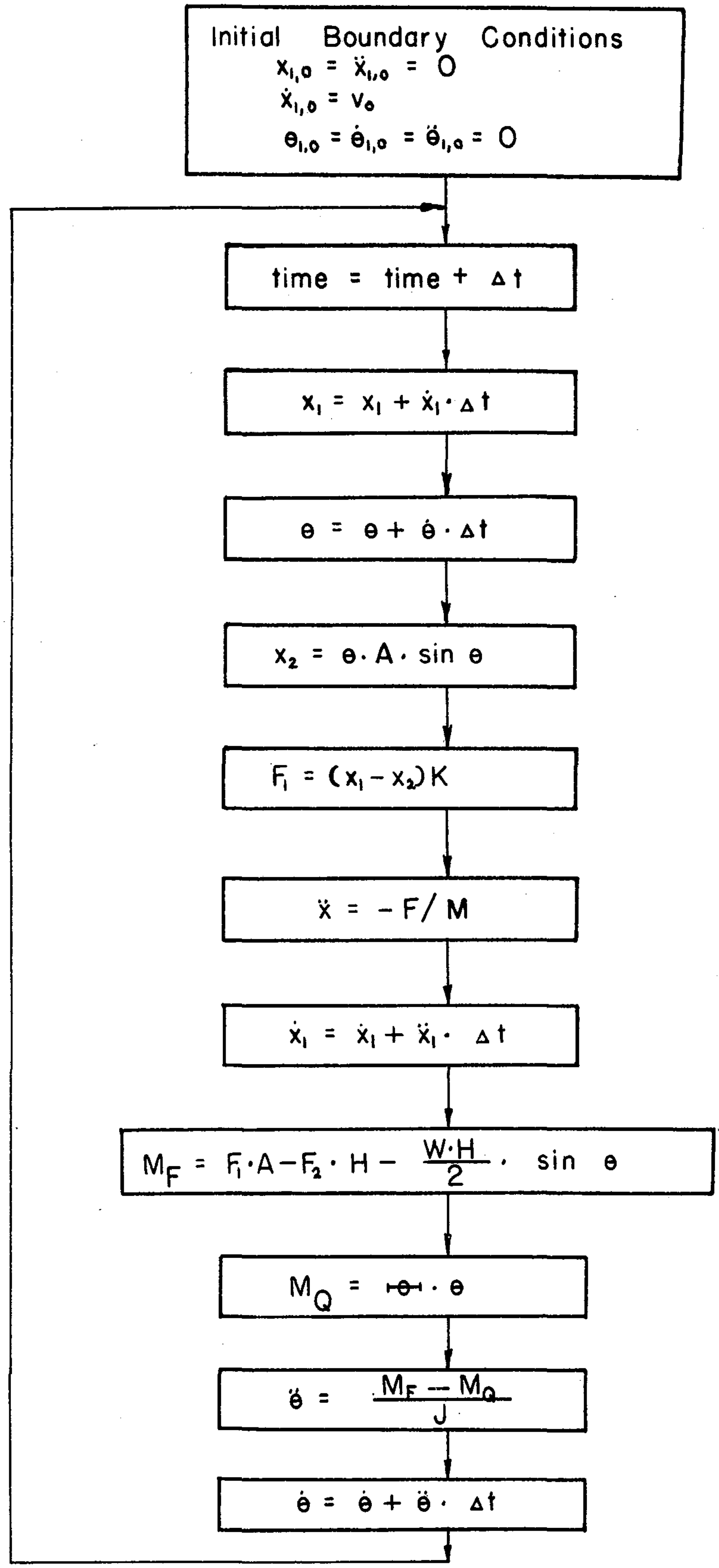
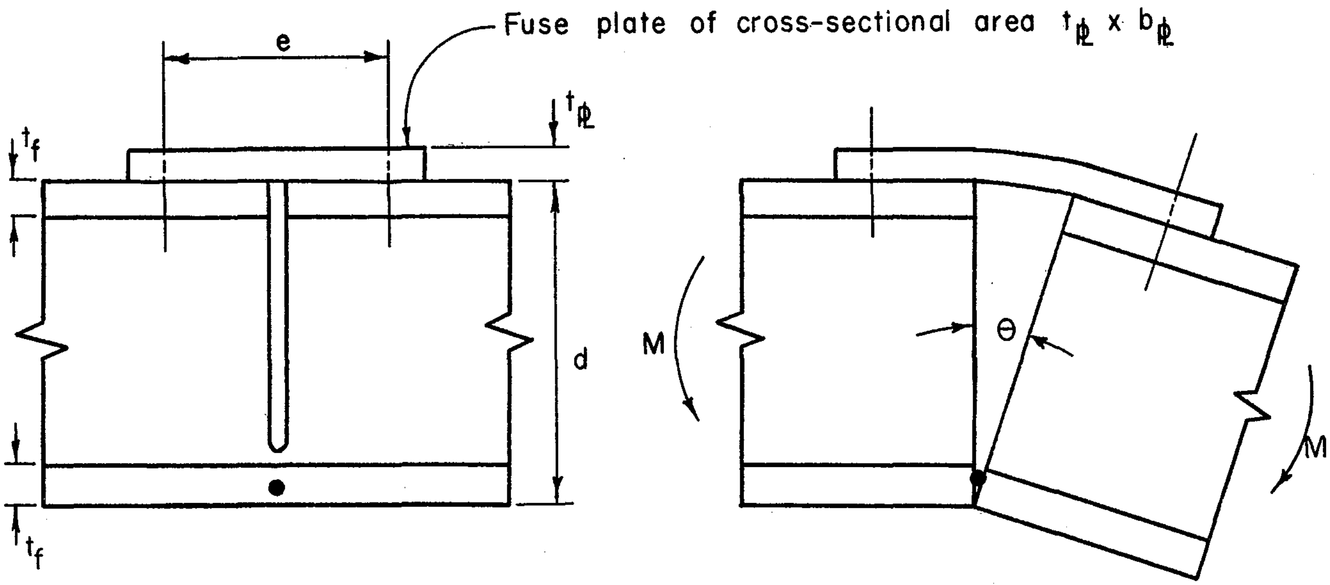


FIGURE 13 — SIMPLIFIED FLOW DIAGRAM

The behavior of the plastic hinge and the resulting equivalent spring stiffness can be determined as follows.



The stress in the plate at any time is

$$f = \frac{M}{\left[d + \frac{(t_{PL} - t_f)}{2}\right] b_{PL}}$$

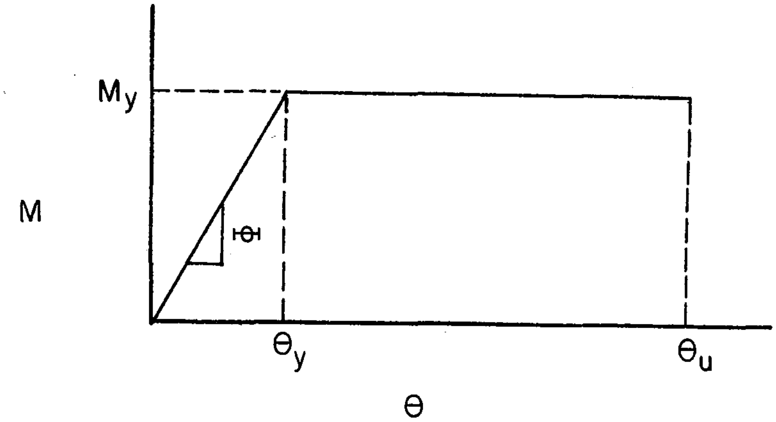
then the strain is

$$\epsilon = f/E$$

and

$$\theta = \epsilon \cdot e \Big/ \left(d - t_f/2\right)$$

An M vs θ diagram can be plotted for the full range of M value up to the full ultimate moment, Mu.



The slope of the elastic portion of the diagram gives the equivalent rotational spring constant of the plastic hinge. This is the value to be used in the numerical analysis solution.

$$K_\theta = My/\theta y$$

Note that the same procedure would be followed for the notched plate mechanical fuse, but the moment would be held at some value less than My due to slipping. Therefore for this type of plate an equivalent y could be obtained to correspond to the strain at first slip.

<u>Discussion of Correlation Between Text Data and the Model</u>

A correlation has been made with the instrumentation data for Test No. 41. The quantities compared are base slip, vehicle displacement, maximum deceleration, maximum vehicle force, change in vehicle velocity and selected time points.

The parameters used in the study are shown in Figure 14.

<u>Fuse Plate</u>: The value of plate strain was taken from the test data.

$$\epsilon_y = 0.000340 \text{ in/in}$$

Using a modulus of elasticity for steel of 30,000,000.0 the apparent slip stress at slip was found to be,

$$f_y = 10,200.0 \text{ psi}$$

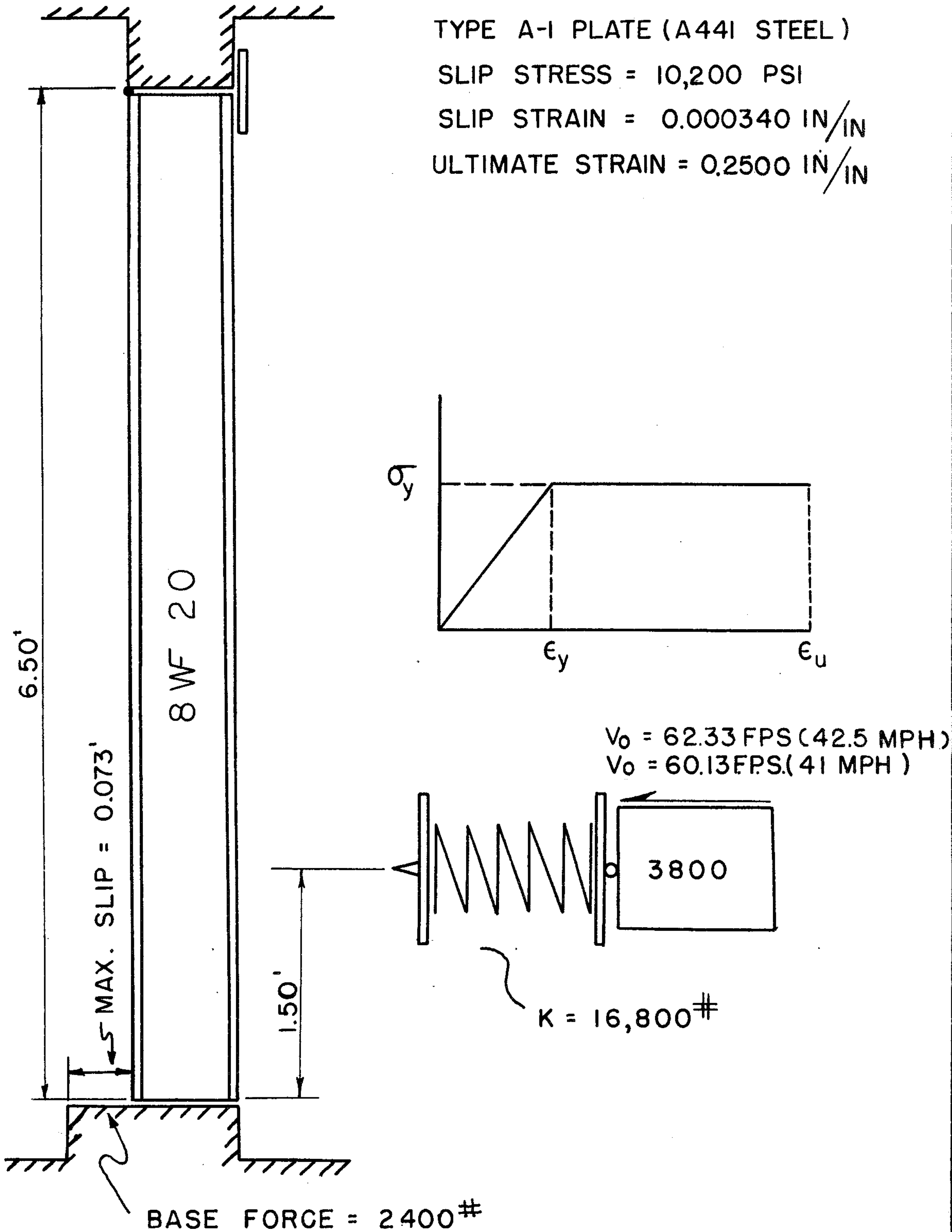


FIGURE 14 PARAMETERS, TEST NO. 41

The strain at which slip occurred was determined by;

$$\epsilon_u = \frac{\text{max. allowable slip}}{\text{dist. between centers of bolts}}$$

The maximum allowable slip was defined as being the distance for the bolt to become disengaged from the notch in the plate. (See Figure 1). Hence,

$$\epsilon_u = \frac{1.000}{4.000} = 0.250 \text{ in/in}$$

Base Friction Force: The friction force at the base was determined analytically by the following relationship

$$\text{bolt force} = \frac{\text{4x (bolt torque)}}{\text{bolt diameter}}$$

$$\text{base force} = \text{bolt load x no. of bolts x coeff. of friction}$$

in this case,

$$\text{base force} = \frac{4(750)}{0.75} \times 4 \times 0.15 = 2400.0 \text{ lb.}$$

Maximum Base Slip: This value was determined in the same manner as the fuse plate allowable slip.

max. base slip = 0.073

Vehicle Impact Velocity: This data was taken from a time motion study of the high speed film and from radar records.

$$V_o = 42.5 \text{ mph (movie)}$$

$$V_o = 41.0 \text{ mph (radar)}$$

Force Application Point; The point of application of the vehicle force was chosen as 1.5 ft. This is the height of the bumper of the vehicle and was taken from actual measurements. (See Appendix D).

Vehicle Spring; The value of the vehicle spring was determined as follows,

$$\text{Spring constant} = \frac{\text{actual measured vehicle force}}{\text{actual measured indention of vehicle}}$$

$$\text{Spring constant} = \frac{14,000.0}{0.8333} = 16,800.0 \text{ lb/ft}$$

Correlation: Figure 15 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 milliseconds and 0.073 ft. slip). After slip is completed the model values lag the 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. Note also the excellent correlation between the times when slip is initiated and when the maximum slip occurs.

Figure 16 is a plot of vehicle displacement vs. time. The results of the model show close agreement with the test data. Note that these plots appear as straight lines. In reality they are not linear but curvilinear in nature. This fact 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.

The following table shows comparison between specific points in the history of the post.

Description	Model	Test
Maximum peak g (g's)	-4.35	-3.69
Maximum vehicle force (lb)	16542	14,000
Time of initial slip (ms)	14.8	15.0
Time post leaves contact with vehicle (ms)	21.8	78.7
Change in vehicle velocity (fps)	1.85	1.10

In Figures 15 and 16 two curves 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

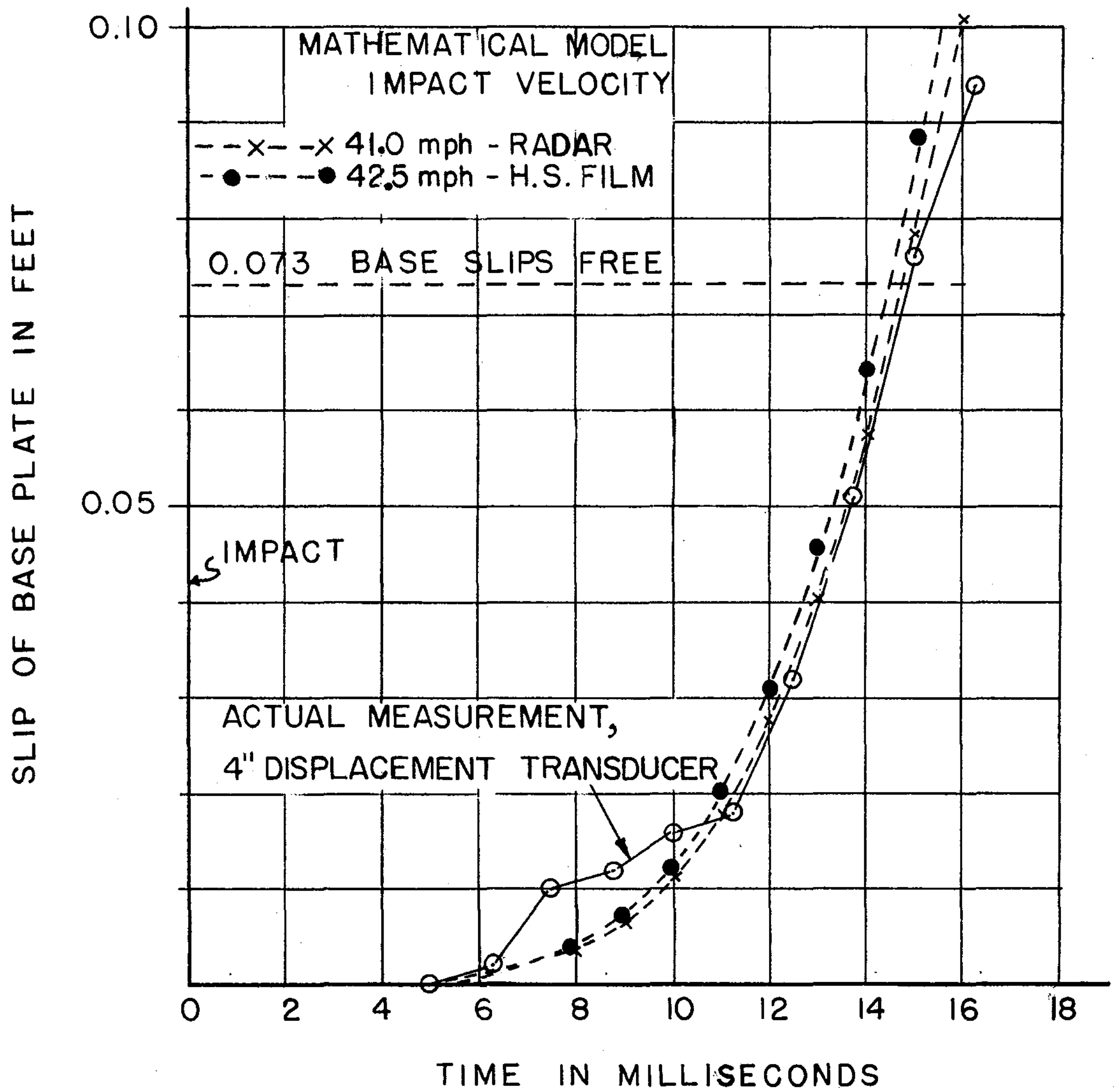
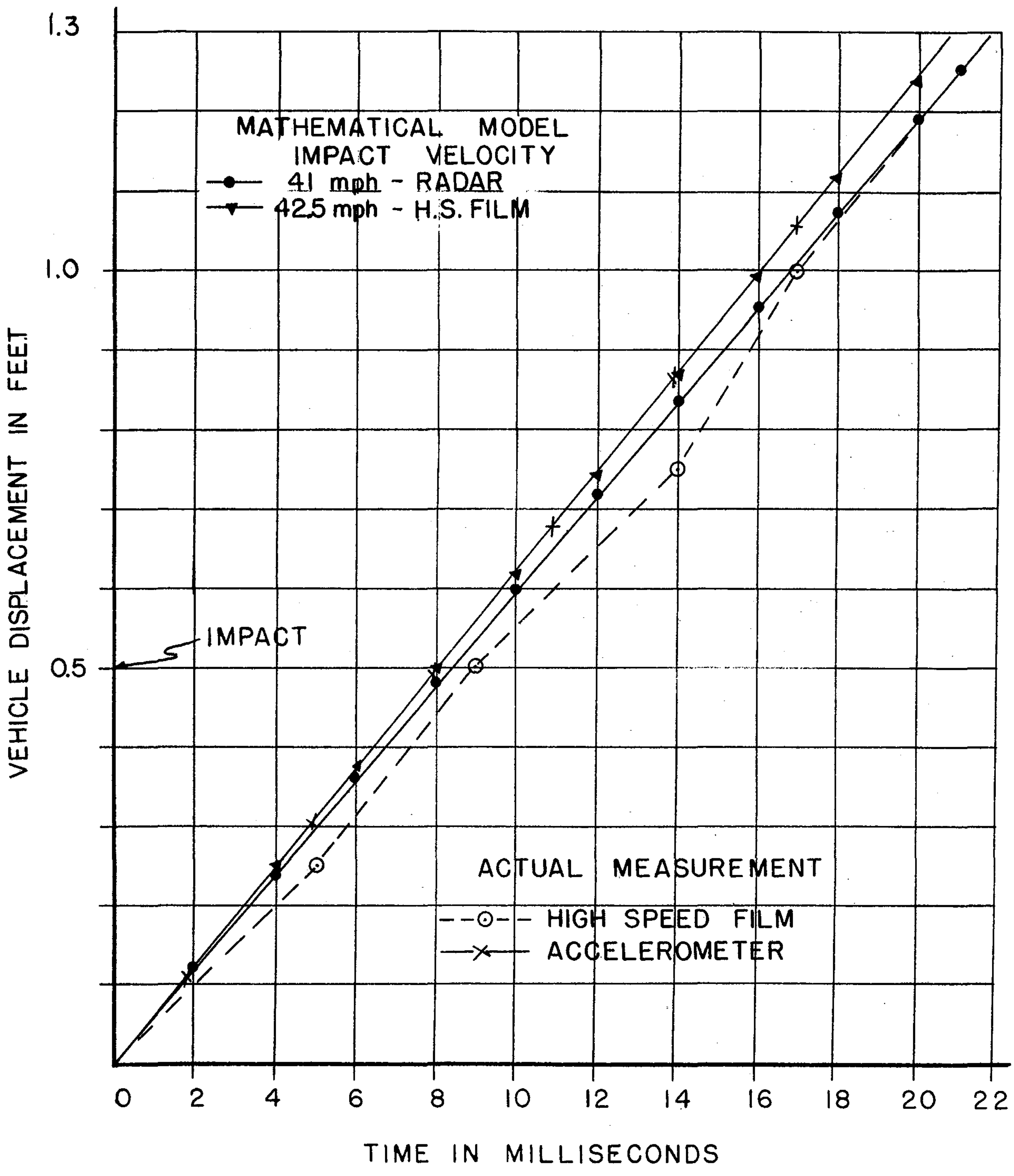

0.10
0.05
MATHEMATICAL MODEL
IMPACT VELOCITY
41.0 mph - RADAR
42.5 mph - H.S. FILM
0.073 BASE SLIPS FREE
IMPACT
ACTUAL MEASUREMENT,
4" DISPLACEMENT TRANSDUCER
0
2
4
6
8
10
12
14
16
18
TIME IN MILLISECONDS
SLIP OF BASE PLATE IN FEET

FIGURE 15



1.3
1.0
0.5
VEHICLE DISPLACEMENT IN FEET
MATHEMATICAL MODEL
IMPACT VELOCITY
41 mph - RADAR
42.5 mph - H.S. FILM
IMPACT
ACTUAL MEASUREMENT
HIGH SPEED FILM
ACCELEROMETER
0 2 4 6 8 10 12 14 16 18 20 22
TIME IN MILLISECONDS

FIGURE 16

included because the exact impact velocity is not precisely known. The radar value and the high-speed film analysis have instrumental error, and the analysis depends upon curve fitting.

Conclusions

The data presented 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. After this time the rotation of the upper post exerts an influence. Therefore in order 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. It is recommended that this model not be used for sign posts smaller than those considered in this investigation.

Appendix E contains the computer output for Test No. 41.

Comparison of results listed in the table on page 40 and in Table V, Appendix B, reveals that all instrumentation data do not correlate precisely. This might be expected owing to the complex nature of the break-away post, the relative precision of the instrumentation, and the dearth of previous analytical knowledge of post behavior under impact loading.

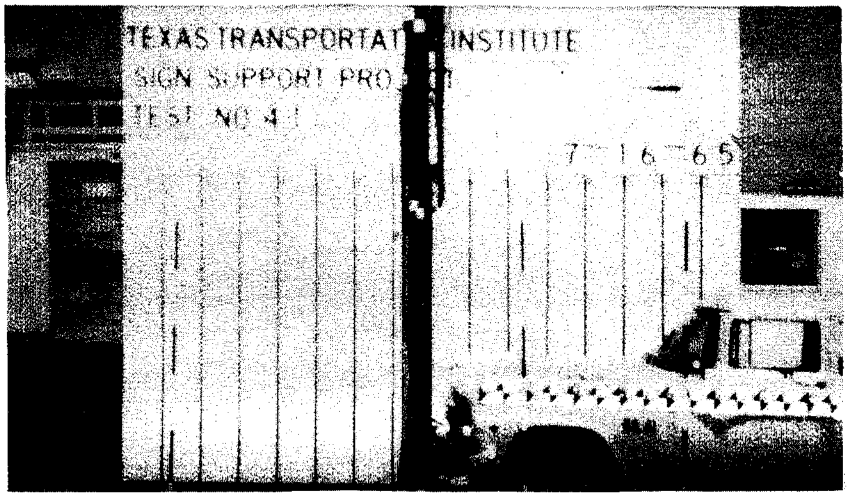
It is difficult to determine the time of critical events from the high speed film with any degree of certainty. Attempts have been made to install other instruments which would verify film observations. These attempts have been only partially successful at this writing. In spite of the difficulties, the investigators have endeavored to make these determinations. Figure 17 contains sequence photographs from the high-speed film showing the results of film observations. The critical events observed are listed below:

$t = 0$ Bumper touches post

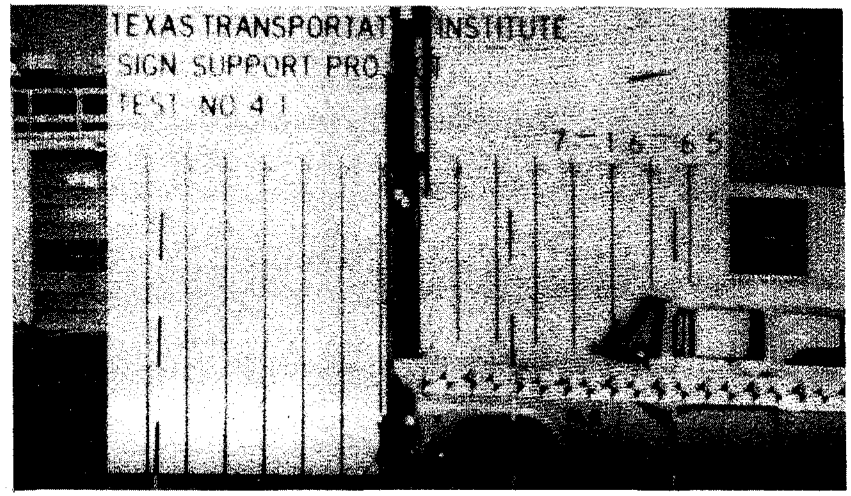
$t = 0.015$ Post base disengages

$t = 0.027$ Mechanical fuse fractures

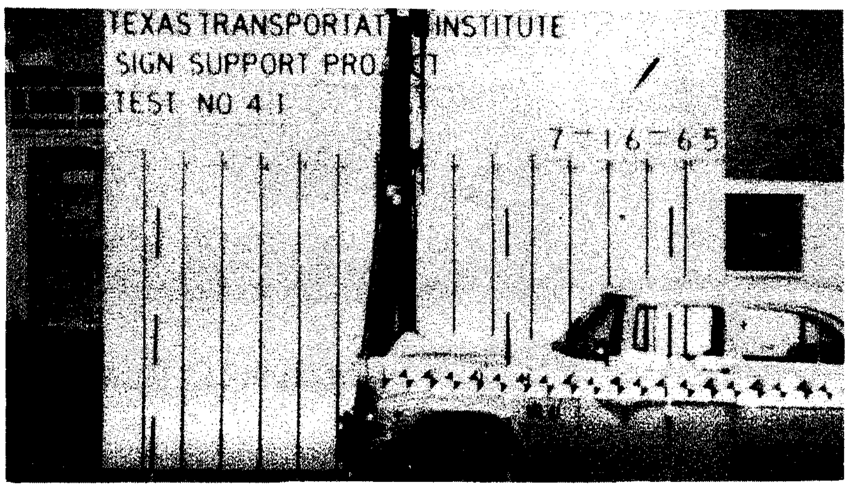
$t = 0.080$ Post leaves contact with the vehicle



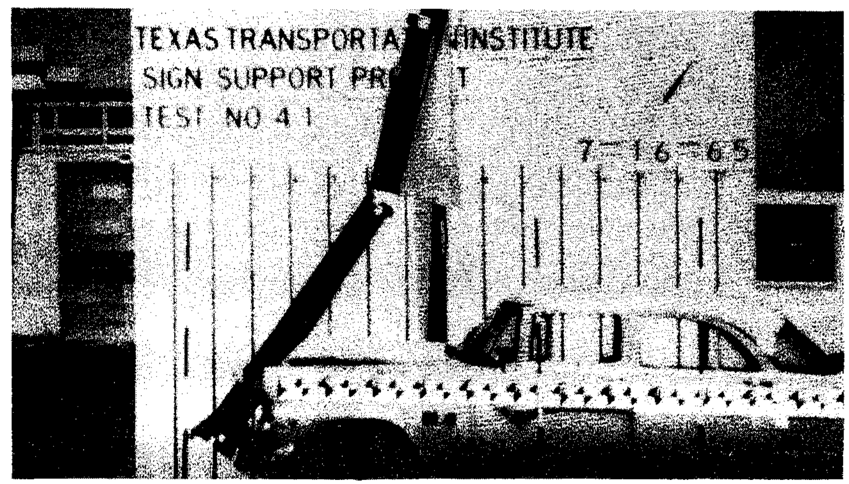
t = 0



t = 0.015



t = 0.027



t = 0.080

FIGURE 17

RECOMMENDATIONS FOR FURTHER STUDIES

I. The Mathematical Model

The development of a mathematical expression for the behavior of break-away sign supports subject to collision loads is a necessary tool for use in refining current designs. By varying post parameters, connections, and colliding masses, results could be predicted mathematically and crash testing could be limited to those design features which appear promising. The mathematical model should be the combination of a series of models, each expressing a different phase in the changing conditions governing post movement and each influenced by the preceding phase. These can be divided as follows:

Phase 1: Encompassing the period from initial vehicle contact with the post to release of the base connection.

Phase 2: From time of release of the base to formation of the hinge through rupture of the mechanical fuse.

Phase 3: From fuse rupture to such time in the vehicle-post contact period that mutual influence ceases to exist. Loss of such contact is a logical termination for the mathematical study.

Phase 4: Space trajectory of the support does not warrant mathematical consideration provided contact with the vehicle is not re-established. Relative motion of vehicle and support can best be determined from photographic records during this phase.

The ultimate function of a mathematical model is to establish design criteria, and design criteria are essential for recognition and acceptance of a concept.

II. Applications to Highway Use

A. Connection of Sign Face to Support Post

For practical use under widely varying site conditions a clamp connection of sign windbeams to the support post flanges is desirable. Such a connection can be made quickly and provides complete field adjustibility in erecting the sign face. It has been found that collision load rather than wind load governs the clamp capacity required to retain control of the post subsequent to base release. The mathematical model would be useful in establishing the magnitude of collision loads for use in design.

In earlier tests, Test No. 7 on aluminum posts (16) and again in Test No. 10 on steel posts (17) partial separation of sign face and post occurred. In these tests the top windbeam remained attached. In both tests the released post moved upward to a horizontal position even with the top of the sign. This behavior has a great deal of appeal when one considers that the windshield area of large trucks extends higher than the bottom of the sign face. It appears that securing the top windbeam to the post with positive connections and using limited capacity clamps on all other windbeam connections would afford the advantages of the clamps. In addition the desired additional vertical clearance for large vehicles would be provided. These aspects depend upon planned collision failure of the clamps, which design in turn depends upon further research and development. Passenger vehicles with a lower point of impact on the post would impose a less severe load on the clamps, but ample vertical clearance would be provided without clamp failure. This behavior would be dependent upon the formation of a plastic hinge provided for by the installation of the mechanical fuse. It is anticipated that the mathematical model will be useful in predicting the feasibility of these concepts.

B. Mechanical Fuse

The cast-iron plate in current use (See Figure 1, page 4) may not be the best material available. The ultimate strength and modulus of rupture of cast-iron varies over a considerable range, so results are not consistent. These plates are foundry products available only on special order, and require special handling.

Perhaps a more consistent fuse could be made by utilizing frictional resistance to slip offered by high strength bolts passing through the post flange and engaging notches in a steel plate. Considerable research has been conducted in this field and the results indicate that adequate resistance to slip can be developed. In Test 41, post response appeared to occur more rapidly than in Test 40. Thus it appears that post response occurs more rapidly with the notched plate fuse than with the cast-iron plate fuse. It should be emphasized that this comparative response is based upon the results of a single instrumented test of each of the two types of mechanical fuse. Static testing would indicate the ability of a notched plate to transfer the required wind moment.

C. Summary

The development of break-away, cantilevered sign supports in these studies has reached the stage where the mathematical model can play a key role. Refinements are needed and mathematics can direct the way. A design incorporating the features outlined should produce a structure well adapted to field use. Should such a design prove practicable the result would be a less hazardous structure, the development of which would fulfill the primary objectives of this research study.

APPENDIX A

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17. See ibid., pages 40-41.

APPENDIX B

APPENDIX B

TABLE I - PHOTOGRAPHIC INSTRUMENTATION - TESTS 32, 33, and 35

ITEM	DEVICE	DESCRIPTION	LOCATION	TO PROVIDE
1	High-speed motion picture camera	Wollensak, Fastax WF-3T, 16 mm Kodachrome II, Daylight KR 449 film, 1000 frames per second	Approximately 100 feet from impact point, at right angles to line of travel of crash vehicle	Crash vehicle Time-Displacement Data
2	Moderately high-speed motion picture camera	Kodak Cine Special II, 16 mm Kodachrome II, Daylight KR 449 film 64 frames per second	Random positions	General views of crash test
3	Standard-speed motion picture camera	Bell & Howell 70 HR, 16 mm Kodachrome II. Daylight KR 449 film 24 frames per second	Random positions	General views of crash test
4	Stadia markers	3/4" wide drafting tape at 1'-0" intervals	On side of crash vehicle	Length reference for analysis of high-speed motion pictures
5	Centi-revolution clock	2-foot diameter clock face, divided into 100 intervals, clock hand attached to 1800 rpm synchronous electric motor	Approximately 20 feet from impact point (about 90 feet from high speed camera)	Time reference for analysis of high-speed motion picture film

APPENDIX B

TABLE II - PHOTOGRAPHIC INSTRUMENTATION - TESTS 39, 40, AND 41

ITEM	DEVICE	DESCRIPTION	LOCATION	TO PROVIDE
1	High-speed motion picture camera	Wollensak, Fastax WF-3T, 16 mm Kodachrome II Daylight KR 449 film 1000 frames per second	Camera A, See Figures 2 and 3	Crash vehicle Time-Displacement data
2	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 Figures 2 and 3	Crash vehicle Time-Displacement data (back-up for Camera A)
3	Moderately high-speed motion picture camera	Kodak Cine Special II, 16 mm Kodachrome II, Daylight KR 449 film, 64 frames/ second	Random positions	General views of crash test
4	Standard-speed motion picture camera	Bell & Howell 70 HR, 16 mm Kodachrome II, Daylight KR 449 film 24 frames per second	Random positions	General views of crash test
5	Stadia reference board	2"x6"x12'-0" pine board with black & white spaces in alternate 12-inch increments	Adjacent ot impact area	A fixed horizontal length reference

APPENDIX B

TABLE II - PHOTOGRAPHIC INSTRUMENTATION - TESTS 39, 40, AND 41
(CONTINUED)

ITEM	DEVICE	DESCRIPTION	LOCATION	TO PROVIDE
6	Stadia markers (reference targets)	6" x 16 gage sheet metal painted with 3"x3" diamond-shaped black triangles on white background	On side of crash vehicle	Length reference for analysis of high-speed motion pictures
7	Range poles	3/4"x8'-0" pipe poles with black & white spaces in alternate 12-inch increments	Adjacent to stadia reference boards	Fixed reference points
8	Centi-revolution clock	2-foot diameter clock face, divided into 100 intervals, clock hand attached to 1800 rpm synchromous electric motor	Mounted on back-board	Time reference for analysis of high-speed motion picture film
9	Backboard	16'-0" x 12'-0" plyboard mounted on wood truss frame	See Figures 2 & 3	Background for photography and pertinent test information

TABLE III - ELECTRONIC INSTRUMENTATION - TESTS 32, 33, AND 35

ITEM	DEVICE	DESCRIPTION	LOCATION	TO PROVIDE
1	Piezoelectric Accelerometer	Endevco Model 2211C with Model 2614B Input Amplifier	Mounted on left main frame member, 9'-0" behind impact point on bumper	Deceleration data
2	Piezoelectric Accelerometer	Endevco Model 2211C with Model 2614B Input Amplifier	Mounted on 150 lb concrete block belted to driver's seat	Deceleration data
3	Recording Oscillograph	Honeywell Visicorder Oscillograph, Model 1508	Situated in rear of station wagon 75 feet from target sign	Paper record of accelerometer and strain gage sensing under dynamic loading conditions
4	Shear force transducer (electric resistance strain gage bridge) (TESTS 33& 35 ONLY)	4 Budd Strain gages Metal film type C6-121	Approximately 1'-0" above base of post on inside of front and rear flanges (TESTS 33& 35 ONLY)	Measurement of slip joint shear force (time variable)
5	Electric resistance strain gage bridge (TEST 33 ONLY)	2 Micro-Measurement strain gages, 90° Rosette (EA-13-125TF-120)	7'-0" above base of post on rear flange (TEST 33 ONLY)	Measurement of strain in rear flange (time variable)
6	Electric resistance strain gage bridge (TEST 33 ONLY)	2 Micro-Measurement strain gages, 90° Rosette (EA-13-125TF-120)	Approximately 8" above base of post on rear flange (TEST 33 ONLY)	Measurement of strain in rear flange (time variable
7	Electric resistance strain gage bridge (TEST 35 ONLY)	2 Micro-Measurement strain gages, 90° Rosette (EA-13-125TF-120)	Mounted on cast-iron fuse plate, 7'-0" above base of post (TEST 35 ONLY)	Measurement of strain in cast-iron plate (time variable)

APPENDIX B

TABLE IV - ELECTRONIC INSTRUMENTATION - TESTS 39, 40 AND 41

ITEM	DEVICE	DESCRIPTION	LOCATION	TO PROVIDE
1	Piezoelectric Accelerometer	Endevco Model 2211C with Model 2614B input amplifier	Mounted on left main frame member 9'-0" behind most forward point on bumper	Deceleration data (crash vehicle)
2	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)
3	Piezoelectric Accelerometer	Endevco Model 2215 with 2614B input amplifier	Mounted near base of post, see Figure 9	Acceleration data (support post)
4	Recording Oscillograph	Honeywell Visicorder Oscillograph, Model 1508	Situated in instrumentation trailer 75 feet from target sign	Paper record of accelerometer and strain gage sensing under dynamic loading conditions
5	Impact force transducer (electric resistance strain gage bridge) (TESTS 40 & 41 ONLY)	4 Budd strain gages, metal film type C6-121	Mounted on flanges of post, see Figure 9 (TESTS 40 & 41 ONLY)	Measurement of impact force (time variable)
6	Electric resistance strain gage bridge (TESTS 40 & 41 ONLY)	2 Micro-Measurement strain gages, 90° Rosette, type EP-30	Mounted on rear flange, see Figure 9 (TEST 40 & 41 ONLY)	Measurement of strain in rear flange (time variable)

APPENDIX B

TABLE IV - ELECTRONIC INSTRUMENTATION - TESTS 39, 40, AND 41
(continued)

ITEM	DEVICE	DESCRIPTION	LOCATION	TO PROVIDE
7	Electric resistance strain gage bridge (TESTS 40 & 41 ONLY)	2 Micro-Measurement strain gages, 90° Rosette, Type EP-03-125TF-120)	Mounted on mechanical fuse, see Figure 9 (TESTS 40 & 41 ONLY)	Measurement of strain in fuse plate (time variable)
8	Linear Displacement Transducer	4" potentiometric displacement transducer	Slip-joint release mechanism at base of post, see Figure 10	Precise determination of post displacement upon impact (time variable)
9	Linear Displacement Transducer	19" potentiometric displacement transducer	Slip-joint release mechanism at base of post, see Figure 10	Precise determination post displacement upon impact (time variable)
10	Radar speed meter	Electro-matic Radar speed meter, Model S2A, with Esterline Angus Graphic Ammeter, Model AW	Near Impact area, see Figures 2 and 3	Velocity of crash vehicle prior to impact

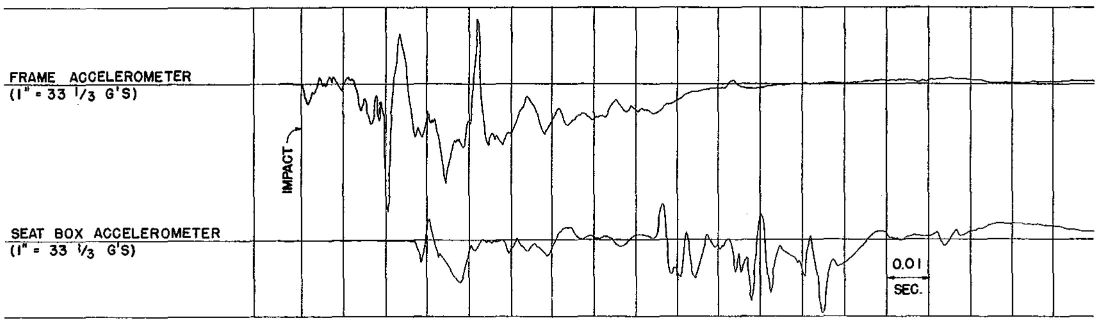
TABLE V
OBSERVED TIME OF CRITICAL EVENTS

TEST NO.	POST BASE DISENGAGES (SECONDS)		FUSE FRACTURES (SECONDS)		POST AND VEHICLE SEPARATE (SECONDS)		NUMBER OF OBSERVATIONS	
	HIGH SPEED FILM	LINEAR DEVICE	HIGH SPEED FILM	LINEAR DEVICE	HIGH SPEED FILM		HIGH SPEED FILM	
32	←			NOTE	1			→
33	0.0153	—	NOTE 2	—	0.0921		16	
35	0.0160	—	NOTE 2	—	0.1238		16	
39	←			NOTE	1			→
40	0.0145	0.0080	0.0300	0.0275	0.0745		14	
41	0.0150	0.0148	0.0270	0.0263	0.0787		18	

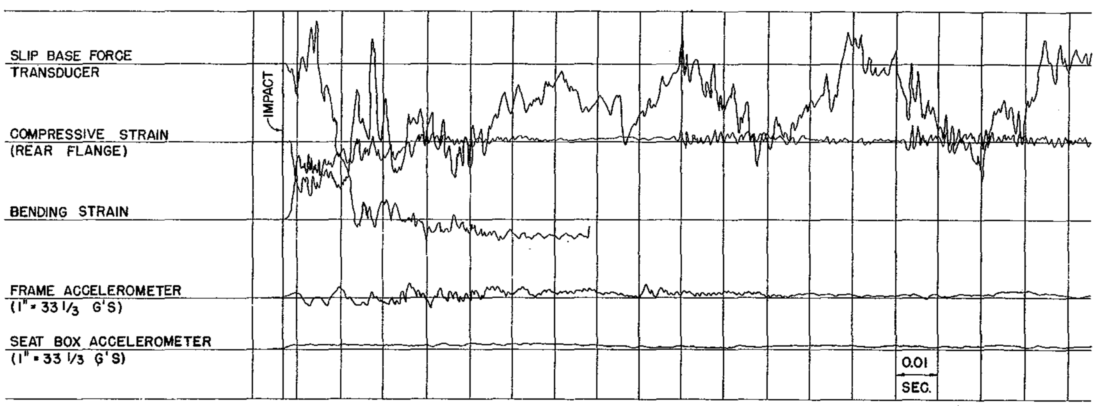
NOTE 1: Sign Support was bolted to concrete drilled footing; no breakaway devices were installed.

NOTE 2: Cast-iron fuse did not fracture in this test.

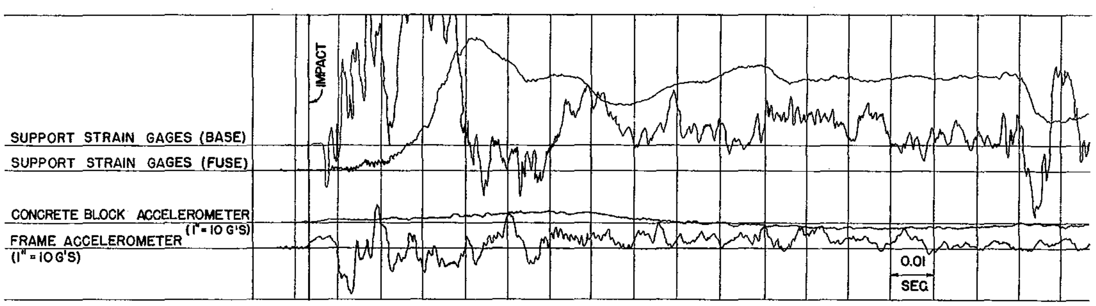
APPENDIX C



TEST NO. 32

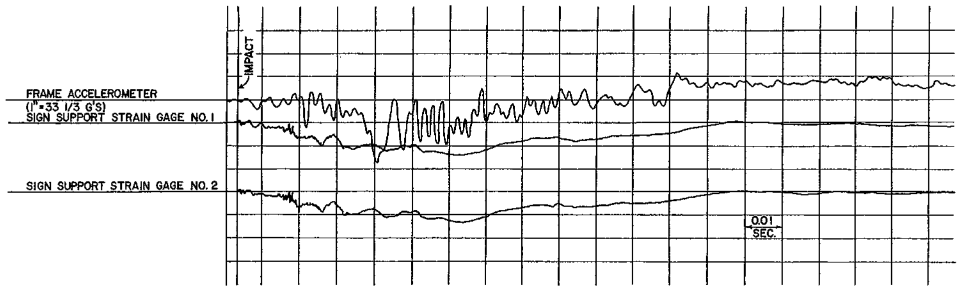


TEST NO. 33

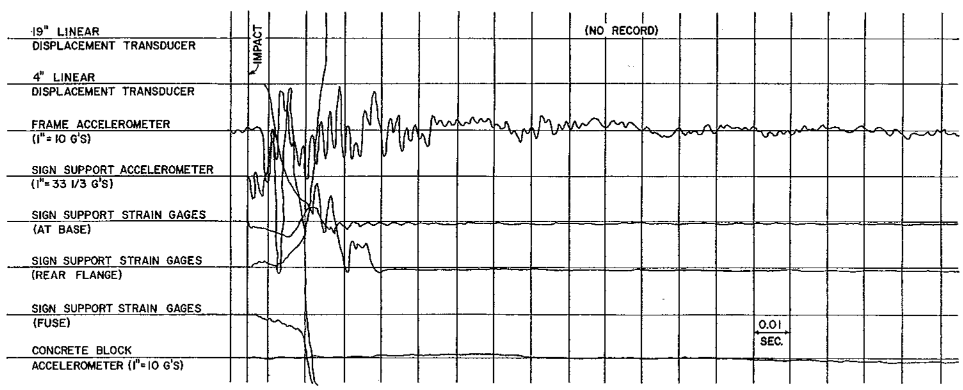


TEST NO. 35

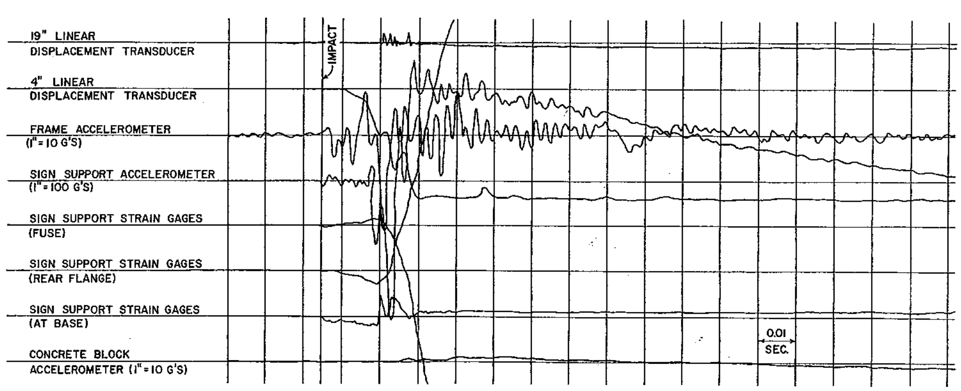
HONEYWELL MODEL 1508 VISICORDER RECORDS



TEST NO. 39



TEST NO. 40



TEST NO. 41

HONEYWELL MODEL 1508 VISICORDER RECORDS

APPENDIX D

TEST NUMBER 41 Date: 7-16-65

<u>Test Vehicle:</u> Make: 1955 Ford V-8

Lic. No. US 8918 Type: 4 door Sedan (Fairlane)

Weight:3620

A. Damage this test:

1. Photos (see slides, etc)

2. Measurements (see attached sheet)

B. Previous Damage:

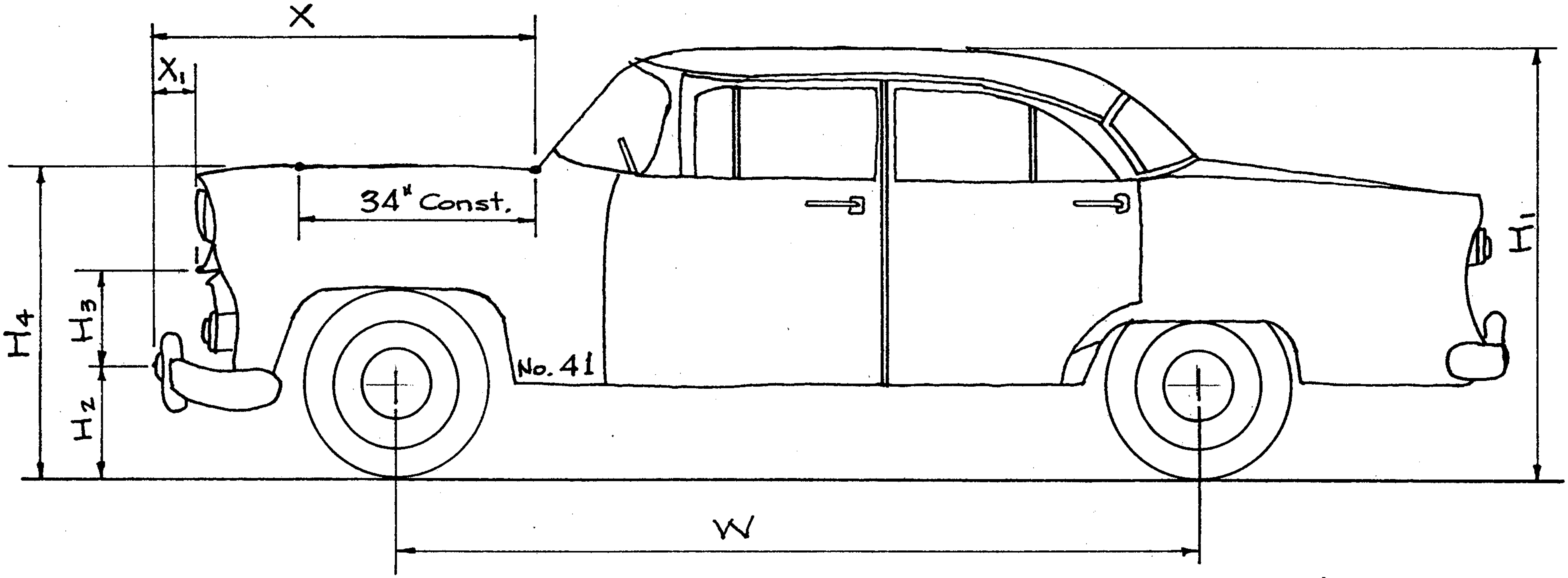
See "Before" photographs

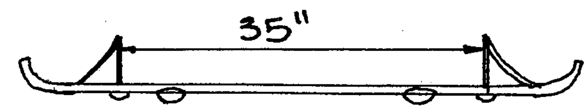
C. Speed "Before" Impact: (Radar) 41 mph)

D. Speed "After" Impact: (Radar) 37 mph

E. Distance traveled after impact: 600'

F. Comments:





BUMPER SUPPORTS

VEHICLE DIMENSIONS

VEHICLE LIC. NO. US 8918 TEST NO. 41

DIMENSION	H_1	H_2	H_3	H_4	W	X	X_1	DIM. BY	DATE
BEFORE	60 3/4"	17 5/8"	10 5/8"	42 3/4"	115"	56 3/4"	3 1/8"	R.M.O.	7/10/65
AFTER	60 3/4"	16 1/4"	10 3/4"	45 1/2"	115"	47 3/4"	13 3/4"	R.M.O.	7/16/65
CHANGE	NONE	- 1 3/8"	+ 1/8"	+ 2 3/4"	NONE	-10"	+10 5/8"	R.M.O.	7/16/65

TEST NUMBER 41

Sign Data:

A. Type of sign: plywood

B. Size of sign face: 8' x 16'

C. Weight of sign face 375#

D. Type of support: 8WF20 (A36 steel) not galvanized

E. Weight of support: 258# (Each support)

F. Location "before" impact (with respect to auto i.e. head-on, one support:

Head-on, one support

G. Location "after" impact:

See photographs

H. Comments:

Galvanized washers at base plate between slip faces.

TEST NUMBER 41

Cameras:

A. Type of cameras used and filming speed:

Camera A WF 3T Fastax (color film) 1000 frames/sec-est.

Camera B WF 3 Fastax (black & white film) 1000 frames/ sec-est.

B. Location of Cameras:

See attached sketch

C. Comments:

Camera A: Film color Kodachrome II, KR 449

Camera B: Film black & white Tri-X Reversal, TXR 430

TEST NUMBER 41

Instrumentation:

A. Vehicle:

1. Type Instrumentation Used: 1. Endevco Acc 2215
2. Endevco Acc 2211C

2. Location: 1. Mounted on 150# concrete block on driver's seat
2. Mounted on main frame (left) 9' behind forward point of front bumper

3. Comments: Amplifier and 112.5 volt batteries in wooden boxes mounted in trunk of crash vehicle.

B. Sign Support:

1. Type Instrumentation Used (to measure what?)

a. Strain gage bridge (to measure impact force)
b. Strain gage bridge on A-441 notched plate (to measure strain in plate)
c. Strain gage bridge on rear flange (to measure strain in flange)
d. Accelerometer mounted at base of post (to measure post acceleration)
e. 4" and 19" linear displacement devices

2. Location:

a. 7" above base of post on inside face of front and rear flanges
b. 6'-6" above base of post on front flange
c. 6'-6" above base of post on rear flange
d. Approx. 2" above base of post on inside of rear flange
e. Mounted on stub and attached to base of sign post

3. Comments:

See plan drawings for details

19" linear displacement device did not operate, it was apparently stuck by the tow cable or the crash vehicle.

TEST NUMBER 41

Recording Equipment: Make: Honeywell

Model 1508 Visicorder
Model 121C-1 Rectifier
Model 121D-1 Regulator
Model 121E-1 Oscillator
Model 119B-1 Carrier Amplifier

A. Location:

B. Recording Speed Used: 80 in/sec

C. Comments: G. H. Clark, operator
See Figure 3, page 45, for sketch of plan of test area. This sketch was prepared from transit and tape measurements made at the test site.

APPENDIX E

POST DATA (TEST NO. 41)

HEIGHT = 6.5000 FT.

POST - 8.1400WF 20.00

AT 1.4680 FT. ABOVE GROUND

MASS MOMENT OF INERTIA = 56.8582 LB. - FT. - SEC. SQ.

PLATE WITH 10200.0 PSI SLIP STRESS

FUSE DATA

4.0000 X 5.2500 X 0.3750 INS.

BASE PLATE FORCE = 2400. AT 0.0730 FT. ALLOWABLE SLIP

SLIP STRAIN = 0.000340 IN./IN.

ULTIMATE STRAIN = 0.250000IN./IN.

SLIP MOMENT = 13619.FT.-LB.

ROTATIONAL SPRING CONSTANT = 81500321. FT.-LB./RADIAN

ROTATION AT SLIP = 0.00016710 RADIANS

ROTATION AT ULTIMATE = 0.12287276 RADIANS

VEHICLE DATA

WEIGHT = 3800.0 LB.

SPRING CONSTANT = 16800.0 LB./FT.

INITIAL VEHICLE VELOCITY = 42.5 MPH (FROM FILM RECORD)

TIME (SEC.)	XBASE (FT.)	THETA (DEGREES)	HNGNFO (LB.)	CAR X (FT.)	VEL 1 (FPS)	F1 (LB)	CAR ACC (G)
0.	0.	0.	0.	0.	62.33	0.	0.
0.0005	0.	0.	118.	0.0312	62.33	524.	-0.14
0.0010	0.	0.	237.	0.0623	62.33	1047.	-0.28
0.0015	0.	0.	355.	0.0935	62.32	1571.	-0.41
0.0020	0.	0.	473.	0.1247	62.31	2094.	-0.55
0.0025	0.	0.	591.	0.1558	62.30	2618.	-0.69
0.0030	0.	0.	694.	0.1870	62.29	3141.	-0.83
0.0035	0.0000	0.0001	653.	0.2181	62.28	3664.	-0.96
0.0040	0.0001	0.0008	826.	0.2492	62.26	4186.	-1.10
0.0045	0.0003	0.0023	1333.	0.2804	62.24	4706.	-1.24
0.0050	0.0006	0.0047	2179.	0.3115	62.22	5225.	-1.37
0.0055	0.0010	0.0076	3250.	0.3426	62.20	5742.	-1.51
0.0060	0.0015	0.0108	3334.	0.3737	62.17	6259.	-1.65
0.0065	0.0019	0.0144	3250.	0.4048	62.14	6775.	-1.78
0.0070	0.0026	0.0191	3168.	0.4358	62.11	7288.	-1.92
0.0075	0.0034	0.0253	3085.	0.4669	62.08	7799.	-2.05
0.0080	0.0045	0.0337	3003.	0.4979	62.05	8306.	-2.19
0.0085	0.0060	0.0447	2922.	0.5289	62.01	8807.	-2.32
0.0090	0.0080	0.0589	2842.	0.5599	61.97	9303.	-2.45
0.0095	0.0104	0.0769	2763.	0.5909	61.93	9792.	-2.58
0.0100	0.0134	0.0991	2686.	0.6219	61.89	10273.	-2.70
0.0105	0.0170	0.1261	2609.	0.6528	61.84	10746.	-2.83
0.0110	0.0214	0.1583	2534.	0.6837	61.80	11208.	-2.95
0.0115	0.0265	0.1962	2461.	0.7146	61.75	11661.	-3.07
0.0120	0.0325	0.2405	2390.	9.7455	61.70	12102.	-3.18
0.0125	0.0393	0.2914	2320.	0.7763	61.65	12530.	-3.30
0.0130	0.0472	0.3495	2253.	0.8071	61.59	12946.	-3.41
0.0135	0.0560	0.4151	2187.	0.8379	61.54	13348.	-3.51
0.0140	0.0660	0.4889	2124.	0.8687	61.48	13735.	-3.61
		ALLOWABLE SLIP EXCEEDED					
0.0145	0.0771	0.5710	863.	0.8994	61.42	14107.	-3.71
0.0150	0.0896	0.6640	806.	0.9301	61.36	14460.	-3.81
0.0155	0.1039	0.7695	752.	0.9607	61.30	14790.	-3.89
0.0160	0.1198	0.8879	701.	0.9914	61.23	15097.	-3.97
0.0165	0.1376	1.0195	654.	1.0220	61.17	15380.	-4.05
0.0170	0.1572	1.1646	611.	1.0526	61.10	15639.	-4.12
0.0175	0.1786	1.3234	572.	1.0831	61.04	15873.	-4.18

APPENDIX E (continued)

TIME (SEC.)	XBASE (FT.)	THETA (DEGREES)	HNGNFO (LB.)	CAR X (FT.)	VEL 1 (FPS)	F 1 (LB)	CAR ACC (G)
0.0180	0.2019	1.4963	537.	1.1136	60.97	16082.	-4.23
0.0185	0.2272	1.6834	506.	1.1441	60.90	16266.	-4.28
0.0190	0.2543	1.8850	478.	1.1745	60.83	16424.	-4.32
0.0195	0.2835	2.1012	455.	1.2049	60.76	16555.	-4.36
0.0200	0.3146	2.3321	436.	1.2353	60.69	16660.	-4.38
0.0205	0.3478	2.5779	421.	1.2656	60.62	16739.	-4.41
0.0210	0.3829	2.8387	411.	1.2959	60.55	16791.	-4.42
0.0215	0.4200	3.1144	404.	1.3261	60.48	16816.	-4.43
	VELOCITY OF POST EQUALS OR EXCEEDS THAT OF THE CAR						
0.0217	0.4355	3.2289	1803.	1.3382	60.45	16819.	-4.43

POST DATA (TEST NO. 41)

HEIGHT = 6.5000 FT.

POST - 8.1400WF 20.00

AT 1.4680 FT. ABOVE GROUND

MASS MOMENT OF INERTIA = 56.8582 LB.-FT.-SEC.SQ.

PLATE WITH 10,200.0 PSI SLIP STRESS

FUSE DATA

4.0000 X 5.2500 X 0.3750 INS.

BASE PLATE FORCE = 2400. AT 0.0730 FT. ALLOWABLE SLIP

SLIP STRAIN = 0.000340 IN./IN.

ULTIMATE STRAIN = 0.250000 IN./IN.

SLIP MOMENT = 13619. FT.-LB.

ROTATIONAL SPRING CONSTANT = 81500321. FT.-LB./RADIAN

ROTATION AT SLIP = 0.00016710 RADIANS

ROTATION AT ULTIMATE = 0.12287276 RADIANS

VEHICLE DATA

WEIGHT = 3800.0 LB.

SPRING CONSTANT = 16800.0 LB./FT.

INITIAL VEHICLE VELOCITY = 41.0 MPH (FROM RADAR)

TIME (SEC.)	XBASE (FT.)	THETA (DEGREES)	HNGNFO (LB.)	CAR X (FT.)	VEL 1 (FPS)	F 1 (LB.)	CAR ACC (G)
0.	0.	0.	0.	0.	60.13	0.	0.
0.0005	0.	0.	114.	0.0301	60.13	505.	-0.13
0.0010	0.	0.	228.	0.0601	60.13	1010.	-0.27
0.0015	0.	0.	342.	0.0902	60.12	1515.	-0.40
0.0020	0.	0.	456.	0.1203	60.12	2020.	-0.53
0.0025	0.	0.	570.	0.1503	60.11	2525.	-0.66
0.0030	0.	0.	684.	0.1804	60.09	3030.	-0.80
0.0035	0.0000	0.0001	652.	0.2104	60.08	3535.	-0.93
0.0040	0.0001	0.0005	760.	0.2404	60.06	4038.	-1.06
0.0045	0.0002	0.0018	1175.	0.2705	60.04	4541.	-1.19
0.0050	0.0005	0.0039	1926.	0.3005	60.02	5041.	-1.33
0.0055	0.0009	0.0067	2926.	0.3305	60.00	5541.	-1.46
0.0060	0.0013	0.0097	3369.	0.3605	59.98	6039.	-1.59
0.0065	0.0017	0.0129	3289.	0.3905	59.95	6537.	-1.72
0.0070	0.0023	0.0170	3209.	0.4204	59.92	7034.	-1.85
0.0075	0.0030	0.0223	3129.	0.4504	59.89	7528.	-1.98
0.0080	0.0040	0.0295	3050.	0.4803	59.86	8018.	-2.11
0.0085	0.0053	0.0390	2971.	0.5103	59.82	8504.	-2.24
0.0090	0.0069	0.0514	2894.	0.5402	59.78	8985.	-2.36
0.0095	0.0091	0.0672	2817.	0.5700	59.75	9459.	-2.49
0.0100	0.0117	0.0868	2742.	0.5999	59.70	9926.	-2.61
0.0105	0.0150	0.1109	2668.	0.6298	59.66	10385.	-2.73
0.0110	0.0189	0.1399	2595.	0.6596	59.62	10835.	-2.85
0.0115	0.0235	0.1741	2523.	0.6894	59.57	11276.	-2.97
0.0120	0.0289	0.2143	2454.	0.7191	59.52	11706.	-3.08
0.0125	0.0352	0.2607	2386.	0.7489	59.47	12124.	-3.19
0.0130	0.0424	0.3138	2320.	0.7786	59.42	12530.	-3.30
0.0135	0.0505	0.3741	2256.	0.8083	59.36	12923.	-3.40
0.0140	0.0597	0.4420	2194.	0.8380	59.31	13302.	-3.50
0.0145	0.0699	0.5179	2135.	0.8676	59.25	13667.	-3.60
ALLOWABLE SLIP EXCEEDED							
0.0150	0.0813	0.6025	878.	0.8972	59.19	14016.	-3.69
0.0155	0.0943	0.6988	824.	0.9268	59.13	14344.	-3.77
0.0160	0.1090	0.8075	774.	0.9564	59.07	14650.	-3.86
0.0165	0.1254	0.9289	727.	0.9859	59.01	14933.	-3.93
0.0170	0.1435	1.0633	684.	1.0154	58.94	15192.	-4.00
0.0175	0.1634	1.2110	645.	1.0449	58.88	15428.	-4.06

APPENDIX E (continued)

TIME (SEC.)	XBASE (FT.)	THETA (DEGREES)	HNGNFO (LB.)	CAR X (FT.)	VEL 1 (FPS)	F 1 (LB)	CAR ACC (G)
0.0180	0.1852	1.3723	609.	1.0743	58.81	15639.	-4.12
0.0185	0.2088	1.5474	578.	1.1037	58.74	15826.	-4.16
0.0190	0.2343	1.7364	550.	1.1330	58.68	15988.	-4.21
0.0195	0.2617	1.9396	526.	1.1624	58.61	16124.	-4.24
0.0200	0.2910	2.1571	506.	1.1916	58.54	16234.	-4.27
0.0205	0.3223	2.3890	491.	1.2209	58.47	16319.	-4.29
0.0210	0.3555	2.6353	479.	1.2501	58.40	16378.	-4.31
0.0215	0.3907	2.8963	471.	1.2793	58.33	16412.	-4.32
VELOCITY OF POST EQUALS OR EXCEEDS THAT OF THE CAR							
0.0219	0.4202	3.1155	1845.	1.3026	58.28	16419.	-4.32