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16. Abstract

Safety of work zones is a major area of concern since it is not always possible to maintain a level of safety comparable to that of a normal highway not under construction. Proper traffic control is critical to the safety of work zones. However, traffic control devices themselves may pose a safety hazard when impacted by errant vehicles. Little is known about the impact performance of many work zone traffic control devices.

The objective of the study was to provide barricades and temporary sign supports for use in work zones that would perform satisfactorily when impacted by errant vehicles. There were two phases to this study. The first phase pertained to the crash testing and evaluation of the impact performance of existing work zone barricades and temporary sign supports. The second phase involved the development and evaluation of alternate barricades and temporary sign supports for use in work zones.

This report summarizes the results of the study conducted under a series of four (4) contracts. A total of 20 full-scale crash tests were conducted on various existing and alternate barricade and temporary sign support designs to assess their safety performance in accordance with guidelines set forth in National Cooperative Highway Research Program (NCHRP) Report 350. Results of these tests indicated that existing wooden barricades and some of the commercially available portable sign supports did not perform satisfactorily in the crash tests. Alternate designs were then developed and evaluated for consideration by the Department. This report presents results of the crash tests together with conclusions and recommendations.

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EVALUATION OF WORK ZONE BARRICADES AND TEMPORARY SIGN SUPPORTS

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IMPLEMENTATION STATEMENT

Safety of work zones is a major area of concern, since it is not always possible to maintain a level of safety comparable to that of a normal highway not under construction. Proper traffic control is critical to the safety of work zones. However, when errant vehicles impact traffic control devices, the devices themselves may pose a safety hazard. It is therefore important to ensure that the traffic control devices used in the work zones meet national safety performance standards. This report covers activities conducted under a series of four contracts in which the safety performance of existing and alternate barricades and temporary sign supports were evaluated through full-scale crash testing. Results of the research will be available for immediate implementation at the end of the study and will include the following:

(a) an assessment of the safety performance of existing barricades and temporary sign supports;
(b) evaluation of alternate barricade designs; and
(c) recommendations on use of existing and alternate barricades and temporary sign supports in work zones.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data and the opinions, findings and conclusions presented herein. The contents do not necessarily reflect the official view or policies of the Federal Highway Administration (FHWA) or the Texas Department of Transportation (TxDOT). This report does not constitute a standard, specification, or regulation, nor is it intended for construction, bidding, or permit purposes. The engineer in charge of the project was King K. Mak, P.E. # 51502.

It is the policy of the Texas Transportation Institute (TTI) and Texas A&M University not to endorse any specific manufacturers, trademarks, or products. However, it is necessary in the report to identify the specific barricades and temporary sign supports tested in the study. It should therefore be noted that the mention of specific manufacturers, trademarks, and products in the report does not constitute endorsement of such manufacturers, trademarks, or products by TTI or Texas A&M University.

ACKNOWLEDGMENT

This study was sponsored by the Texas Department of Transportation (TxDOT), in cooperation with the Federal Highway Administration (FHWA). Ms. Meg Moore and Mr. Rick Collins were the Project Directors for TxDOT, and their guidance and support are deeply appreciated. Mr. Lewis Rhodes, Ms. Cathy Wood, and Mr. David Valdez of TxDOT and Mr. Bob Musselman of the Federal Highway Administration (FHWA) also provided information and direction on the study, and their assistance is gratefully acknowledged.

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SUMMARY

Safety of work zones is a major area of concern since it is not always possible to maintain a level of safety comparable to that of a normal highway not under construction. Proper traffic control is critical to the safety of work zones. However, traffic control devices themselves may pose a safety hazard when impacted by errant vehicles. Little is known about the impact performance of many work zone traffic control devices. The Texas Department of Transportation (TxDOT) has sponsored other studies at the Texas Transportation Institute (TTI) to assess the impact performance of various plastic traffic drums and sign substrates. However, there are other work zone traffic control devices, such as barricades and temporary sign supports, that have not been crash tested and evaluated. There is a need for assessing the safety performance of barricades and temporary sign supports that are currently in use and, if necessary, for developing alternate barricade and temporary sign support designs that would perform satisfactorily when impacted by errant vehicles.

The objective of the study was to provide barricades and temporary sign supports for use in work zones that would perform satisfactorily when impacted by errant vehicles. There were two phases to this study. The first phase pertained to the crash testing and evaluation of the impact performance of existing work zone barricades and temporary sign supports. The second phase involved the development and evaluation of alternate barricades and temporary sign supports for use in work zones.

This report summarizes the results of the study conducted under a series of four (4) contracts. A total of 20 full-scale crash tests were conducted on various existing and alternate barricade and temporary sign support designs to assess their safety performance in accordance with guidelines set forth in National Cooperative Highway Research Program (NCHRP) Report 350. Results of these tests indicated that existing wooden barricades and some of the commercially available portable sign supports did not perform satisfactorily in the crash tests. Alternate designs were then developed and evaluated for consideration by the Department. This report presents results of the crash tests together with conclusions and recommendations.

I. INTRODUCTION

1.1 BACKGROUND

Safety of work zones is a major area of concern since it is not always possible to maintain a level of safety comparable to that of a normal highway not under construction. Proper traffic control is critical to the safety of work zones. However, traffic control devices themselves may pose a safety hazard when impacted by errant vehicles. It is therefore important to ensure that the traffic control devices used in the work zones meet national safety performance standards. For the past few years, the Texas Department of Transportation (TxDOT) has sponsored a number of studies at the Texas Transportation Institute (TTI) to assess the impact performance of various work zone traffic control devices, including plastic drums, sign substrates, barricades and temporary sign supports. (*1-3*)

A literature search was conducted using computerized databases such as the Transportation Research Information System (TRIS). Publications identified in the literature search were then obtained through the library or contacts with the respective organizations and authors. The references list pertinent publications. (*4-8*) Of particular interest are the studies by the Federal Highway Administration (FHWA) and the New York Department of Transportation (NYDOT). (*5-7*) These studies crash tested and evaluated a number of work zone barricades and sign supports, including Type I and Type III barricades, skid mounted sign supports, and easel portable sign supports. The literature provided some useful information, but there remained unanswered questions regarding the performance of work zone traffic control devices specified in the TxDOT standards, which are somewhat different from those crash tested. Also, the previous crash tests were not conducted or evaluated in accordance with current guidelines set forth in National Cooperative Highway Research Program (NCHRP) Report 350. (*9*)

1.2 STUDY OBJECTIVE AND SCOPE

The goal of the study was to provide barricades and temporary sign supports for use in work zones that would perform satisfactorily when impacted by errant vehicles in accordance with national safety performance guidelines set forth in NCHRP Report 350. This study was conducted in two phases under four separate contracts. The first phase pertained to the crash testing and evaluation of the impact performance of existing work zone barricades and temporary sign supports. The second phase involved the development, crash testing and evaluation of alternate barricade and temporary sign support designs for use in work zones. The four contracts under which this study was conducted were: IAC(92-92)1118, IAC(92-93)1900, 584xxA1018, and 585xxA3014.

Chapter II outlines the study approach, including a list of the crash tests conducted and descriptions of the crash test procedures. Chapter III presents results of the crash tests on existing work zone traffic control devices. Chapter IV describes efforts to develop and evaluate alternate barricade designs and sign attachment mechanisms. Chapter V presents the study conclusions and recommendations.

II. STUDY APPROACH

2.1 WORK ZONE CONTROL DEVICES CRASH TESTED

A total of 20 existing and alternate work zone traffic control devices were crash tested under this study, a list of which is shown in Table 1. Ten of the crash tests were conducted on existing work zone traffic control devices, including four on wooden barricades, four on portable sign supports, one on a transportable sign support and one on a skid-mounted sign support. These existing traffic control devices were either constructed or purchased commercially, and they were in accordance with the specifications outlined in the "Barricade and Construction Standards" sheets dated April 1992.

The wooden barricades tested included:

1. Test no. 453360-1. A 1.22 m wide Type III barricade with a 1219 mm x 1219 mm wooden sign panel mounted at a height of 914 mm from the ground to the bottom of the sign panel;

2. Test no. 453360-4. A 1.22 m wide Type III barricade without any sign attachment;

3. Test no. 453360-5. A 3.7 m long Type I barricade with a 1219 mm x 1219 mm wooden sign panel mounted at a height of 30.5 mm from the ground to the bottom of the sign panel; and

4. Test no. 453880-4. A 1.22 m wide Type III barricade without any sign attachment impacted from the end-on position.

Four different portable sign supports were crash tested:

1. Test no. 453360-2. A spring mounted sign support with a 1219 mm x 1219 mm wooden sign panel mounted at a height of 30.5 mm from the ground to the bottom of the sign panel;

2. Test no. 453580-1. A spring mounted sign support with a 1219 mm x 1219 mm plastic/ fabric sign mounted at a height of 30.5 mm from the ground to the bottom of the sign panel;

3. Test no. 453580-2. A easel sign support with a 1219 mm x 1219 mm wooden sign panel mounted at a height of 30.5 mm from the ground to the bottom of the sign panel; and

4. Test no. 453790-1. A portable sign support with a 1219 mm x 1219 mm plastic/ fabric sign mounted at a height of 30.5 mm from the ground to the bottom of the sign panel.

Table 1. List of Crash Tests Conducted

EXISTING WORK ZONE TRAFFIC CONTROL DEVICES

WOODEN BARRICADES

Test No. 453360-1	Type III Wooden Barricade, Wooden Sign Panel.
Test No. 453360-4	Type III Wooden Barricade, No Sign Panel.
Test No. 453360-5	Type I Wooden Barricade, Wooden Sign Panel.
Test No. 453880-4	Type III Wooden Barricade, No Sign Panel, End-On Test.

PORTABLE SIGN SUPPORTS

Test No. 453360-2	Spring-Mounted Sign Support, Wooden Sign Panel.
Test No. 453580-1	Spring-Mounted Sign Support, Plastic/Fabric Sign Panel.
Test No. 453580-2	Easel Temporary Sign, Plastic/Fabric Sign Panel.
Test No. 453790-1	Portable Sign Support, Plastic/Fabric Sign Panel.

TRANSPORTABLE SIGN SUPPORT

Test No. 453580-3	GSD Sign Support Trailer, Wooden Sign Panel.

FIXED SIGN SUPPORT

Test No. 453360-3	Skid-Mounted Sign Support, Wooden Sign Panel.

ALTERNATE BARRICADE DESIGNS

TYPE III BARRICADES WITHOUT SIGN ATTACHMENT

Test No. 453790-3	Perforated Tubing with Plastic Rail Elements.
Test No. 453880-1	Perforated Tubing with Plastic Rail Elements, Wet Soil.
Test No. 453880-2	Perforated Tubing with Wooden Rail Elements, Wet Soil.
Test No. 453790-2	Plastic Type III Barricade by Tex-Mex Barricade.
Test No. 453790-4	Hollow Core Plastic Material with Wooden Base.
Test No. 453880-3	Hollow Core Plastic Materials with Wooden Base, Wet Soil.
Test No. 453790-5	Solid Recycled Plastic Material.

TYPE III BARRICADES WITH SIGN ATTACHMENT

Test No. 453880-5	Perforated Tubing with Sign Panel Attached to Wooden Rail Elements.
Test No. 453880-6	Hollow Core Plastic Material with Solid Recycled Plastic Base.
Test No. 453880-7	Perforated Tubing with Sign Panel Attached to Cross Members.

Another test involved a GSD trailer-mounted sign support with a 1219 mm x 1219 mm wooden sign panel mounted at a height of 1.52 m from the ground to the bottom of the sign panel (test no. 453580-3). The other test involved a skid-mounted fixed sign support with a 1219 mm x 1219 mm wooden sign panel mounted at a height of 1.52 m from the ground to the bottom of the sign panel (test no. 453360-3).

Tests on the wooden barricades revealed potential problems associated with the wooden barricades, both with and without sign attachment. Two of the four portable sign supports performed unsatisfactorily while the other two performed satisfactorily. Tests on the fixed sign support and the transportable sign support were both successful.

Based on the results of the crash tests with existing traffic control devices, it was decided that the remaining effort in the study be devoted to developing and evaluating alternate barricade designs, both with and without sign attachment, which accounted for the remaining 10 tests. Also, it was decided that the effort be concentrated on Type III barricades since they present the most critical or worst case conditions.

Seven of the 10 tests were conducted on alternate Type III barricade designs with no sign attachment. Alternate materials were considered for fabrication of the Type III barricades, including plastic, perforated steel tubing, hollow core recycled plastic, and solid recycled plastic. Type III barricades constructed from perforated steel tubing and hollow core recycled plastic were also crash tested under wet soil conditions to evaluate their impact performance under such conditions. The seven tests included:

1. Test no. 453790-3. Barricade fabricated from perforated steel tubing with plastic rail elements distributed by TrafFix Devices.

2. Test no. 453880-1. Barricade fabricated from perforated steel tubing with plastic panels distributed by TrafFix Devices tested under wet soil conditions.

3. Test no. 453880-2. Barricade fabricated from perforated steel tubing with wooden panels tested under wet soil conditions.

4. Test no. 453790-2. Plastic barricade manufactured by Tex-Mex Barricade.

5. Test no. 453790-4. Barricade fabricated from hollow core recycled plastic material with a wood base.

6. Test no. 453880-3. Barricade fabricated from hollow core recycled plastic material with a wood base tested under wet soil conditions.

7. Test no. 453790-5. Barricade fabricated from solid recycled plastic material.

The remaining three crash tested were conducted on alternate Type III barricade designs with sign panel attached:

1. Test no. 453880-5. Barricade fabricated from perforated steel tubing with wooden panels. A 1219 mm x 1219 mm aluminum sign panel mounted at a height of 1.52 m from the ground to the bottom of the sign panel was attached to the wooden panels.

2. Test no. 453880-6. Barricade fabricated from hollow core recycled plastic material with a base constructed with solid recycled plastic material. A 1219 mm x 1219 mm aluminum sign panel mounted at a height of 1.52 m from the ground to the bottom of the sign panel was attached to the barricade.

3. Test no. 453880-7. Barricade fabricated from perforated steel tubing with wooden panels. A 1219 mm x 1219 mm aluminum sign panel mounted at a height of 914 mm from the ground to the bottom of the sign panel was attached to cross members made of perforated steel tubing.

Chapter III presents results of the crash tests on existing work zone traffic control devices. Chapter IV presents the results of the efforts to develop and evaluate alternate barricade designs. As part of the evaluation effort for the alternate barricade designs, a wind load analysis was conducted to assess if the alternate barricade designs are adequate to handle the expected wind loads and the amount of ballast (sandbags) required to maintain stability of the barricade. Chapter IV presents the results of the wind load analysis.

2.2 CRASH TEST AND DATA ANALYSIS PROCEDURES

The crash test and data analysis procedures were in accordance with guidelines presented in NCHRP Report 350. Brief descriptions of these procedures are as follows.

2.2.1 Electronic Instrumentation and Data Processing

The test vehicle was instrumented with three solid-state angular rate transducers to measure roll, pitch and yaw rates; a triaxial accelerometer near the vehicle center-of-gravity to measure longitudinal, lateral, and vertical acceleration levels, and a back-up biaxial accelerometer in the rear of the vehicle to measure longitudinal and lateral acceleration levels. The accelerometers were strain gauge type with a linear millivolt output proportional to acceleration.

The electronic signals from the accelerometers and transducers were transmitted to a base station by means of constant bandwidth FM/FM telemetry link for recording on magnetic tape and for display on a real-time strip chart. Calibration signals were recorded before and after the test, and an accurate time reference signal was simultaneously recorded with the data. Pressure sensitive switches on the bumper of the impacting vehicle were actuated just prior to impact by wooden dowels to indicate the elapsed time over a known distance to provide a measurement of impact velocity. The initial contact also produced an "event" mark on the data record to establish the exact instant of contact with the traffic control device.

The multiplex of data channels, transmitted on one radio frequency, were received at the data acquisition station and demultiplexed into separate tracks of Inter-Range Instrumentation Group (I.R.I.G.) tape recorders. After the test, the data were played back from the tape machines, filtered with an SAE J211 filter, and digitized using a microcomputer for analysis and evaluation of impact performance. The digitized data were then processed using two computer programs: DIGITIZE and PLOTANGLE.

The DIGITIZE program uses digitized data from vehicle-mounted linear accelerometers to compute occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, and the highest 10-ms average ridedown acceleration. The DIGITIZE program also calculates a vehicle impact velocity and the change in vehicle velocity at the end of a given impulse period. In addition, maximum average accelerations over 50-ms intervals in each of the three directions are computed. For reporting purposes, the data from the vehicle-mounted accelerometers were then filtered with a 60 Hz digital filter and acceleration versus time curves for the longitudinal, lateral, and vertical directions were plotted using a commercially available software package (QUATTRO PRO).

The PLOTANGLE program used the digitized data from the yaw, pitch, and roll rate transducers to compute angular displacement in degrees at 0.00067-second intervals and then instructs a plotter to draw a reproducible plot: yaw, pitch, and roll versus time. These displacements are in reference to the vehicle-fixed coordinate system with the initial position and orientation of the vehicle-fixed coordinate system being that which existed at initial impact.

2.2.2 Anthropomorphic Dummy Instrumentation

An Alderson Research Laboratories Hybrid II, 50th percentile male anthropomorphic dummy, restrained with lap and shoulder belts, was placed in the driver's position of the vehicle. The dummy was uninstrumented.

2.2.3 Photographic Instrumentation and Data Processing

Photographic coverage of the test included two high-speed cameras: one perpendicular to the path of the vehicle in line with the test article and the other at an angle to the path of the vehicle and the test article. A flashbulb activated by pressure sensitive tapeswitches was positioned on the impacting vehicle to indicate the instant of contact with the test article and was visible from each camera. The films from these high-speed cameras were analyzed on a computer-linked Motion Analyzer to observe phenomena occurring during the collision and to obtain time-event, displacement and angular data. A Betacam and a VHS-format video cameras and recorders, and still cameras were used for to record and document conditions of the test vehicle and the test article before and after the test.

2.2.4 Test Vehicle Propulsion and Guidance

The test vehicle was towed into the test article using a steel cable guidance and reverse tow system. A steel cable for guiding the test vehicle was tensioned along the path, anchored at each end, and threaded through an attachment to the front wheel of the test vehicle. An additional steel cable was connected to the test vehicle, passed around a pulley near the impact point through a pulley on the tow vehicle, and then anchored to the ground so that the tow vehicle moved away from the test site. A 2 to 1 speed ratio between the test and tow vehicle existed with this system. Just prior to impact with the test article, the test vehicle was released to be free-wheeling and unrestrained. The vehicle remained free-wheeling, i.e., no steering or braking inputs, until the vehicle cleared the immediate area of the test site, at which time brakes on the vehicle were activated to bring the vehicle to a safe and controlled stop.

2.2.5 Test Conditions and Evaluation Criteria

One crash test is recommended for evaluation of work zone traffic control devices in accordance with guidelines set forth in NCHRP Report 350. The test involves an 820-kg passenger car impacting the device at a nominal speed of 100 km/h for test level 3 (TL-3) conditions. The test is intended to evaluate vehicular stability, test article trajectory, and occupant risk factors. With the exception of Test no. 453360-3, all the crash tests were conducted with a 820-kg passenger car. A 50th percentile male anthropomorphric dummy was placed in the driver's position and restrained with standard equipment lap and shoulder belts, thus increasing the test weight of the vehicle to 892 kg.

A 2,043-kg pickup truck was used in Test no. 453360-3 which involved a skid-mounted fixed sign support in lieu of the 820-kg passenger car. The pickup truck was selected over the passenger car for this test because a pickup truck would pose a higher potential of penetrating the occupant compartment due to the geometry of the test article. A dummy was not used for this test.

All crash tests were head-on impacts with the centerline of the vehicle aligned with the centerline of the test article, except for the end-on test for a Type III wooden barricade in Test no. 453880-4. In the end-on test, the centerline of the vehicle was aligned with the ends of the rail elements of the barricade. The nominal impact speed was 100 km/h. The vehicle was directed into the test article using the cable reverse tow and guidance system and was released to be free-wheeling and unrestrained just prior to impact. The test article was placed on a concrete pavement surface in all the crash tests except for test nos. 453880-1, 2, 3, and 4 in which the test article was placed on wet soil to simulate conditions encountered on the roadside.

NCHRP Report 350 sets forth the following evaluation criteria for the assessment of the impact performance of traffic control devices:

- Structural Adequacy

  B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.

- Occupant Risk

  E. Detached elements, fragments or other debris from the test article, or vehicular damage should not block the driver's vision or otherwise cause the driver to lose control of the vehicle.

  H. Occupant impact velocities should satisfy the following:

Component	Occupant Impact Velocity Limits (m/s) Preferred	Maximum
Longitudinal	3	5

  I. Occupant ridedown accelerations should satisfy the following:

Component	Occupant Ridedown Acceleration Limits (G's) Preferred	Maximum
Longitudinal and Lateral	15	20

- Vehicle Trajectory

  N. Vehicle trajectory behind the test article is acceptable.

All the crash tests were evaluated in accordance with the criteria described above. Results of the crash test results are presented in Chapter III for the existing work zone traffic control devices and in Chapter IV for the alternate barricade designs. The Appendix provides detailed dimensions and information on the test vehicles. NCHRP Report 350 guidelines also require that plots of the vehicle angular displacements, i.e., vehicle roll, pitch and yaw, and accelerometer traces be included in the report. However, since the vehicle angular displacements and acceleration levels experienced in these crash tests with work zone traffic control devices were very low and of little significance, it was decided not to include plots of the vehicle angular displacements and acceleration traces in the report to keep the report concise.

III. EXISTING WORK ZONE TRAFFIC CONTROL DEVICES

Existing work zone traffic control devices were first crash tested to evaluate their impact performance. Given the large number of existing work zone traffic control devices and possible configurations, only selected traffic control devices and configurations could be crash tested and evaluated. The selection was a joint effort between TxDOT and the project staff and was done in an incremental or step-by-step manner. Typically, three to four traffic control devices and configurations would be selected and crash tested at each step. Depending on the outcomes of the tests conducted in the previous step(s), additional traffic control devices and configurations would then be identified and selected for further crash testing.

Ten crash tests were conducted on existing work zone traffic control devices, which covered the following four types of traffic control devices: (1) wooden barricade, (2) portable sign support, (3) transportable sign support, and (4) skid-mounted sign support. The TxDOT "Barricade and Construction Standards" sheets, dated April 1992, specify all of these traffic control devices.

3.1 WOODEN BARRICADE

One of the most common traffic control devices used in construction zones is barricades. There are three types of barricades—Type I, Type II and Type III—which indicates the number of rail elements with alternating reflective orange and white stripes. The Type I barricade has two rail elements and uses a saw-horse type of support. The Type II barricade has two rail elements attached to vertical supports with a skid-mounted base. The Type III barricade has similar construction details as a Type II barricade, but with three rail elements. Barricades are typically constructed of wood. There are some portable light-weight A-frame Type I and Type II barricades made of plastic or sheet metal available commercially, but their application is mainly limited to short-term maintenance or utility work activity.

It was decided to crash test only the Type I and III wooden barricades. The Type II barricade was not crash tested since its construction is similar to that of the Type III barricade, which was considered to be more critical due to the additional rail element. The portable light-weight A-frame barricades were not selected for testing due to their limited use in construction zones. For the Type III barricade, the shortest width of 1.2 m was used so that the test vehicle would impact both vertical supports simultaneously, which was considered to be the worst practical condition. The barricades were weighted down with eight 11.3-kg sandbags, four on each side with two in front and two in the rear.

In the first test with the Type III wooden barricade (test no. 453360-1), a 1219 mm x 1219 mm wooden sign panel was attached to the barricade at a mounting height of 914 mm from the ground to the bottom of the sign panel. The sign panel impacted the roof of the vehicle, and the fractured vertical supports impacted and penetrated the windshield. Therefore, the performance of the barricade with sign attachment was judged to be unsatisfactory. The test was then repeated without the sign attachment (test no. 453360-4). Again, the fractured vertical supports impacted and penetrated the windshield and the performance of the barricade without sign attachment was also judged to be unsatisfactory.

The Type III wooden barricade was then impacted in an end-on position in the third crash test (test no. 453880-4). Wooden barricades are sometimes placed in such a manner that an errant vehicle could impact the barricade in an end-on position. There was some concern that, when a barricade is impacted in the end-on position, the rail elements could potentially impact the windshield and penetrate the occupant compartment. This test was conducted to evaluate the potential hazard associated with such impacts. However, contrary to the initial concern, the barricade performed satisfactorily in this crash test.

In the test with the Type I wooden barricade (test no. 453360-5), a 1219 mm x 1219 mm wooden sign panel was attached to the barricade at a mounting height of 305 mm from the ground to the bottom of the sign panel. The sign panel and top rail element impacted and penetrated the windshield. The performance of the Type I barricade with sign attachment was judged to be unsatisfactory.

The following sections present details of the four crash tests on wooden barricades.

3.1.1 Type III Wooden Barricade with Wooden Sign Panel (Test No. 453360-1)

Figure 1 shows s schematic of the Type III barricade with a 1219 mm x 1219 mm sign panel mounted at a height of 914 mm. The test vehicle was a 1981 Honda Civic 3-door, as shown in Figure 2. Appendix Figure 88 gives dimensions and information on the vehicle. The test vehicle impacted the barricade head-on with the centerline of the vehicle aligned with the centerline of the barricade, traveling at a speed of 101.2 km/h.

At 10 msec after initial impact, the sign panel broke loose from the barricade, and the vertical supports began to break loose from the bases. The sign panel struck the roof just above the windshield at 62 msec. The top of the vertical supports, which had broken off at the base, impacted and penetrated the windshield at 74 msec. As the vehicle continued forward, the sign panel rotated up and over the vehicle, striking the telemetry antenna resulting in loss of data transmission at about 93 msec. The time at loss of contact with the barricade, i.e., when the support ended contact with the vehicle, was 209 msec and the vehicle had slowed to 84.5 km/h. The support rotated as it went over the vehicle, and one leg momentarily contacted the rear portion of the roof just above the rear hatch at about 307 msec. Brakes on the vehicle were applied at 1.05 seconds after impact, which was after the vehicle cleared the immediate test site. Prior to brake application, the test vehicle was traveling on a relatively straight-forward path. However, one brake did not actuate upon application, causing the vehicle to yaw in a clockwise rotation. The vehicle subsequently came to rest 137 m down and 37 m to the right of the point of impact. Figure 3 shows sequential photographs of the test period.

As can be seen in Figure 2, the Type III Wood Barricade separated upon impact. Debris and sand were strewn along the path of the vehicle in an area 11 m wide by 37 m long. Figure 2 shows damage to the vehicle. There were two dents in the bumper, 38 mm and 19 mm from

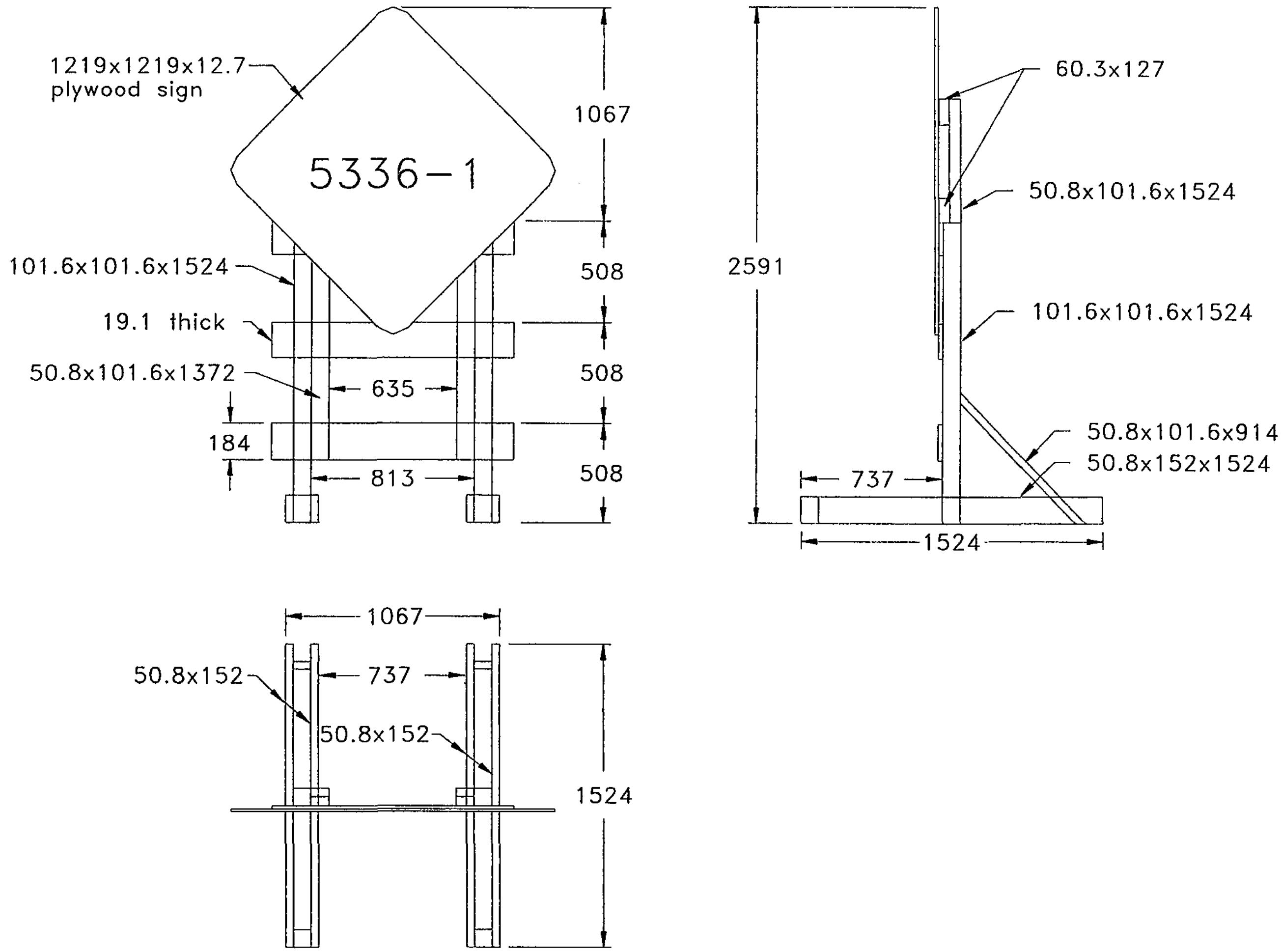


Figure 1. Schematic of Type III Wooden Barricade with Wooden Sign Panel (Test No. 453360-1)

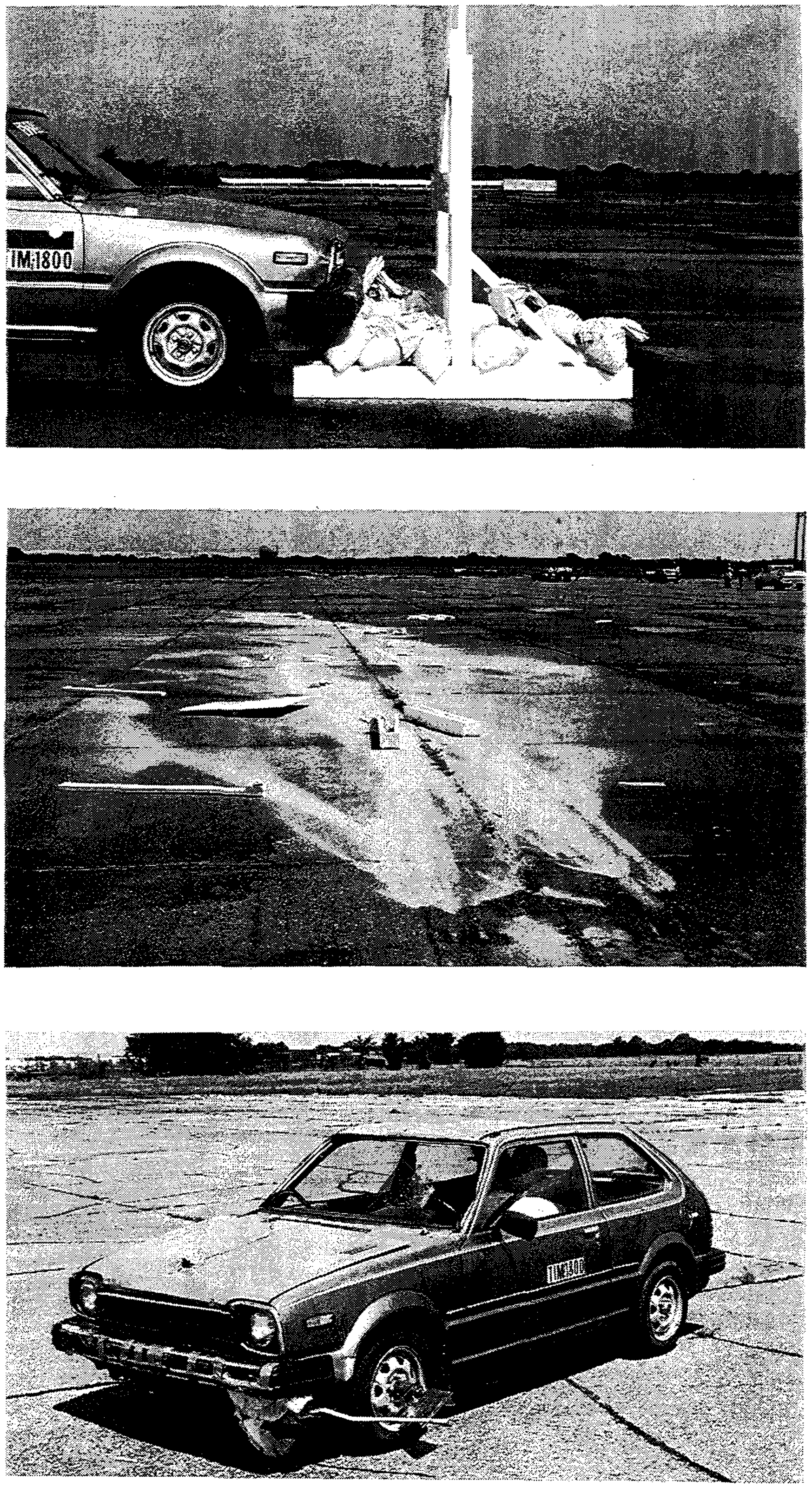
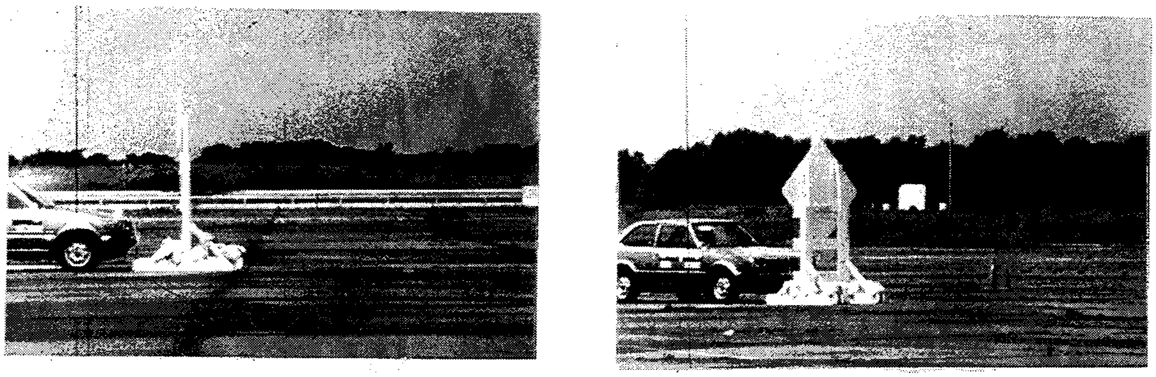
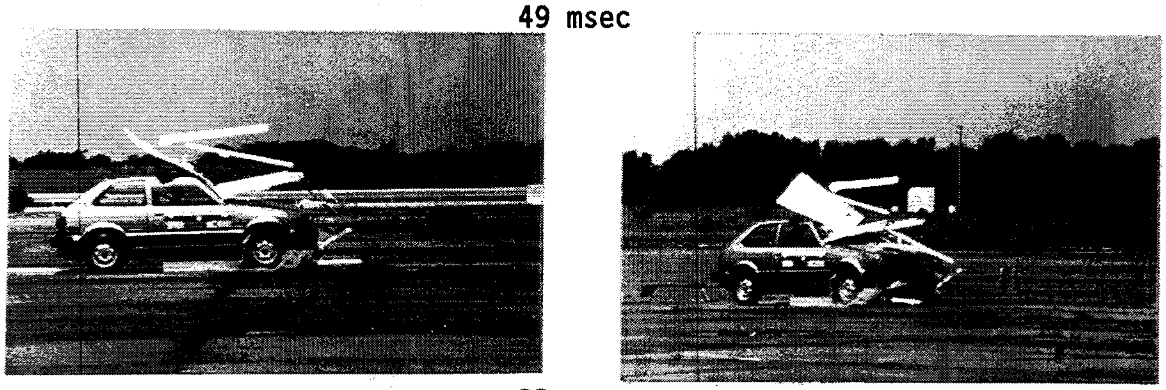


Figure 2. Vehicle and Barricade for Test No. 453360-1

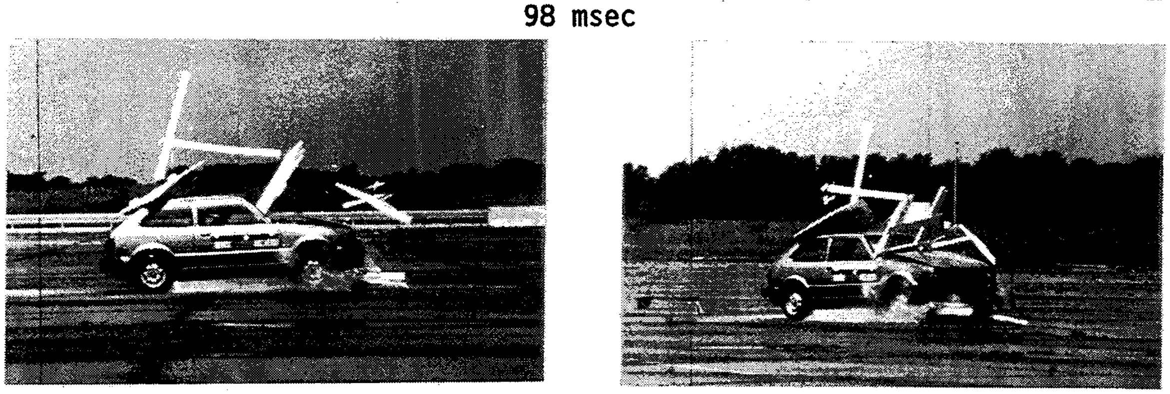


0 msec

49 msec

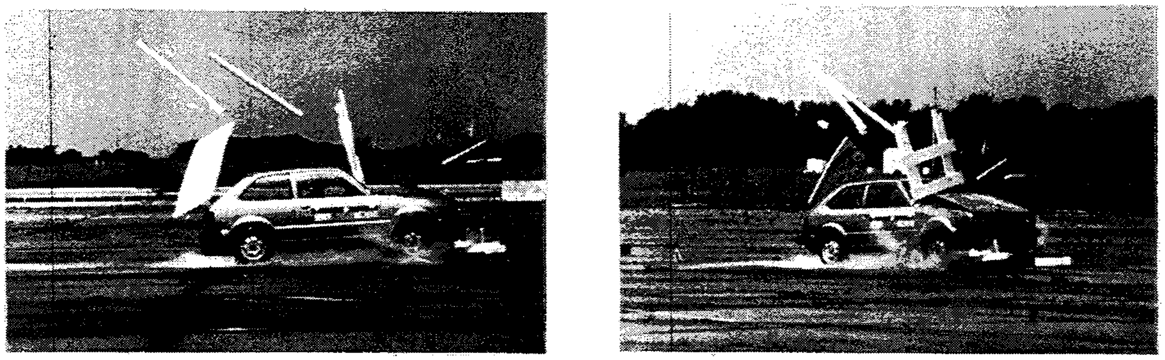


98 msec

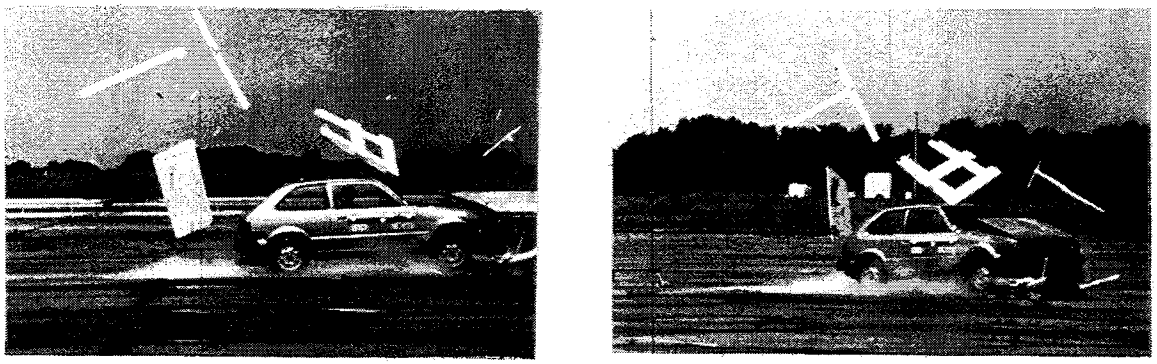


148 msec

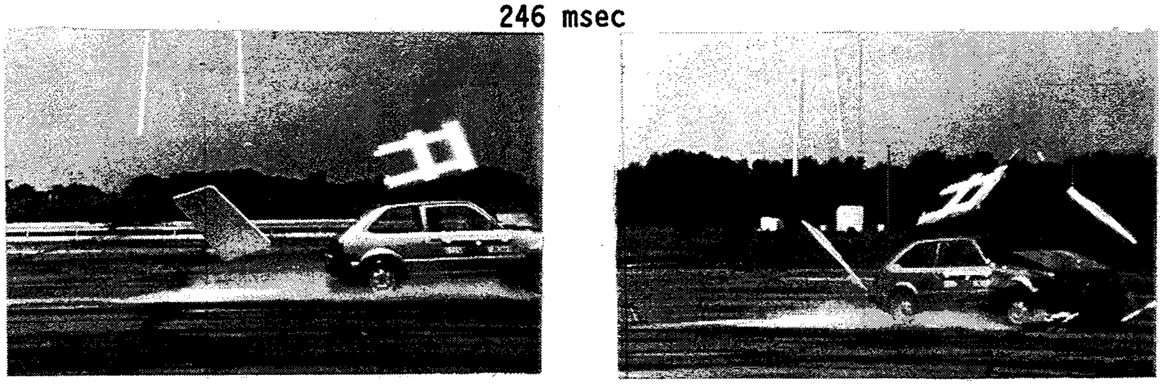
Figure 3. Sequential Photographs for Test No. 453360-1



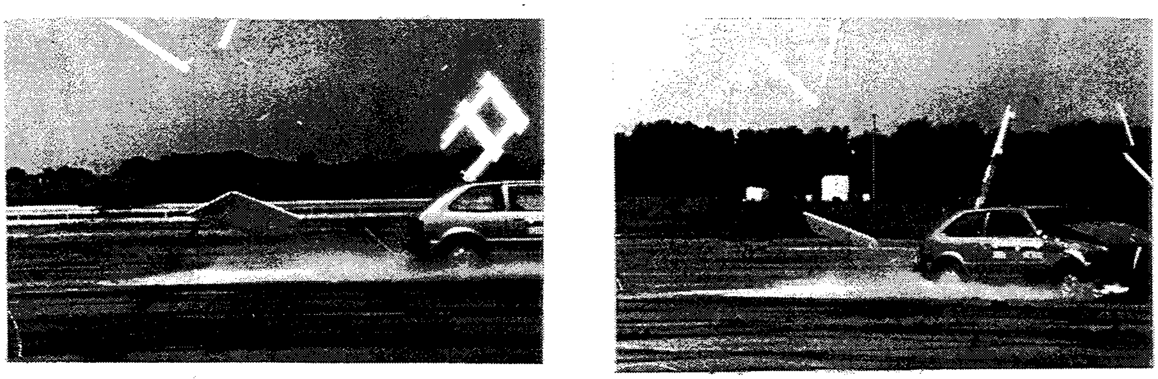
197 msec



246 msec



295 msec



344 msec

Figure 3. Sequential Photographs for Test No. 453360-1 (continued)

impact with the vertical supports of the barricade. There was a 40 mm x 200 mm dent in the hood, the windshield was broken and had fallen into the occupant compartment, and there was a small dent in the rear roof near the hatch.

Figure 4 presents a brief summary of the results of this test. The barricade shattered upon impact. The vertical supports broke from the bases and impacted and penetrated the windshield, resulting in broken glass entering the occupant compartment. The sign panel was detached from the barricade and impacted the roof of the vehicle. Debris from the barricade was thrown along an area 11 m wide by 37 m long. Some fragments were fairly large, which could pose potential hazard to oncoming traffic in adjacent lanes and to workers in the area. Sand was also scattered on the pavement, which could lead to loss of control of other vehicles. The vehicle sustained damage to the front bumper, hood, windshield and roof. There was no occupant contact during the test period. The maximum 50-msec average accelerations were -5.9 g in the longitudinal direction and 1.1 g in the lateral direction. The vehicle exited the immediate test site in a relatively smooth, stable manner and showed no potential for intrusion into adjacent traffic lanes.

In summary, the performance of the barricade was judged to be unsatisfactory due to penetration of the windshield and the occupant compartment by the fractured vertical supports of the barricade.

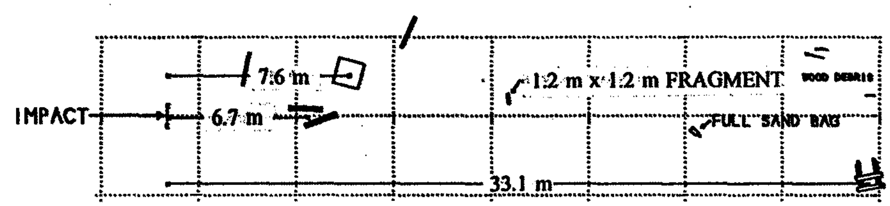
3.1.2 Type III Wooden Barricade without Sign (Test No. 453360-4)

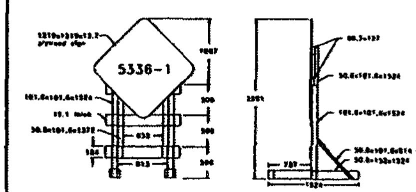
Figure 5 shows a schematic of the Type III barricade. The test vehicle was a 1986 Yugo GV, as shown in Figure 6. Appendix Figure 89 gives dimensions and information on the vehicle. The test vehicle impacted the barricade head-on with the centerline of the vehicle aligned with the centerline of the barricade, traveling at a speed of 102.5 km/h.

Upon impact, the vertical supports fractured and contacted the hood of the vehicle while the vehicle traveled over the bases. The top rear section of the barricade separated at 17 msec and made contact with the windshield at 40 msec. The windshield broke at 45 msec, and a fragment of the barricade entered the occupant compartment at 72 msec. As the vehicle continued forward, the other fragments contacted the roof of the vehicle just above the windshield at 117 msec and then lost contact at 164 msec. At this time, the vehicle had slowed to 84.5 km/h. The fragments rotated as they went over the vehicle and momentarily contacted the left rear portion of the roof at about 226 msec. After the vehicle cleared the immediate test site, brakes on the vehicle were applied at 860 msec. Prior to brake application, the test vehicle was traveling on a relatively straight-forward path. The vehicle subsequently came to rest 71 m down from the point of impact. Figure 7 shows sequential photographs of the test period.

The barricade shattered upon impact, as can be seen in Figure 6. Debris and sand were strewn along the path of the vehicle in an area 18 m wide by 56 m long. Figure 6 shows damage to the vehicle. There were two dents in the bumper, 89 mm and 64 mm from impact with the vertical supports. The windshield was broken and had fallen into the occupant compartment,

0.000 s	0.098 s	0.197 s	0.295 s





Type III Wood Barricade

General Information	
Test Agency	Texas Transportation Institute
Test No.	5336-1
Date	05/22/92
Test Article	
Type	Traffic Control Device
	Type III Wood Barricade
Installation Length (ft)	5.0 (1.5 m)
Size and/or dimension and material of key elements	8.5 (2.6 m) high Wood
Soil Type and Condition	N/A
Test Vehicle	
Type	Production Model
Designation	820 C
Model	1981 Honda Civic
Mass (lb) Curb	N/A
Test Inertial	1,800 (817 kg)
Dummy	170 (77 kg)
Gross Static	1,970 (894 kg)

Impact Conditions	
Speed (mi/h)	62.9 (101.2 km/h)
Angle (deg)	0
Exit Conditions	
Speed (mi/h)	52.5 (84.5 km/h)
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (ft/s)	
x-direction	No contact
y-direction	No contact
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	N/A
y-direction	N/A
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Averages (g's)	
x-direction	-5.9
y-direction	1.1
z-direction	2.2

Test Article Deflections (ft)	
Dyanmic	Broke apart
Permanent	Broke apart
Vehicle Damage	
Exterior	
VDS	12FD1
CDC	12FDEK1 &12FDGW6
Interior	
OCDI	FS0000000
Maximum Exterior Vehicle Crush (in)	1.5 (3.8 cm)
Max. Occ. Compart. Deformation (in)	Broken windshield
Post-Impact Behavior	
Max. Roll Angle (deg)	0.3
Max. Pitch Angle (deg)	1.9
Max. Yaw Angle (deg)	0.2

Figure 4. Summary of Results for Test No. 453360-1

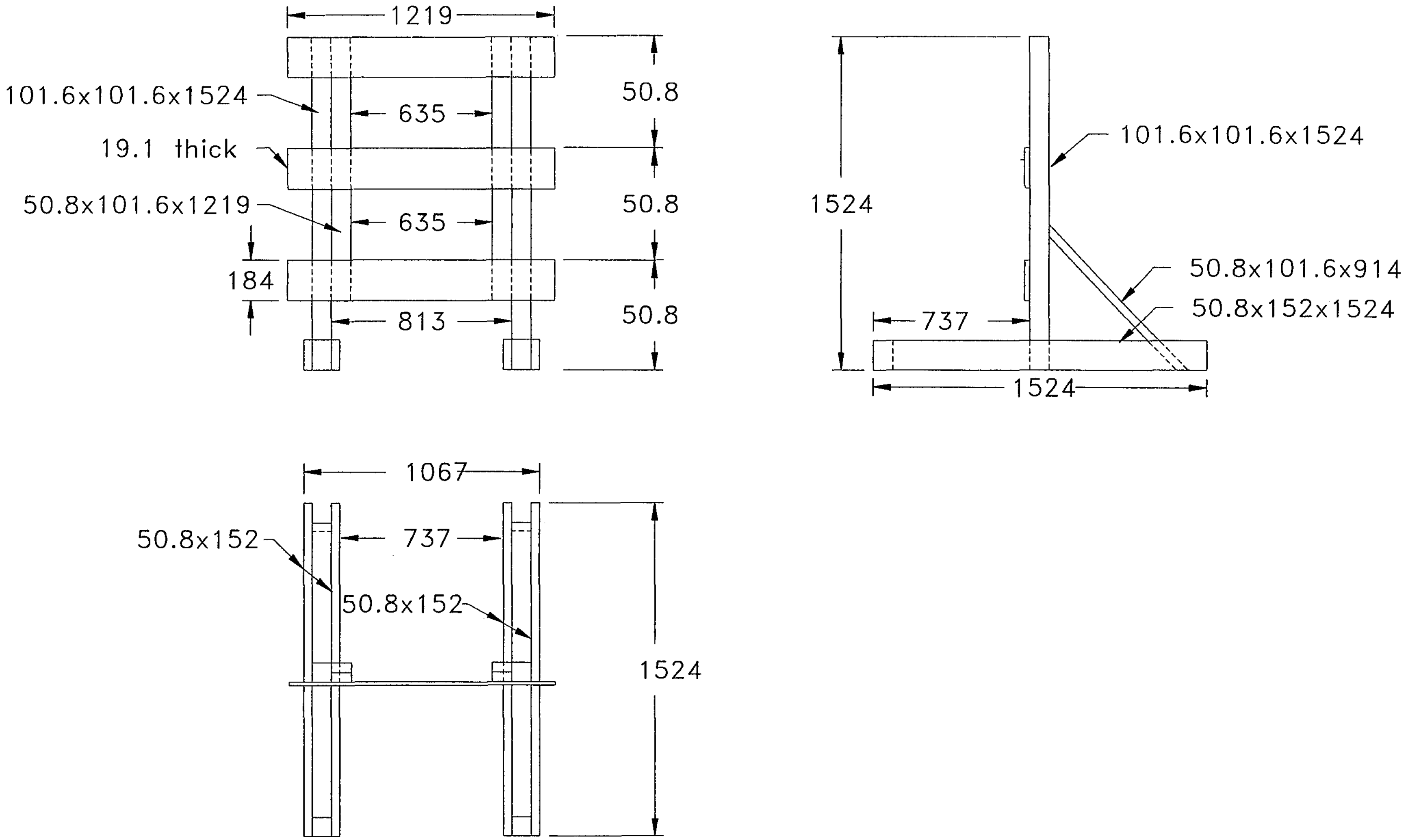


Figure 5. Schematic of Type III Wooden Barricade without Sign (Test No. 453360-4)

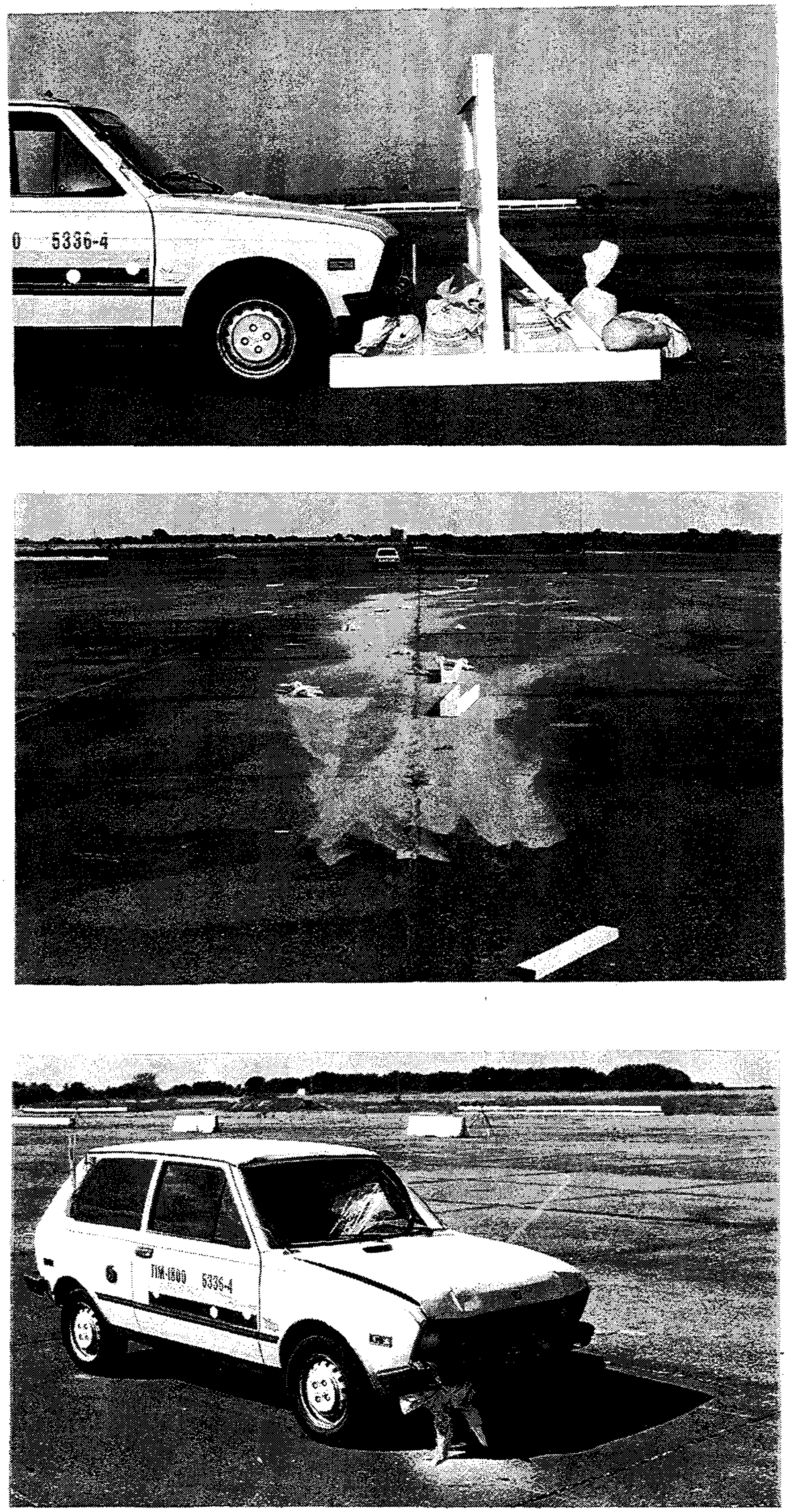


Figure 6. Vehicle and Barricade for Test No. 453360-4

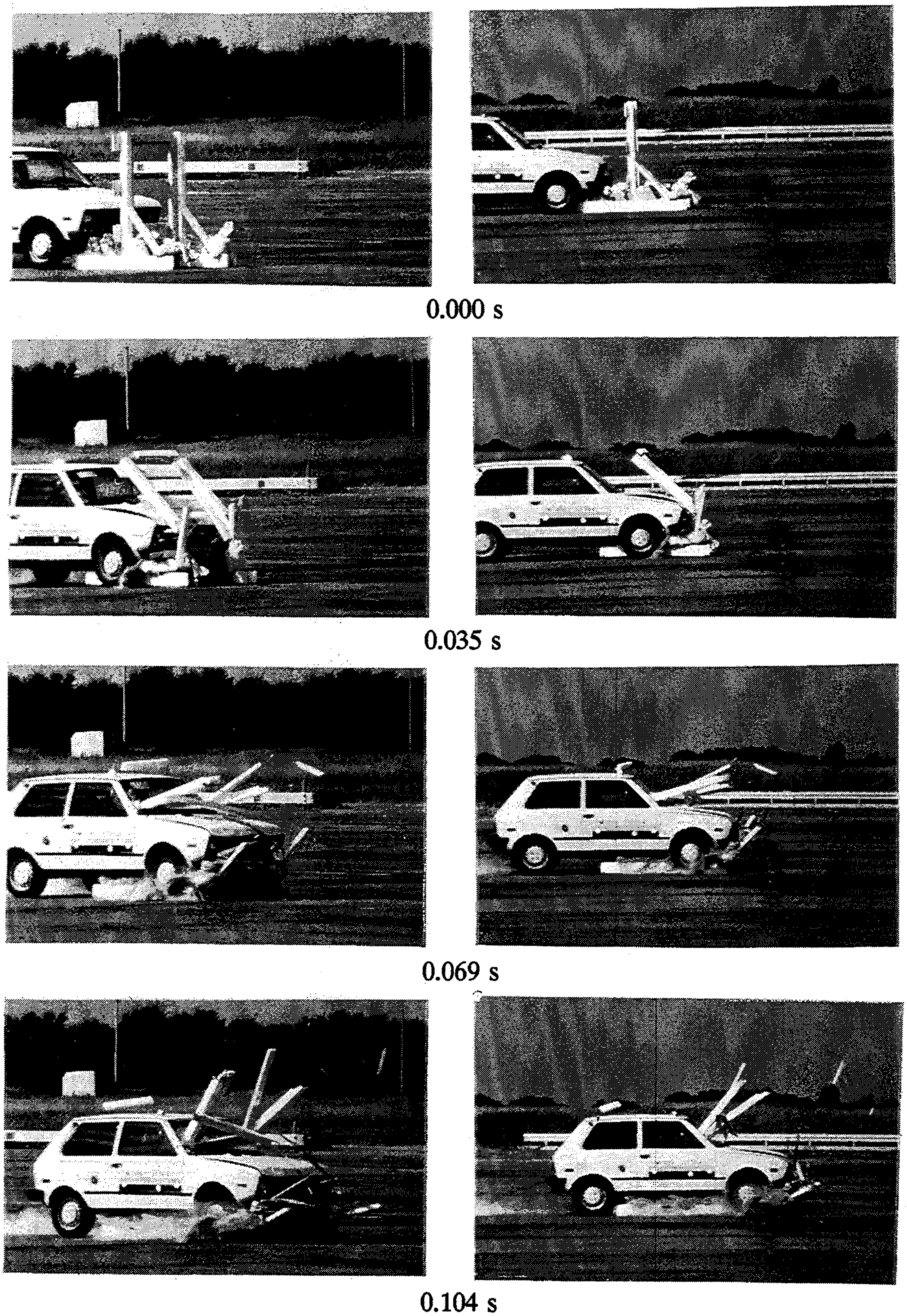
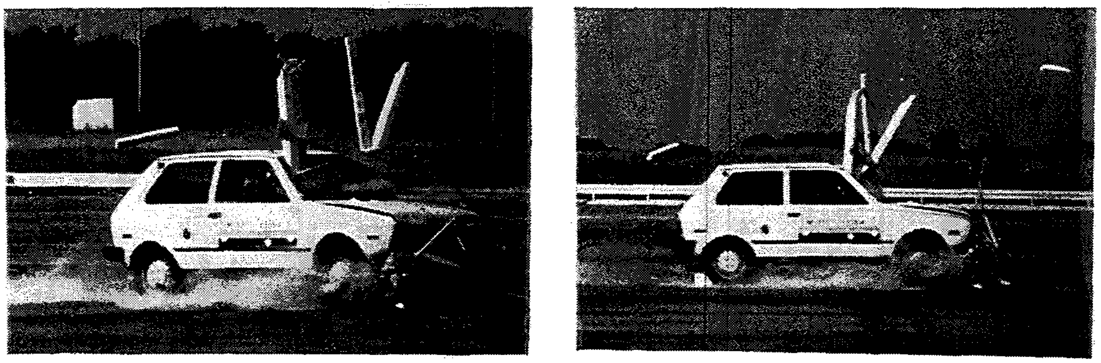
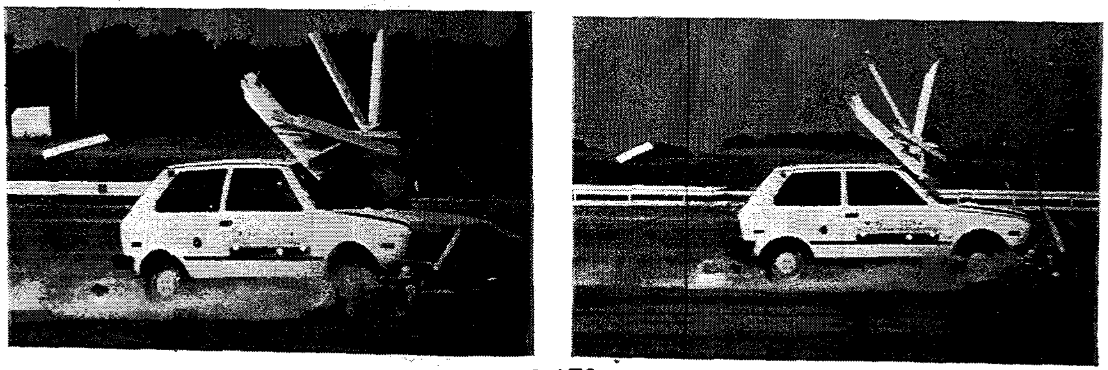


Figure 7. Sequential Photographs for Test No. 453360-4

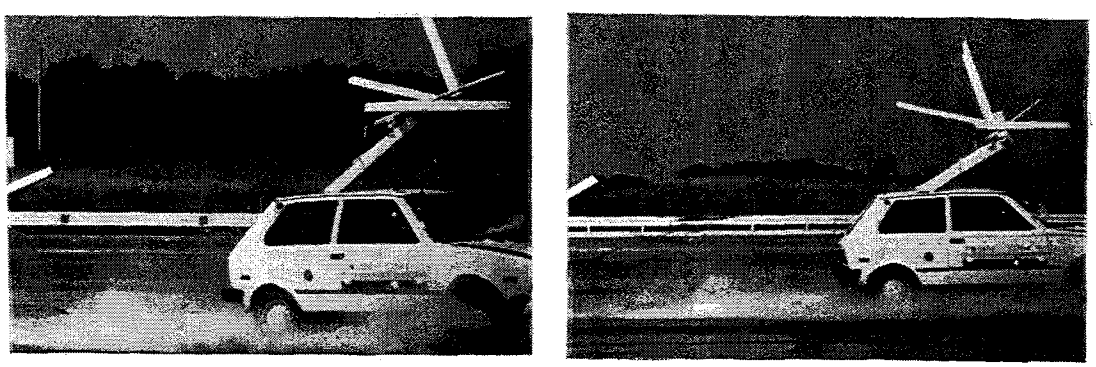


0.138 s



0.173 s

0.207 s



0.242 s

Figure 7. Sequential Photographs for Test No. 453360-4 (continued)

and there was a 533 mm long fragment of the barricade in the rear passenger section of the vehicle. There was a small dent, 13 mm deep, on the left rear side of the roof.

Figure 8 presents a brief summary of the results of this test. The barricade shattered upon impact, and a segment of the barricade impacted the windshield, penetrated and intruded into the occupant compartment. The 533 mm long fragment was found in the rear section of the occupant compartment, showing potential risk to occupants in the vehicle. Sand and many fragments of the barricade were scattered along an area 18 m wide by 56 m long. Some fragments were fairly large, which could pose potential hazard to oncoming traffic in adjacent lanes and to workers in the area. Sand was also scattered on the pavement, which could lead to loss of control of other vehicles. The vehicle sustained damage to the front bumper, hood, windshield and roof. The longitudinal occupant impact velocity was 2.8 m/s and the highest 10-msec average ridedown acceleration was -0.9 g. There was no lateral occupant contact during the test period. The 50-msec average accelerations were -4.8 g in the longitudinal direction and 0.7 g in the lateral direction. The vehicle exited the immediate test site in a relatively smooth, stable manner and showed no potential for intrusion into adjacent traffic lanes.

In summary, the performance of the barricade was judged to be unsatisfactory due to penetration of the windshield and the occupant compartment by the fractured vertical supports of the barricade.

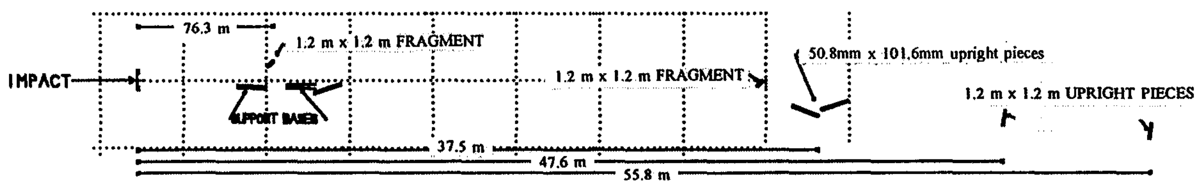
3.1.3 End-On Test of Type III Wooden Barricade without Sign (Test No. 453880-4)

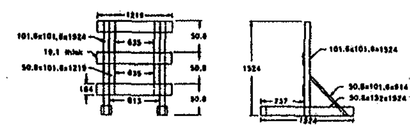
Figure 9 shows a schematic of the Type III barricade without sign attachment. The test vehicle was a 1989 Chevrolet Sprint as shown in Figure 10. Appendix Figure 90 gives dimensions and information on the vehicle. The test vehicle impacted the barricade end-on with the centerline of the vehicle aligned with the centerline of the end of the barricade, traveling at a speed of 99.6 km/h.

As the vehicle impacted the end of the rail elements, the right vertical support separated from the base. The vehicle contacted the right vertical support at 7 msec. At 12 msec, the lower rail element separated from the vertical supports. At 17 msec, the middle rail element separated from the vertical support and contacted the hood of the vehicle at 20 msec. The front tires of the vehicle rode over the right base, which separated from the vertical support. The left vertical support separated at 48 msec, and the vehicle rode over the left base, carrying the remaining debris of the barricade with it. At 221 msec, the vehicle cleared the installation site traveling at a speed of 93.1 km/h. Prior to brake application, the vehicle was tracking straight forward. The vehicle subsequently came to rest 102.4 m down and 1.7 m to the right of the point of impact. Figure 11 shows sequential photographs of the test period.

The barricade separated from the base upon impact, as can be seen in Figure 10. Debris and sand were strewn along the path of the vehicle in an area 4.3 m wide by 58.8 m long. Figure 10 shows damage to the vehicle. Maximum crush to the exterior of the vehicle was 190 mm to the center front bumper. The right front door was jammed, and there was damage to the bumper, grill, and hood. The right front tire was flat.

0.000 s	0.069 s	0.138 s	0.207 s





Type III Wood Barricade without sign panel

General Information	
Test Agency	Texas Transportation Institute
Test No.	5336-4
Date	09/18/92
Test Article	
Type	Traffic Control Device
	Type III Wood Barricade
Installation Length (ft)	5.0 (1.5 m)
Size and/or dimension and material of key elements	8.5 (2.6 m) high Wood
Soil Type and Condition	N/A
Test Vehicle	
Type	Production Model
Designation	820 C
Model	1986 Yugo GV
Mass (lb) Curb	1,833 (832 kg)
Test Inertial	1,800 (817 kg)
Dummy	170 (77 kg)
Gross Static	1,970 (894 kg)

Impact Conditions	
Speed (mi/h)	63.7 (102.5 km/h)
Angle (deg)	0
Exit Conditions	
Speed (mi/h)	52.5 (84.5 km/h)
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (ft/s)	
x-direction	9.1 (2.8 m)
y-direction	No contact
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-0.9
y-direction	N/A
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Averages (g's)	
x-direction	-4.8
y-direction	0.7
z-direction	-1.3

Test Article Deflections (ft)	
Dyanmic	Broke apart
Permanent	Broke apart
Vehicle Damage	
Exterior	
VDS	12FD1
CDC	12FDEK1 &12FDGW6
Interior	
OCDI	FS0000000
Maximum Exterior Vehicle Crush (in)	3.5 (8.9 cm)
Max. Occ. Compart. Deformation (in)	Broken windshield
Post-Impact Behavior	
Max. Roll Angle (deg)	-2.5
Max. Pitch Angle (deg)	-2.9
Max. Yaw Angle (deg)	-1.4

Figure 8. Summary of Results for Test No. 453360-4

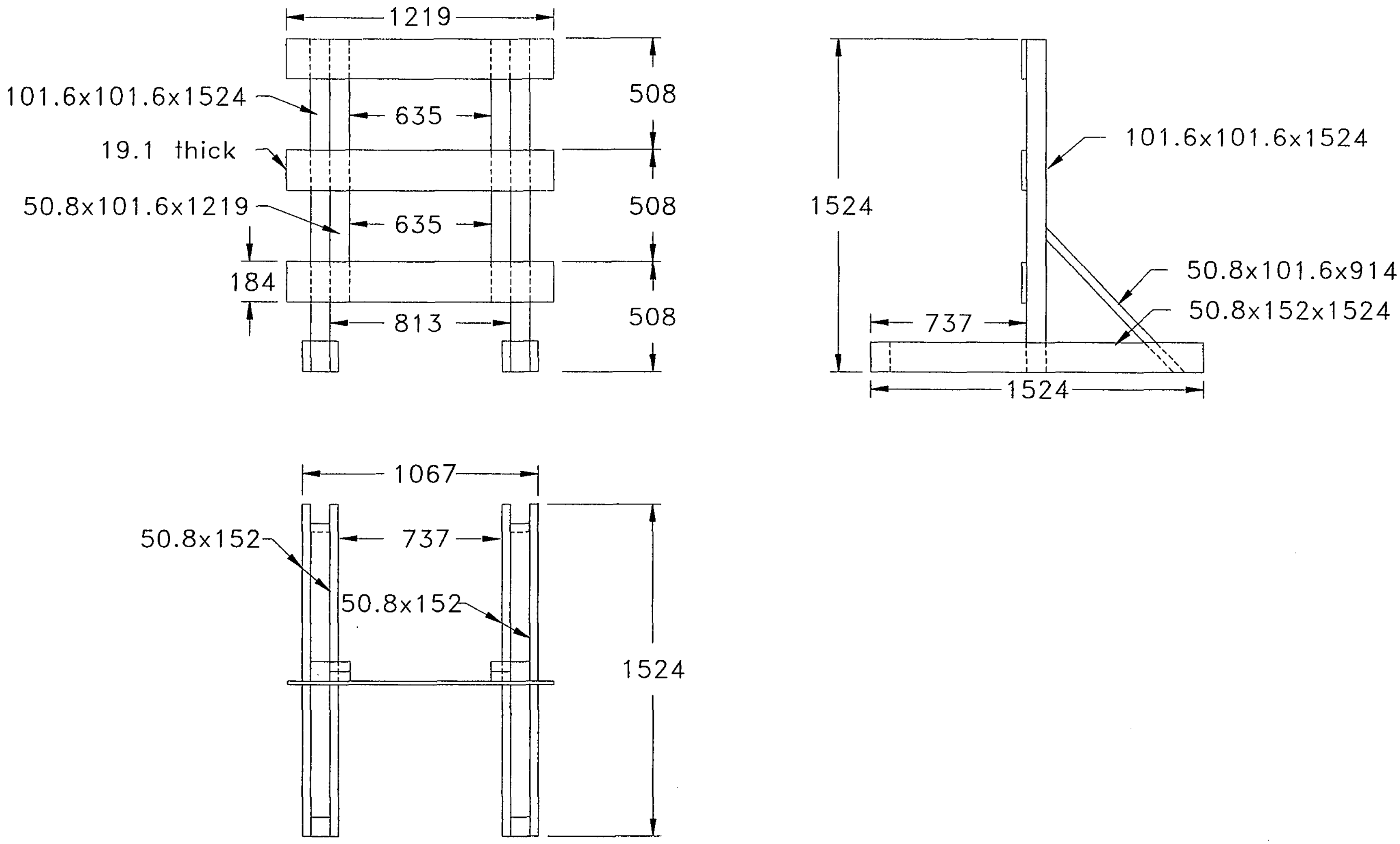


Figure 9. Schematic of Type III Wooden Barricade without Sign (Test No. 453880-4)

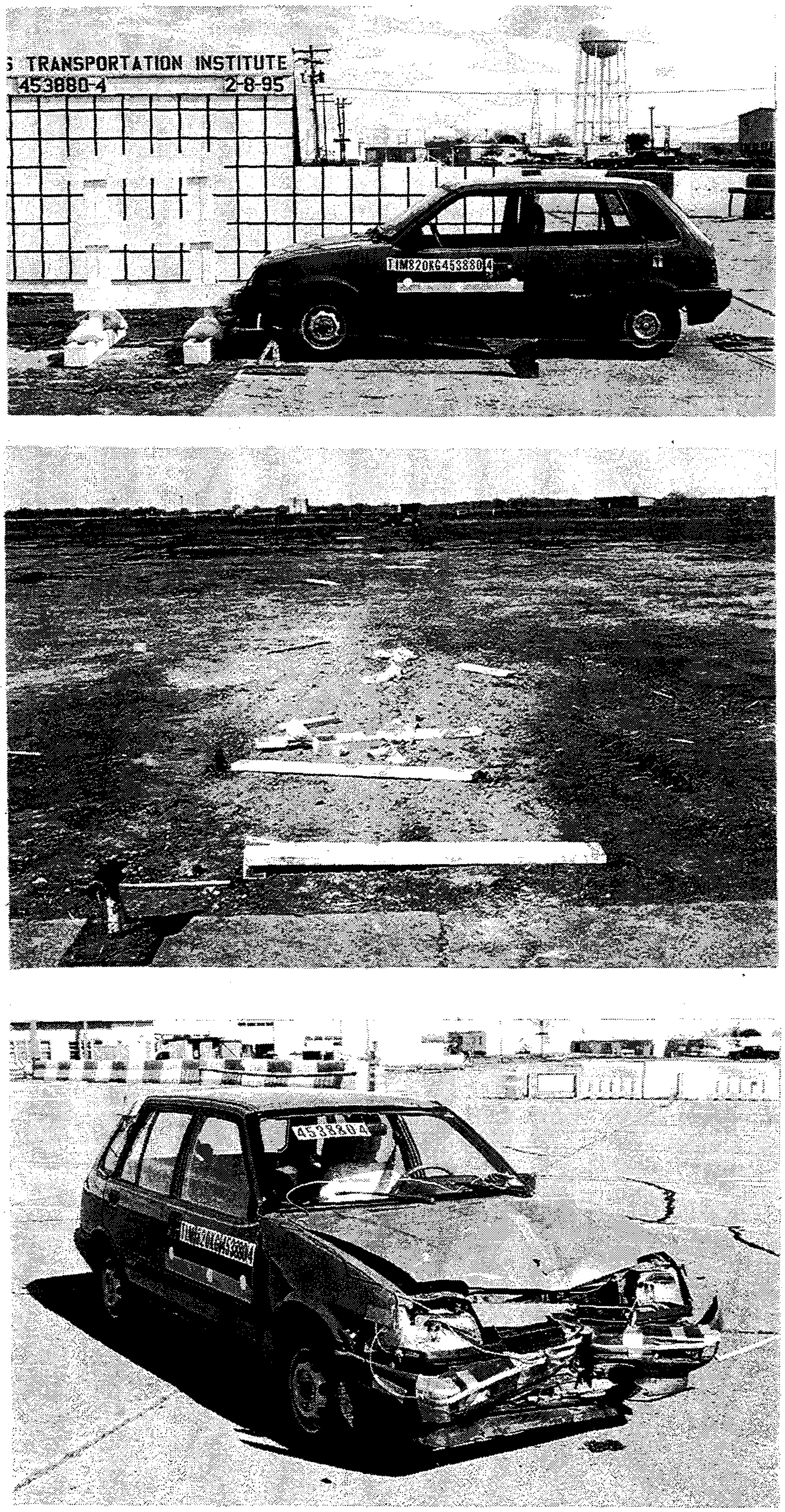
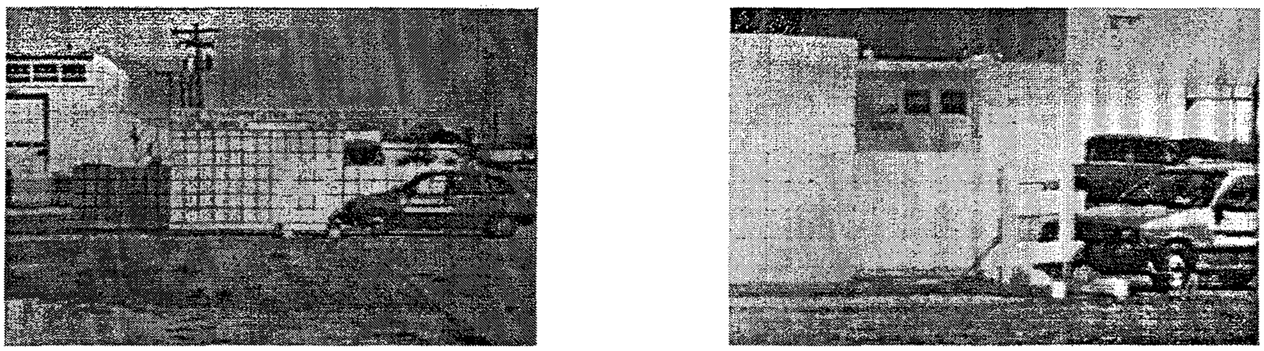
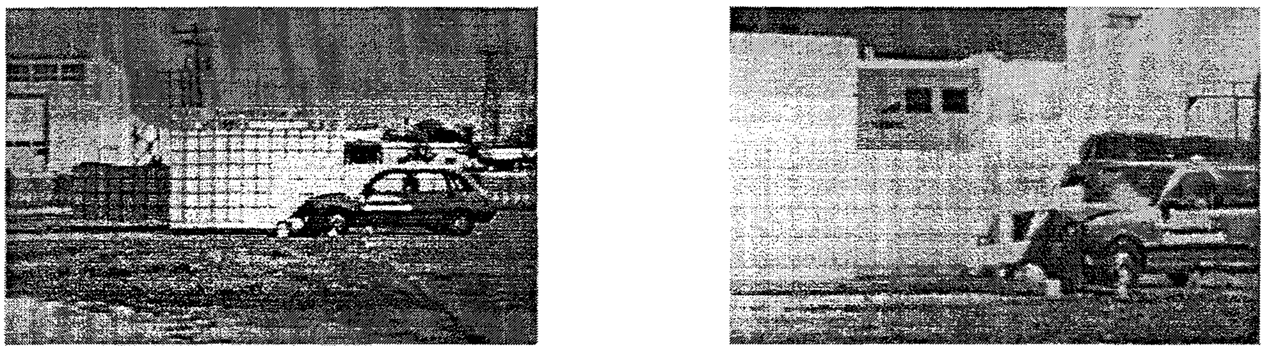


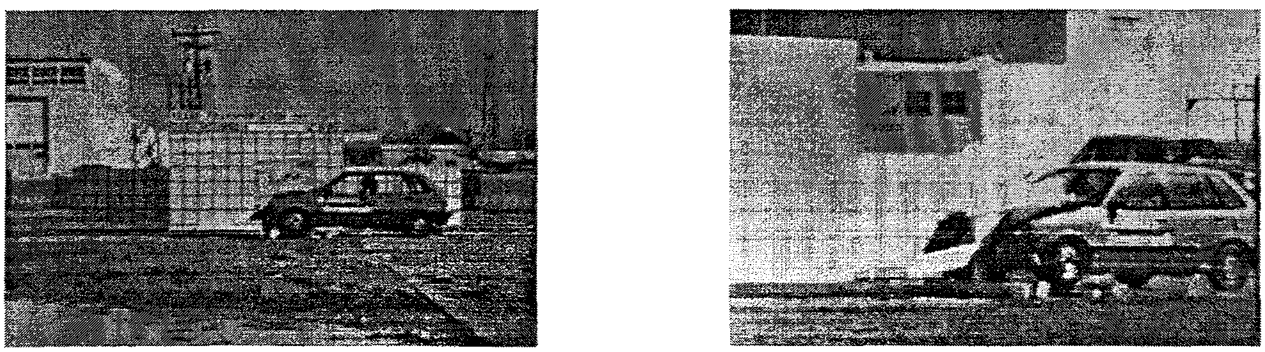
Figure 10. Vehicle and Barricade for Test No. 453880-4



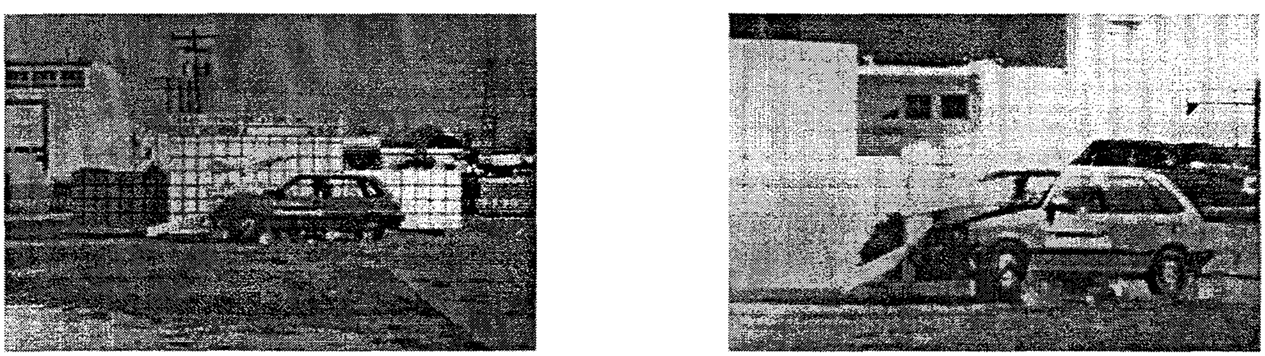
0.000 s



0.030 s

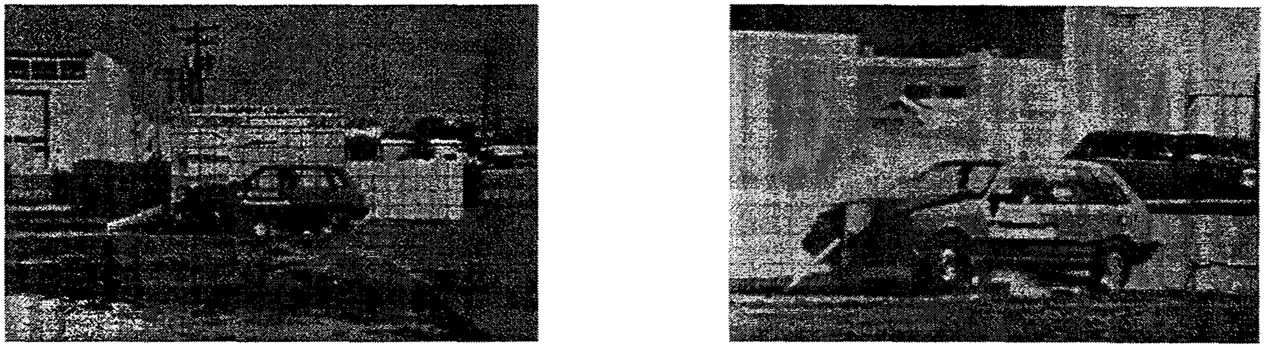


0.059 s



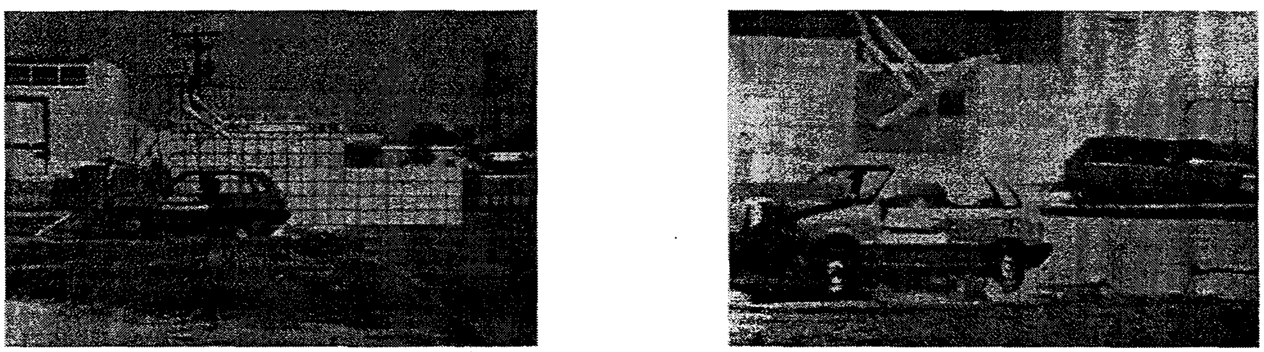
0.091 s

Figure 11. Sequential Photographs for Test No. 453880-4

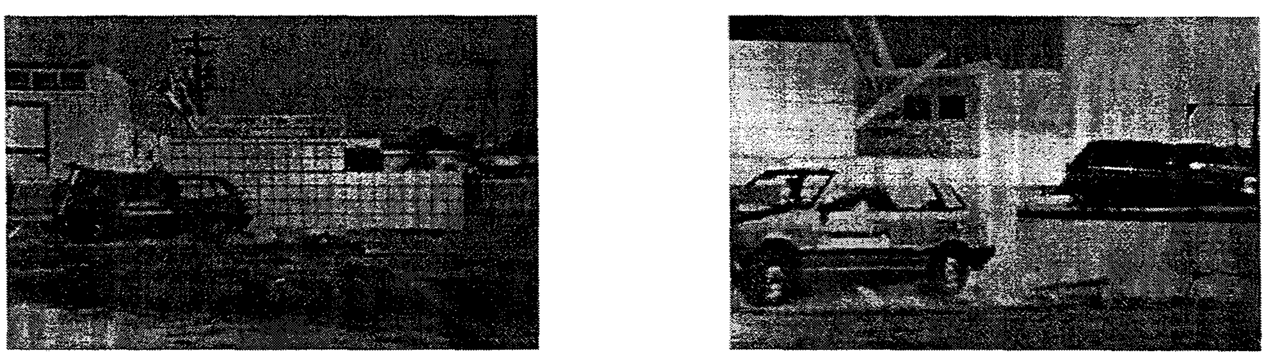


0.121 s

0.150 s



0.180 s



0.210 s

Figure 11. Sequential Photographs for Test No. 453880-4 (continued)

Figure 12 presents a brief summary of the results of this test. The barricade came apart upon impact; however, there was no penetration or intrusion into the occupant compartment. Sand and fragments of the barricade were scattered along an area 4.3 m wide by 58.8 m long. However, most fragments were not large enough to pose potential hazard to oncoming traffic in adjacent lanes or to construction workers in the area. The vehicle sustained minor damage to the bumper, grill and hood. Maximum crush to the center front bumper was 190 mm. The longitudinal occupant impact velocity was 2.1 m/s, and the highest 10-msec average ridedown acceleration was -2.4 g. Lateral occupant impact velocity was 0.9 m/s, and the highest 10-msec average ridedown acceleration was -5.4 g. The 50-msec average accelerations were -3.2 g in the longitudinal direction and 1.1 g in the lateral direction. The vehicle exited the immediate test site in a relatively smooth, stable manner and showed no potential for intrusion into adjacent traffic lanes.

In summary, the barricade was judged to have met all evaluation criteria set forth in NCHRP Report 350 for this end-on test.

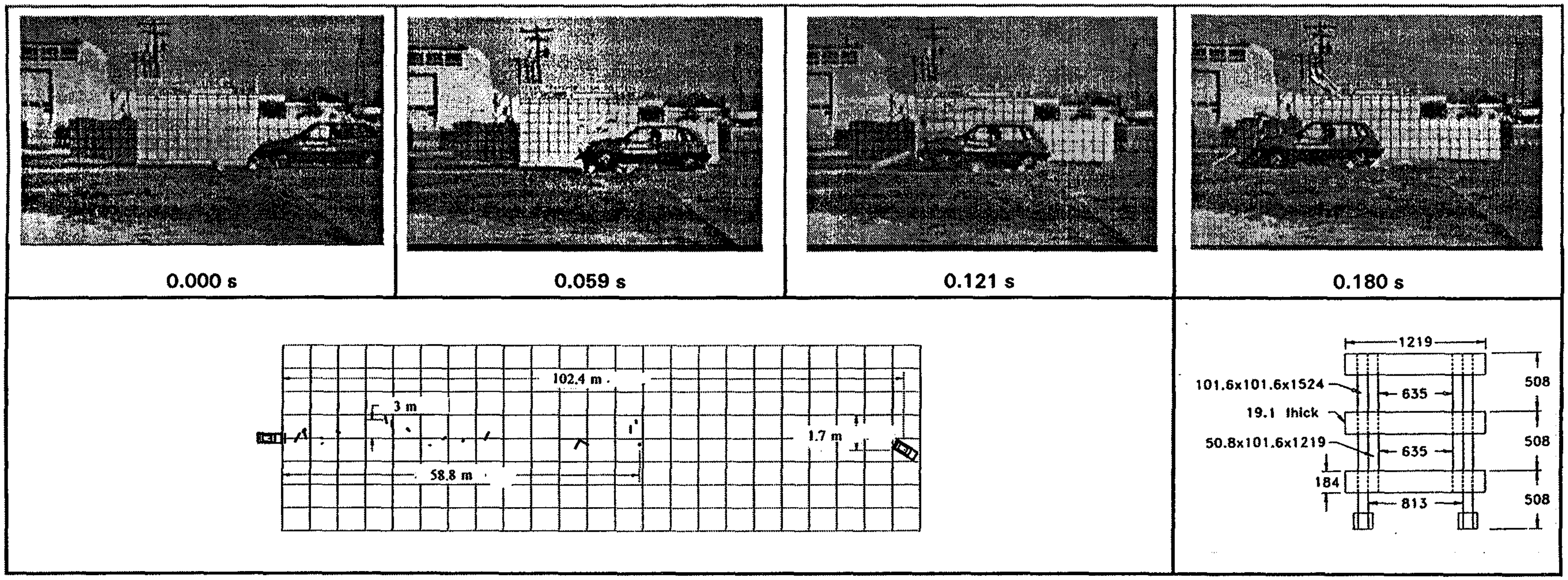
3.1.4 Type I Wooden Barricade with Wooden Sign Panel (Test No. 453360-5)

Figure 13 shows a schematic of the Type I barricade with a 1219 mm x 1219 mm sign panel mounted at a height of 305 mm. The test vehicle was a 1989 Yugo GV, as shown in Figure 14. Appendix Figure 91 gives dimensions and information on the vehicle. The test vehicle impacted the barricade head-on with the centerline of the barricade, traveling at a speed of 99.4 km/h.

Upon impact, the bottom rail element broke. At 15 msec after impact, the sign panel cracked. As the vehicle continued forward, the fragments rose and struck the windshield, which broke at 57 msec. At the same time, the top rail element of the barricade contacted the A-pillars of the vehicle. The sign panel continued to go up and lost contact with the vehicle at 122 msec, while the remaining fragments of the rail elements lost contact at 156 msec. The vehicle had slowed to 91.2 km/h by this time. After the vehicle cleared the immediate test site, brakes on the vehicle were applied at 960 msec after impact. Prior to brake application, the test vehicle was traveling on a relatively straightforward path. The vehicle subsequently came to rest 68 m down from the point of impact. Figure 15 shows sequential photographs of the test period.

The barricade shattered upon impact, as can be seen in Figure 14. Debris and sand were strewn along the path of the vehicle in an area 15 m wide by 53 m long. Figure 14 shows damage to the vehicle. There were two dents in the bumper, 38 mm and 19 mm from impact with the rail elements. There were scrapes in the hood leading up to the windshield, the windshield was broken and fallen into the occupant compartment, and there were dents on the A-pillars starting 152 mm above the bottom of the windshield frame and ending at the top edge of the roof.

Figure 16 presents a brief summary of the results of this test. The barricade shattered upon impact, and a segment of the barricade impacted the windshield, penetrating and intruding into the occupant compartment, showing potential risk to occupants of the vehicle. Sand and many



General Information

Test Agency	Texas Transportation Institute
Test No.	453880-4
Date	02/08/95
Test Article	
Type	Type III Barricade
Name or Manufacturer	Wood
Installation Length (m)	1.2 m (4.0 ft)
Size and/or dimension and material of key elements	Wood
Soil Type and Condition	Strong soil, damp
Test Vehicle	
Type	Production
Designation	820C
Model	1989 Chevrolet Sprint
Mass (kg) Curb	713 (1570 lb)
Test Inertial	820 (1806 lb)
Dummy	75 (165 lb)
Gross Static	897 (1975 lb)

Impact Conditions

Speed (km/h)	99.6 (61.9 mi/h)
Angle (deg)	0 (end-on)
Exit Conditions	
Speed (km/h)	93.1 (57.9 mi/h)
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	2.1 (6.9 ft/s)
y-direction	0.9 (3.1 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-2.4
y-direction	-5.4
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Average (g's)	
x-direction	-3.2
y-direction	1.1
z-direction	-1.4

Test Article Deflections (m)

Thrown Forward	58.2 (193.0 ft)
Thrown Laterally	3.0 (10.0 ft)
Vehicle Damage	
Exterior	
VDS	12FC2
CDC	12FCEN2
Interior	
OCDI	FS0000000
Maximum Exterior Vehicle Crush (mm)	190 (7.5 in)
Max. Occ. Compart. Deformation (mm)	0
Post-Impact Behavior	
Max. Roll Angle (deg)	2.9
Max. Pitch Angle (deg)	2.3
Max. Yaw Angle (deg)	4.7

Figure 12. Summary of Results for Test No. 453880-4

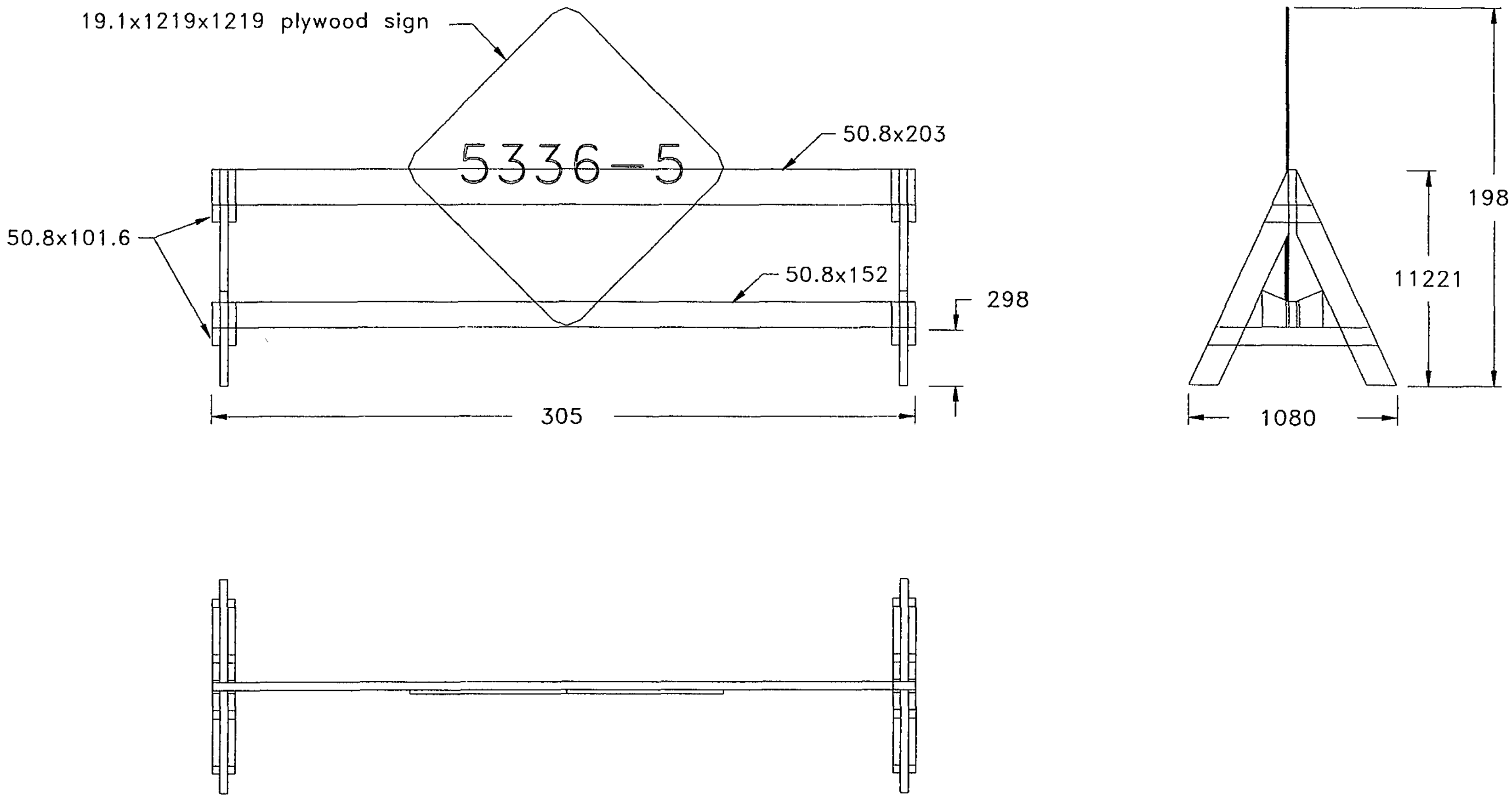


Figure 13. Schematic of Type I Wooden Barricade with Wooden Sign Panel (Test No. 453360-5)

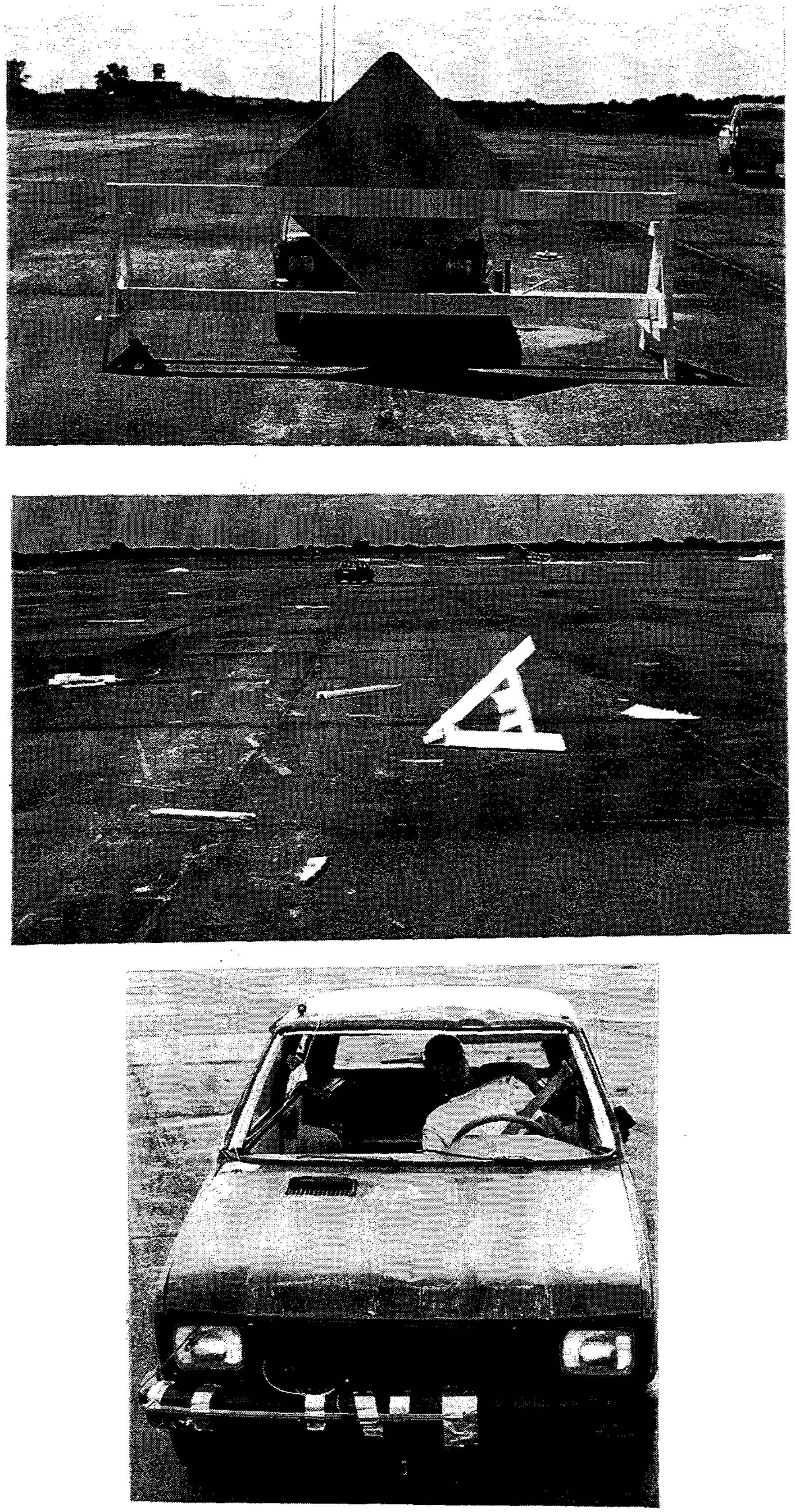
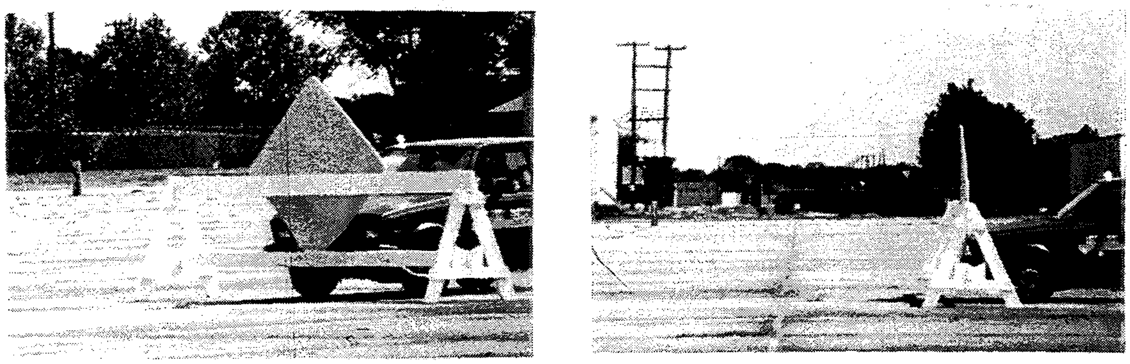
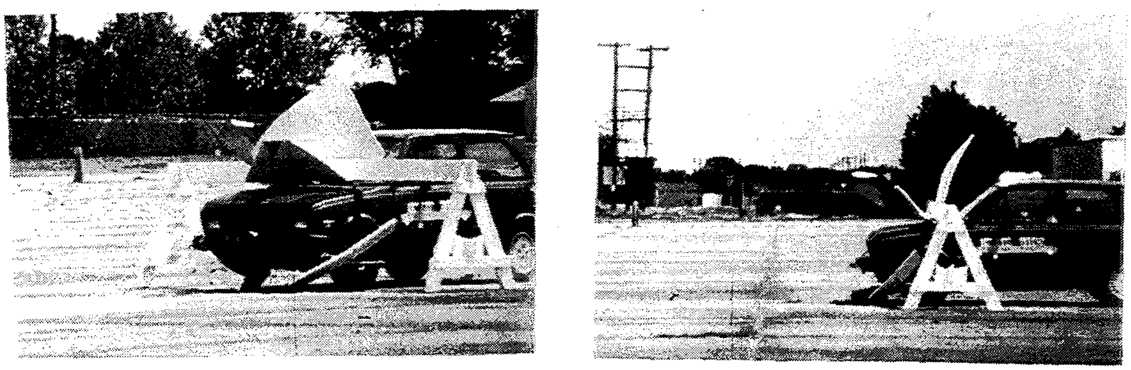


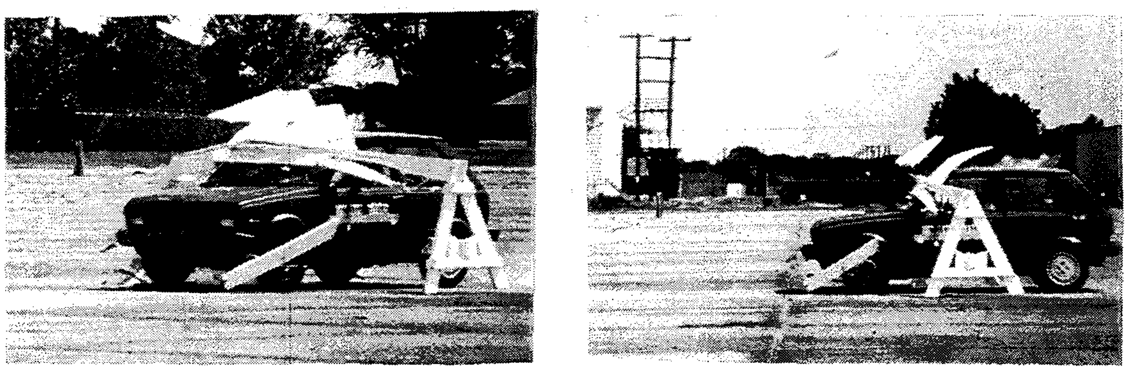
Figure 14. Vehicle and Barricade for Test No. 453360-5



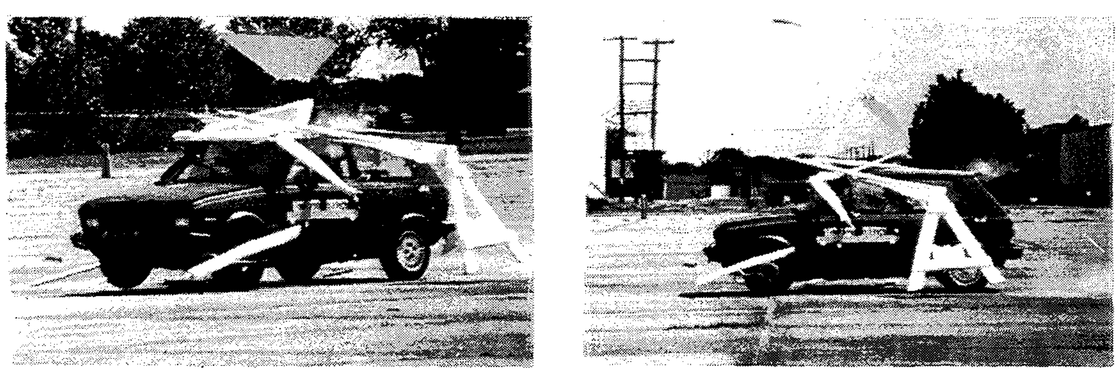
0.000 s



0.035 s

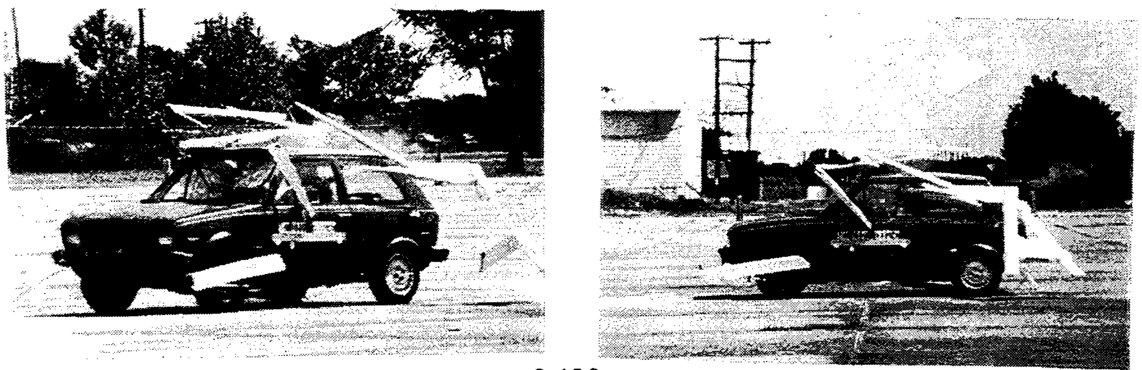


0.069 s

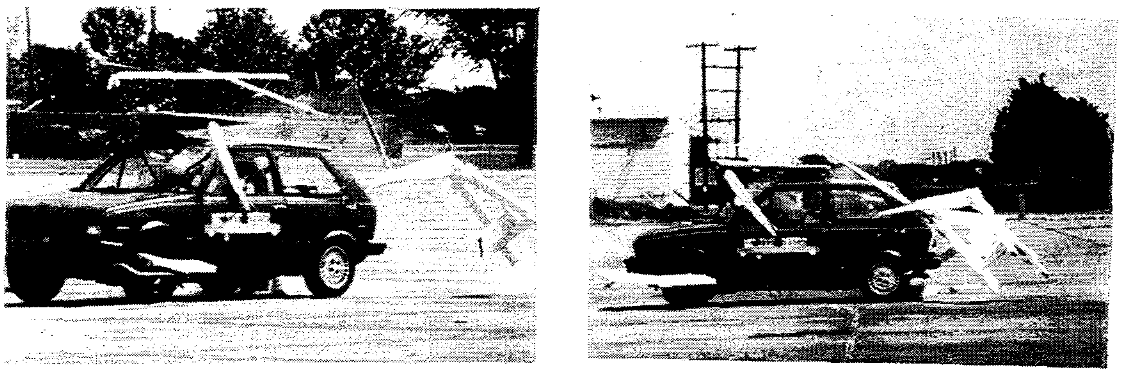


0.104 s

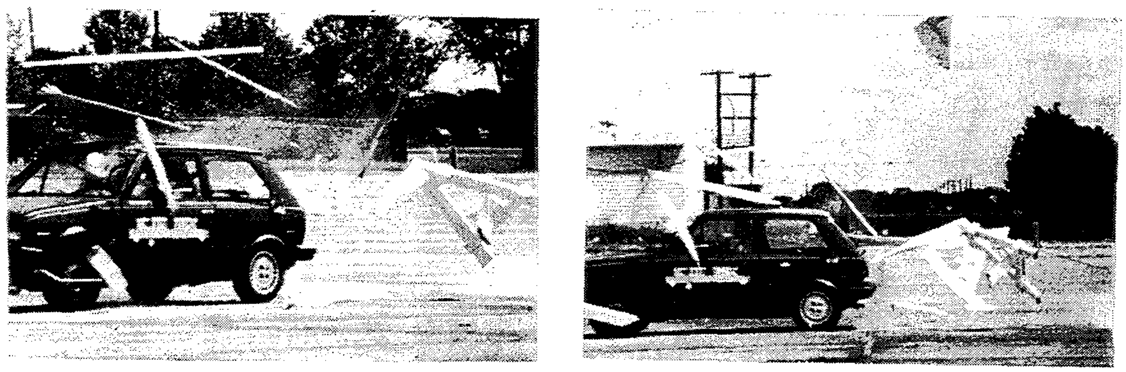
Figure 15. Sequential Photographs for Test No. 453360-5



0.139 s



0.174 s



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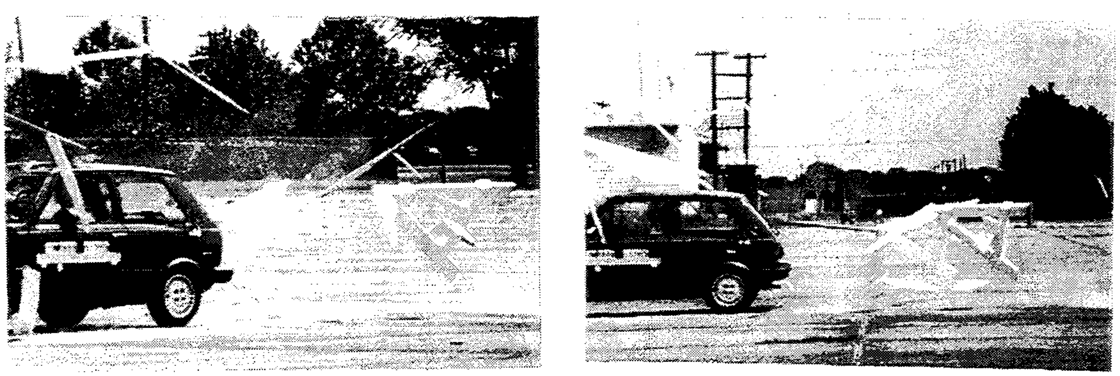
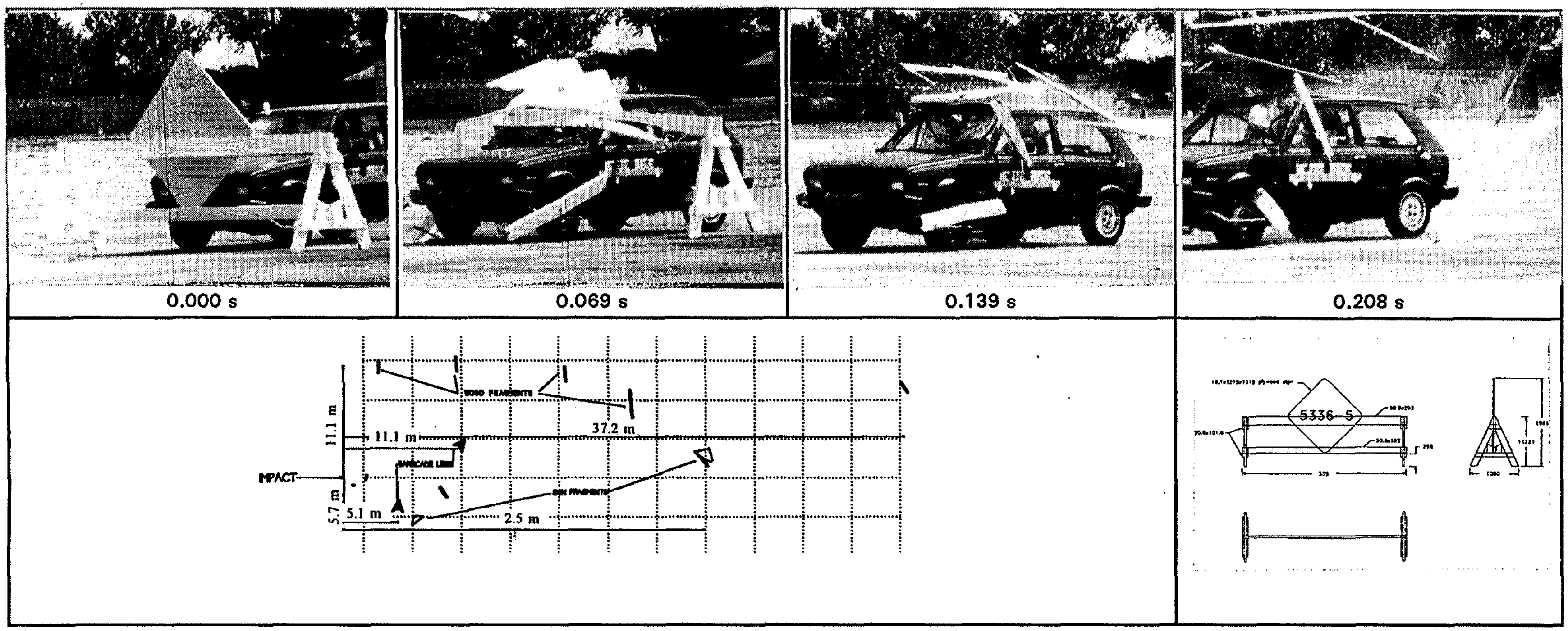


0.243 s

Figure 15. Sequential Photographs for Test No. 453360-5 (continued)



General Information	
Test Agency	Texas Transportation Institute
Test No.	5336-5
Date	09/18/92
Test Article	
Type	Traffic Control Device
	Type I Wood Barricade
Installation Length (ft)	6.5 (2.0 m)
Size and/or dimension and material of key elements	6.5 (2.0 m) high Wood
Soil Type and Condition	N/A
Test Vehicle	
Type	Production Model
Designation	820 C
Model	1989 Yugo GV
Mass (lb) Curb	1,814 (824 kg)
Test Inertial	1,800 (817 kg)
Dummy	170 (77 kg)
Gross Static	1,970 (894 kg)

Impact Conditions	
Speed (mi/h)	61.8 (99.4 km/h)
Angle (deg)	0
Exit Conditions	
Speed (mi/h)	56.7 (91.2 km/h)
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (ft/s)	
x-direction	2.7 (0.8 m)
y-direction	No contact
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-0.1
y-direction	N/A
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Averages (g's)	
x-direction	-1.1
y-direction	0.5
z-direction	-0.7

Test Article Deflections (ft)	
Dyanmic	Broke apart
Permanent	Broke apart
Vehicle Damage	
Exterior	
VDS	12FD1
CDC	12FDEK1 &12FDGW6
Interior	
OCDI	FS0000000
Maximum Exterior Vehicle Crush (in)	1.5 (3.8 cm)
Max. Occ. Compart. Deformation (in)	Broken windshield
Post-Impact Behavior	
Max. Roll Angle (deg)	-2.2
Max. Pitch Angle (deg)	-1.9
Max. Yaw Angle (deg)	2.1

Figure 16. Summary of Results for Test No. 453360-5

fragments of the barricade were scattered along an area 15 m wide by 53 m long. Some fragments were fairly large, which could pose potential hazard to oncoming traffic in adjacent lanes and to workers in the area. Sand was also scattered on the pavement, which could lead to loss of control of other vehicles. The longitudinal occupant impact velocity was 0.8 m/s and the highest 10-msec average ridedown acceleration was -0.1 g. There was no lateral occupant contact during the test period. The 50-msec average accelerations were -1.1 g in the longitudinal direction and 0.5 g in the lateral direction. The vehicle exited the immediate test site in a relatively smooth, stable manner and showed no potential for intrusion into adjacent traffic lanes.

In summary, the performance of the barricade was judged to be unsatisfactory due to penetration of the windshield and the occupant compartment by the fractured vertical supports of the barricade.

3.2 PORTABLE SIGN SUPPORT

Three types of portable sign supports were tested:

(1) a spring-mounted sign support,
(2) an easel sign support, and
(3) a portable sign support.

These portable sign supports were selected from commercially available models currently used by TxDOT and purchased from the manufacturers or distributors. These portable sign supports are typically constructed of tubular or angle steel and can be assembled and dismantled readily. The sign support can accommodate up to a 1219 mm x 1219 mm sign panel with a mounting of height of approximately 305 mm from the ground to the bottom of the sign.

The first portable sign support tested was a spring-mounted support with a wooden sign panel attached (test no. 453360-2). The sign panel and portions of the sign support impacted and penetrated the windshield, and the performance of the sign support was judged to be unsatisfactory. The spring-mounted sign support was tested again, but with a plastic/fabric sign panel, and the test was successful (test no. 453580-1). This indicates that, for portable sign supports, the sign panel has a high probability of impacting the windshield due to the geometry and the construction of the sign support. Thus, wooden sign panels should not be used with portable sign supports. The plastic/fabric sign panels appear to perform satisfactorily and are therefore recommended. Other lightweight sign substrates, such as reinforced fiber plastic or aluminum, may also perform satisfactorily. However, no testing was conducted with these alternate sign substrates.

The easel portable sign support was tested with a plastic/fabric sign panel (test no. 453580-2). The top of the easel sign support, which acted like a pointed object, impacted and penetrated the windshield, and the test was judged to be unsatisfactory. The use of the easel sign support is therefore not recommended.

Another portable sign support with similar construction to the spring-mounted sign support, but without the springs, was tested with a plastic/fabric sign panel (test no. 453790-1). The sign support performed satisfactorily in the crash test.

The following sections present descriptions of the individual crash tests and the results of the crash tests.

3.2.1 Spring-Mounted Sign Support with Wooden Sign Panel (Test No. 453660-2)

Figure 17 shows a schematic of the spring-mounted portable sign support with a 1219 mm x 1219 mm wooden sign panel mounted at a height of 305 mm. The test vehicle was a 1988 Yugo GV, as shown in Figure 18. Appendix Figure 92 gives dimensions and information on the vehicle. The test vehicle impacted the sign support head-on with the centerline of the vehicle aligned with the centerline of the sign support, traveling at a speed of 97.0 km/h.

At approximately 10 msec after impact, the sign panel began to crack. The bracket supporting the sign panel broke at 17 msec, and at 22 msec the sign panel slipped out of the bracket. The sign panel continued moving upward and contacted the edge of the roof of the vehicle just above the windshield. As the vehicle continued forward, the sign panel deformed, impacted and penetrated the windshield, the bracket went over the roof, and the base hung up on the undercarriage of the vehicle. The panel rotated up and over the vehicle and lost contact at 200 msec, at which time the vehicle had slowed to 91.4 km/h. After the vehicle cleared the immediate test site, brakes on the vehicle were applied at 937 msec after impact. Prior to brake application, the test vehicle was traveling on a relatively straight-forward path. The vehicle subsequently came to rest 59 m down and 6 m to the east of the point of impact. Figure 19 shows sequential photographs of the test period.

The spring-mounted portable sign support shattered upon impact, as can be seen in Figure 18. Debris were strewn along the path of the vehicle in an area 17 m wide by 21 m long. Figure 18 shows damage to the vehicle. There was a maximum crush of 89 mm in the bumper from impact with the sign support. There was a 25-mm deep dent in the roof just above the windshield, and the windshield was broken and had partially fallen into the occupant compartment.

A brief summary of the results of this test is presented in Figure 20. The sign support shattered upon impact. The wooden sign panel and a segment of the sign support impacted and penetrated the windshield, showing potential risk to occupants in the vehicle. Debris of the sign support were scattered along an area 17 m wide by 21 m long. Some of the fragments were fairly large, which could pose potential hazard to oncoming traffic in adjacent lanes and to workers in the area. The vehicle sustained damage to the front bumper, hood, windshield and roof. The longitudinal occupant impact velocity was 1.7 m/s, and the highest 10-msec average ridedown acceleration was -1.5 g. There was no occupant contact in the lateral direction during the test period. The maximum 50-msec average accelerations were -1.3 g in the longitudinal direction and 0.6 g in the lateral direction. The vehicle exited the immediate test site in a relatively smooth, stable manner and showed no potential for intrusion into adjacent traffic lanes.

In summary, the performance of the spring-mounted portable sign support with a wooden sign panel was judged to be unsatisfactory due to penetration of the windshield and the occupant compartment by the sign panel and a portion of the sign support.

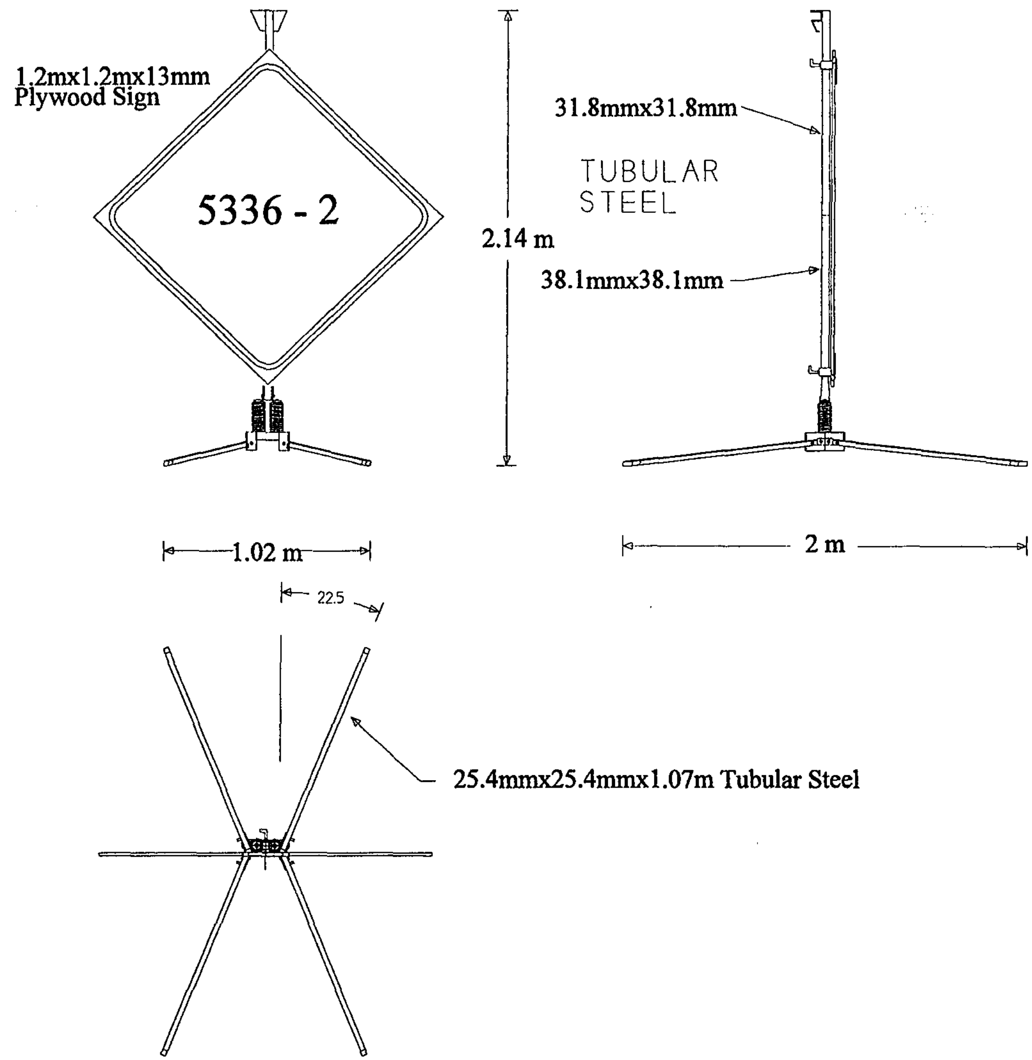


Figure 17. Schematic of Spring Mounted Sign Support with Wooden Sign Panel (Test No. 453360-2)

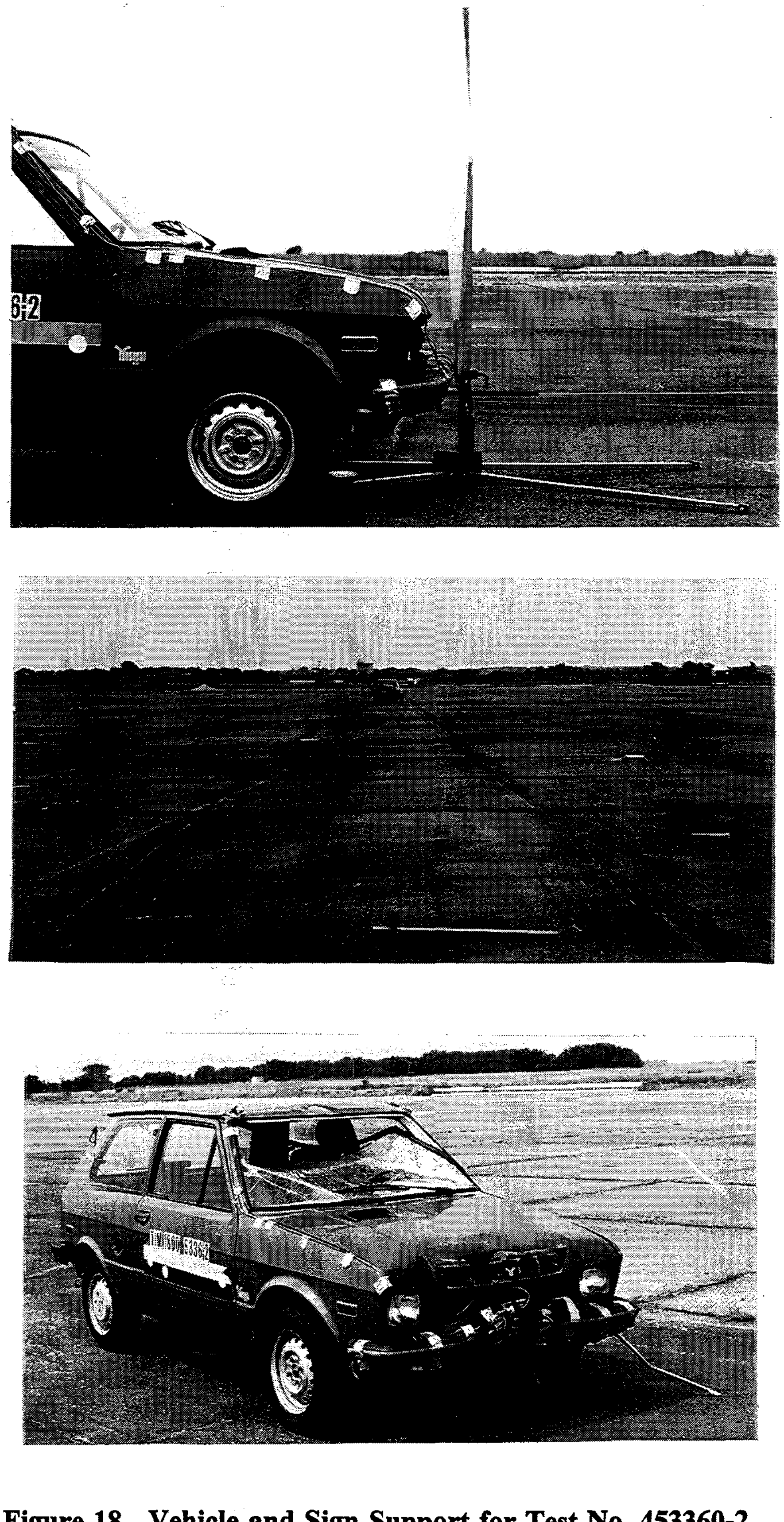
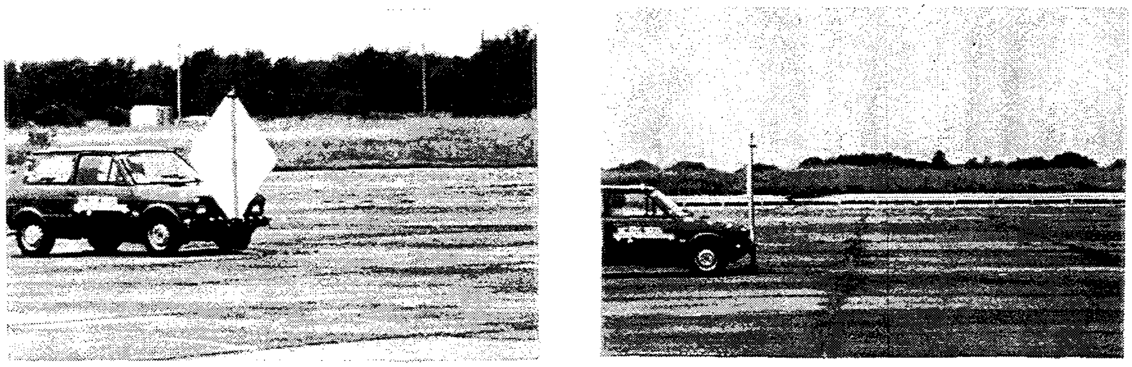


Figure 18. Vehicle and Sign Support for Test No. 453360-2



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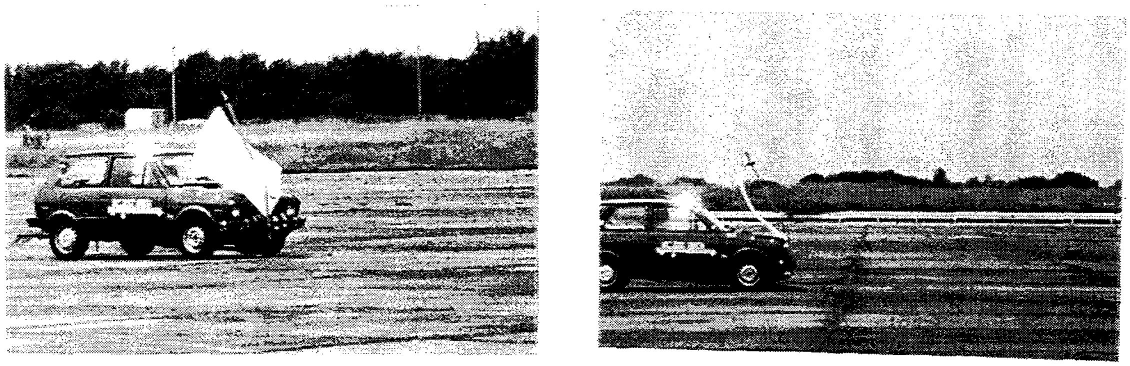

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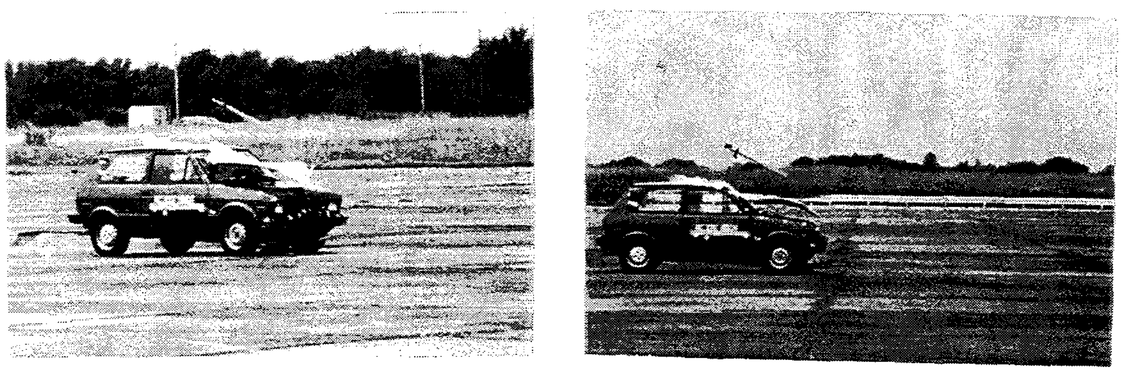

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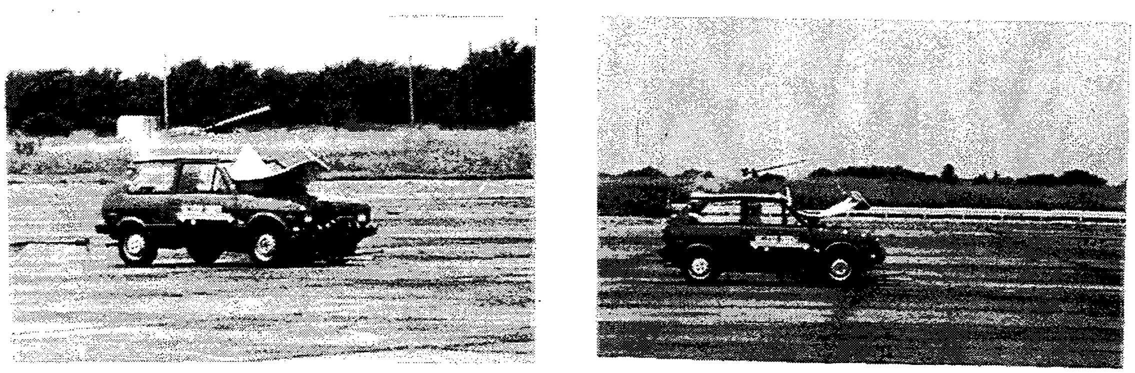

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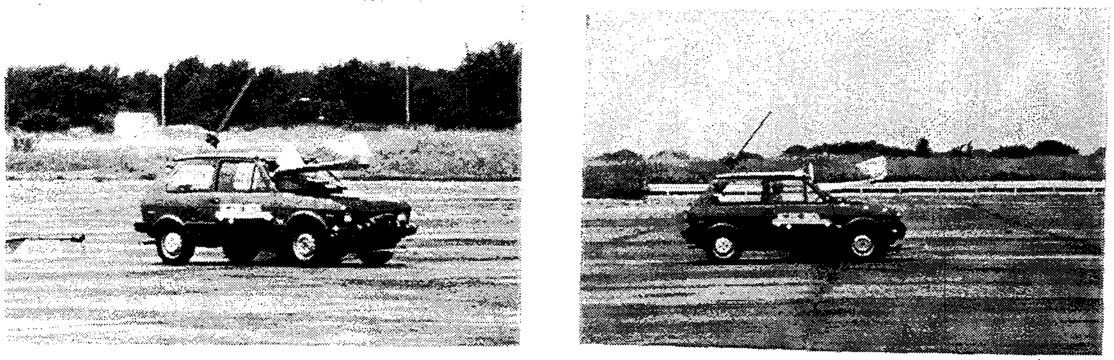
Figure 19. Sequential Photographs for Test No. 453360-2



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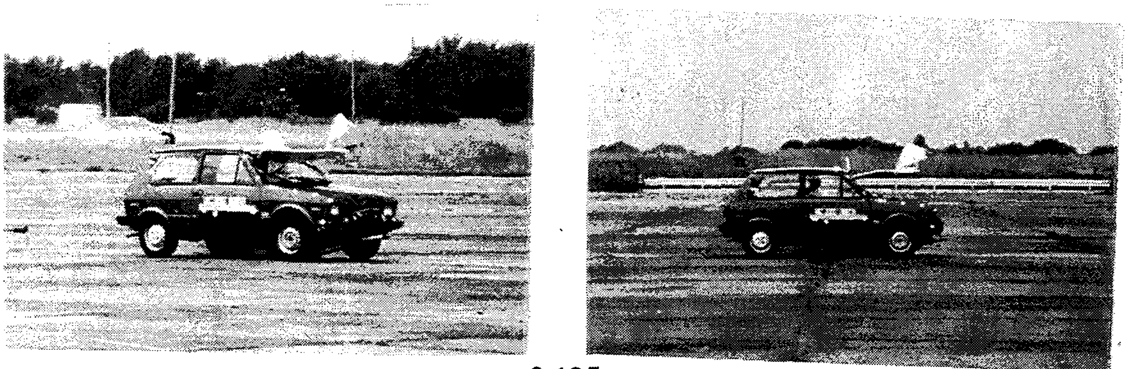
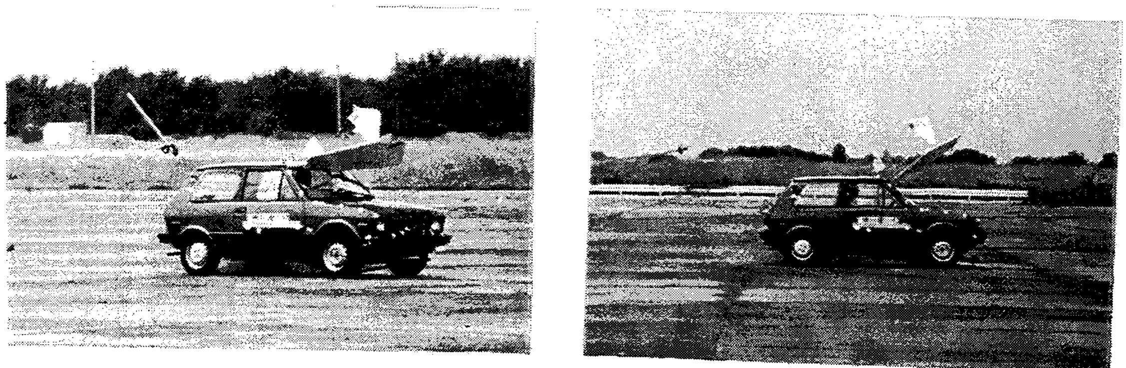


0.125 s



0.160 s

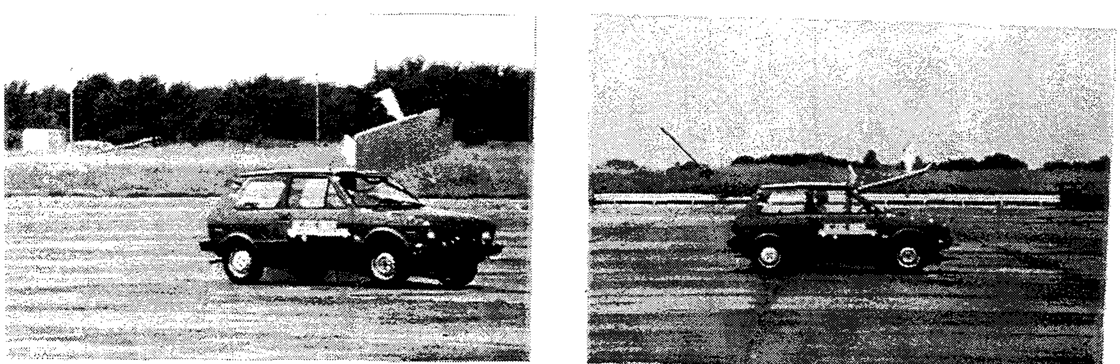


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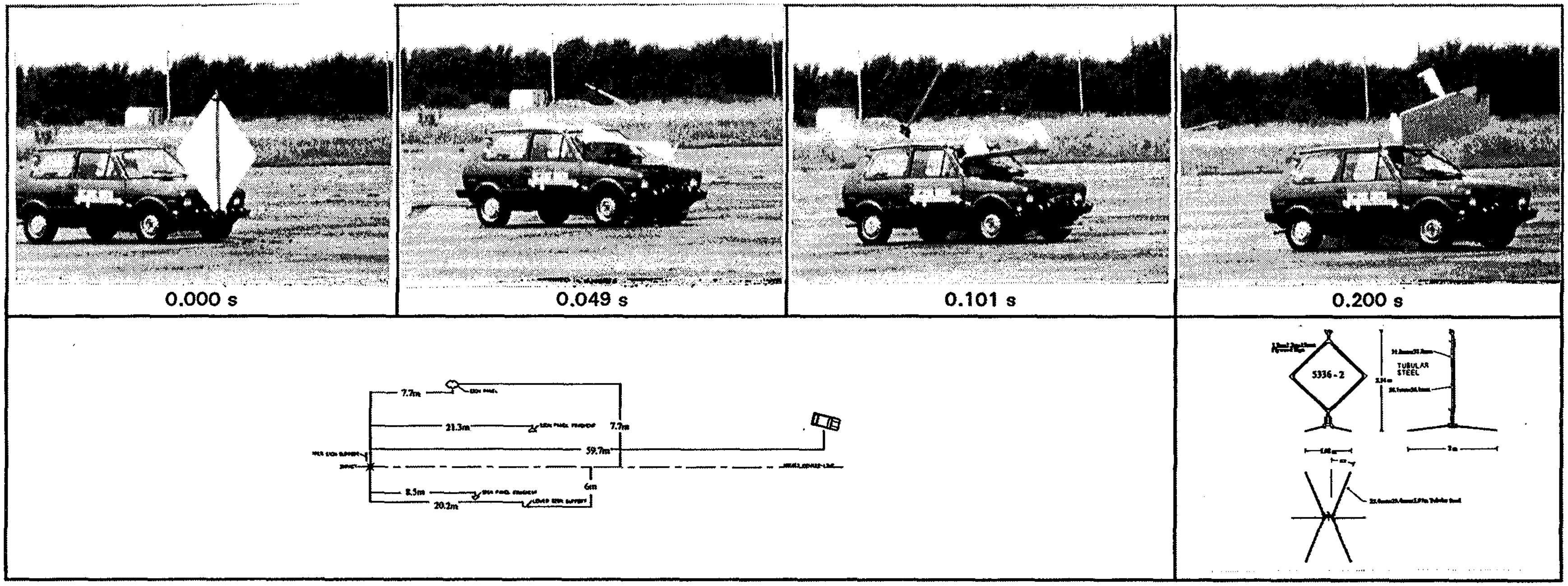
Figure 19. Sequential Photographs for Test No. 453360-2 (continued)



General Information	
Test Agency	Texas Transportation Institute
Test No.	5336-2
Date	08/19/92
Test Article	
Type	Traffic Control Device
. . . .	Spring-mounted Sign Support
Installation Length (ft) . .	6.5 (2.0 m)
Size and/or dimension and material of key elements	7.0 (2.1 m) high Tubular Steel
Soil Type and Condition . . .	N/A
Test Vehicle	
Type	Production Model
Designation	820 C
Model	1988 Yugo GV
Mass (lb) Curb	1,809 (821 kg)
Test Inertial .	1,800 (817 kg)
Dummy	168 (76 kg)
Gross Static .	1,968 (893 kg)

Impact Conditions	
Speed (mi/h)	60.3 (97.0 km/h)
Angle (deg)	0
Exit Conditions	
Speed (mi/h)	56.8 (91.4 km/h)
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (ft/s)	
x-direction	5.5 (1.7 m/s)
y-direction	No contact
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-1.5
y-direction	N/A
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Averages (g's)	
x-direction	-1.3
y-direction	0.6
z-direction	1.7

Test Article Deflections (ft)	
Dyanmic	Broke apart
Permanent.	Broke apart
Vehicle Damage	
Exterior	
VDS	12FD1
CDC	12FDEK1 &12FDGW6
Interior	
OCDI.	FS0000000
Maximum Exterior Vehicle Crush (in). . .	3.5 (8.9 cm)
Max. Occ. Compart. Deformation (in) . . .	Broken windshield
Post-Impact Behavior	
Max. Roll Angle (deg). .	-1.4
Max. Pitch Angle (deg) .	-2.0
Max. Yaw Angle (deg) .	0.4

Figure 20. Summary of Results for Test No. 453360-2

3.2.2 Spring-Mounted Sign Support with Plastic/Fabric Sign Panel (Test No. 453580-1)

Figure 21 shows a schematic of the spring-mounted portable sign support with a 1219 mm x 1219 mm plastic/fabric sign mounted at a height of 305 mm. The test vehicle was a 1987 Yugo GV, as shown in Figure 22. Dimensions and information on the vehicle are given in Appendix Figure 93. The test vehicle impacted the sign support head-on with the centerline of the vehicle aligned with the centerline of the sign support, traveling at a speed of 99.0 km/h.

Upon impact, the plastic/fabric sign panel and the upper support arm began to deform on the hood. At 20 msec after impact, the upper support arm separated from the lower support arm, and the upper corner of the sign panel released. The lower corner of the sign panel released at 39 msec. The upper support arm and sign panel flipped up and contacted the roof of the vehicle at 98 msec. The support and panel lost contact at 119 msec, as the vehicle was traveling at a speed of 93.6 km/h. The support base hung up on the undercarriage of the vehicle and rode along with the vehicle. After the vehicle cleared the immediate test site, brakes on the vehicle were applied at 500 msec after impact. Prior to brake application, the test vehicle was traveling on a relatively straightforward path. The vehicle subsequently came to rest 58 m down and 3 m to the west of the point of impact. The base support continued forward another 15 m after the vehicle had stopped. Figure 23 shows sequential photographs of the test period.

The spring-mounted portable sign support separated upon impact, as can be seen in Figure 22. Debris were strewn along the path of the vehicle in an area 3 m wide by 73 m long. Figure 22 shows damage to the vehicle. There was a maximum crush in the bumper of 70 mm from impact with the support. There was a 32 mm deep dent in the roof toward the rear, the windshield received a small chip, and the hood, bumper, and grill were dented and scratched.

A brief summary of the results of this test is presented in Figure 24. The plastic/fabric sign panel and upper support arm of the spring-mounted portable sign support separated and went up and over the vehicle, contacting the roof, but did not show potential risk of intrusion into the passenger compartment. Debris from the sign support remained along the path of the vehicle posing only minor potential hazard to other traffic or workers. The vehicle sustained damage to the front bumper, hood, windshield and roof. The longitudinal occupant impact velocity was 2.2 m/s, and the highest 10-msec average ridedown acceleration was -1.1 g. There was no occupant contact in the lateral direction during the test period. The maximum 50-msec average accelerations were -1.4 g in the longitudinal direction and -0.3 g in the lateral direction. The vehicle exited the immediate test site in a relatively smooth, stable manner and showed no potential for intrusion into adjacent traffic lanes.

In summary, the spring-mounted portable sign support with plastic/fabric sign panel was judged to have met all evaluation criteria set forth in NCHRP Report 350.

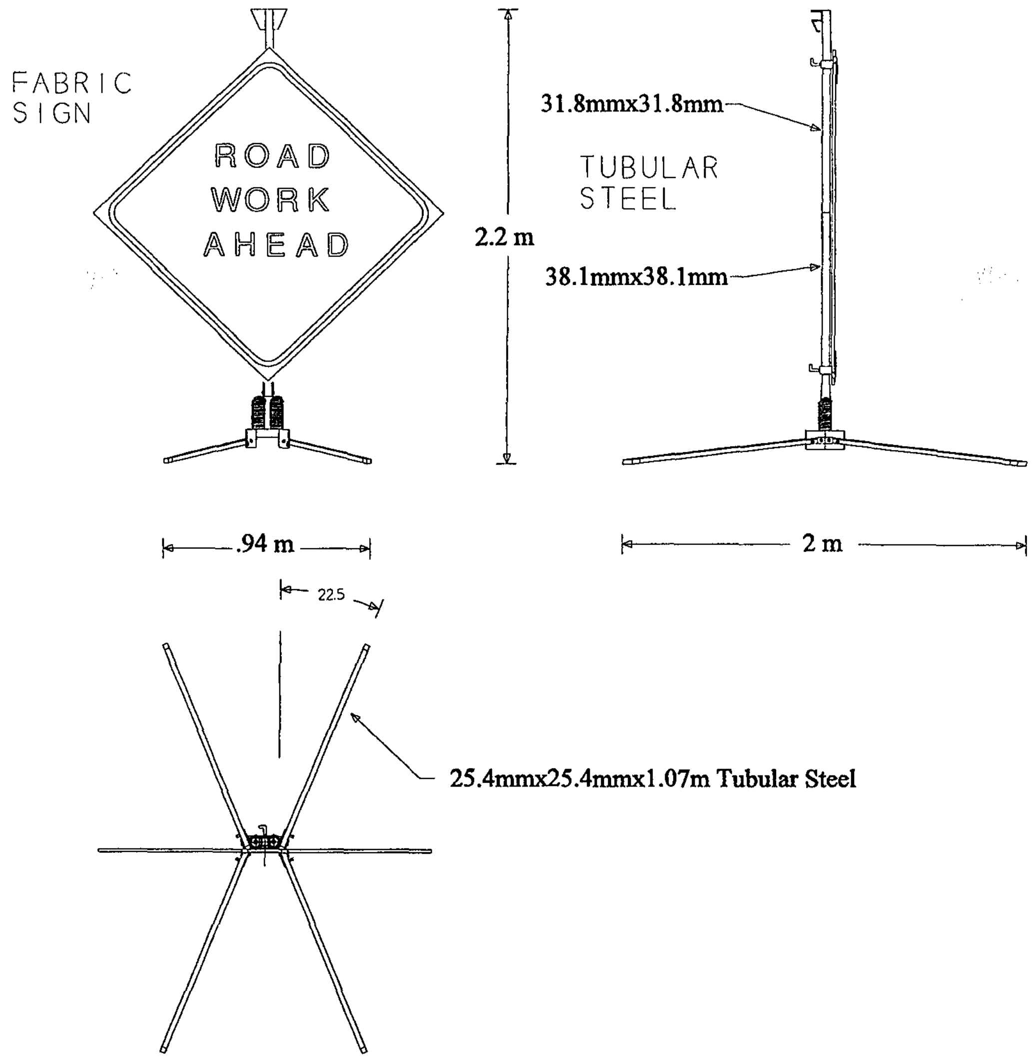
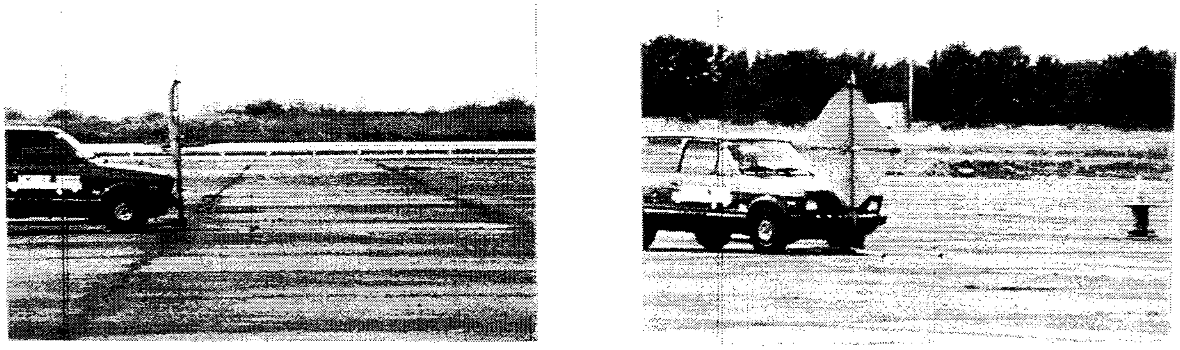


Figure 21. Schematic of Spring Mounted Sign Support with Plastic/Fabric Sign (Test No. 453580-1)

Figure 22. Vehicle and Sign Support for Test No. 453580-1



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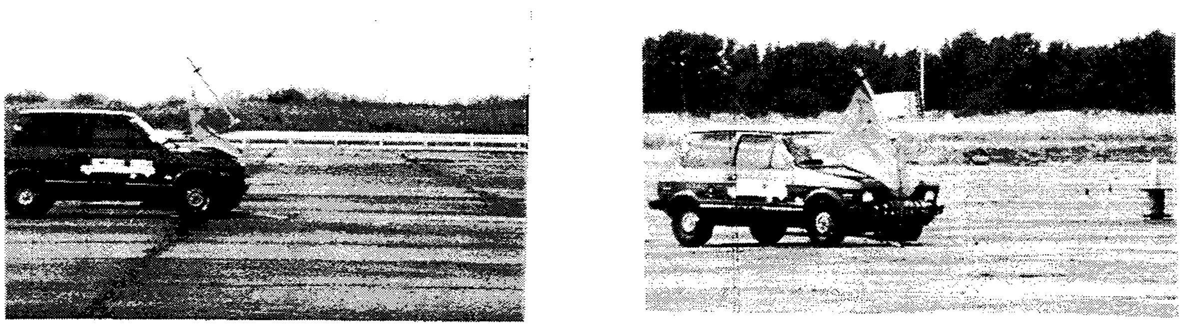

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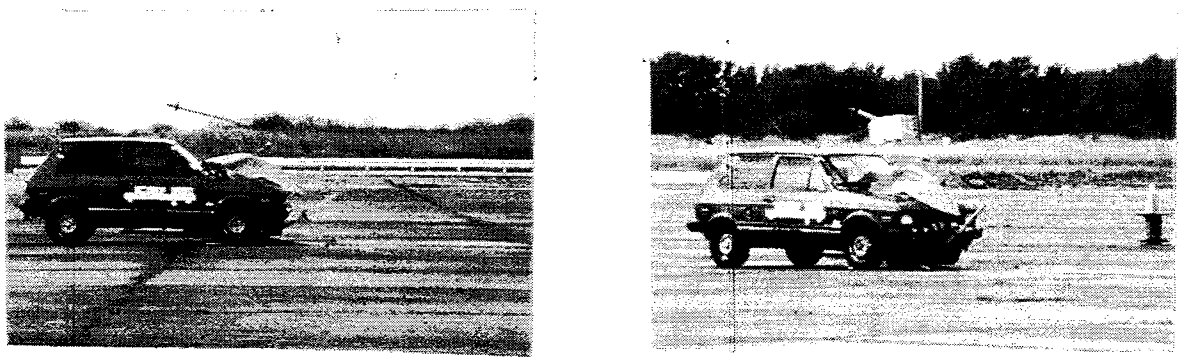

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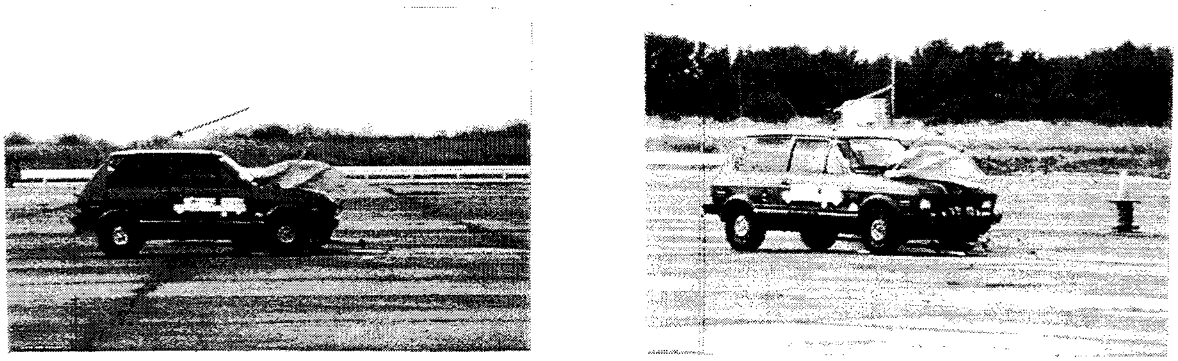

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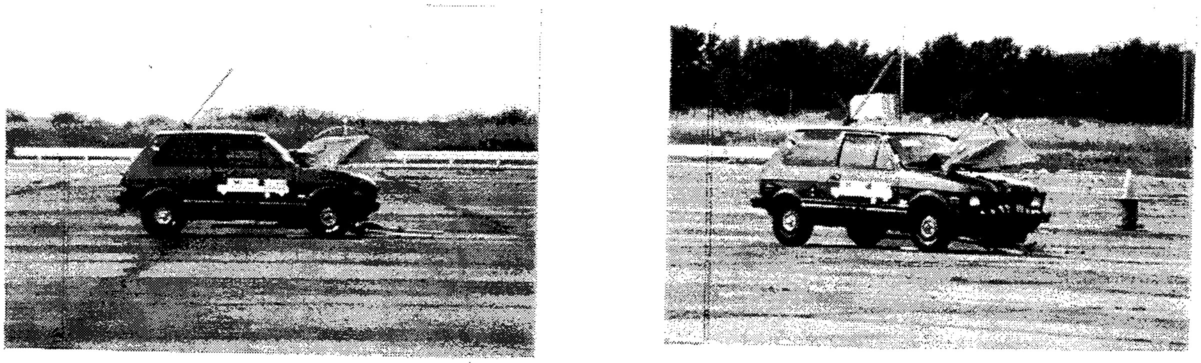
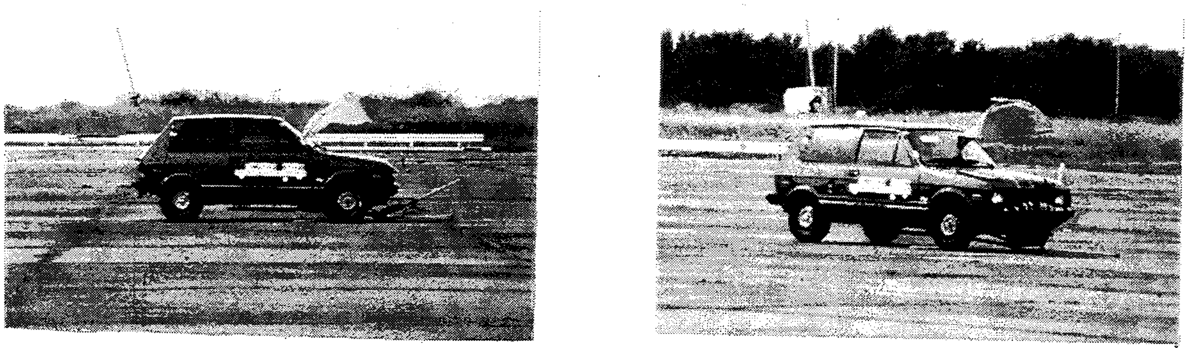
Figure 23. Sequential Photographs for Test No. 453580-1



0.100 s



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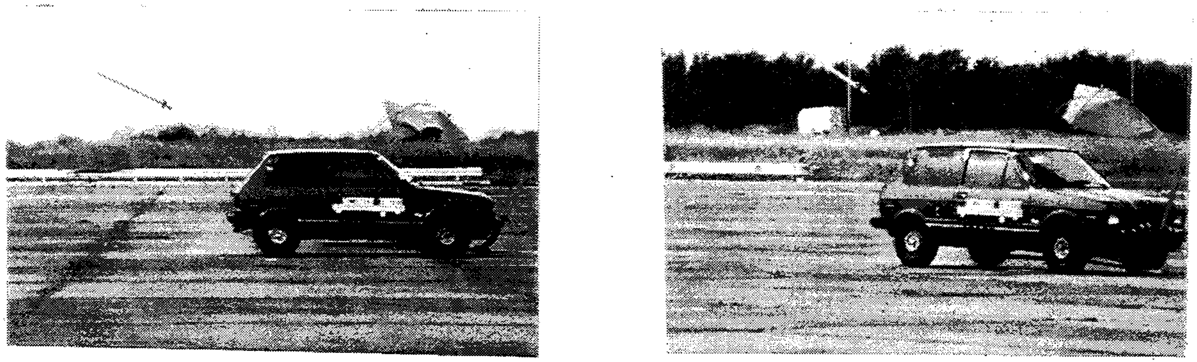

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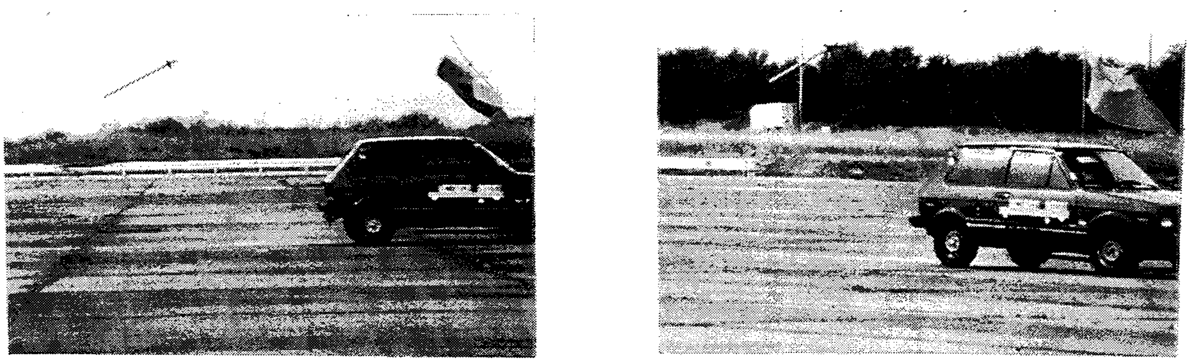
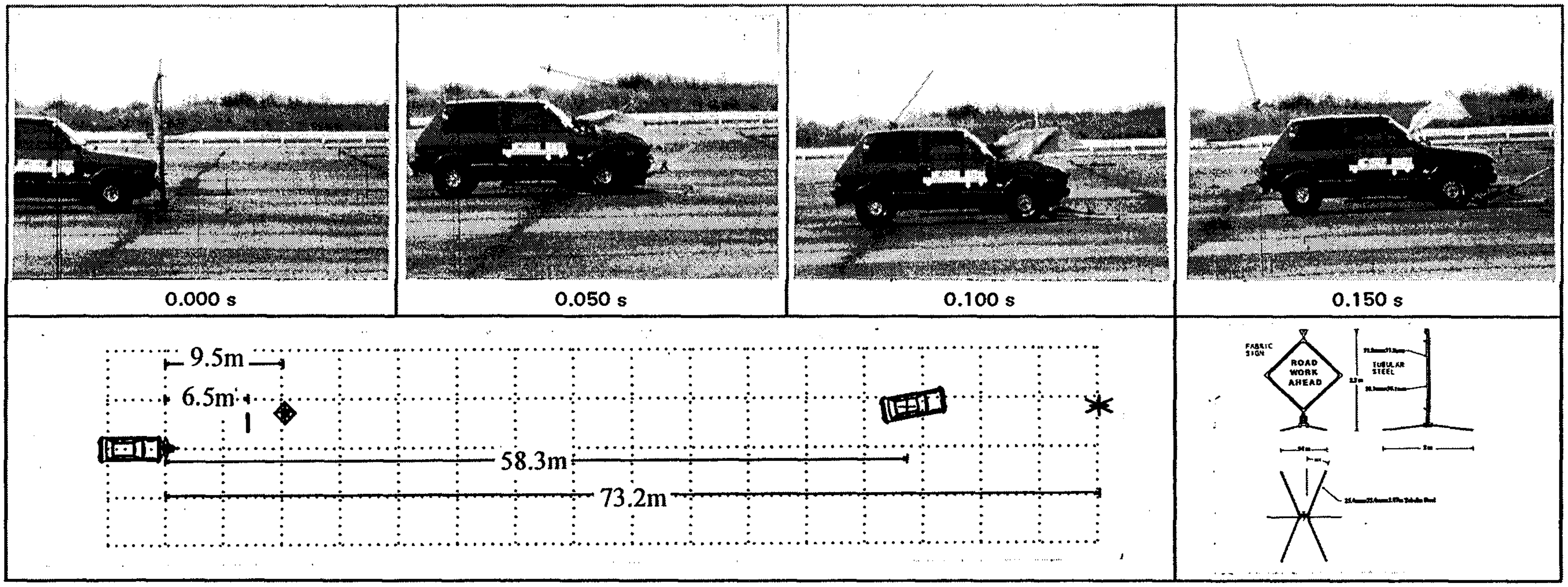


0.250 s

Figure 23. Sequential Photographs for Test No. 453580-1 (continued)



General Information	
Test Agency	Texas Transportation Institute
Test No.	53580-1
Date	02/17/93
Test Article	
Type	Traffic Control Device
	Spring-mounted Sign Support
Installation Length (ft)	6.5 (2.0 m)
Size and/or dimension and material of key elements	7.25 (2.2 m) high Tubular Steel
Soil Type and Condition	N/A
Test Vehicle	
Type	Production Model
Designation	820 C
Model	1987 Yugo GV
Mass (lb) Curb	1,806 (820 kg)
Test Inertial	1,806 (820 kg)
Dummy	159 (72 kg)
Gross Static	1,965 (892 kg)

Impact Conditions	
Speed (mi/h)	61.5 (99.0 km/h)
Angle (deg)	0
Exit Conditions	
Speed (mi/h)	58.2 (93.6 km/h)
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (ft/s)	
x-direction	7.2 (2.2 m/s)
y-direction	No contact
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-1.1
y-direction	N/A
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Averages (g's)	
x-direction	-1.4
y-direction	-0.3
z-direction	-0.9

Test Article Deflections (ft)	
Dyanmic	Broke apart
Permanent	Broke apart
Vehicle Damage	
Exterior	
VDS	12FC1
CDC	12FCEN1
Interior	
OCDI	FS0000000
Maximum Exterior Vehicle Crush (in)	2.8 (7.0 cm)
Max. Occ. Compart. Deformation (in)	0.0
Post-Impact Behavior	
Max. Roll Angle (deg)	-0.7
Max. Pitch Angle (deg)	0.1
Max. Yaw Angle (deg)	-1.5

Figure 24. Summary of Results for Test No. 453580-1

3.2.3 Easel Sign Support with Plastic/Fabric Sign (Test No. 453580-2)

Figure 25 shows a schematic of the easel portable sign support with a 1219 mm x 1219 mm plastic/fabric sign mounted at a height of 305 mm. The test vehicle was a 1987 Yugo GV, as shown in Figure 26. Appendix 93 gives dimensions and information on the vehicle. The test vehicle impacted the sign support head-on with the centerline of the vehicle aligned with the centerline of the sign support, traveling at a speed of 98.8 km/h.

Upon impact, the front legs of the support bent at bumper height. At 17 msec, the top of the sign panel released from the top of the support. The easel support flipped up and the top of the support contacted and penetrated the windshield at 60 msec. At 251 msec, the easel support lost contact with the vehicle and windshield. Speed of the vehicle at loss of contact was 95.1 km/h. After the vehicle cleared the immediate test site, brakes on the vehicle were applied at 1.3 seconds after impact. Prior to brake application, the test vehicle was traveling on a relatively straightforward path. The vehicle subsequently came to rest 71 m down and 3 m to the left of the point of impact. Sequential photographs of the test period are shown in Figure 27.

As Figure 26 shows, the sign panel of the easel sign support released, and the support came apart upon impact. Debris were strewn along the path of the vehicle in an area 4 m wide by 32 m long. Figure 26 shows damage to the vehicle. There was no measurable crush to the exterior of the vehicle. There was a small hole in the windshield caused by penetration of the top of the easel support and a small dent in the hood.

Figure 28 shows a brief summary of the results of this test. The sign panel, upon release from the support, went up and contacted the windshield and then went over the top of the vehicle. The easel support rotated upon impact, and the top of the easel support impacted and penetrated the windshield, exhibiting potential risk of intrusion into the occupant compartment. Debris from the sign support remained along the path of the vehicle, posing only minor potential hazard to other traffic or workers in the area. Other than the penetration of the windshield by the top of the easel support, there was little damage to the vehicle. There was no occupant contact in the longitudinal or lateral direction during the test period. The maximum 50-msec average accelerations were -0.7 g in the longitudinal direction and -0.1 g in the lateral direction. The vehicle exited the immediate test site in a relatively smooth, stable manner and showed minimal intrusion into adjacent traffic lanes.

In summary, the easel portable sign support failed to meet the evaluation criteria set forth in NCHRP Report 350 and is not recommended for further field use.

3.2.4 Portable Sign Support with Plastic/Fabric Sign (Test No. 453790-1)

Figure 29 shows a schematic of the portable sign support with a 1219 mm x 1219 mm plastic/fabric sign mounted at a height of 305 mm. The test vehicle was a 1988 Chevrolet Sprint, as shown in Figure 30. Appendix Figure 94 gives dimensions and information on the vehicle. The test vehicle impacted the sign support head-on with the centerline of the vehicle aligned with the centerline of the sign support, traveling at a speed of 97.9 km/h.

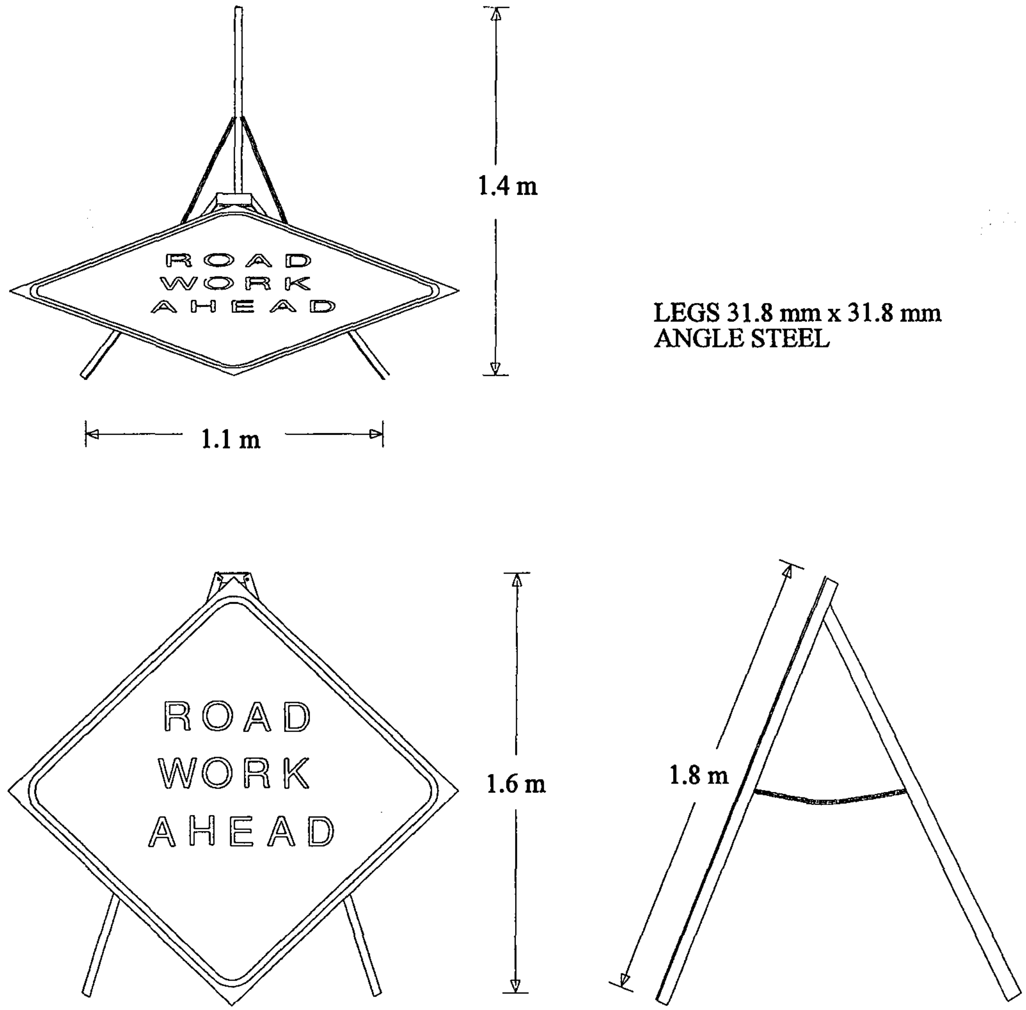


Figure 25. Schematic of Easel Sign Support with Plastic/Fabric Sign (Test No. 453580-2)

Figure 26. Vehicle and Sign Support for Test No. 453580-2

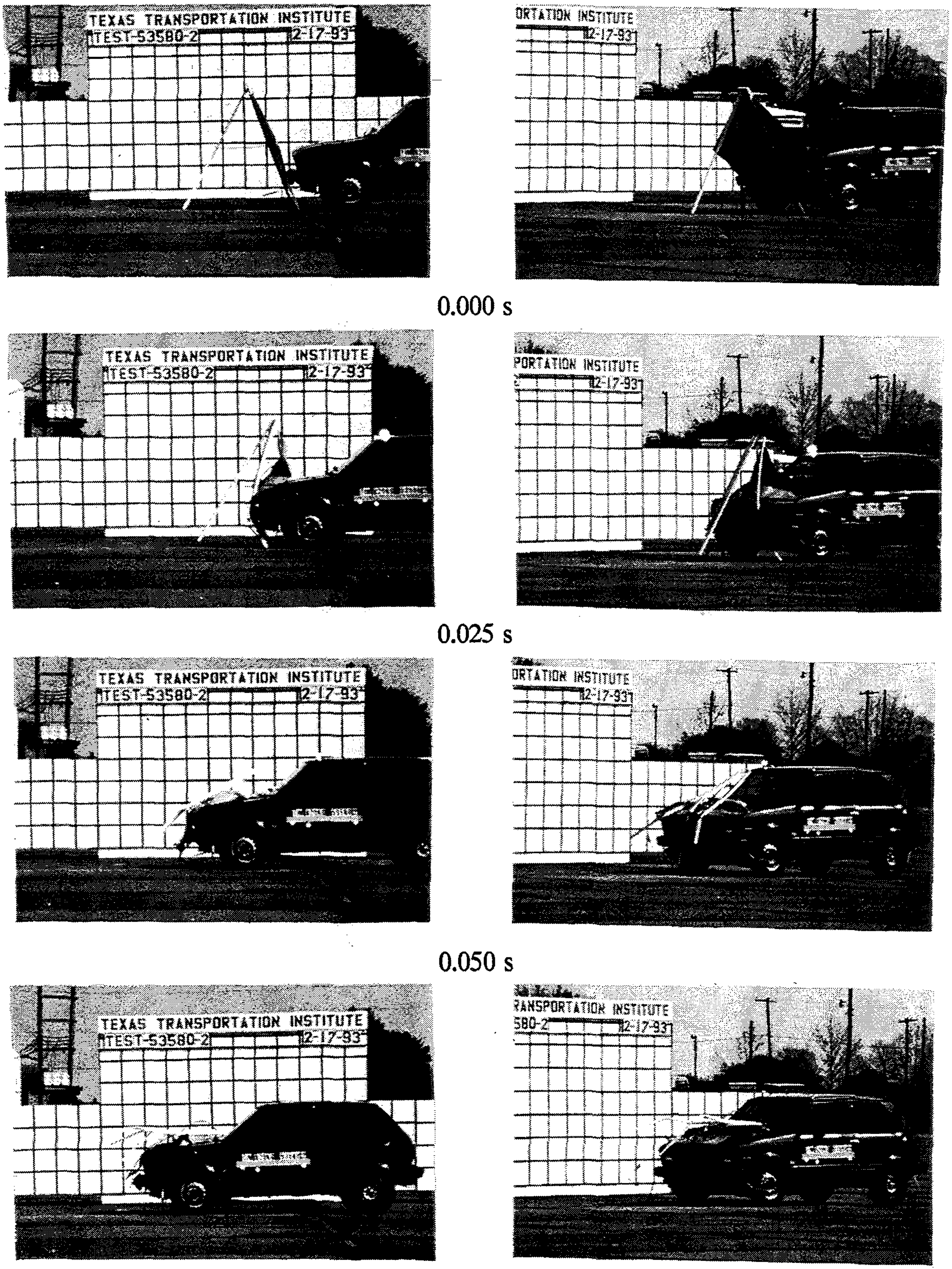
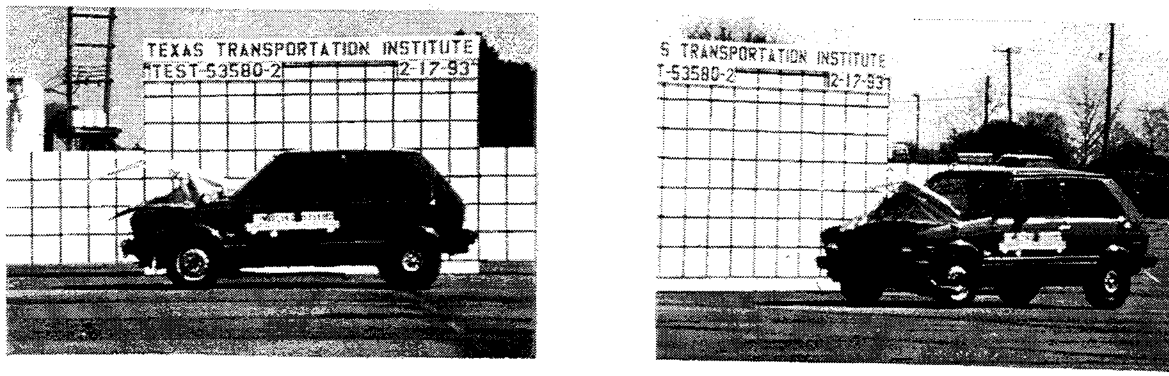


Figure 27. Sequential Photographs for Test No. 453580-2



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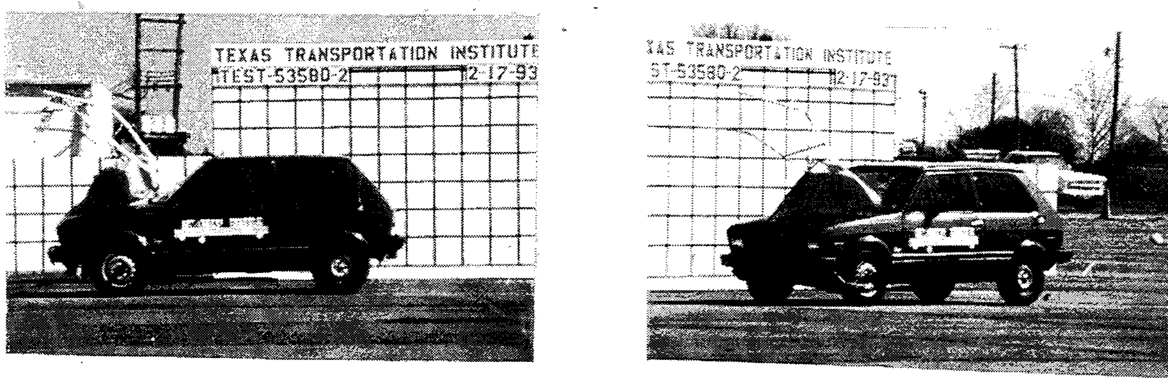

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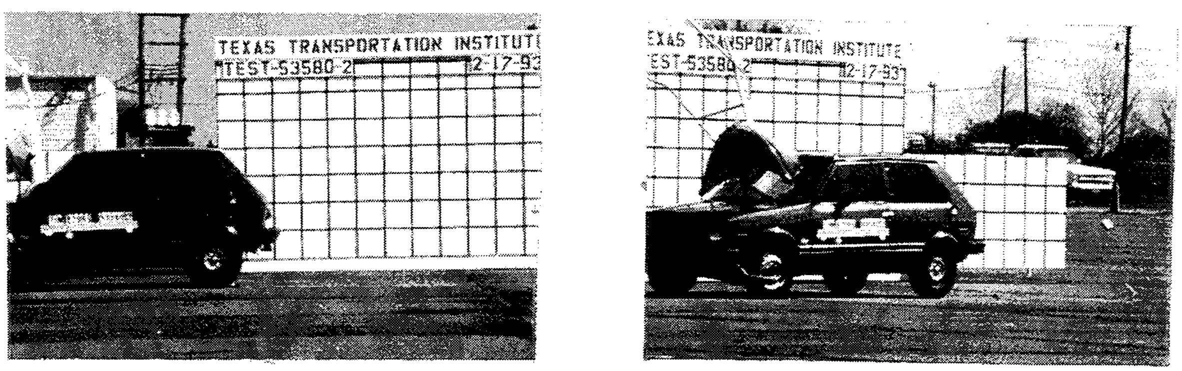
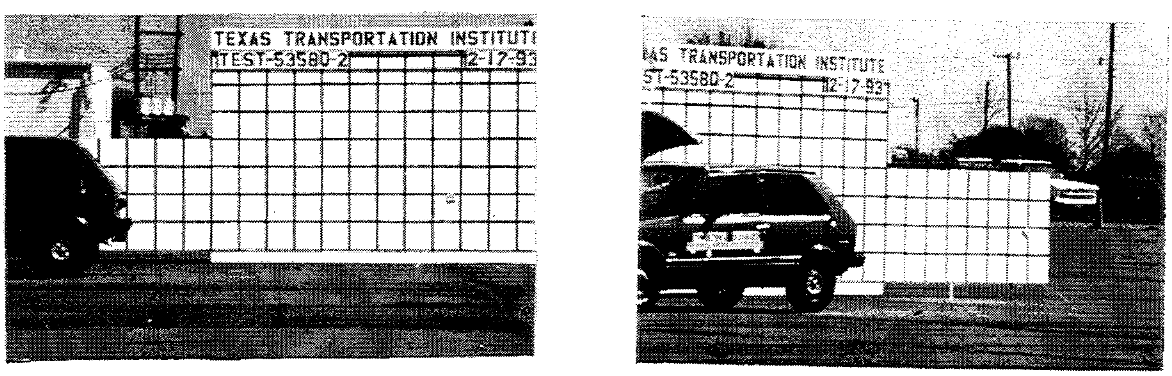
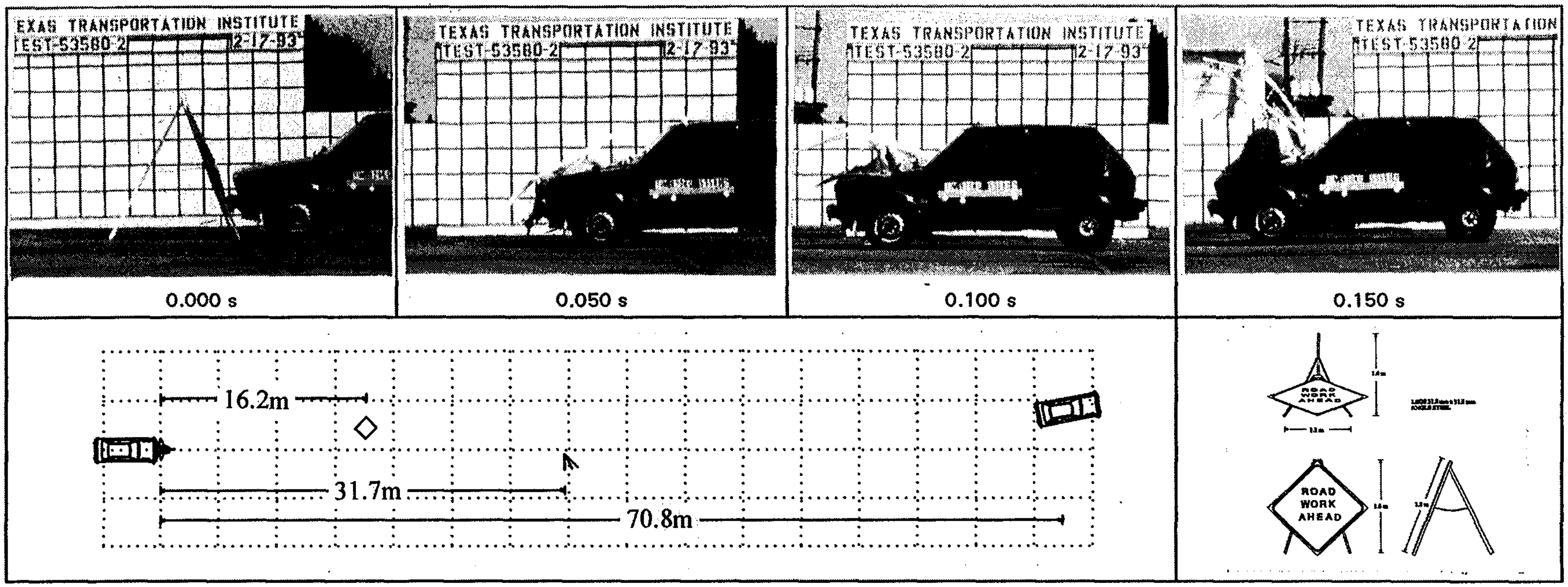


0.200 s



0.250 s

Figure 27. Sequential Photographs for Test No. 453580-2 (continued)



General Information	
Test Agency	Texas Transportation Institute
Test No.	53580-2
Date	02/17/93
Test Article	
Type	Traffic Control Device
	Easel Sign Support
Installation Length (ft)	4.7 (1.4 m)
Size and/or dimension and material of key elements	5.25 (1.6 m) high 1-1/4 in Steel Angle
Soil Type and Condition	N/A
Test Vehicle	
Type	Production Model
Designation	820 C
Model	1987 Yugo GV
Mass (lb) Curb	1,806 (820 kg)
Test Inertial	1,806 (820 kg)
Dummy	159 (72 kg)
Gross Static	1,965 (892 kg)

Impact Conditions	
Speed (mi/h)	61.4 (98.8 km/h)
Angle (deg)	0
Exit Conditions	
Speed (mi/h)	59.1 (95.1 km/h)
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (ft/s)	
x-direction	No contact
y-direction	No contact
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	N/A
y-direction	N/A
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Averages (g's)	
x-direction	-0.7
y-direction	-0.1
z-direction	-0.2

Test Article Deflections (ft)	
Dyanmic	Broke apart
Permanent	Broke apart
Vehicle Damage	
Exterior	
VDS	12FC1
CDC	12FCEN1 & 12FCGN6
Interior	
OCDI	FS0000000
Maximum Exterior Vehicle Crush (in)	0.2 (0.5 cm)
Max. Occ. Compart. Deformation (in)	Broke windshield
Post-Impact Behavior	
Max. Roll Angle (deg)	-0.7
Max. Pitch Angle (deg)	0.5
Max. Yaw Angle (deg)	0.6

Figure 28. Summary of Results for Test No. 453580-2

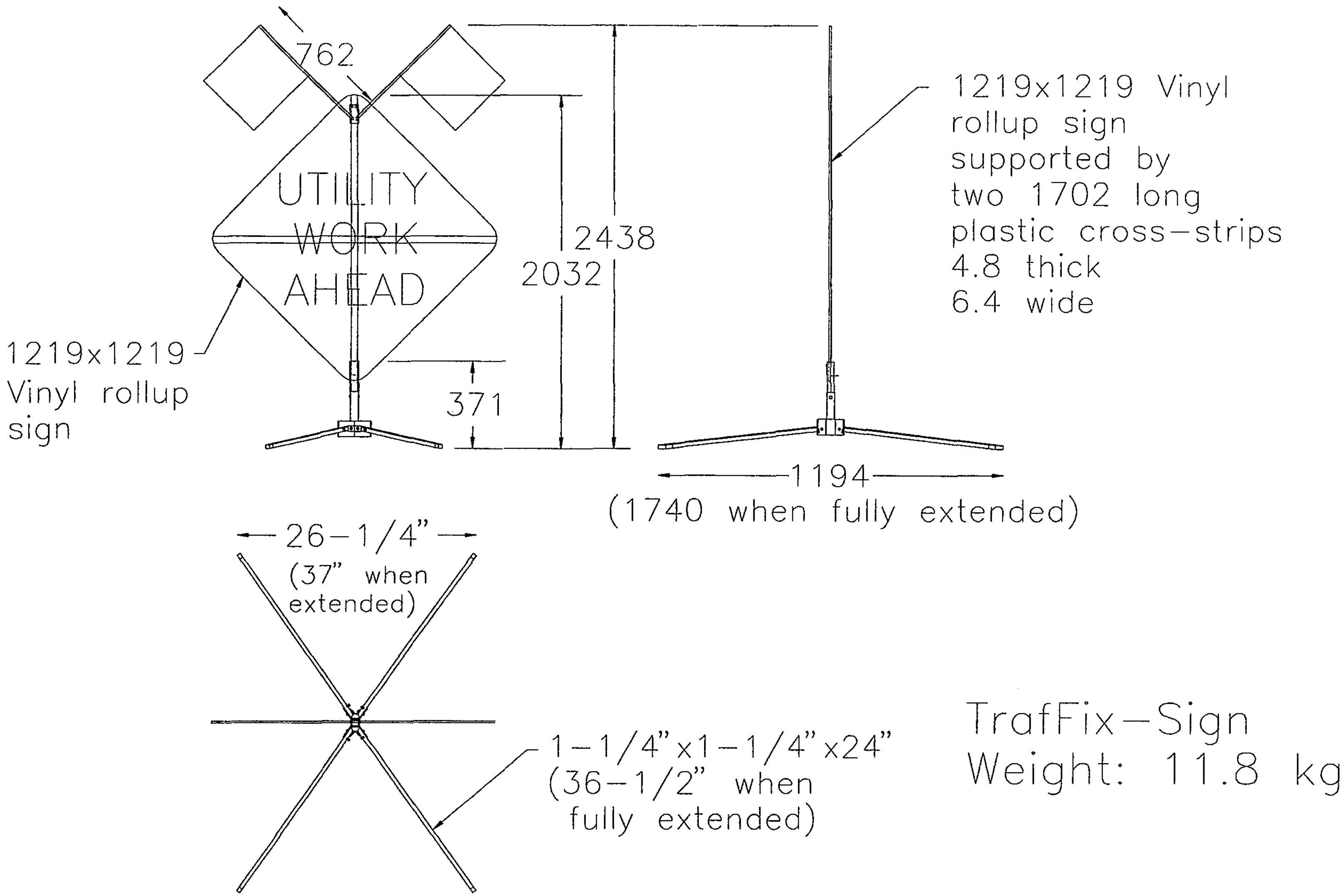


Figure 29. Schematic of Portable Sign Support with Plastic/Fabric Sign (Test No. 453790-1)

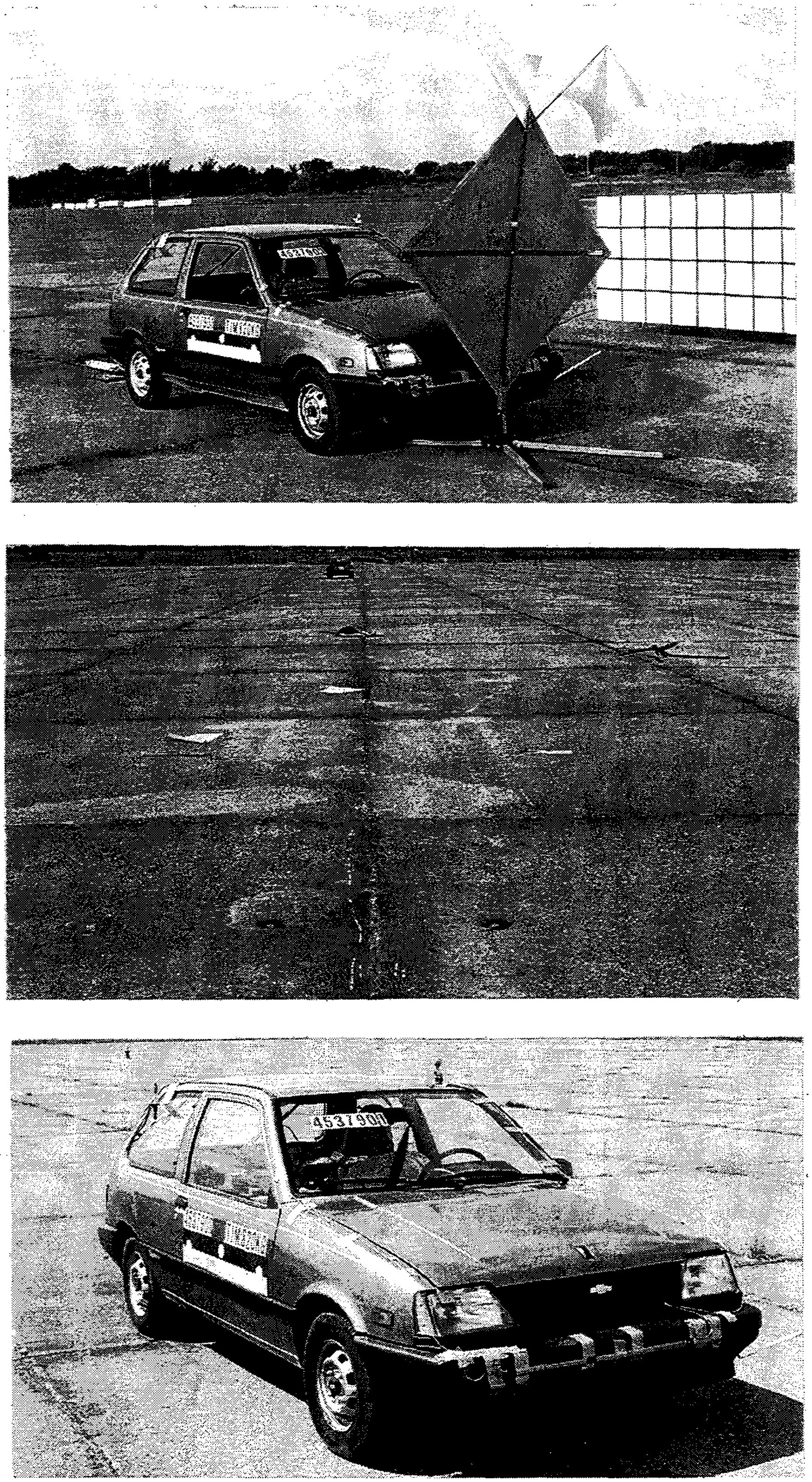


Figure 30. Vehicle and Sign Support for Test No. 453790-1

As the vehicle impacted the portable sign support, the upper portion of the sign separated from the base, and the plastic/fabric sign panel formed to the front of the vehicle. The plastic/fabric sign panel and reinforcement strips contacted the windshield at 50 msec and 69 msec, respectively. At 100 msec, the flags contacted the roof of the vehicle and separated from the sign panel. At 221 msec, the vehicle cleared the installation site traveling at a speed of 95.8 km/h. Prior to brake application, the vehicle was tracking straightforward. The vehicle subsequently came to rest 102 m down and 1.7 m to the right of the point of impact. Figure 31 shows sequential photographs of the test period.

The portable sign support separated upon impact, as can be seen in Figure 30. Fragments of the sign were strewn along the path of the vehicle in an area 5.5 m wide by 19.3 m long. Figure 30 shows damage to the vehicle. There was no measurable crush to the exterior of the vehicle, only scratches on the hood and on the roof where the flags made contact.

Figure 32 presents a brief summary of the results of this test. The portable sign support shattered upon impact. Fragments of the plastic/fabric sign panel and the sign support made contact with the roof, but there was no penetration or intrusion into the occupant compartment. Debris from the sign was thrown along an area 5.5 m wide by 19.3 m long. The fragments were not large enough to pose potential hazard to oncoming traffic in adjacent lanes or to workers in the area. The vehicle sustained minor scratches to the hood and roof. There was no measurable crush to the exterior of the vehicle. There was no longitudinal or lateral occupant impact. The 50-msec average accelerations were -0.6 g in the longitudinal direction and -0.4 g in the lateral direction. The vehicle exited the immediate test site in a relatively smooth, stable manner and showed no potential for intrusion into adjacent traffic lanes.

In summary, the portable sign support with plastic/fabric sign panel was judged to have met all evaluation criteria set forth in NCHRP Report 350.

3.3 TRANSPORTABLE SIGN SUPPORT (Test No. 453580-3)

The General Services Division designed and fabricated a transportable sign support trailer for use in maintenance operations. The trailer allows the sign support to be transported from site to site and set up with minimal effort. Figure 33 shows a schematic of the GSD sign trailer with a 1219 mm x 1219 mm wooden sign panel mounted at a height of 1.52 m. The test vehicle was a 1987 Yugo GV, as shown in Figure 34. Appendix 93 gives dimensions and information on the vehicle. The test vehicle impacted the sign trailer head-on with the centerline of the vehicle aligned with the centerline of the trailer, traveling at a speed of 98.6 km/h.

At 12 msec after impact, the trailer wheels began to move. The sign panel support released from the trailer support at 53 msec. By 104 msec, the sign panel and support separated from the trailer. The sign panel and support went over the vehicle and made contact with the roof at 138 msec. Loss of contact with the sign panel and support occurred at 160 msec when the vehicle had slowed to 88.1 km/h. The trailer remained in contact with the front of the vehicle until brakes were applied at 3.0 seconds after impact. The vehicle subsequently came to rest 99

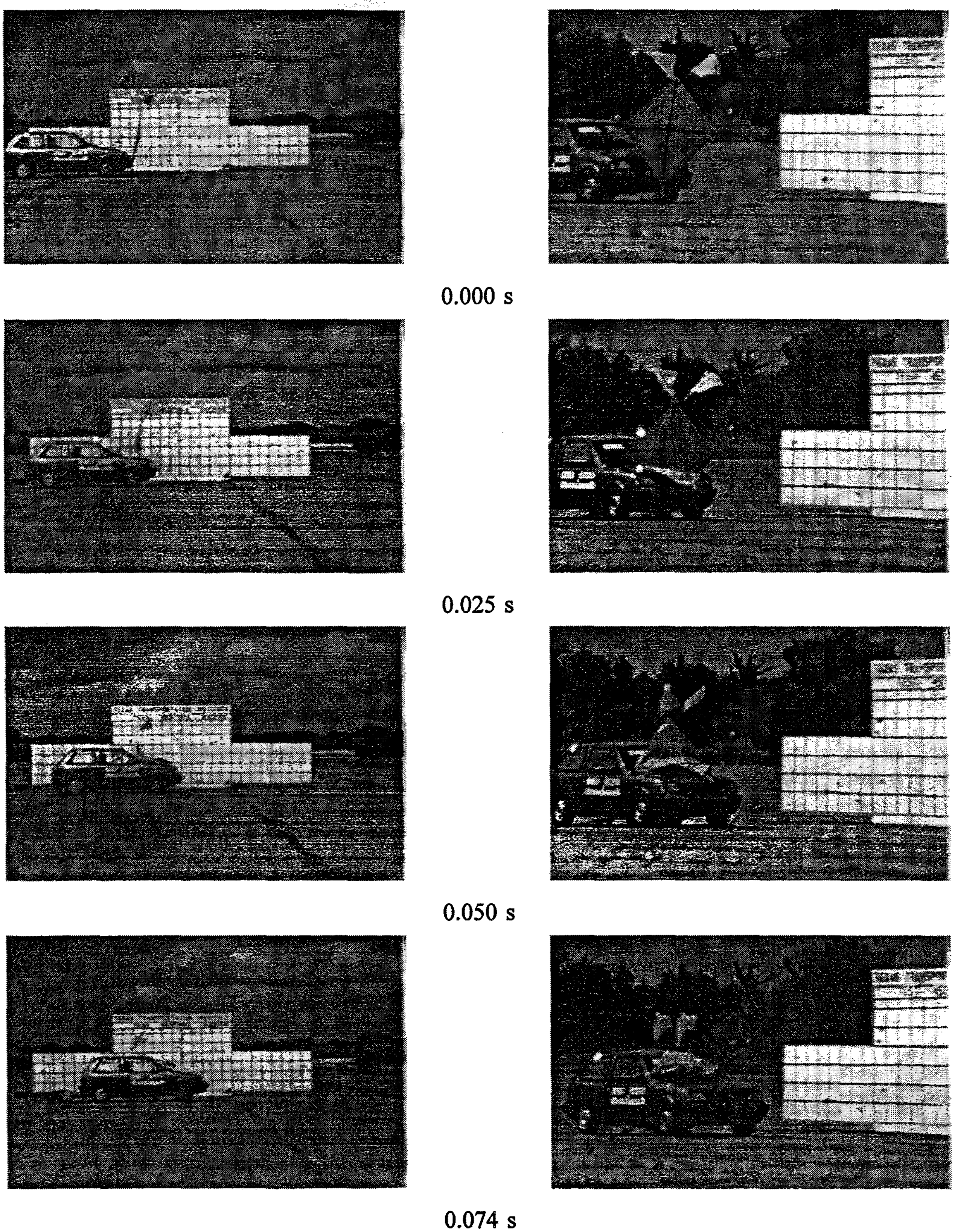
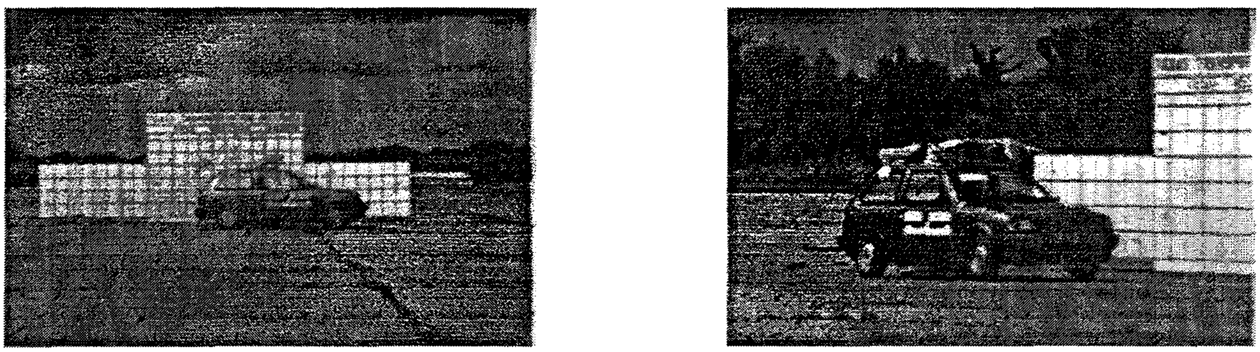
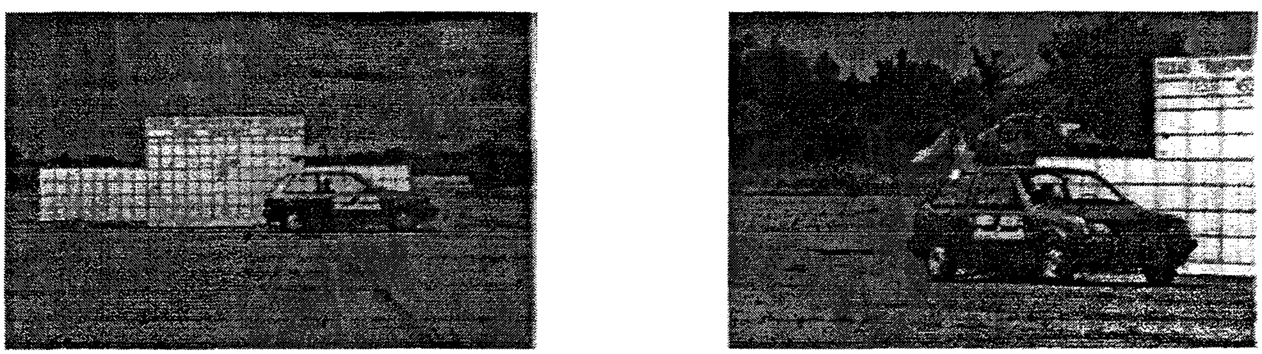


Figure 31. Sequential Photographs for Test No. 453790-1

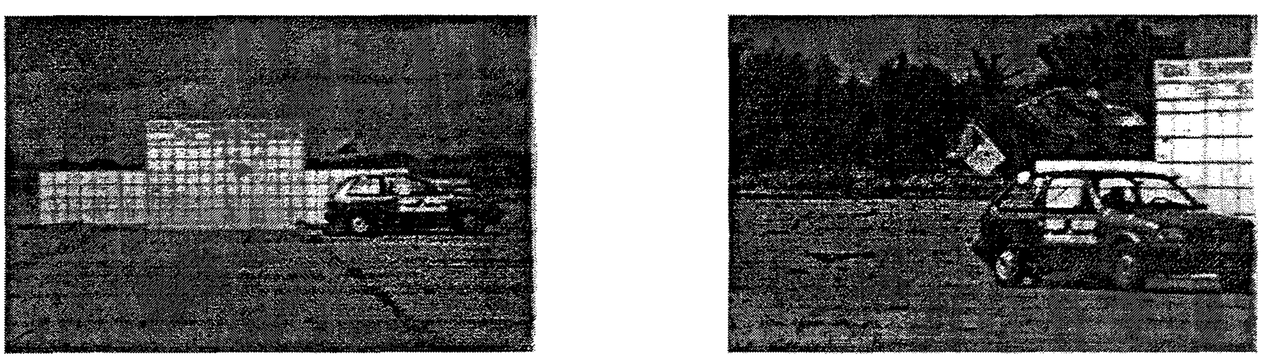
0.099 s



0.149 s

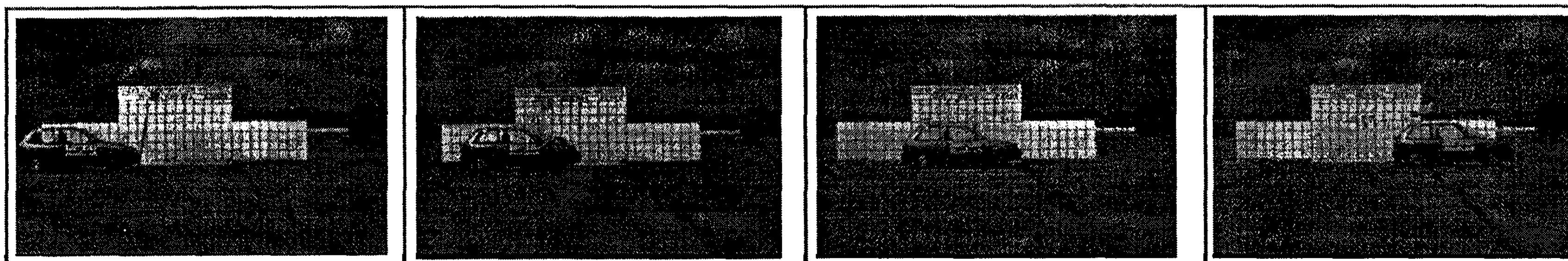


0.201 s

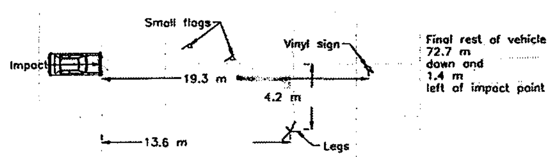


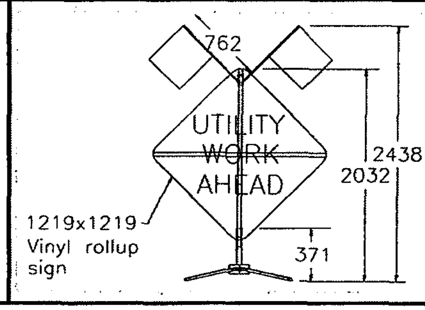
0.250 s

Figure 31. Sequential Photographs for Test No. 453790-1 (continued)



0.000 s	0.050 s	0.099 s	0.201 s





General Information	
Test Agency	Texas Transportation Institute
Test No.	453790-1
Date	08/23/94
Test Article	
Type	Portable Traffic Sign
Name or Manufacturer	TrafFix-Sign
Installation Lentth (m)	1.2 (4.0 ft)
Size and/or dimension and material of key elements	Aluminum base with Vinyl rollup sign
Soil Type and Condition	on Pavement, dry
Test Vehicle	
Type	Production
Designation	820C
Model	1988 Chevrolet Sprint
Mass (kg) Curb	719 (1584 lb)
Test Inertial	820 (1806 lb)
Dummy	75 (165 lb)
Gross Static	897 (1976 lb)

Impact Conditions	
Speed (km/h)	97.9 (60.9 mi/h)
Angle (deg)	0
Exit Conditions	
Speed (km/h)	95.8 (59.6 mi/h)
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	No Contact
y-direction	No Contact
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	No Contact
y-direction	No Contact
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Average (g's)	
x-direction	-0.6
y-direction	-0.4
z-direction	0.7

Test Article Deflections (m)	
Thrown Forward	19.3 (63.3 ft)
Thrown Laterally	4.2 (13.8 ft)
Vehicle Damage	
Exterior	
VDS	12FC1
CDC	12FCEN1
Interior	
OCDI	FS0000000
Maximum Exterior Vehicle Crush (mm)	Nil (scratched)
Max. Occ. Compart. Deformation (mm)	0 (0 in)
Post-Impact Behavior	
Max. Roll Angle (deg)	0.7
Max. Pitch Angle (deg)	1.1
Max. Yaw Angle (deg)	-1.9

Figure 32. Summary of Results for Test No. 453790-1

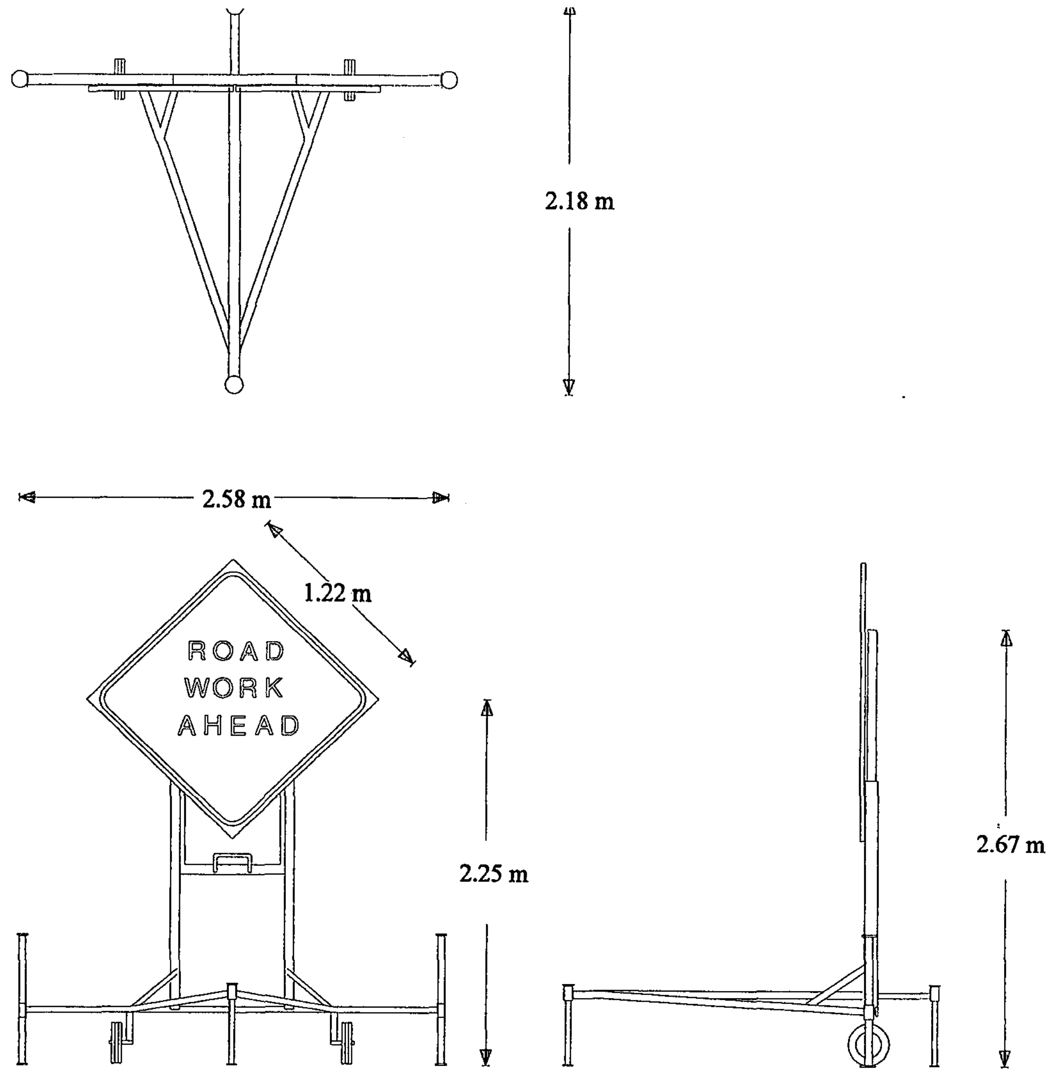


Figure 33. Schematic of D-4 Sign Trailer with Wooden Sign Panel (Test No. 453580-3)

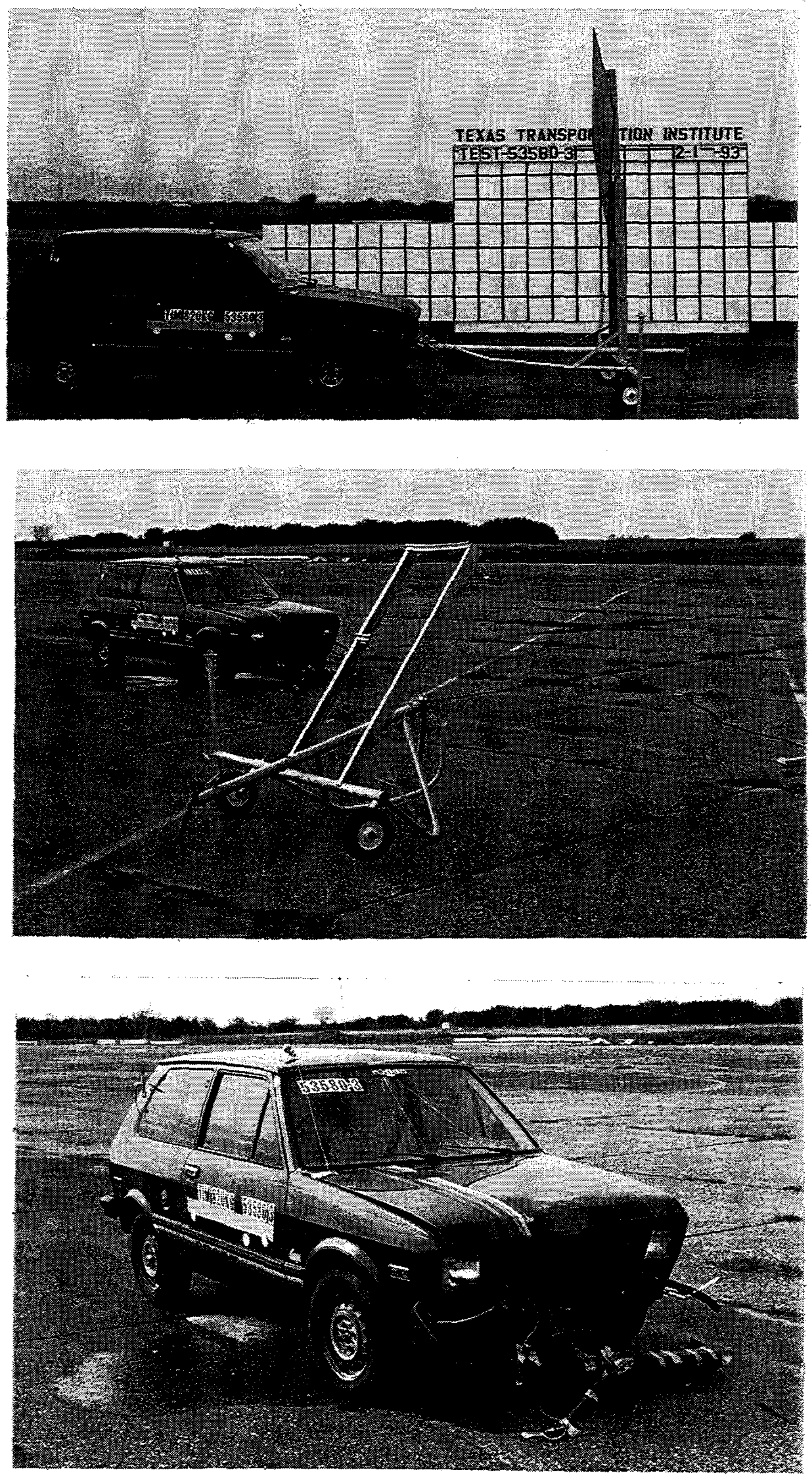


Figure 34. Vehicle and Sign Trailer for Test No. 453580-3

m down and 2 m to the west of the point of impact. The trailer continued another 7 m forward before coming to rest. Figure 35 shows sequential photographs of the test period.

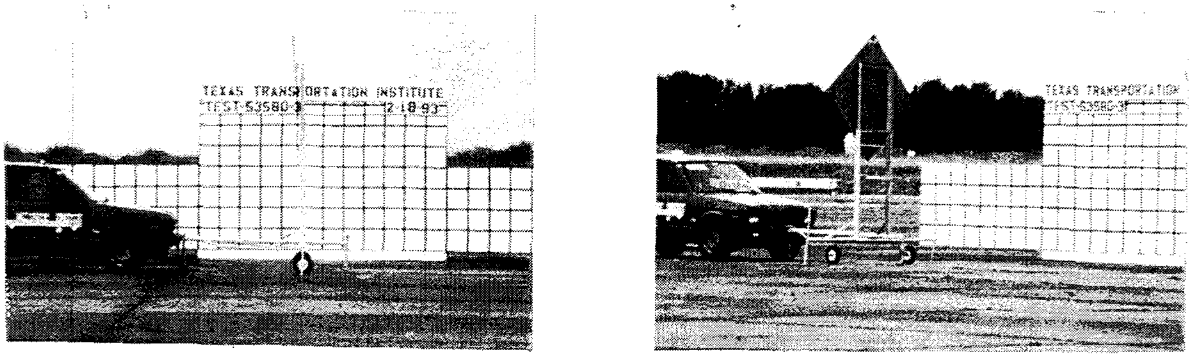
As Figure 34 shows, the sign panel and support separated from the trailer upon impact. The sign panel and upper support structure came to rest 2 m down and 4 m to the left side of the vehicle path. The sign support trailer came to rest 106 m down and 3 m to the right of the point of impact with a fragment 3.4 m west of the trailer. The trailer was deformed and some of the welds broken. As Figure 34 also shows, the vehicle sustained moderate damage to the front. The maximum crush at bumper height was 330 mm. The windshield was cracked starting at the edge of the roof near the center. There were also two dents in the roof, the deepest approximately 8 mm. There were dents and scratches on the hood and the bumper, and the grill and radiator were damaged.

A brief summary of the results of this test is presented in Figure 36. The sign panel and upper support structure separated from the trailer upon impact and went up and over the vehicle, contacting the roof just above the windshield, causing a few stress cracks. There was no penetration of the passenger compartment, and the cracks did not impair driver vision. Debris from the sign support trailer remained along the path of the vehicle, posing minimal potential hazard to other traffic or workers. The trailer was deformed, and some of the welds on the frame had separated. The vehicle sustained a 330 mm crush to the center front at bumper height, and the bumper was partially detached from the vehicle. The hood was scratched and dented, the windshield was cracked, and the roof was deformed slightly. The longitudinal occupant impact velocity was 2.0 m/s, and the highest 10-msec ridedown acceleration was 0.4 g. There was no occupant contact in the lateral direction during the test period. The maximum 50-msec average accelerations were -3.2 g in the longitudinal direction and -0.3 g in the lateral direction. The vehicle exited the immediate test site in a relatively smooth, stable manner and showed no potential for intrusion into adjacent traffic lanes.

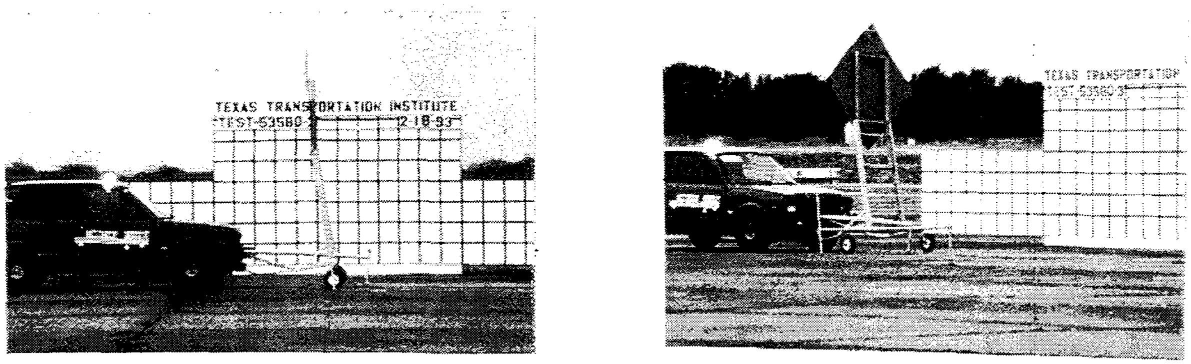
In summary, the transportable GSD sign trailer with a wooden sign panel mounted at a height of 1.52 m was judged to have met all evaluation criteria set forth in NCHRP Report 350. Also, based on the results of the crash test, it is the opinion of the researchers that the sign trailer would also perform satisfactorily with a higher mounting height of 2.13 m for the sign panel. However, there is insufficient data to evaluate the performance of the sign trailer with a lower mounting height, such as 0.91 m, for the sign panel.

3.4 FIXED SIGN SUPPORT (Test No. 453360-3)

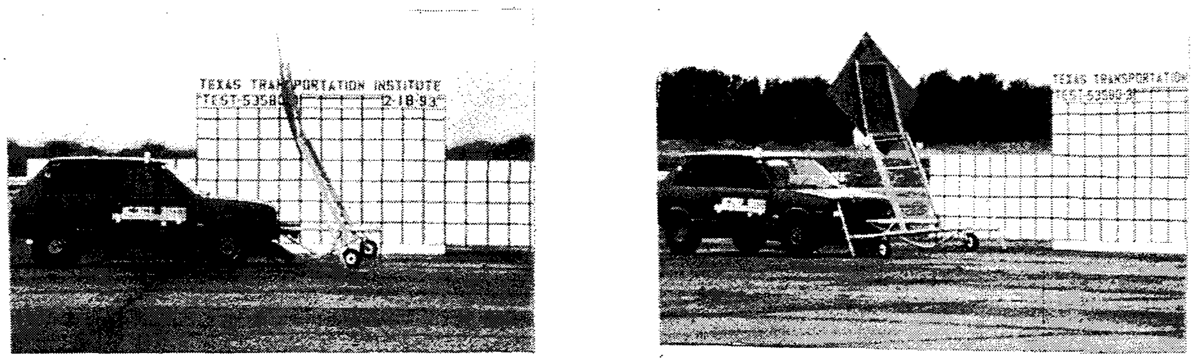
The skid-mounted sign support is shown in the TxDOT "Barricade and Construction Standards" sheets as one of the approved fixed sign support designs. Signs erected on fixed supports are required to have a minimum height from the ground to the bottom of the sign panel of 1.52 m in rural areas and 2.13 m in urban applications. The mounting height of 1.52 m was considered to have a higher potential for impacting and penetrating the windshield of an impacting vehicle and thus a more critical condition. Also, a pickup truck was considered a more critical test vehicle than the small passenger car due to the geometry of the sign support in



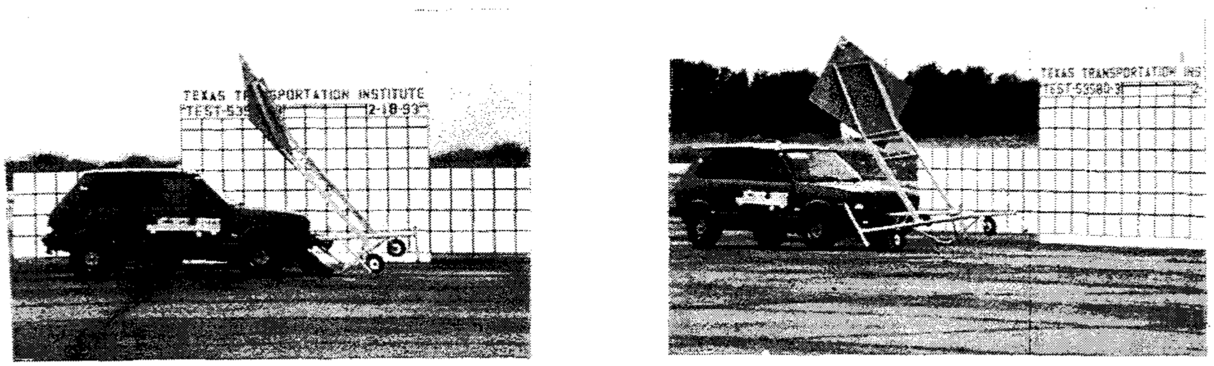
0.000 s



0.025 s

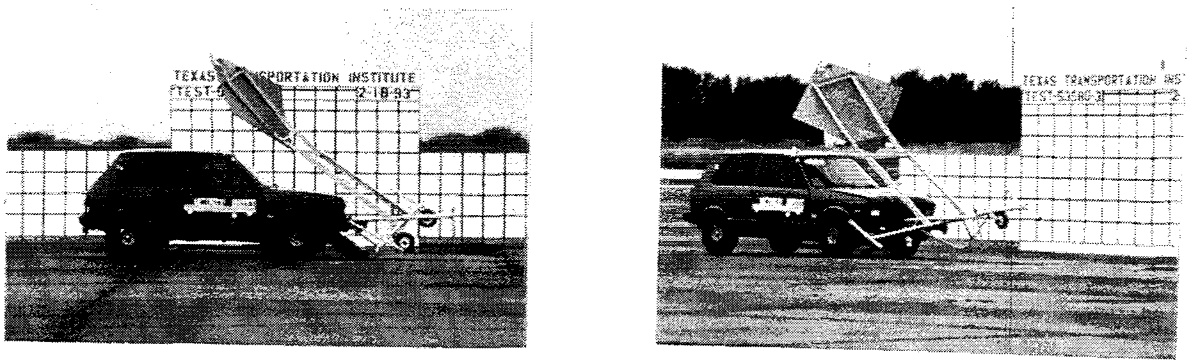


0.050 s

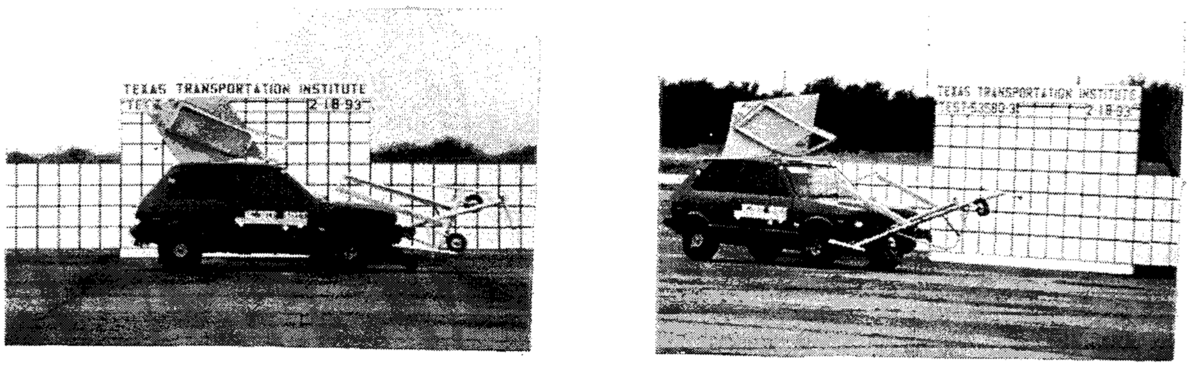


0.075 s

Figure 35. Sequential Photographs for Test No. 453580-3



0.100 s



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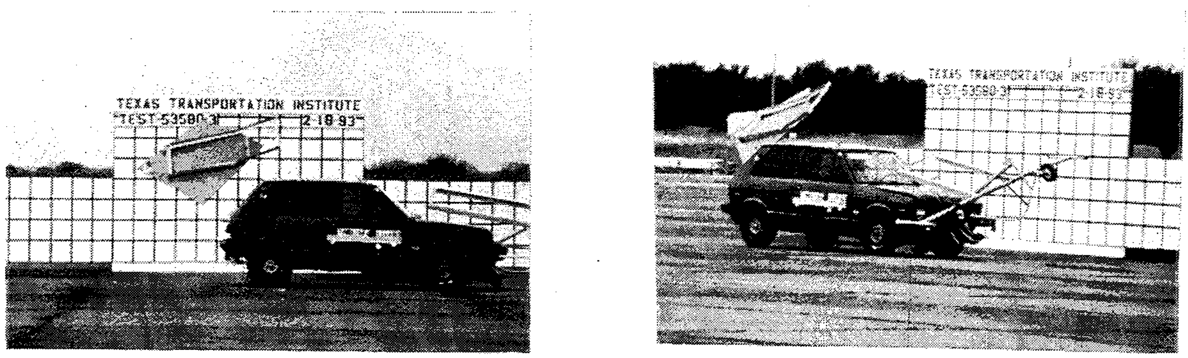
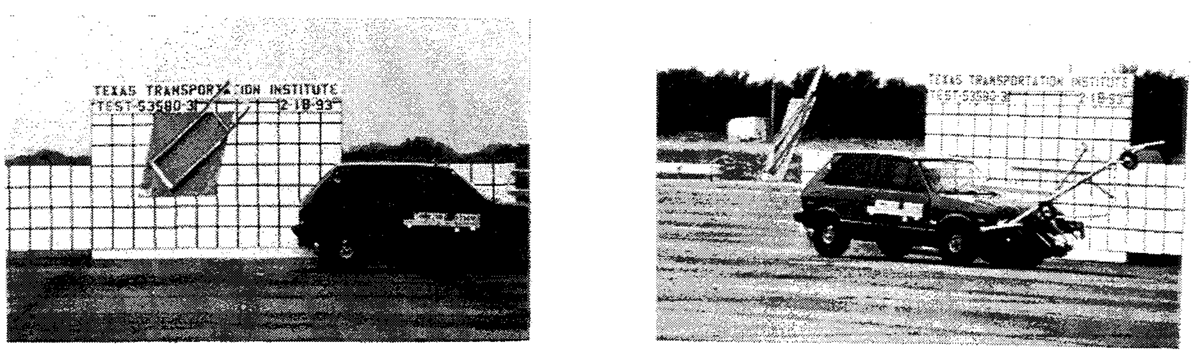
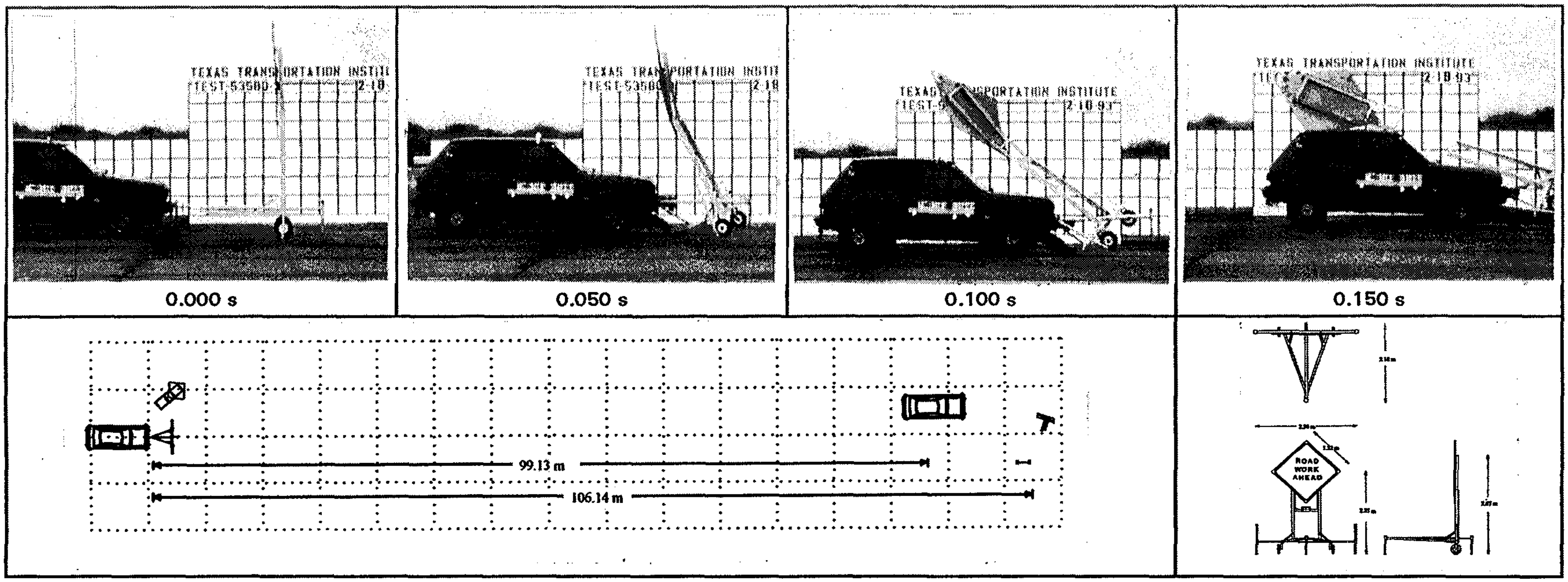


0.200 s



0.250 s

Figure 35. Sequential Photographs for Test No. 453580-3 (continued)



General Information	
Test Agency	Texas Transportation Institute
Test No.	53580-3
Date	02/18/93
Test Article	
Type	Traffic Control Device
	Sign Support Trailer
Installation Length (ft)	
Size and/or dimension and material of key elements	8.75 (2.7 m) high
Soil Type and Condition	N/A
Test Vehicle	
Type	Production Model
Designation	820 C
Model	1987 Yugo GV
Mass (lb) Curb	1,806 (820 kg)
Test Inertial	1,806 (820 kg)
Dummy	159 (72 kg)
Gross Static	1,965 (892 kg)

Impact Conditions	
Speed (mi/h)	61.3 (98.6 km/h)
Angle (deg)	0
Exit Conditions	
Speed (mi/h)	N/A
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (ft/s)	
x-direction	6.6 (2.0 m/s)
y-direction	No contact
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	0.4
y-direction	N/A
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Averages (g's)	
x-direction	-3.2
y-direction	-0.3
z-direction	-1.1

Test Article Deflections (ft)	
Dyanmic	Broke apart
Permanent	Broke apart
Vehicle Damage	
Exterior	
VDS	12FC2
CDC	12FCEN2 & 12FCGN7
Interior	
OCDI	FS0000000
Maximum Exterior Vehicle Crush (in)	13.0 (33 cm)
Max. Occ. Compart. Deformation (in)	Cracked windshield
Post-Impact Behavior	
Max. Roll Angle (deg)	-0.8
Max. Pitch Angle (deg)	0.9
Max. Yaw Angle (deg)	1.0

Figure 36. Summary of Results for Test No. 453580-3

relation to the vehicle. Thus, a mounting height of 1.52 m for the sign panel was selected for the test, as well as a pickup truck.

Note that TxDOT has since revised its standards to use a sign panel mounting height of 2.13 m for all fixed sign supports in both rural and urban applications. However, since the 1.52-m mounting height is considered more critical from the impact standpoint, results of this crash test should also apply to a fixed sign support with a mounting height of 2.13 m. In other words, it is believed that a fixed sign support with a mounting height of 2.13 m would perform equally, if not better, than one with a mounting height of 1.52 m. Since the sign support performed satisfactorily in this crash test, it can be concluded that a fixed sign support with a 2.13-m mounting height would also perform satisfactorily, and there is no need to rerun the test with the higher mounting height.

Figure 37 shows a schematic of the skid-mounted sign support with a 1219 mm x 1219 mm wooden sign panel mounted at a height of 1.52 m. The test vehicle was a 1984 Chevrolet pickup truck, as shown in Figure 38. Appendix Figure 95 gives dimensions and information on the vehicle. The test vehicle impacted the skid mounted sign support head-on with the centerline of the vehicle aligned with the centerline of the sign support, traveling at a speed of 98.0 km/h.

Immediately upon impact, the vertical supports began to fracture at bumper height and approximately 1.8 m above ground level. The panel and pieces of the support rose up and over the hood of the pickup, while the pickup traveled over the bases. A broken segment of the support then struck the roof near the rear of the cab at 79 msec and bounced off at 126 msec. Pieces of the support continued over the pickup with several pieces landing in the bed of the pickup. The time at loss of contact with the sign support, i.e., when the fractured support ended contact with the vehicle, was 126 msec, and the vehicle had slowed to 91.4 km/h. After the vehicle cleared the immediate test site, brakes on the vehicle were applied at 950 msec after impact. Prior to brake application, the test vehicle was traveling on a relatively straightforward path. The vehicle subsequently came to rest 133 m down and 4 m to the left of the point of impact. Figure 39 shows sequential photographs of the test period.

As Figure 38 shows, the skid-mounted sign support fractured upon impact. Debris and sand were strewn along the path of the vehicle in an area 9 m wide by 59 m long. Figure 38 also shows damage to the vehicle. There were two dents in the bumper, 13 mm and 19 mm, from impact with the supports. There was a small dent in the rear of the roof of the cab.

Figure 40 presents a brief summary of the results of this test. The vertical supports fractured upon impact, and the sign panel and fractured vertical support impacted the roof of the vehicle but did not deform into the occupant compartment, therefore showing no potential risk to occupants of the vehicle. Debris from the barricade was thrown along an area 9 m wide by 59 m long. Some fragments were fairly large, which could pose a potential hazard to oncoming traffic in adjacent lanes and to workers in the area. Sand was also scattered on the pavement, which could lead to loss of control of other vehicles. The vehicle sustained damage to the front bumper, hood, and roof. The longitudinal occupant impact velocity was 0.7 m/s and the highest 10-msec average ridedown acceleration was -0.1 g. The lateral occupant impact velocity was 0.8

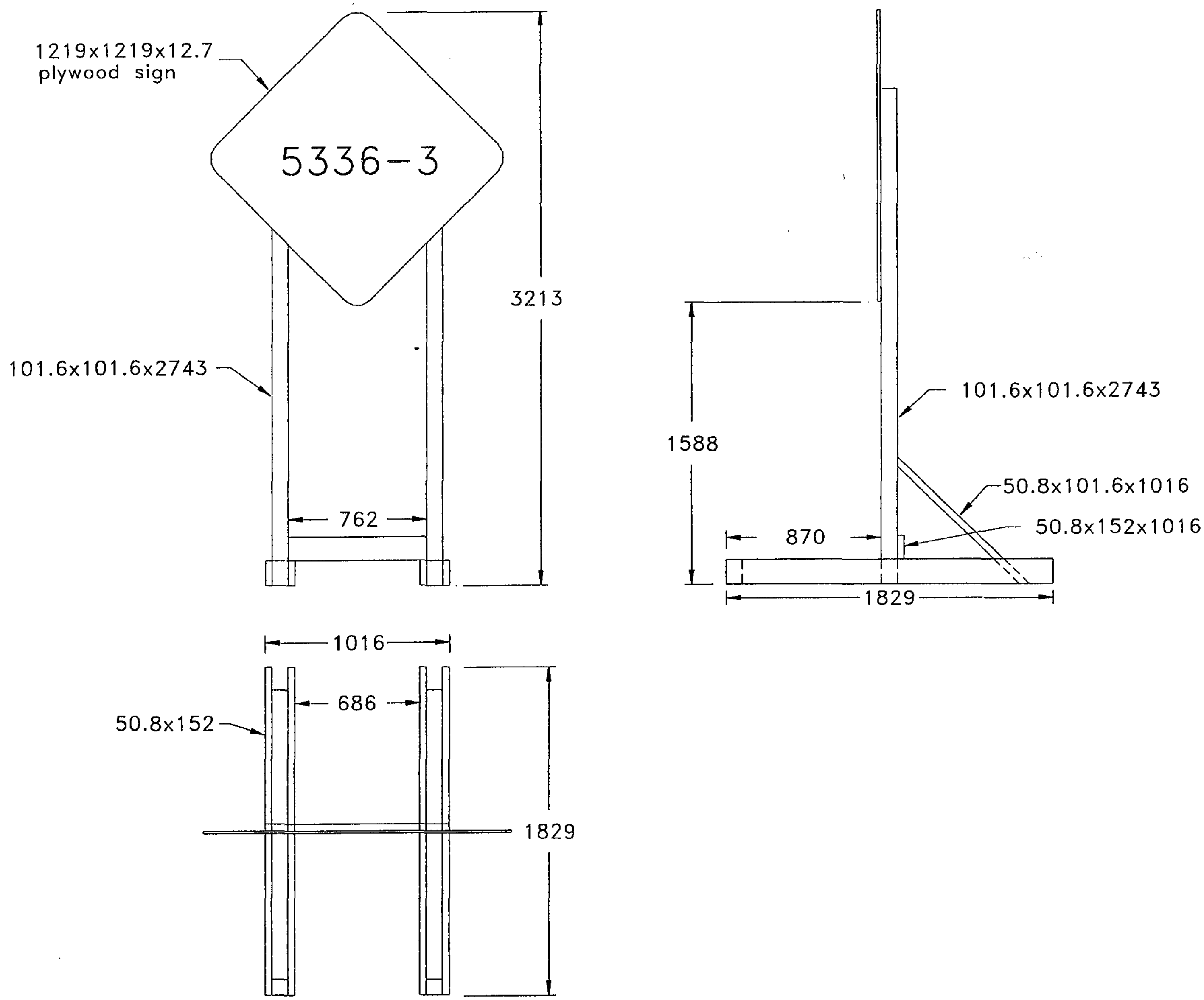


Figure 37. Schematic of Skid-Mounted Sign Support with Wooden Sign Panel (Test No. 453360-3)

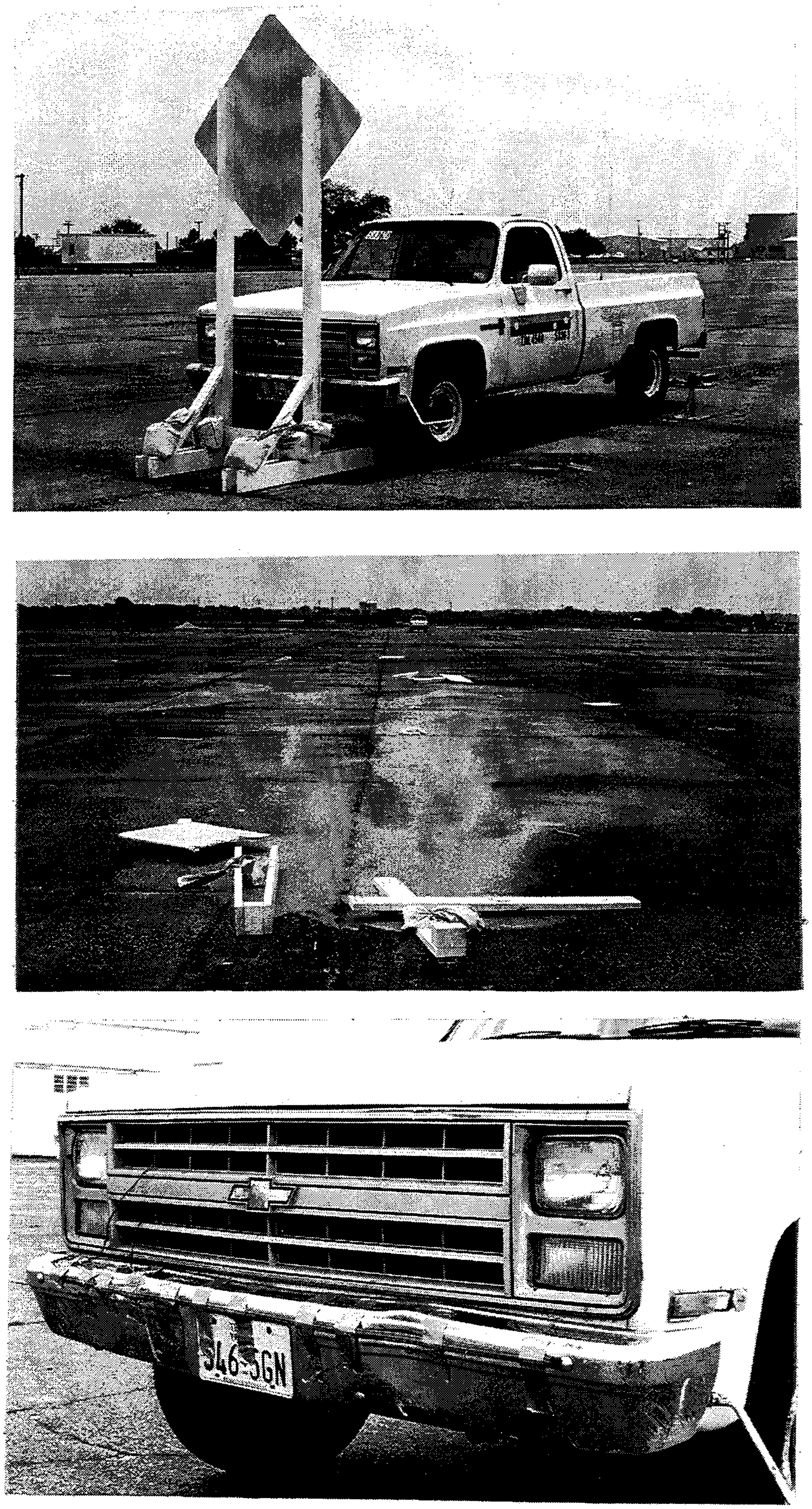
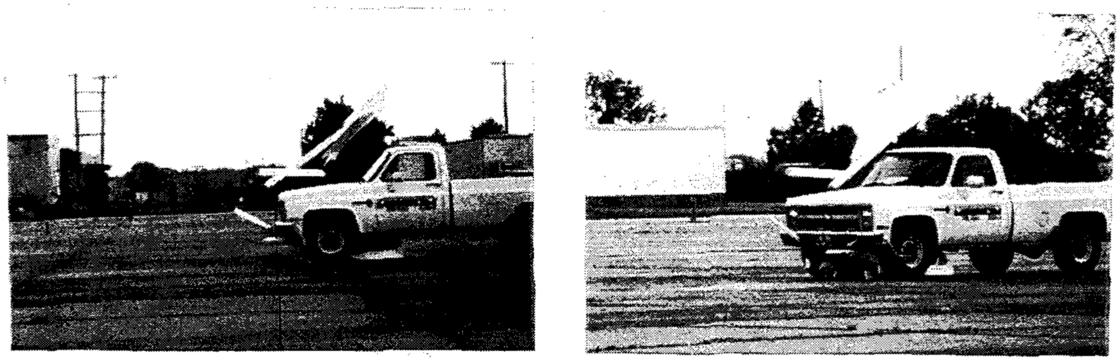


Figure 38. Vehicle and Sign Support for Test No. 453360-3

0.000 s

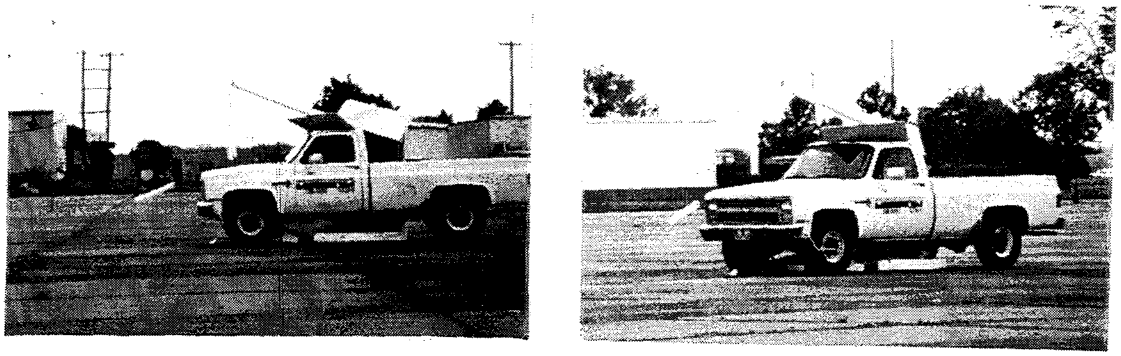
0.025 s



0.049 s

0.074 s

Figure 39. Sequential Photographs for Test No. 453360-3



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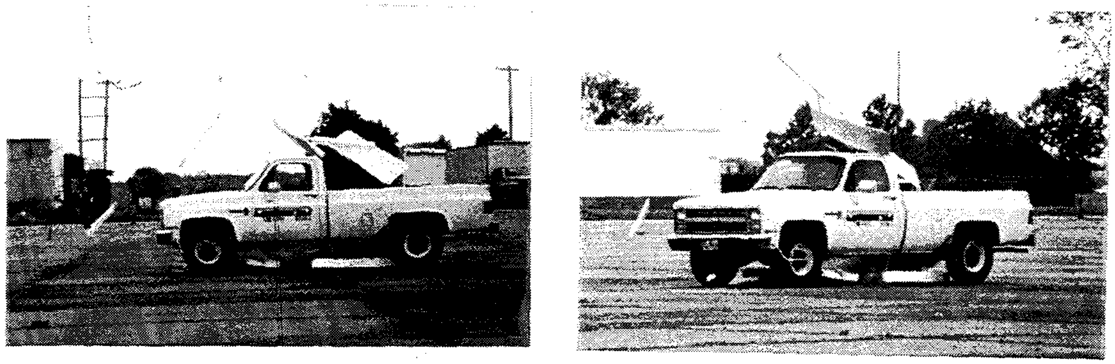
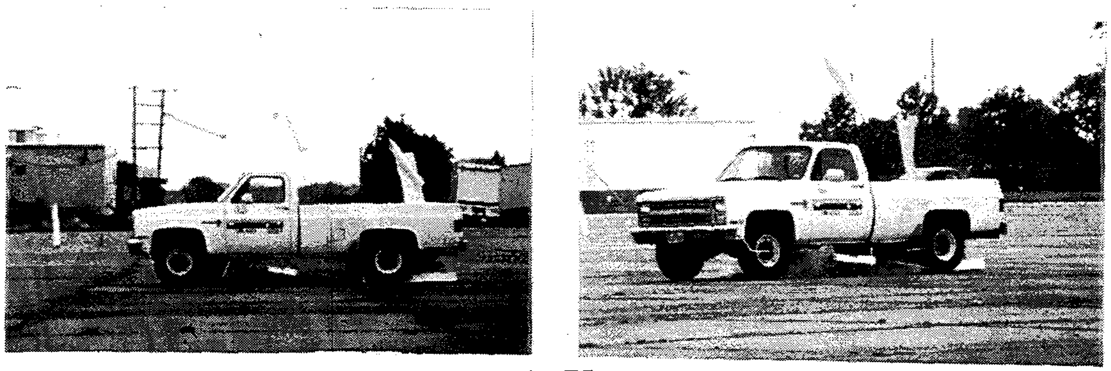
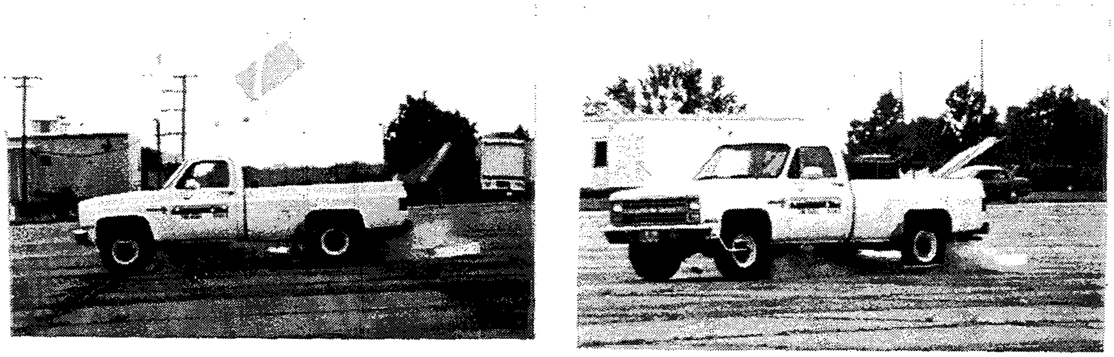


0.126 s

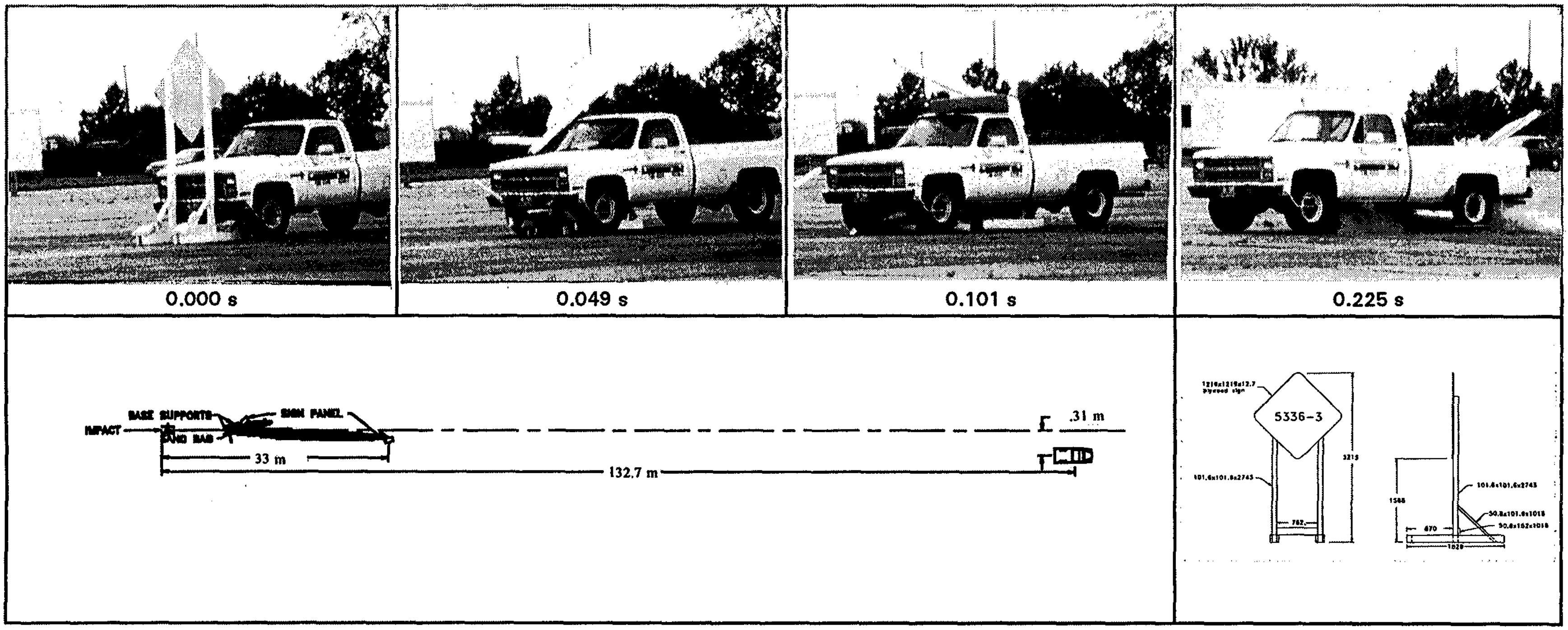


0.175 s



0.225 s

Figure 39. Sequential Photographs for Test No. 453360-3 (continued)



General Information	
Test Agency	Texas Transportation Institute
Test No.	5336-3
Date	08/19/92
Test Article	
Type	Traffic Control Device
. . . .	Skid-mounted Sign Support
Installation Length (ft) . .	6.0 (1.8 m)
Size and/or dimension and material of key elements	10.5 (3.2 m) high Wood
Soil Type and Condition . . .	N/A
Test Vehicle	
Type	Production Model
Designation	2000 P
Model	1984 Chevrolet Pickup
Mass (lb) Curb	4,672 (2,121 kg)
Test Inertial .	4,500 (2,043 kg)
Dummy	None
Gross Static .	4,500 (2,043 kg)

Impact Conditions	
Speed (mi/h)	60.9 (98.0 km/h)
Angle (deg)	0
Exit Conditions	
Speed (mi/h)	56.8 (91.4 km/h)
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (ft/s)	
x-direction	2.2 (0.7 m/s)
y-direction	2.6 (0.8 m/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-0.1
y-direction	-0.2
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Averages (g's)	
x-direction	-0.8
y-direction	0.5
z-direction	-1.0

Test Article Deflections (ft)	
Dyanmic	Broke apart
Permanent.	Broke apart
Vehicle Damage	
Exterior	
VDS	12FD1
CDC	12FDEW1
Interior	
OCDI.	None
Maximum Exterior Vehicle Crush (in). . .	0.75 (1.9 cm)
Max. Occ. Compart. Deformation (in) . . .	0
Post-Impact Behavior	
Max. Roll Angle (deg). .	1.9
Max. Pitch Angle (deg) .	1.1
Max. Yaw Angle (deg) .	2.0

Figure 40. Summary of Results for Test No. 453360-3

m/s and the highest 10-msec average ridedown acceleration was -0.2 g. The maximum 50-msec average accelerations were -0.8 g in the longitudinal direction and 0.5 g in the lateral direction. The vehicle exited the immediate test site in a relatively smooth, stable manner and showed no potential for intrusion into adjacent traffic lanes.

In summary, the skid-mounted sign support with wooden sign panel was judged to have met all evaluation criteria set forth in NCHRP Report 350. As discussed previously, this assessment would apply to both mounting heights of 1.52 m and 2.13 m.

3.5 SUMMARY

A total of 10 crash tests were conducted on various existing work zone traffic control devices, including: (1) wooden barricade, (2) portable sign support, (3) transportable sign trailer, and (4) skid-mounted fixed sign support. A summary of the findings from the crash tests are as follows:

1. Existing wooden barricades, with or without sign panel attachment, pose potential hazards to impacting vehicles due to the propensity for the sign panel or the fractured vertical supports to impact and penetrate the windshield. With the widespread use of wooden barricades in construction zones, it is important to develop alternate barricade designs that would perform satisfactorily when impacted by errant vehicles.

2. A Type III wooden barricade, impacted in an end-on position, performed satisfactorily, which was contrary to the initial concern that the rail elements of the barricade would impact the windshield and penetrate the occupant compartment when impacted in this manner. Despite the satisfactory results of this test, this potential hazard remains, given the geometry of the barricade relative to the front of the vehicle when impacted in an end-on position. A longer Type III barricade, e.g., 3.7 m, with the increased length of rail elements, the addition of an intermediate vertical support, and the increased weight, may not have performed satisfactorily. Also, field experience, though anecdotal in nature, indicates the potential for such occurrence. Thus, it is still recommended that barricades not be placed in such a manner as to expose the barricades to end-on impacts.

3. Wooden sign panels, when used with portable sign supports, have the propensity to disengage from the support and impact the windshield of the impacting vehicle and potentially penetrate the occupant compartment. The use of wooden sign panels with portable sign supports is thus not recommended. A plastic/fabric type of sign panel, being lightweight, does not pose such hazard and is recommended for use with portable sign supports.

4. The crash test with the easel sign support showed the potential for the sign support to rotate and flip up in the air, resulting in the top of the support impacting and

penetrating the windshield of the impacting vehicle. The use of the easel portable sign support is therefore not recommended.

5. The GSD sign trailer, with a wooden sign panel, performed satisfactorily in the crash test. The sign panel and the upper vertical supports separated from the trailer and impacted the roof of the impacting vehicle. However, there was no penetration into the occupant compartment.

6. A skid-mounted fixed sign support with a wooden sign panel mounted at a height of 1.52 m performed satisfactorily in the crash test. The wooden vertical supports fractured upon impact. The sign panel and the fractured vertical supports impacted the roof of the impacting vehicle, but there was no penetration into the occupant compartment. It is believed that a higher sign mounting height of 2.1 m would perform equally as well, if not better, than the 1.52 m mounting height since the sign panel and fractured vertical supports would more likely go over the top of the impacting vehicle.

In summary, results of crash testing of existing work zone traffic control devices indicated that the biggest potential problem is with wooden barricades, both with or without sign attachment. Portable sign supports, except for the easel sign support, would perform satisfactorily when used with plastic/fabric sign panels. The GSD transportable sign trailer and the skid-mounted fixed sign support performed satisfactorily. Thus, the remaining effort in the study was devoted to the development and evaluation of alternate barricade designs and sign attachment mechanisms.

IV. ALTERNATE BARRICADE DESIGNS

As presented in the previous chapter, results of the crash testing indicated that existing wooden barricades, with or without sign panel attachment, pose potential hazards to impacting vehicles due to the propensity for the sign panel or the fractured vertical supports to impact and penetrate the windshield. The remaining effort in the study was directed first at developing and evaluating alternate barricade designs without sign attachment and then at developing and evaluating alternate sign attachment mechanisms.

4.1 ALTERNATE BARRICADE DESIGNS

It was demonstrated during full-scale crash testing (test no. 453360-4) that the vertical supports of existing wooden barricades tend to fracture upon impact and rotate with the attached rail elements into the windshield of the impacting vehicle, resulting in shattering and penetration of the windshield. There are two approaches to alleviating this problem. The first approach is to change the failure mechanism of the vertical supports to prevent them from fracturing or separating from the base, thus eliminating the potential for the detached vertical supports and rail elements to rotate into the windshield. Another approach is to use lighter weight materials for the vertical supports and horizontal rail elements so that, in the event the vertical supports fracture or become detached from the base during impact, they will not have sufficient mass to shatter and penetrate the windshield.

4.1.1 Perforated Steel Tube Barricade

The New York Department of Transportation (NYDOT) has previously tested with success a barricade fabricated from perforated tubing. The same perforated tubing is currently used for small sign supports and is available commercially from two manufacturers: Unistrut Corporation and Allied Tubing. The square tubing is roll formed from 2.7-mm thick steel conforming to ASTM Specification No. A-446 and welded in the corner by high-frequency resistance welding. The tubing has 11.1-mm diameter holes spaced 25.4 mm on center along the centerline of each of the four sides and is galvanized in accordance with zinc coating designation G-90. Standard sizes for the perforated square tubing include 38.1 mm, 44.5 mm, 50.8 mm, 57.2 mm, and 63.5 mm. Appendix B provides general specifications for the perforated steel tubing.

The frame of the tubular steel barricade is erected using 38.1-mm and 44.5-mm perforated square tubing and splice plates fabricated from 6.4-mm steel plate as shown in Figure 41. The base for each vertical support consists of a single 44.5-mm perforated steel tube 1524 mm in length. A 254-mm sleeve, also fabricated from 44.5-mm tubing, is connected vertically to the center of the base support using two splice plates as shown in Detail A of Figure 41. Two 9.5-mm bolts, one through the base support and one through the sleeve, are used to provide the connection. Moment resistance against wind loads is provided by two 6.4-mm bolts that run between the splice plates and along the outside faces of the vertical sleeve. These small bolts

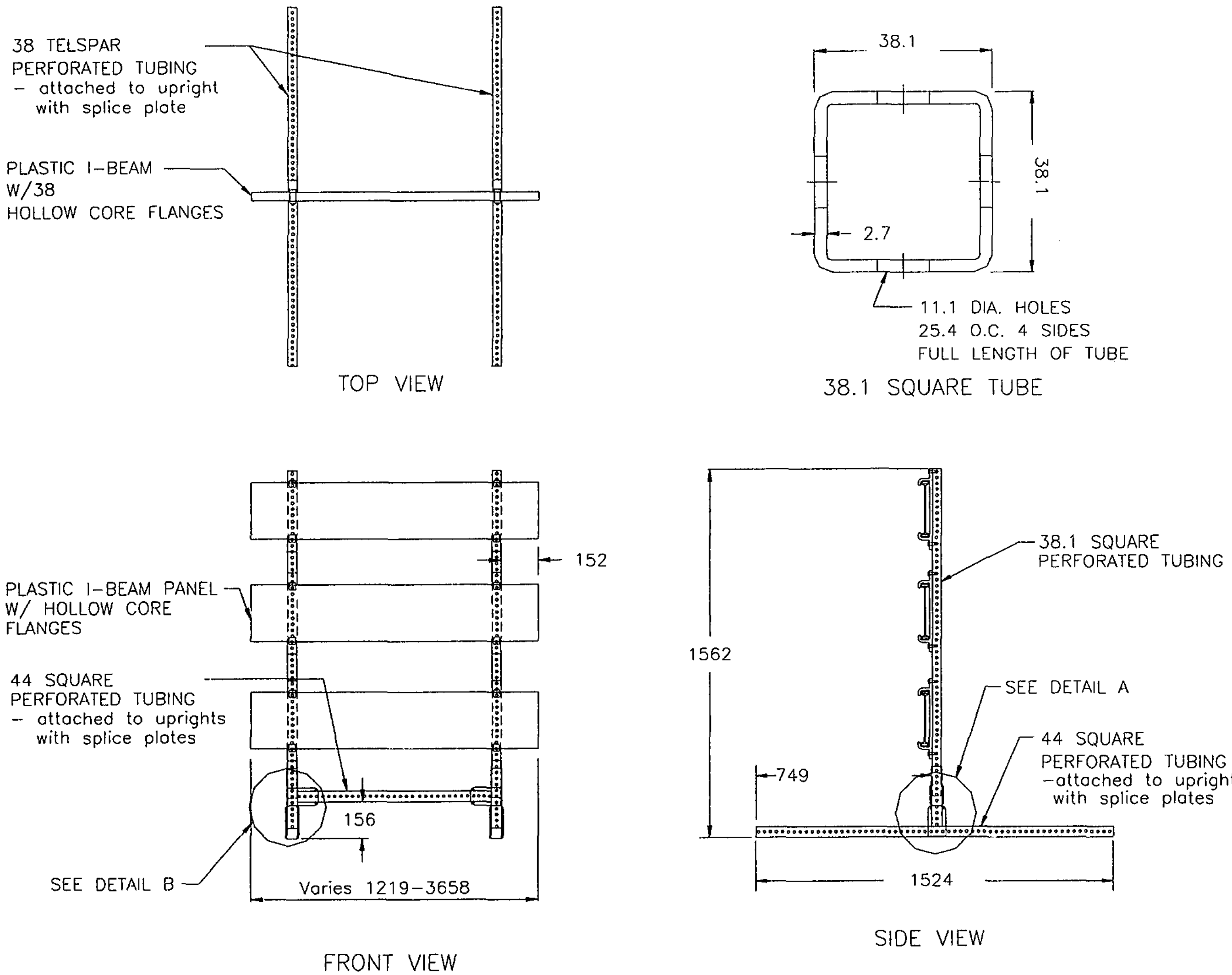


Figure 41. Perforated Steel Tube Type III Barricade with Plastic Panels

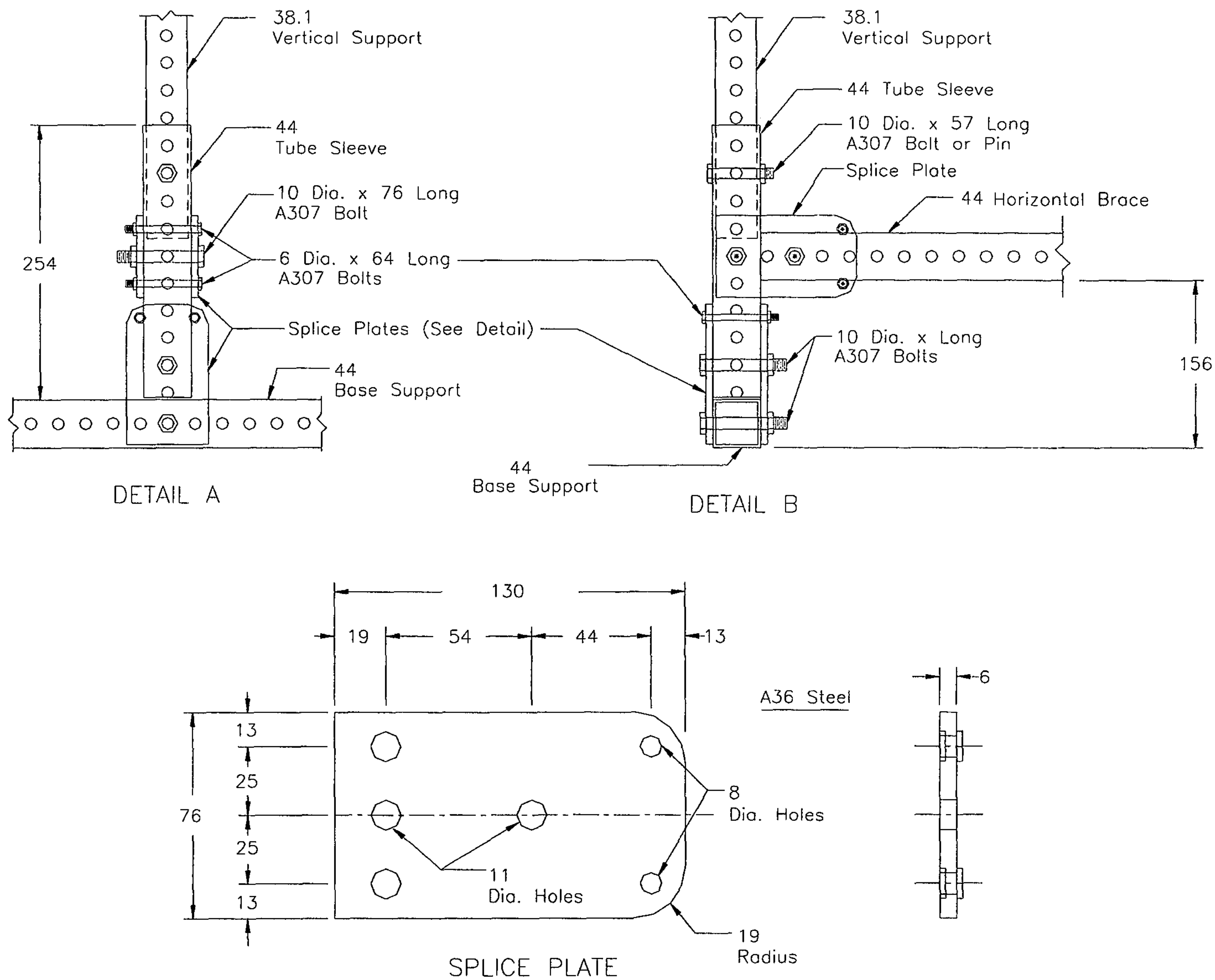


Figure 41. Perforated Steel Tube Type III Barricade with Plastic Panels (continued)

are designed to fail in shear upon impact, thus permitting the vertical supports to rotate downward about the 9.5-mm connection bolt. Additionally, one end of the splice plate is stamped to provide two raised circular protrusions that match the hole pattern on the base support and keep the plate from rotating.

A horizontal brace fabricated from 44.5-mm tubing extends between the vertical sleeves to provide stability to the steel frame. As in Detail B of Figure 41 shows, this horizontal brace is connected to the vertical sleeves using two splice plates on each end in a manner similar to the base support/sleeve connection. The vertical supports or uprights are fabricated from 38.1-mm perforated tubing. The vertical members insert into the 44.5-mm sleeves and are secured using a 9.5-mm pin or bolt.

Two different types of horizontal rail elements can be used in conjunction with the perforated tube frame. The first is a specially fabricated plastic rail element and attachment bracket, which is marketed by TrafFix Devices Inc. This plastic rail element is extruded into an I-beam shape having a 38.1-mm hollow core flange and a 3.2-mm web. The overall depth of the section is 241.3 mm, with the web being 204.8-mm in depth. In addition to increasing the rigidity of the rail element, the I-beam shape provides a recessed region for application of the required reflective tape. If the rails become separated from the frame during impact, the flanges protect the reflective tape from being damaged as the rail slides along the ground or roadway surface. Specially designed brackets are attached to the vertical support members using vandal resistant rivets. The plastic I-beam rail elements clip into the brackets for easy installation and removal. Figure 41 shows details of the perforated tube Type III barricade with plastic rail elements.

The perforated tube Type III barricade with plastic rail elements was crash tested with satisfactorily results (test no. 453790-3). The test was conducted with the barricade placed on a concrete pavement surface. The barricade stayed with the vehicle and slid on the concrete pavement until the vehicle came to final rest. There was some concern that, had the barricade been on a wet soil or grassy surface, as is typically found on the roadside, the base support of the barricade may have dug into the ground and caused a stability problem for the impacting vehicle. A second test of the perforated tube Type III barricade with plastic rail elements was therefore conducted with the barricade placed on a wet soil surface (test no. 453880-1). The barricade again performed satisfactorily under the wet soil conditions.

As mentioned previously, the barricades crash tested in these two tests were purchased from TrafFix Devices Inc. with the proprietary plastic rail elements. After discussions with TxDOT personnel, it was decided that it would be desirable to provide an alternative to the proprietary plastic rails. A generic barricade was therefore constructed using the perforated square steel tubing and standard dimensional wooden rail elements. Figure 42 shows details of this generic Type III perforated tube barricade with wooden rail elements. The 25.4-mm x 203.2-mm wooden rails are bolted directly to the vertical uprights through the existing 11.1-mm holes. This generic barricade system was crash tested under wet soil conditions with satisfactory results (test no. 453880-2).

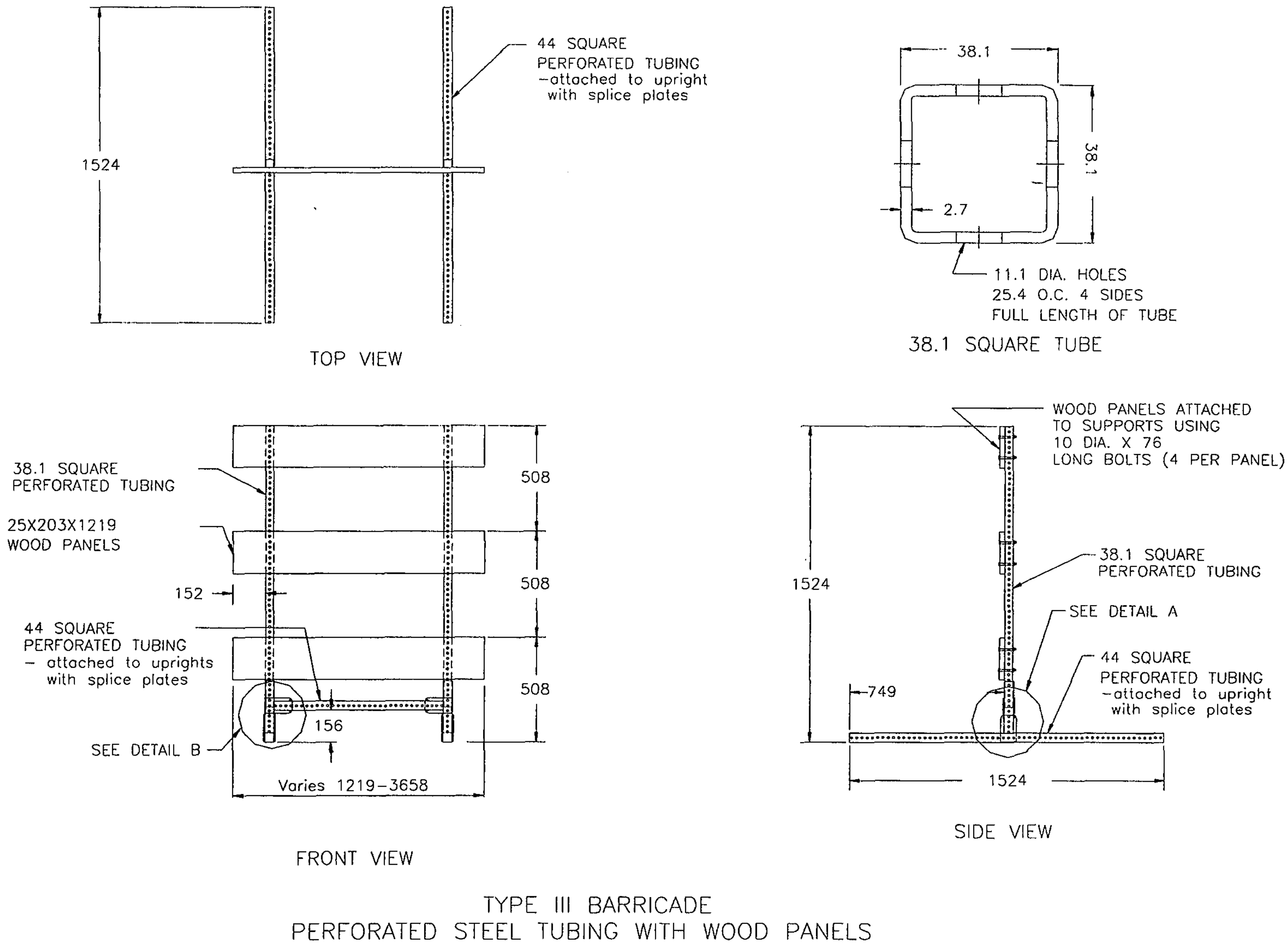


Figure 42. Perforated Steel Tube Type III Barricade with Wood Panels

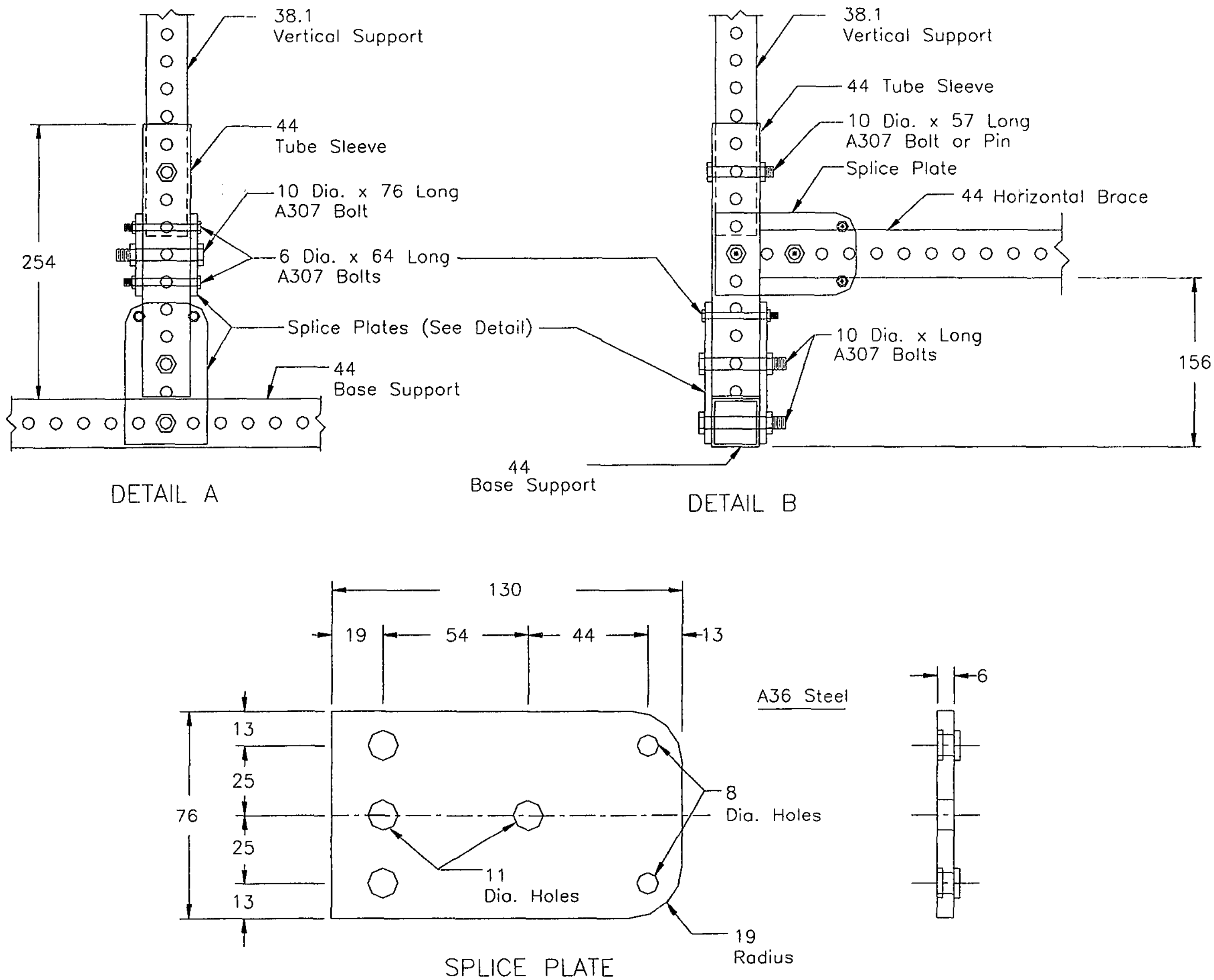


Figure 42. Perforated Steel Tube Type III Barricade with Wood Panels (continued)

It should be noted that there are comparative advantages and disadvantages associated with the use of the two different types of rail elements. Use of the plastic rails allows for quick assembly and disassembly of the barricade, and the rails are provided in the color white to eliminate the need for painting. Additionally, the plastic rail elements are typically reusable after an impact, thus avoiding the cost of replacing the rail and reflective sheeting. However, the flexible plastic rails have a tendency to bow or warp and may require additional horizontal bracing for longer barricade lengths. Also, movement of the completed barricade assembly is difficult due to the propensity for the plastic rails to release from the attachment brackets.

On the other hand, the wooden rails are readily available, and the initial cost of the wooden rail design will be less than that of the plastic rail alternative. Additionally, use of the wooden rails gives the barricade much more rigidity, thereby eliminating the need for additional bracing and making handling and movement of the barricade more efficient. However, in the event of an impact, the wooden rail elements tend to fracture and would require replacement of both the rails and reflective sheeting.

4.1.2 Hollow Core Recycled Plastic Barricade

As mentioned previously, the other approach to eliminating the penetration hazard associated with conventional wooden barricades is to use a lighter weight material for fabrication of the vertical supports and rail elements. After looking at a number of different materials and their properties, it was decided to focus on plastic materials, particularly recycled plastics. First, TxDOT is very interested in the increased use of recycled materials as evidenced by an ongoing recycling initiative (*10*) and an ongoing research project investigating the use of recycled materials in roadside safety applications. (*11*) Second, the recycled plastic materials are commercially available in a variety of standard dimensional lumber sizes, which are currently being used as an alternate to wood in the construction of fences, park benches, etc.

Specifically, barricades fabricated from two different materials were selected for further evaluation: (1) hollow core recycled plastic material, and (2) solid recycled plastic lumber. In addition, a third plastic Type III barricade manufactured by Tex-Mex Barricades was also crash tested at the direction of TxDOT.

The hollow core recycled plastic material was obtained from Recycled Plastic Products, Inc. These 100 percent recycled products are manufactured from a combination of post-consumer and post-industrial fractional melt high density polyethylene (HDPE) which has been recycled from items such as milk, water, and bleach bottles. Anti-oxidants (for heat stabilization), ultraviolet (UV) stabilizers, and non-toxic colorants are added to the product to help ensure product quality and durability. Available sizes include 102 mm x 102 mm, 25.4 mm x 102 mm, and 25.4 mm x 152 mm. Although a 25.4 mm x 203 mm member was not available for evaluation under this project, the manufacturer indicated that this size could be fabricated upon request. The material can be sawed and connected using lag screws or bolts in the same manner as conventional wood members.

Appendix B provides specifications for the hollow core, recycled plastic material as crash tested. Note that there are other commercially available hollow core, recycled plastic material that may have specifications slightly different from those shown in Appendix B. However, it is the opinion of the researchers that barricades fabricated from other commercially available hollow core, recycled plastic material would also perform satisfactorily.

The Type III barricade was constructed using hollow core 102 mm x 102 mm vertical uprights attached to a standard wooden base. Since a 25.4 mm x 203 mm member was not available, each of the three horizontal rails was constructed from two 25.4 mm x 102 mm members, as shown in Figure 43. This hollow core recycled plastic Type III barricade was crash tested with satisfactory results (test no. 453790-4). The test was conducted with the barricade placed on a concrete pavement surface. During impact, the vertical supports and rail elements separated from the wooden base as a single unit and made contact with the hood and windshield of the vehicle. However, due to the lightweight nature of the hollow core material, the supports bounced harmlessly off the vehicle and did not penetrate the occupant compartment. Thus, the performance of the Type III barricade constructed with hollow core plastic material was judged to be satisfactory in accordance with evaluation criteria set forth in NCHRP Report 350.

As mentioned previously, barricades are sometimes placed at locations where an errant vehicle could impact the barricade in an end-on position. To evaluate the potential hazard associated with such impacts, a second crash test of the hollow core recycled plastic Type III barricade was conducted in an end-on position (test no. 453880-3). The performance of the barricade for this impact condition was judged to be satisfactory.

The initial cost of the hollow core recycled plastic components is anticipated to be greater than wooden members of comparable size. However, since colorants used in the manufacturing process can provide a permanent white pigmentation, the additional cost is partially offset through the elimination of painting. The hollow core materials are durable and lightweight, and the fabrication, handling, and appearance of the barricade should be similar to standard wooden barricades. For barricade lengths greater than 1.8 m, an intermediate vertical support centered between the two end supports, is recommended to prevent thermoplastic sag in hot weather.

4.1.3 Solid Recycled Plastic Lumber Barricade

As Figure 44 shows, the construction of the solid recycled plastic barricade was similar to that of the Type III wooden barricade. Solid recycled plastic lumber is available in standard dimensional lumber sizes from numerous manufacturers located across the country. These products were designed to be used as a direct substitute to wooden members in a variety of different applications. Plastic lumber can be cut and fastened using standard woodworking tools and hardware. The composition and properties of different plastic lumber products varies with the manufacturer, but most are comprised in part or whole of high density polyethylene (HDPE). Generally speaking, these products tend to be denser and less stiff than their wooden counterparts. When evaluated in a full-scale crash test (test no. 453790-5), the vertical supports and horizontal rails fractured upon impact. As observed with the standard Type III wooden barricade, segments of the fractured vertical supports and rails broke the windshield and penetrated into the occupant

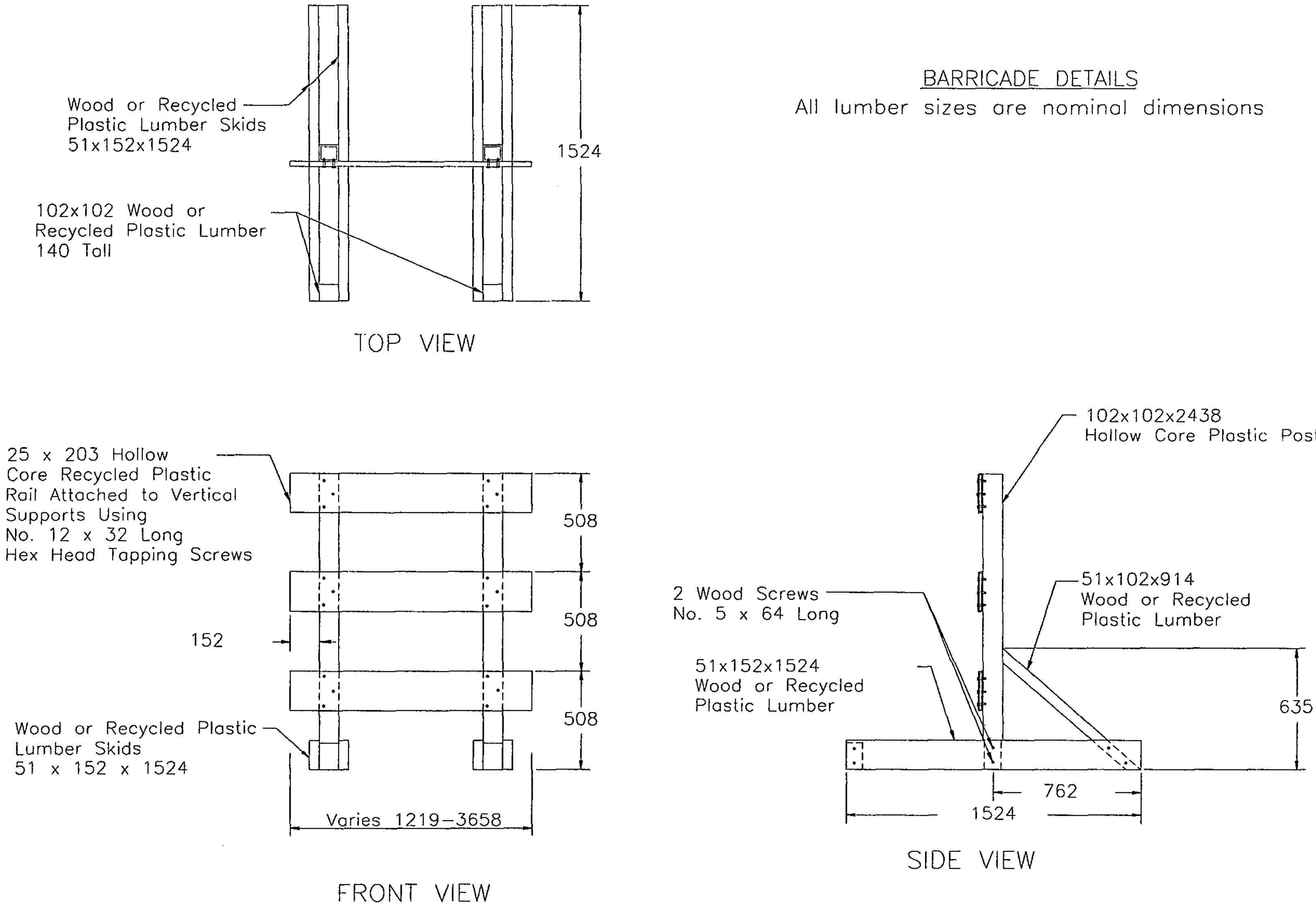


Figure 43. Hollow Core Recycled Plastic Type III Barricade

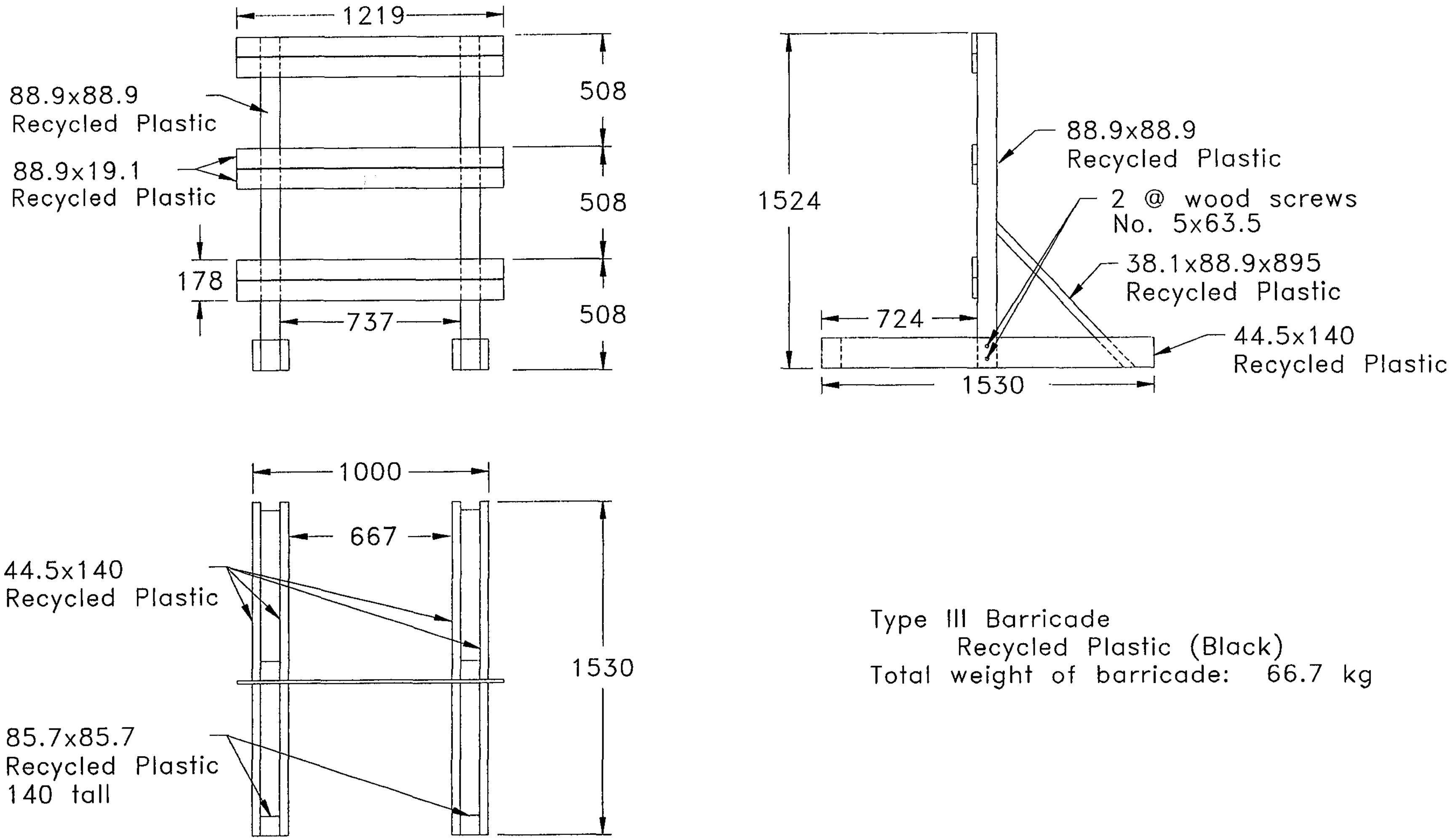


Figure 44. Solid Recycled Plastic Lumber Barricade

compartment. Due to the occupant compartment intrusion, the performance of the solid recycled plastic lumber Type III barricade was judged to be unsatisfactory.

4.1.4 Other Barricades

At the direction of TxDOT, a third plastic Type III barricade alternative, provided by Tex-Mex Barricades, was also tested (test no. 453790-2). No technical information was available on the composition or properties of the plastic material, but it appeared to be some form of hollow extruded plastic. The performance of this barricade was judged to be satisfactory during a frontal impact with the barricade placed on a concrete pavement surface.

4.2 CRASH TESTS OF ALTERNATE BARRICADE DESIGNS

A total of seven crash tests were conducted to assess the performance of alternate barricade designs. The objective of the testing was to identify one or more designs which will serve as acceptable alternatives to the standard wooden barricade which exhibited undesirable behavior during full-scale testing. The alternate barricade designs that were evaluated include:

(1) perforated steel tubing with plastic rail elements,
(2) perforated steel tubing with wooden rail elements,
(3) hollow core recycled plastic,
(4) solid recycled plastic lumber, and
(5) plastic Type III barricade by Tex-Mex Barricades.

The following sections present detailed descriptions of the crash tests conducted on these barricades.

4.2.1 Perforated Tubing with Plastic Rail Elements (Test No. 453790-3)

Figure 45 shows a schematic of the Type III barricade fabricated from perforated steel tubing with plastic rail elements. The barricade was purchased from TrafFix Devices, Inc. The test vehicle was a 1988 Chevrolet Sprint, as shown in Figure 46. Appendix 94 gives dimensions and information on the vehicle. The test vehicle impacted the barricade head-on with the centerline of the vehicle aligned with the centerline of the barricade, traveling at a speed of 102.0 km/h.

As the vehicle impacted the vertical supports, the middle and upper plastic rail elements separated from the vertical supports. The lower plastic rail element and vertical supports deformed and wrapped around the front of the vehicle. Windshield contact by the middle plastic rail element occurred at 42 msec and with the upper rail element at 54 msec. The vehicle lost contact with the barricade at 69 msec, traveling at a speed of 95.2 km/h. Prior to brake application, the vehicle was tracking straightforward. The vehicle subsequently came to rest 91.7 m down and 7.9 m to the left of the point of impact. Figure 47 shows sequential photographs of the test period.

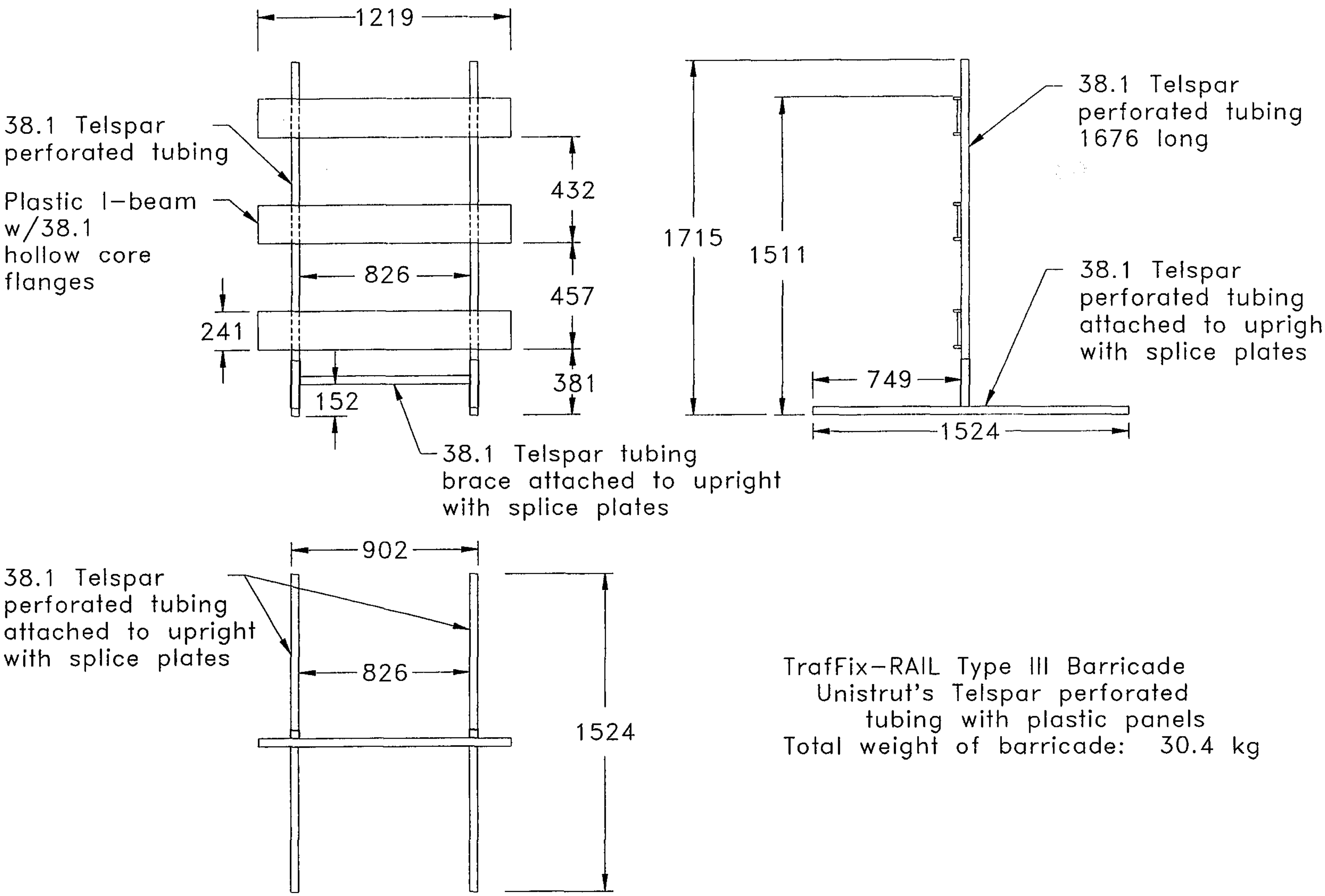


Figure 45. Schematic of Perforated Tubing Type III Barricade with Plastic Rail Elements (Test No. 453790-3)

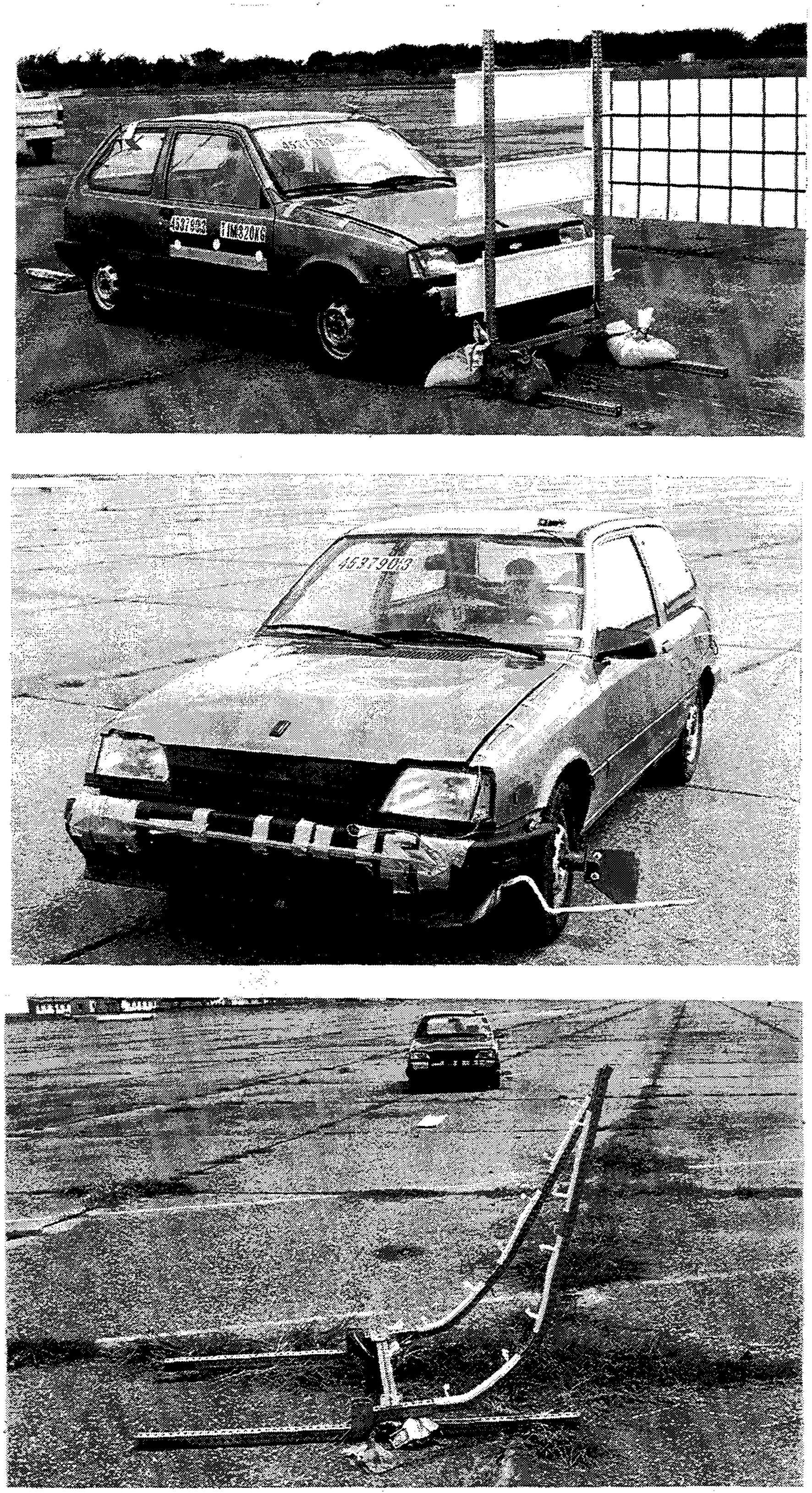
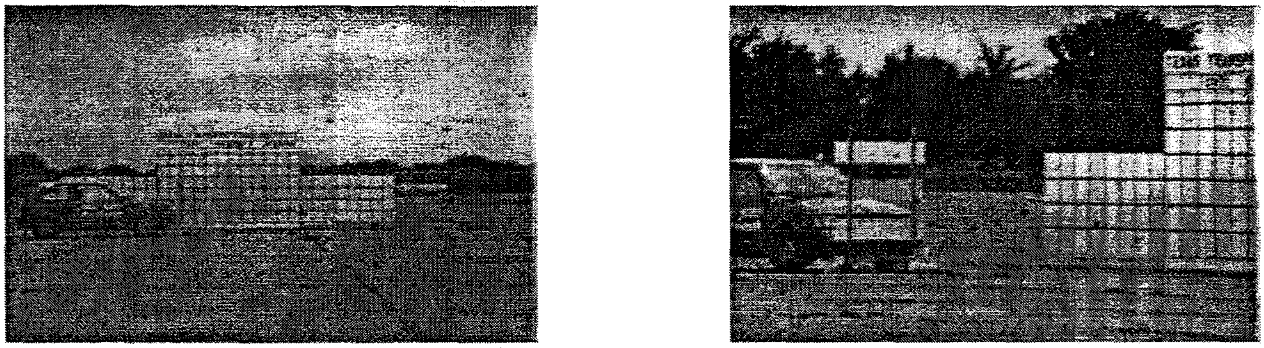


Figure 46. Vehicle and Barricade for Test No. 453790-3



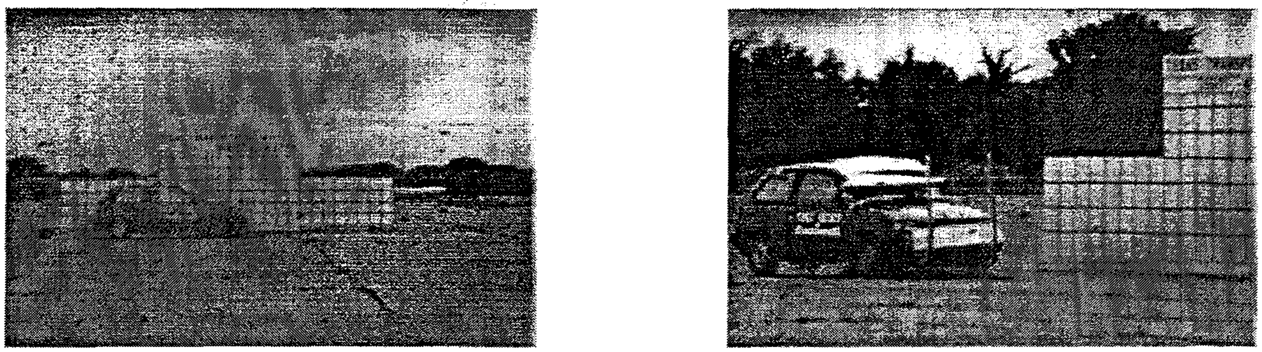
0.000 s

0.015 s

0.030 s

0.044 s

Figure 47. Sequential Photographs for Test No. 453790-3



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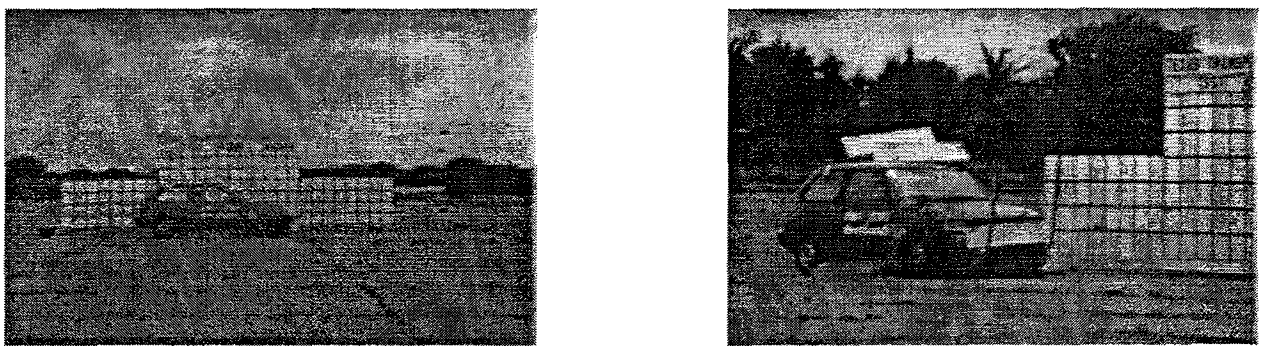

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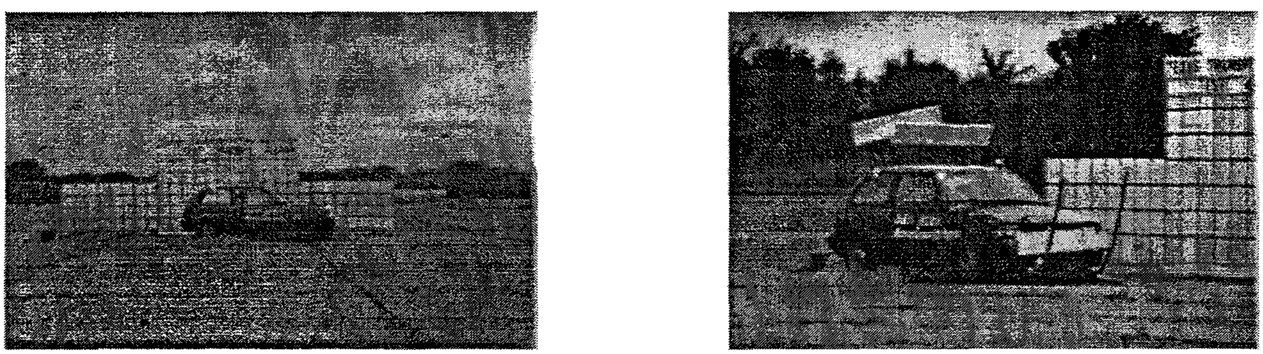

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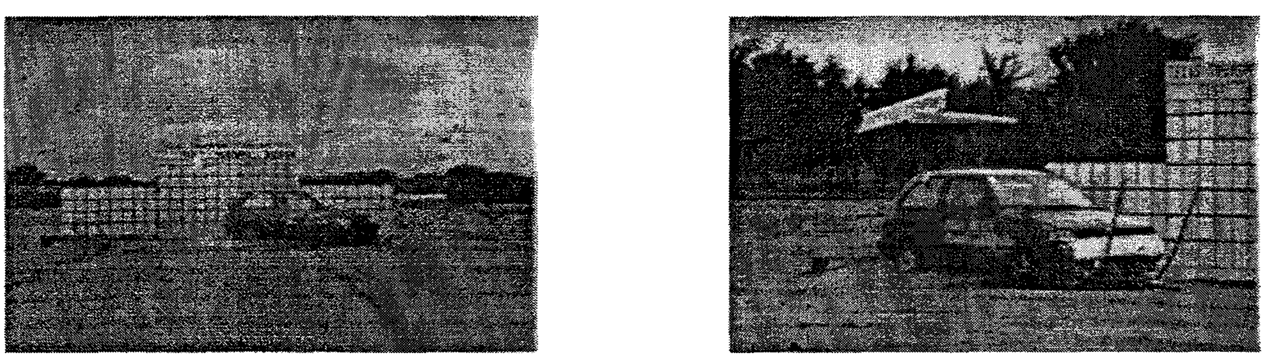


0.173 s

Figure 47. Sequential Photographs for Test No. 453790-3 (continued)

As Figure 46 shows, the plastic rail elements separated from the vertical supports upon impact. The shear pins for the vertical supports sheared as designed, but the impact speed was too high for the vertical supports to fold down. Instead, the vertical supports wrapped around the front the vehicle and stayed with the vehicle until final rest. Debris and sand were strewn along the path of the vehicle in an area 11 m wide by 109 m long. Figure 46 shows damage to the vehicle. The bumper, grill, and hood were dented and scratched. The windshield was cracked; however, no penetration or intrusion of the occupant compartment occurred. Maximum crush to the exterior of the vehicle at the left front corner of the bumper was 70 mm.

Figure 48 presents a brief summary of the results of this test. The plastic rail elements separated from the vertical supports and made contact with the hood and windshield, but did not penetrate the occupant compartment. Debris from the barricade was thrown along an area 11 m wide by 109 m long. The metal supports and bases rode along in front of the vehicle, and most of the remaining fragments were not large or heavy enough to pose potential hazard to oncoming traffic in adjacent lanes or to workers in the area. Damage to the vehicle included dents and scratches to the bumper, grill, and hood. The windshield was cracked by contact with the plastic rail elements, but there was no penetration or intrusion into the occupant compartment. The longitudinal occupant impact velocity was 1.7 m/s and the highest 10-msec average ridedown acceleration was -0.3 g. There was no lateral occupant contact. The 50-msec average accelerations were -2.9 g in the longitudinal direction and -0.5 g in the lateral direction. The vehicle exited the immediate test site in a relatively smooth, stable manner and showed no potential for intrusion into adjacent traffic lanes.

In summary, the Type III barricade fabricated from perforated tubing with plastic rail elements was judged to have met all evaluation criteria set forth in NCHRP Report 350.

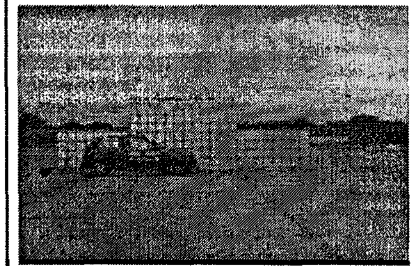
4.2.2 Perforated Tubing with Plastic Rail Elements, Wet Soil Condition (Test No. 453880-1)

A Type III barricade fabricated from perforated steel tubing with plastic rail elements, similar to that used in test no. 453790-3, was tested under wet soil condition, i.e., the barricade was placed on wet soil instead of a concrete pavement surface. Figure 49 shows a schematic of the barricade. The barricade was purchased from TrafFix Devices, Inc. The test vehicle was a 1989 Chevrolet Sprint, as shown in Figure 50. Dimensions and information on the vehicle are given in Appendix Figure 90. The test vehicle impacted the plastic Type III barricade head-on with the centerline of the vehicle aligned with the centerline of the barricade, traveling at a speed of 100.5 km/h.

Upon impact, the middle and top rail elements separated from the vertical supports while the vertical support uprights deformed and wrapped around the front of the vehicle. At 7 msec, the middle rail element contacted the hood of the vehicle. The vehicle lost contact with the left vertical support at 37 msec. The top rail element contacted the windshield at 47 msec, and the middle rail element contacted the windshield at 49 msec. However, the windshield remained intact. The vehicle lost contact with the right vertical support, which then rode underneath the vehicle, and the lower rail element rode along on the bumper. At 142 msec, the vehicle cleared

0.000 s

0.030 s



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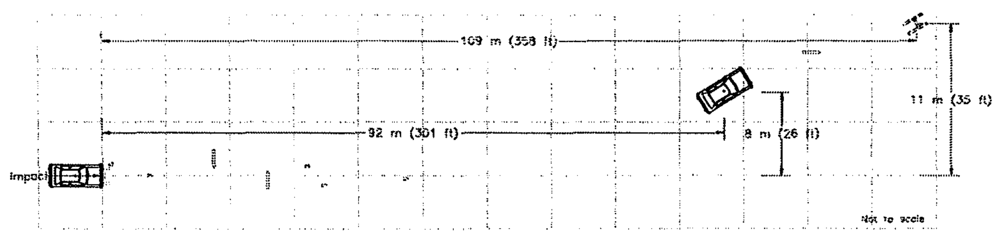
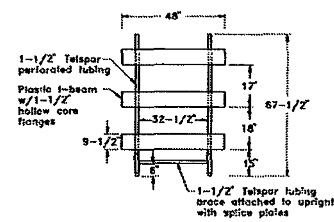




General Information		**Impact Conditions**		**Test Article Deflections (m)**	
Test Agency	Texas Transportation Institute	Speed (km/h)	102.0 (63.4 mi/h)	Thrown Forward	109 (358 ft)
Test No.	453790-3	Angle (deg)	0	Thrown Laterally	11 (35 ft)
Date	08/23/94	**Exit Conditions**			
Test Article		Speed (km/h)	95.2 (59.2 mi/h)	**Vehicle Damage**	
Type	Type III Barricade	Angle (deg)	0	Exterior	
Name or Manufacturer	TrafFix-RAIL	**Occupant Risk Values**		VDS	12FD1
Installation Length (m)	1.2 (4.0 ft)	Impact Velocity (m/s)		CDC	12FDEW1
Size and/or dimension and material of key elements	Plastic panels on 38 mm (1-1/2 in) Telspar perforated tubing	x-direction	1.7 (5.7 ft/s)	Interior	
		y-direction	No Contact	OCDI	FS0000000
		THIV (optional)		Maximum Exterior Vehicle Crush (mm) ..	70 (2.8 in)
Soil Type and Condition .	on Pavement, dry	Ridedown Accelerations (g's)			
Test Vehicle		x-direction	-0.3	Max. Occ. Compart. Deformation (mm) ...	0 (0 in)
Type	Production	y-direction	No Contact		
Designation	820C	PHD (optional)			
Model	1988 Chevrolet Sprint	ASI (optional)		**Post-Impact Behavior**	
Mass (kg) Curb	719 (1584 lb)	Max. 0.050-sec Average (g's)		Max. Roll Angle (deg) .	0.5
Test Inertial	820 (1806 lb)	x-direction	-2.9	Max. Pitch Angle (deg)	-1.2
Dummy ..	75 (165 lb)	y-direction	-0.5	Max. Yaw Angle (deg)	-2.2
Gross Static	897 (1976 lb)	z-direction	0.8		

Figure 48. Summary of Results for Test No. 453790-3

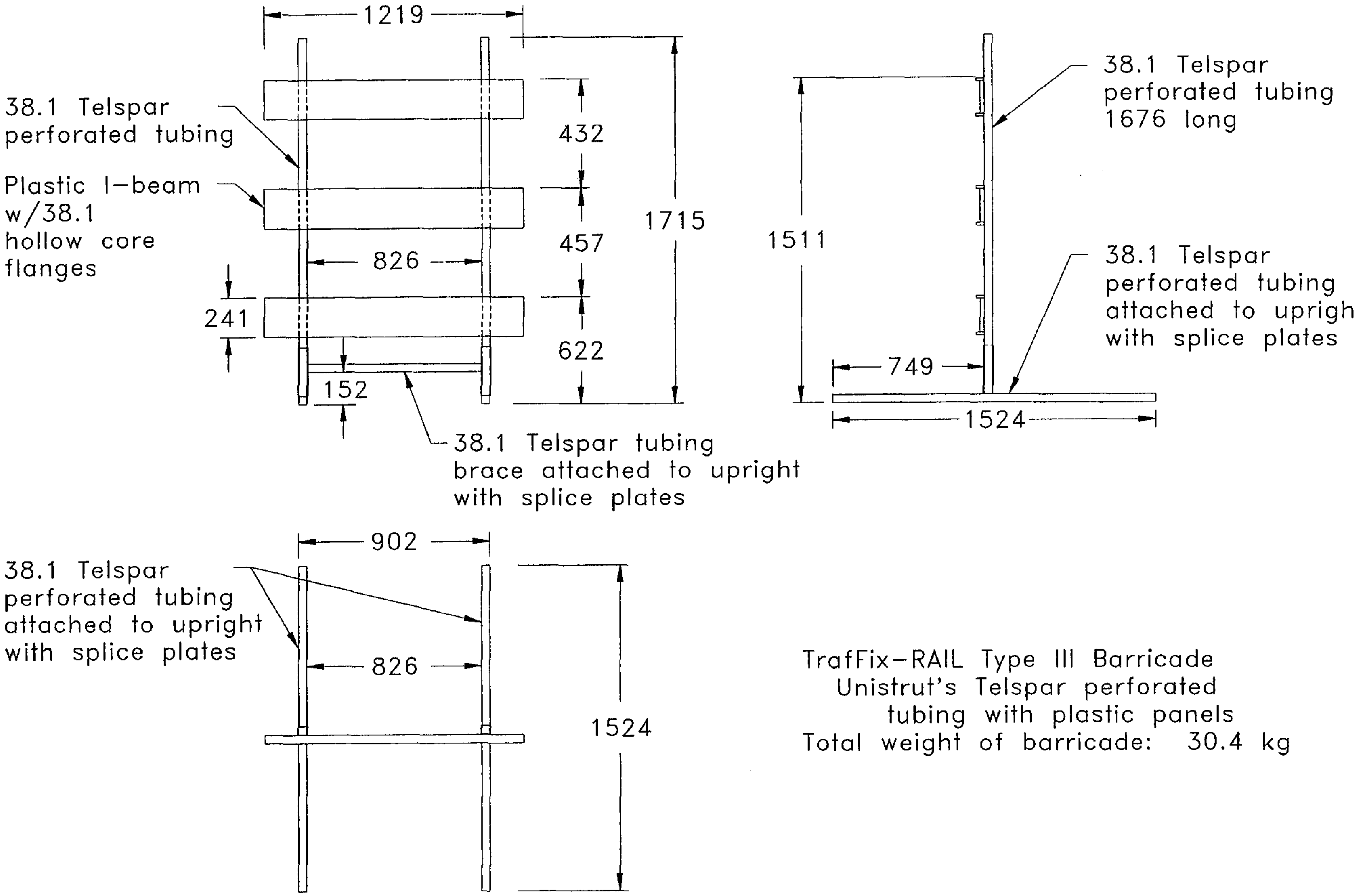


Figure 49. Schematic of Perforated Tubing Type III Barricade with Plastic Rail Elements (Test No. 453880-1)

Figure 50. Vehicle and Barricade for Test No. 453880-1

the installation site traveling at a speed of 92.2 km/h. Prior to brake application, the vehicle was tracking straightforward. The vehicle subsequently came to rest 123 m down and 7.6 m to the left of the point of impact. Figure 51 shows sequential photographs of the test period.

As Figure 50 shows, the plastic rail elements separated from the barricade upon impact, and the barricade came apart subsequently. Debris and sand were strewn along the path of the vehicle in an area 12.6 m wide by 121 m long. Damage to the vehicle is also shown in Figure 50. There were three dents in the roof from impact with the plastic rail elements, and the windshield was cracked. A vertical support made a cut on the roof 15 mm deep and 55 mm long just above the windshield on the driver's side. There were scratches along the hood.

Figure 52 presents a brief summary of the results of this test. The barricade came apart upon impact, and the broken segments contacted the hood, windshield, and roof of the vehicle. However, there was no penetration or intrusion into the occupant compartment. Sand and fragments of the barricade were scattered along an area 12.6 m wide by 121 m long. Most fragments were not large enough to pose potential hazard to oncoming traffic in adjacent lanes; however, the metal tubing from the vertical support could pose a hazard to workers in the area. The vehicle sustained minor damage to the hood and windshield, with a small cut in the roof. The longitudinal occupant impact velocity was 1.9 m/s and the highest 10-msec average ridedown acceleration was -2.7 g. The lateral occupant impact velocity was 1.0 m/s and the highest 10-msec average ridedown acceleration was -3.6 g. The 50-msec average accelerations were -3.3 g in the longitudinal direction and -0.8 g in the lateral direction. The vehicle exited the immediate test site in a relatively smooth, stable manner and showed no potential for intrusion into adjacent traffic lanes.

In summary, the Type III barricade fabricated from perforated tubing with plastic rail elements tested with wet soil condition was judged to have met all evaluation criteria set forth in NCHRP Report 350.

4.2.3 Perforated Tubing with Wooden Rail Elements, Wet Soil Condition (Test No. 453880-2)

A Type III barricade fabricated from perforated steel tubing with wooden rail elements, similar to that used in test nos. 453790-3 and 453880-1, was tested under wet soil condition, i.e., the barricade was placed on wet soil instead of a concrete pavement surface. Figure 53 shows a schematic of the barricade. The barricade was fabricated from perforated steel tubing and wooden panels. The test vehicle was a 1989 Chevrolet Sprint, as shown in Figure 54. Dimensions and information on the vehicle are given in Appendix Figure 90. The test vehicle impacted the plastic Type III barricade head-on with the centerline of the vehicle aligned with the centerline of the barricade, traveling at a speed of 102.7 km/h.

As the vehicle impacted the lower rail element of the barricade, the wooden rail element split and then shattered. The vertical supports deformed and wrapped around the front of the vehicle. At 12 msec after impact, the middle wooden rail element split. At 14 msec, the right vertical support fractured at bumper height, and at 19 msec, the left vertical support also fractured

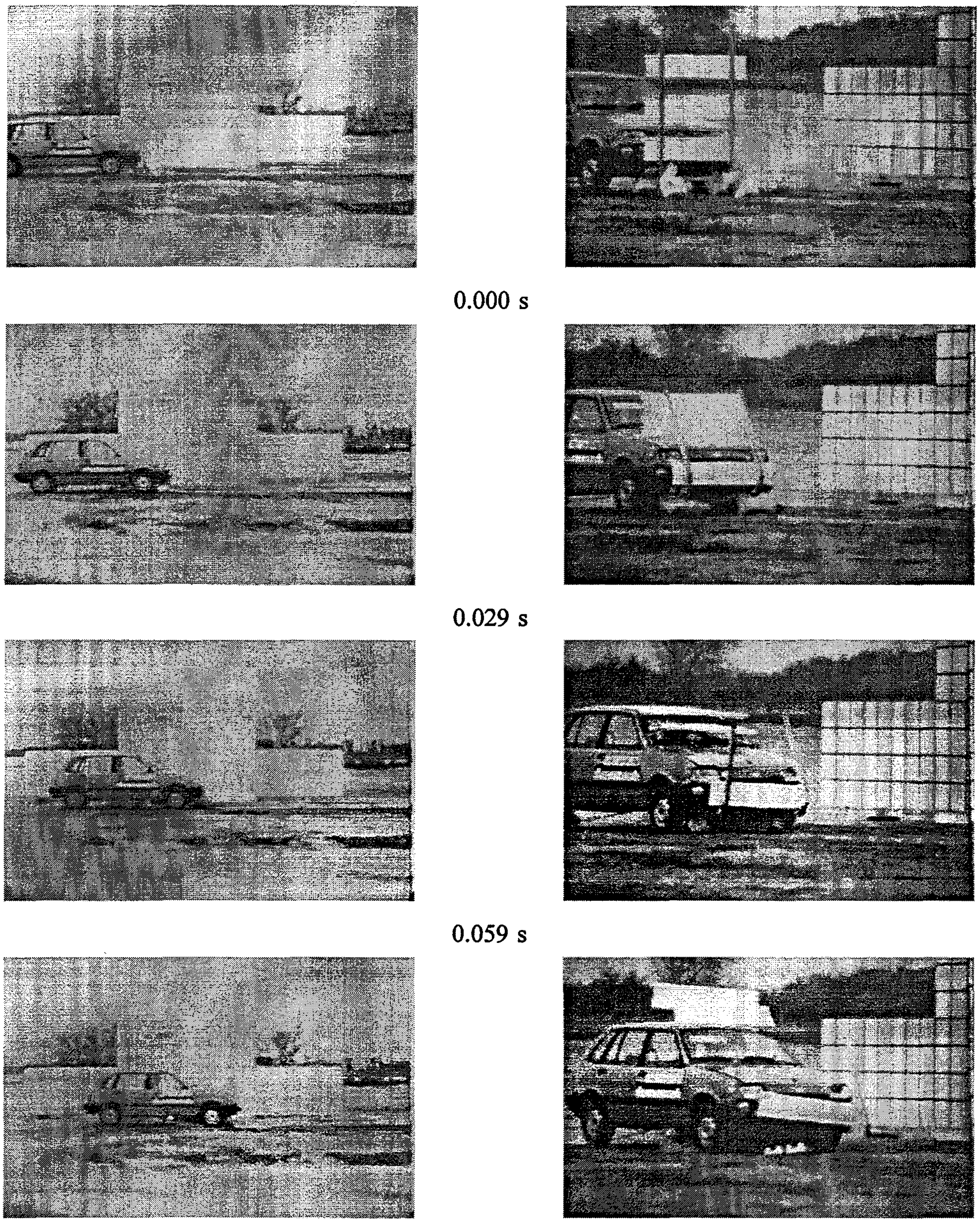
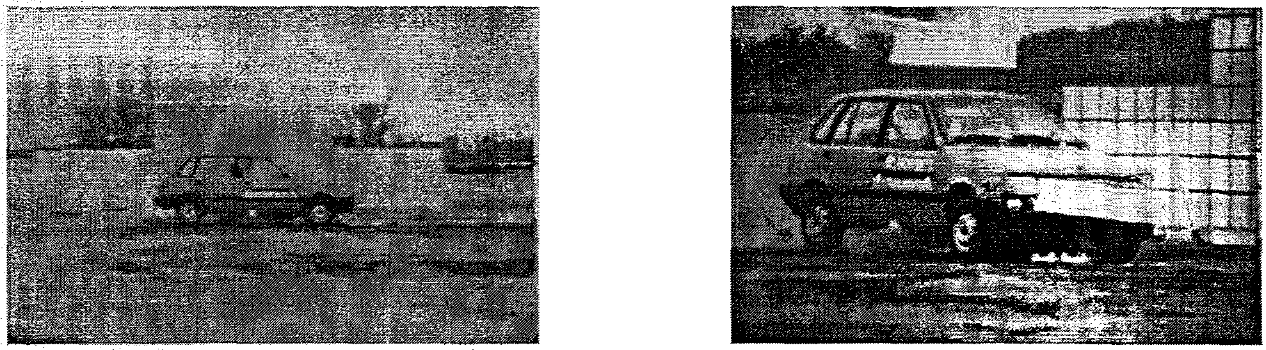
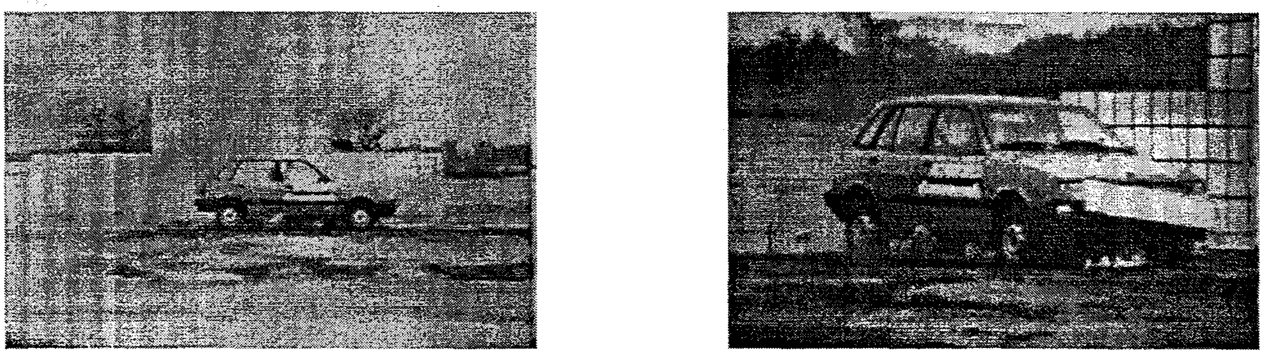


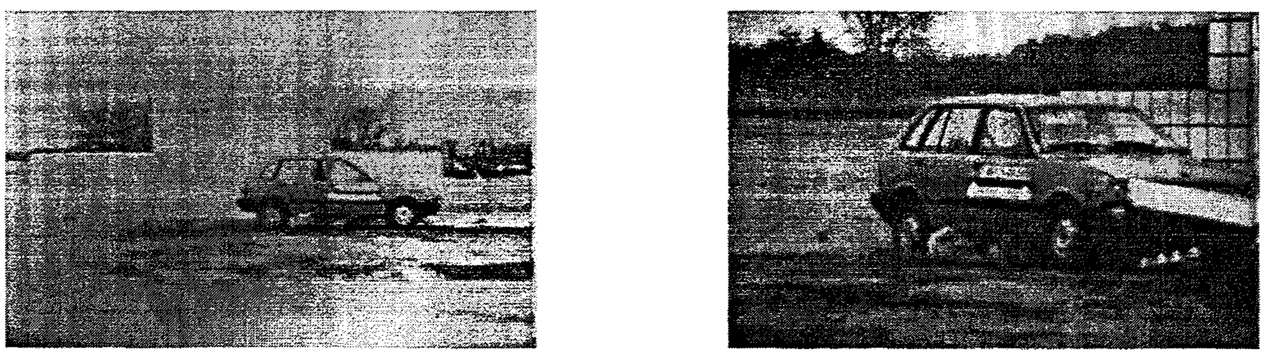
Figure 51. Sequential Photographs for Test No. 453880-1



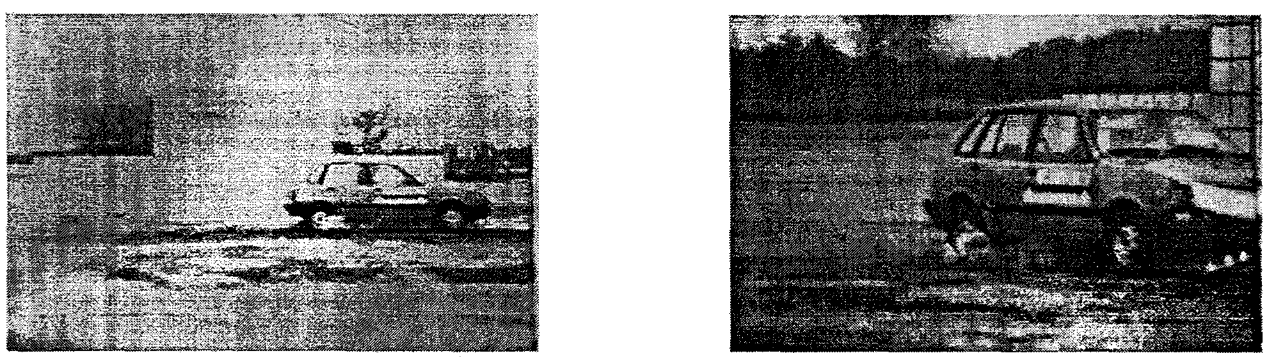
0.120 s



0.150 s

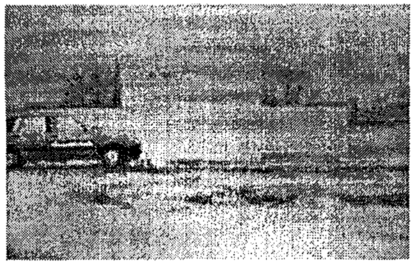


0.179 s

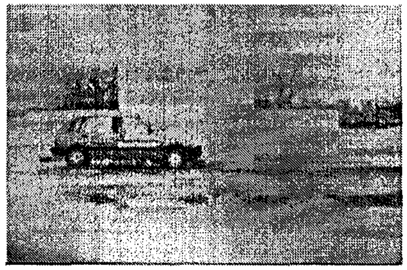


0.211 s

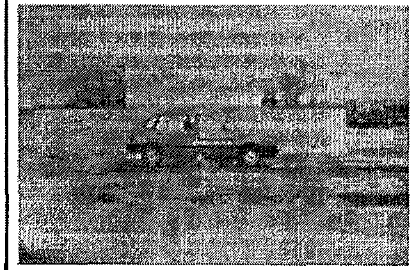
Figure 51. Sequential Photographs for Test No. 453880-1 (continued)



0.000 s

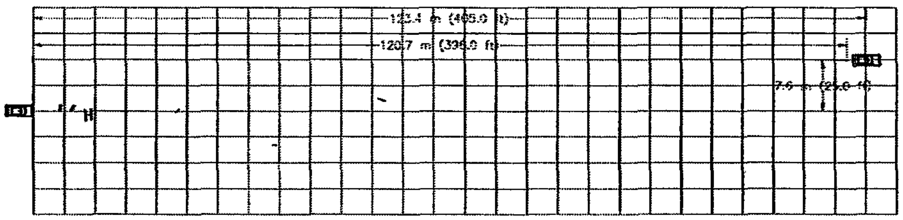


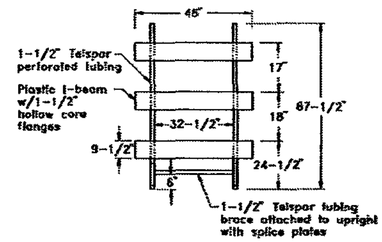
0.059 s



0.120 s

0.179 s





General Information	
Test Agency	Texas Transportation Institute
Test No.	453880-1
Date	02/07/95
Test Article	
Type	Type III Barricade
Name or Manufacturer	TrafFix-RAIL
Installation Length (m) .	1.2 m (4.0 ft)
Size and/or dimension and material of key elements	Plastic panels on 38 mm (1.5 in) Telspar perforated tubing
Soil Type and Condition ..	Strong soil, wet
Test Vehicle	
Type	Production
Designation	820C
Model	1989 Chevrolet Sprint
Mass (kg) Curb	713 (1570 lb)
Test Inertial	820 (1806 lb)
Dummy ...	75 (165 lb)
Gross Static	897 (1975 lb)

Impact Conditions	
Speed (km/h)	100.5 (62.5 mi/h)
Angle (deg)	0
Exit Conditions	
Speed (km/h)	92.2 (57.3 mi/h)
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	1.9 (6.2 ft/s)
y-direction	1.0 (3.4 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-2.7
y-direction	-3.6
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Average (g's)	
x-direction	-3.3
y-direction	-0.8
z-direction	1.7

Test Article Deflections (m)	
Thrown Forward	120.7 (396.0 ft)
Thrown Laterally	7.6 (25.0 ft)
Vehicle Damage	
Exterior	
VDS	12FD1
CDC	12FDEW1
Interior	
OCDI	FS0000000
Maximum Exterior Vehicle Crush (mm) ..	15 (0.6 in)
Max. Occ. Compart. Deformation (mm) ...	0
Post-Impact Behavior	
Max. Roll Angle (deg) ..	-2.0
Max. Pitch Angle (deg) .	-4.2
Max. Yaw Angle (deg) .	-2.2

Figure 52. Summary of Results for Test No. 453880-1

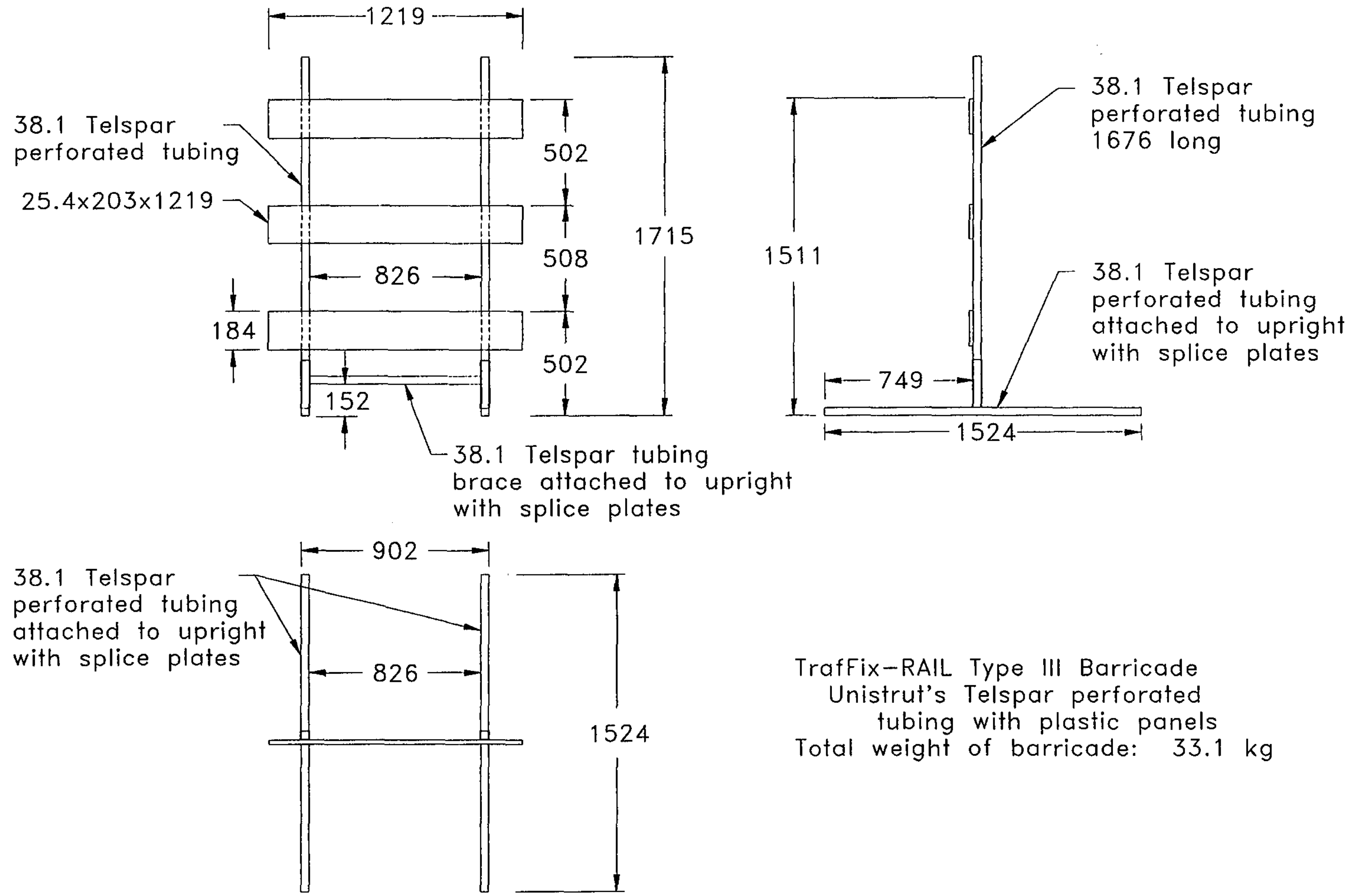


Figure 53. Schematic of Perforated Tubing Type III Barricade with Wooden Rail Elements (Test No. 453880-2)

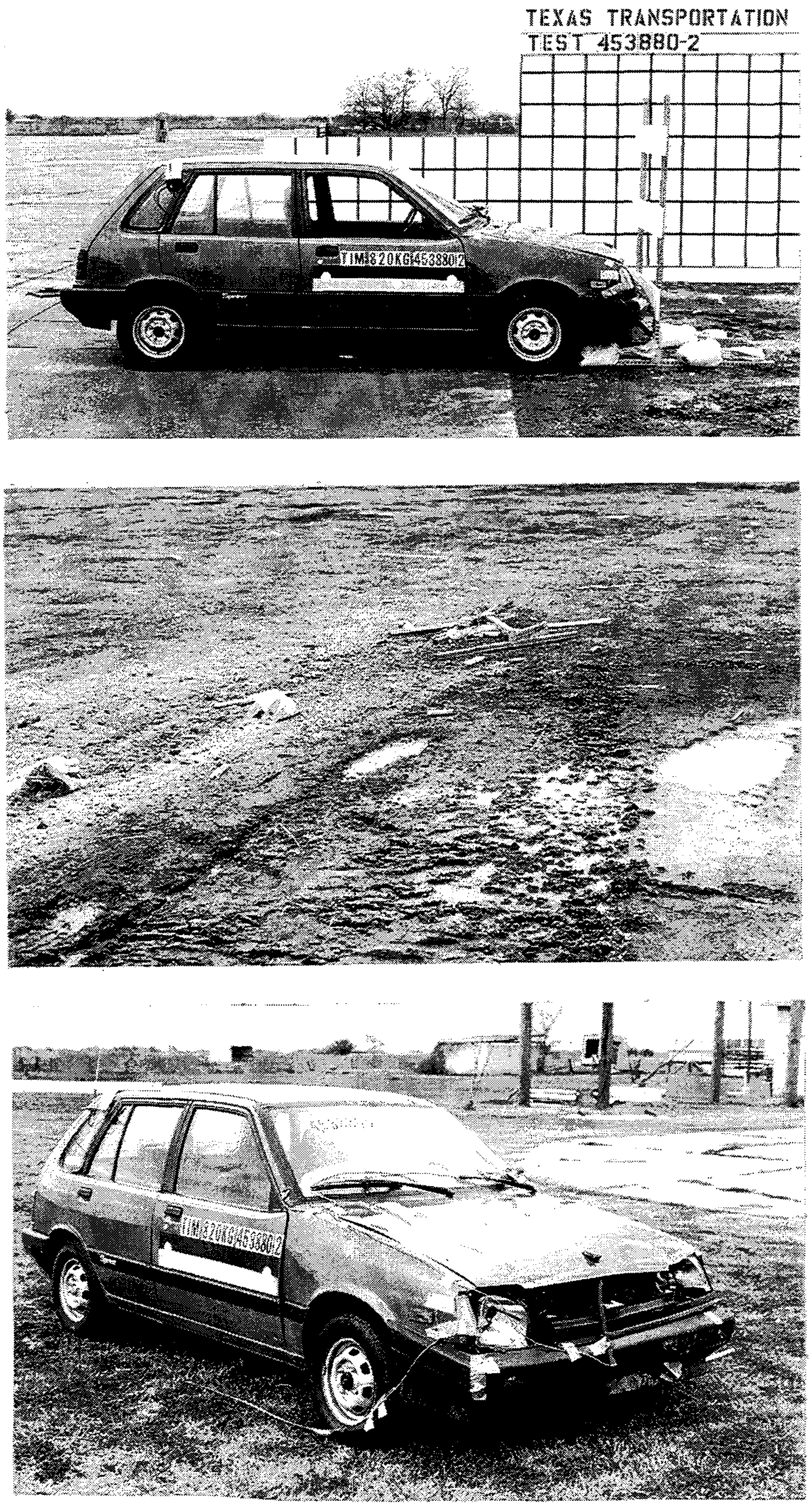


Figure 54. Vehicle and Barricade for Test No. 453880-2

at bumper height. The top wooden rail element contacted the hood of the vehicle at 38 msec. At 46 msec, the right vertical support separated from the rail element and became airborne while the vehicle was traveling at a speed of 93.4 km/h. The left vertical support rode along the front of the vehicle and lost contact with the vehicle at 176 msec as the vehicle had slowed to 92.5 km/h. Prior to brake application, the vehicle was tracking straight-forward. The vehicle subsequently came to rest 116 m down and 6.7 m left of the point of impact. Figure 55 shows sequential photographs of the test period.

As Figure 54 shows, the barricade shattered upon impact. Debris and sand were strewn along the path of the vehicle in an area 11 m wide by 46 m long. Figure 54 shows damage to the vehicle. There were dents and scratches along the bumper, grill, and hood, and the left rear tire was flat.

A brief summary of the results of this test is presented in Figure 56. The barricade shattered upon impact and broken segments of the barricade made contact with the hood but did not penetrate the occupant compartment. Debris from the barricade was thrown along an area 11 m wide by 46 m long. Most fragments were not large enough to pose potential hazard to oncoming traffic in adjacent lanes. The fractured metal vertical supports could cause minor hazard to workers in the area. The vehicle sustained minor damage to the bumper, grill, and hood. There was no penetration or intrusion into the occupant compartment. The longitudinal occupant impact velocity was 2.3 m/s, and the highest 10-msec average ridedown acceleration was -1.8 g. There was no lateral occupant contact. The 50-msec average accelerations were -3.5 g in the longitudinal direction and 0.7 g in the lateral direction. The vehicle exited the immediate test site in a relatively smooth, stable manner and showed no potential for intrusion into adjacent traffic lanes.

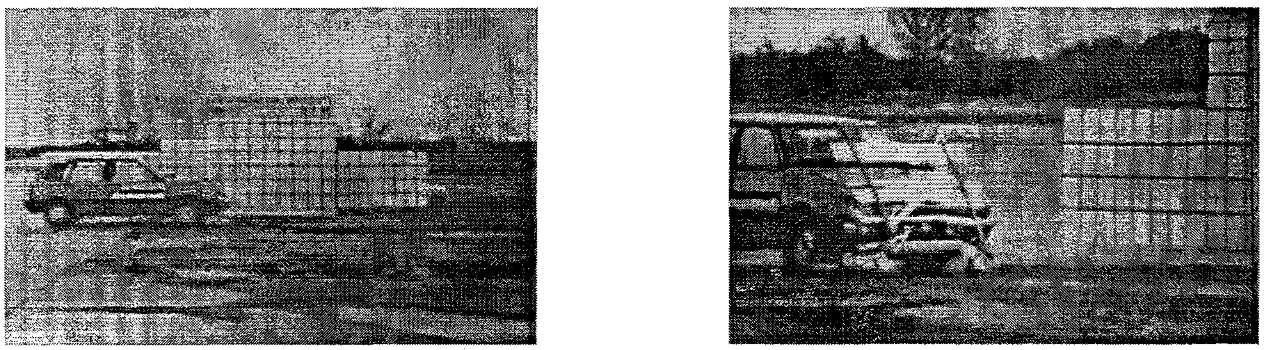
In summary, the Type III barricade fabricated from perforated tubing with wooden rail elements tested with wet soil condition was also judged to have met all evaluation criteria set forth in NCHRP Report 350.

4.2.4 Plastic Type III Barricade by Tex-Mex Barricade (Test No. 453790-2)

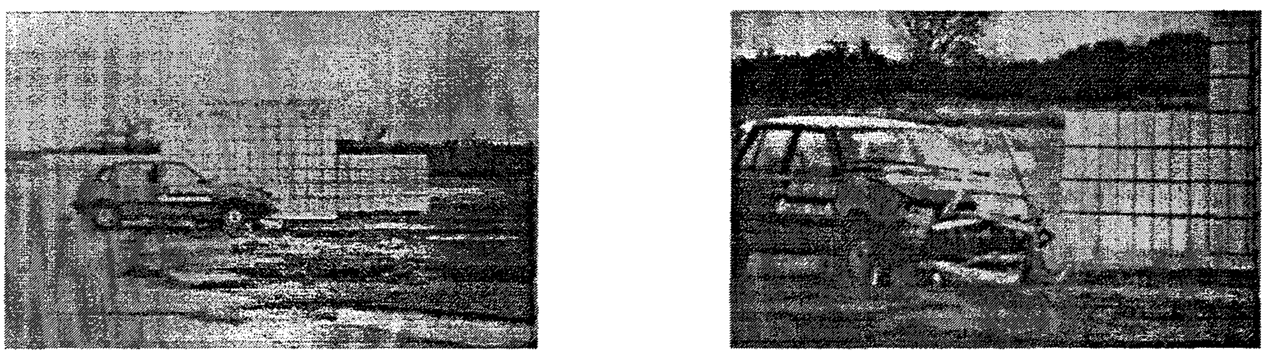
Figure 57 shows a schematic of the plastic Type III barricade manufactured by Tex-Mex Barricade. The test vehicle was a 1988 Chevrolet Sprint, as shown in Figure 58. Appendix Figure 94 gives dimensions and information on the vehicle. The test vehicle impacted the plastic Type III barricade head-on with the centerline of the vehicle aligned with the centerline of the barricade, traveling at a speed of 100.3 km/h.

As the vehicle impacted the barricade, the vertical supports separated from the base as one unit and deformed to the front of the vehicle. At 57 msec, the barricade was in full contact with the hood of the vehicle and continued up and over the vehicle. The vehicle lost contact with the barricade at 69 msec, traveling at a speed of 96.3 km/h. Prior to brake application, the vehicle was tracking straightforward. The vehicle subsequently came to rest 85 m down and 2.6 m left of the point of impact. Figure 59 shows sequential photographs of the test period.

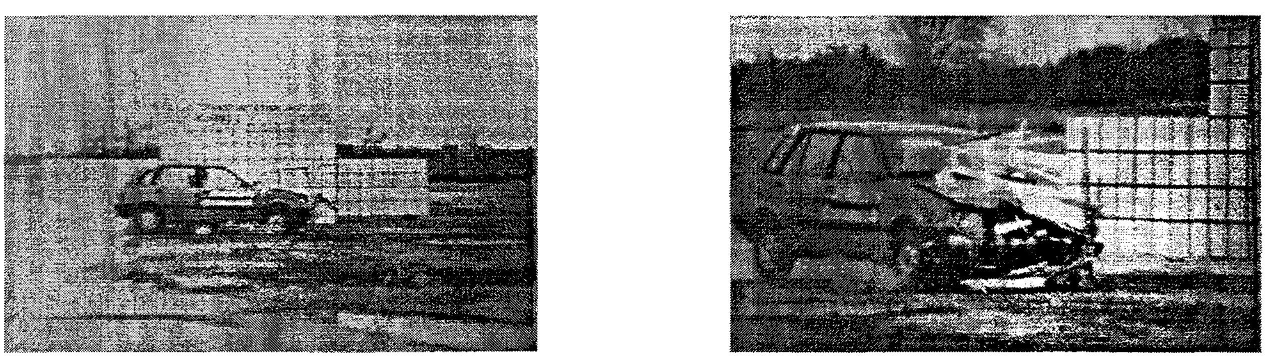
0.000 s



0.029 s



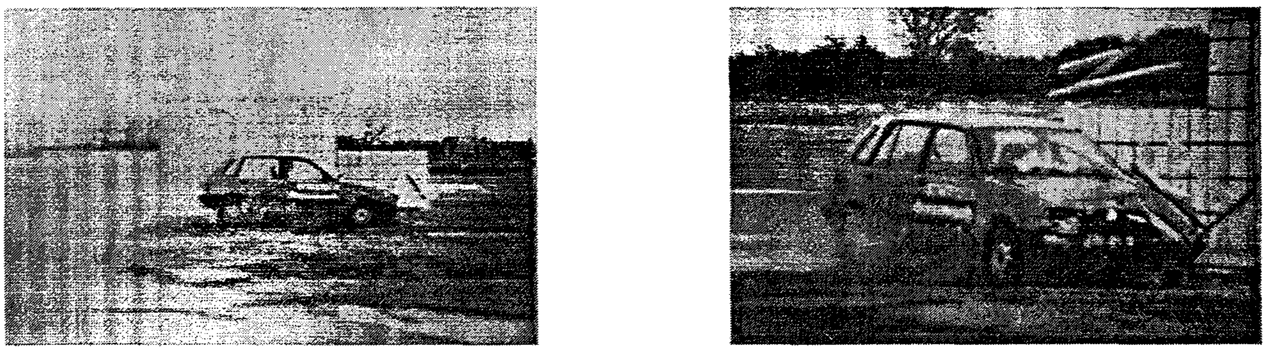
0.061 s



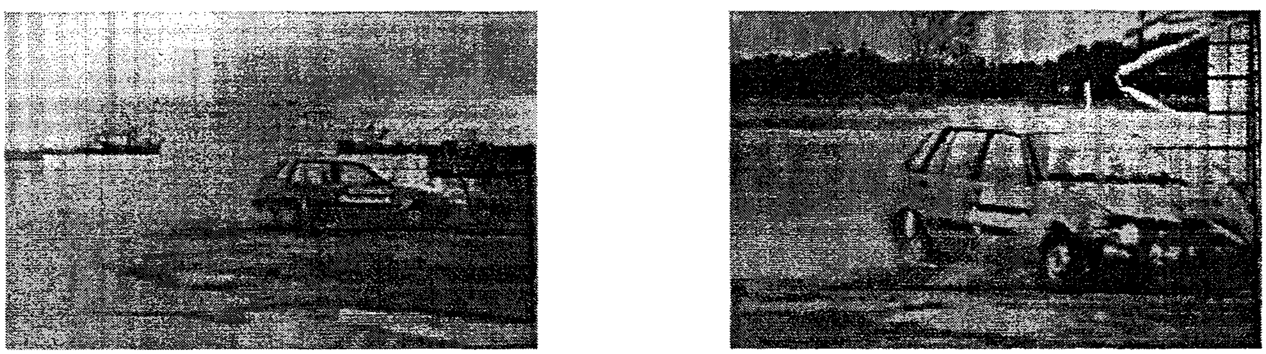
0.091 s

Figure 55. Sequential Photographs for Test No. 453880-2

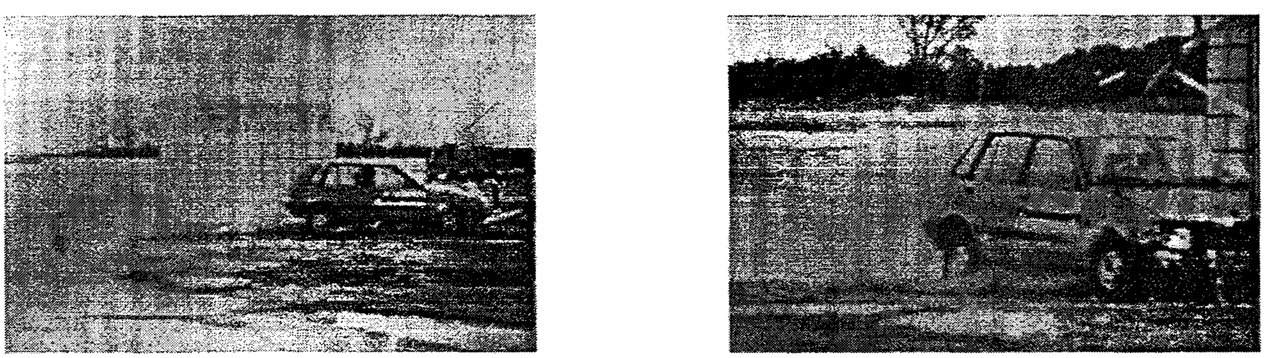
0.120 s



0.149 s

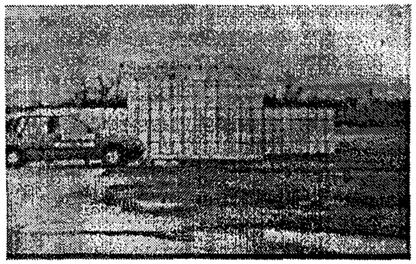


0.181 s

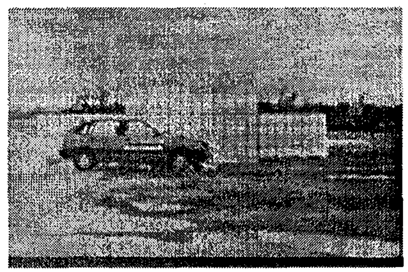


0.211 s

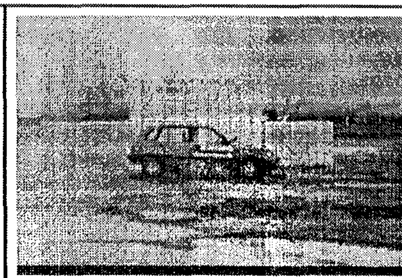
Figure 55. Sequential Photographs for Test No. 453880-2 (continued)



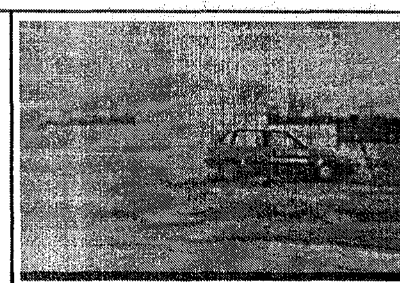
0.000 s



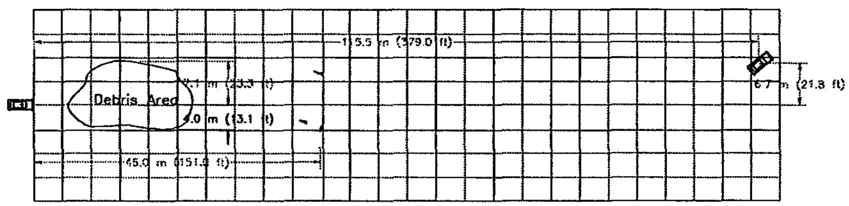
0.061 s

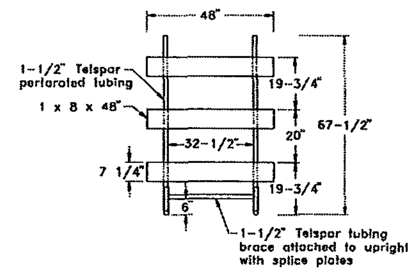


0.120 s



0.181 s





General Information		**Impact Conditions**		**Test Article Deflections (m)**	
Test Agency	Texas Transportation Institute	Speed (km/h)	102.7 (63.4 mi/h)	Thrown Forward	46.0 (151.0 ft)
Test No.	453880-2	Angle (deg)	0	Thrown Laterally	7.1 (23.3 ft)
Date	02/07/95	**Exit Conditions**			
Test Article		Speed (km/h)	92.5 (57.5 mi/h)	**Vehicle Damage**	
Type	Type III Barricade	Angle (deg)	0	Exterior	
Name or Manufacturer	TrafFix-RAIL	**Occupant Risk Values**		VDS	12FD1
Installation Length (m)	1.2 m (4.0 ft)	Impact Velocity (m/s)		CDC	12FDEW1
Size and/or dimension	Wood panels on	x-direction	2.3 (7.6 ft/s)	Interior	
and material of key	38 mm (1.5 in) Telspar	y-direction	No Contact	OCDI	FS0000000
elements	perforated tubing	THIV (optional)		Maximum Exterior	
Soil Type and Condition	Strong soil, wet	Ridedown Accelerations (g's)		Vehicle Crush (mm)	0
Test Vehicle		x-direction	-1.8	Max. Occ. Compart.	
Type	Production	y-direction	N/A	Deformation (mm)	0
Designation	820C	PHD (optional)			
Model	1989 Chevrolet Sprint	ASI (optional)		**Post-Impact Behavior**	
Mass (kg) Curb	713 (1570 lb)	Max. 0.050-sec Average (g's)		Max. Roll Angle (deg)	6.2
Test Inertial	820 (1806 lb)	x-direction	-3.5	Max. Pitch Angle (deg)	-2.5
Dummy	75 (165 lb)	y-direction	0.7	Max. Yaw Angle (deg)	-4.5
Gross Static	897 (1975 lb)	z-direction	2.2		

Figure 56. Summary of Results for Test No. 453880-2

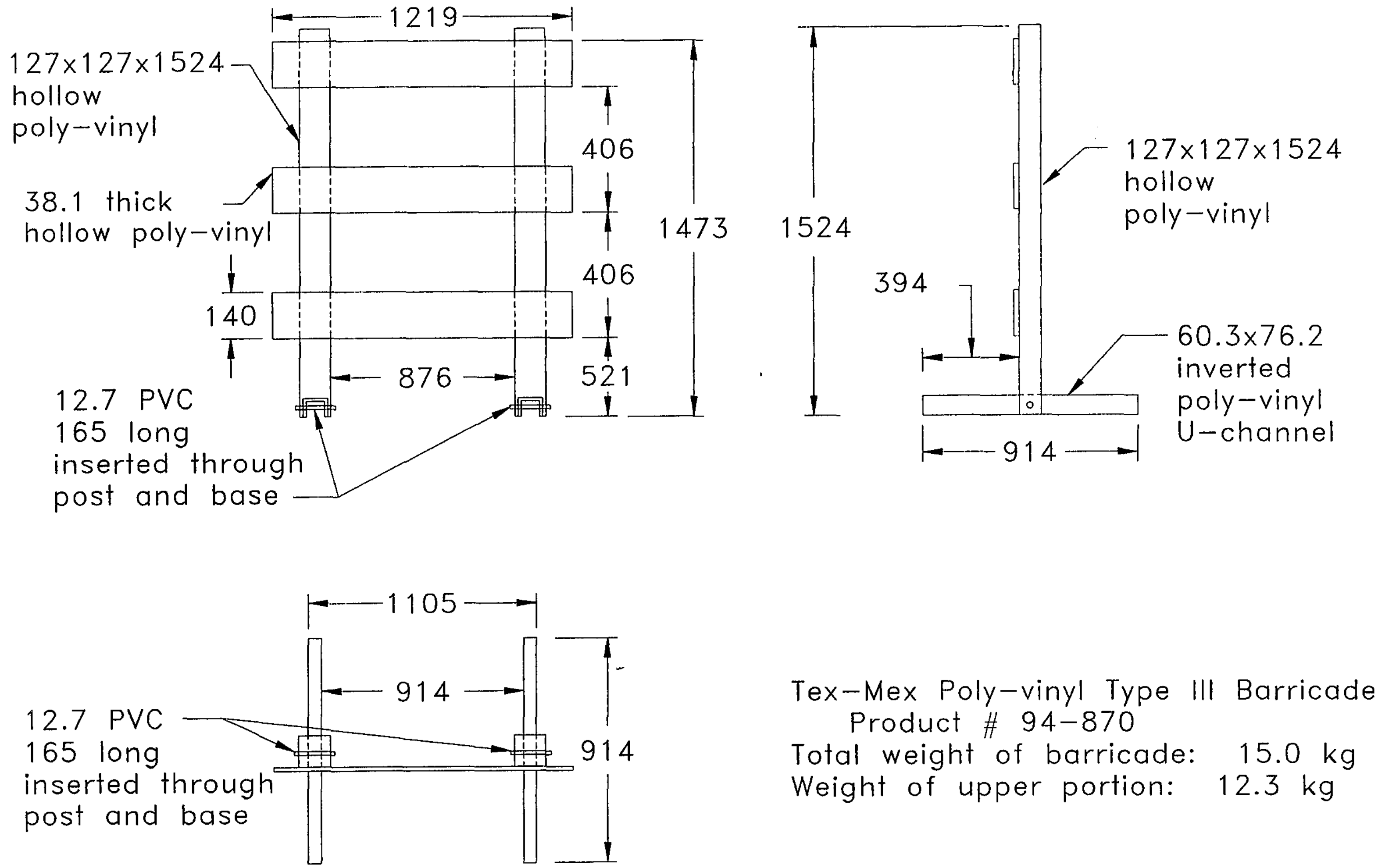


Figure 57. Schematic of Plastic Type III Barricade by Tex-Mex Barricade (Test No. 453790-2)

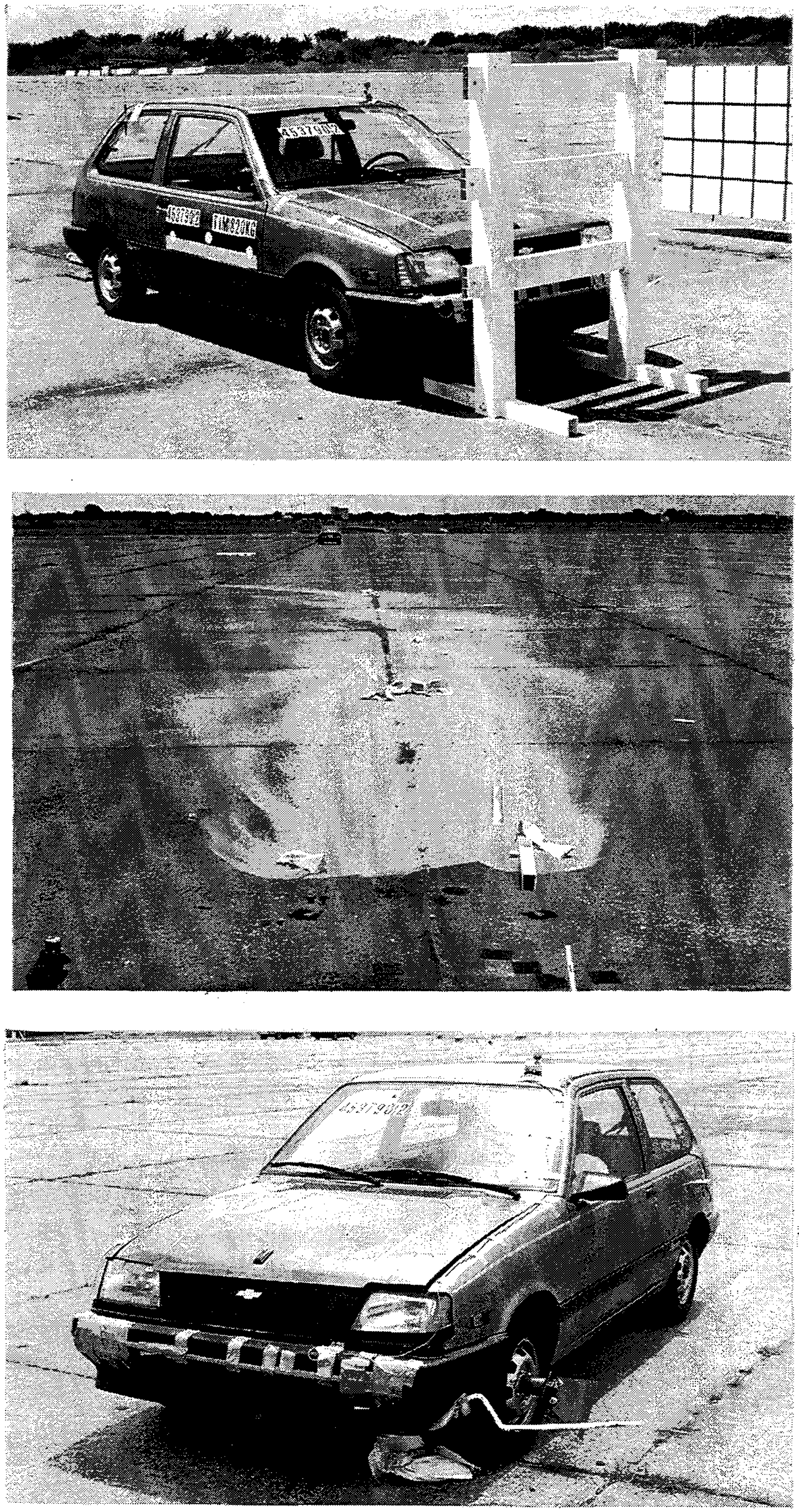
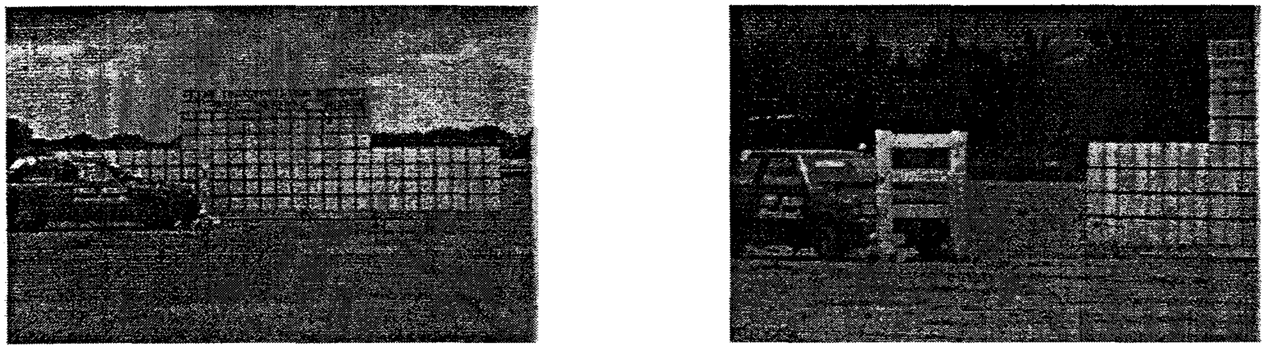
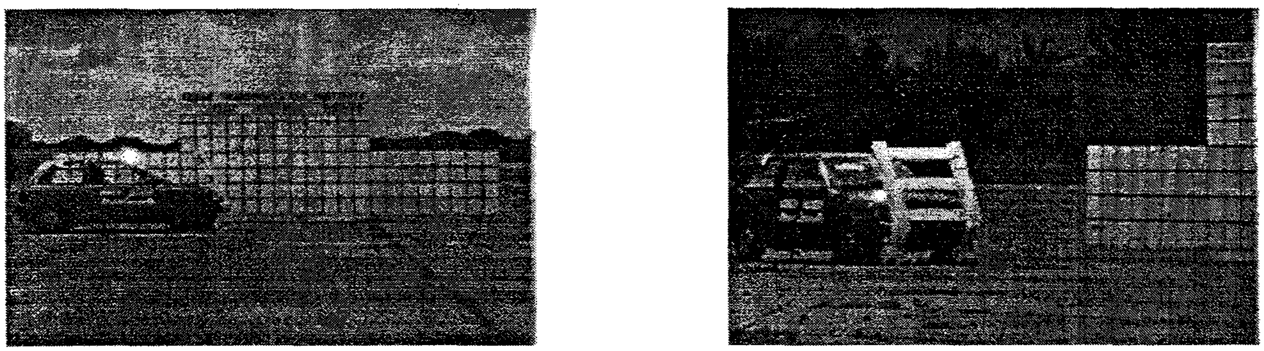


Figure 58. Vehicle and barricade for Test No. 453790-2



0.000 s

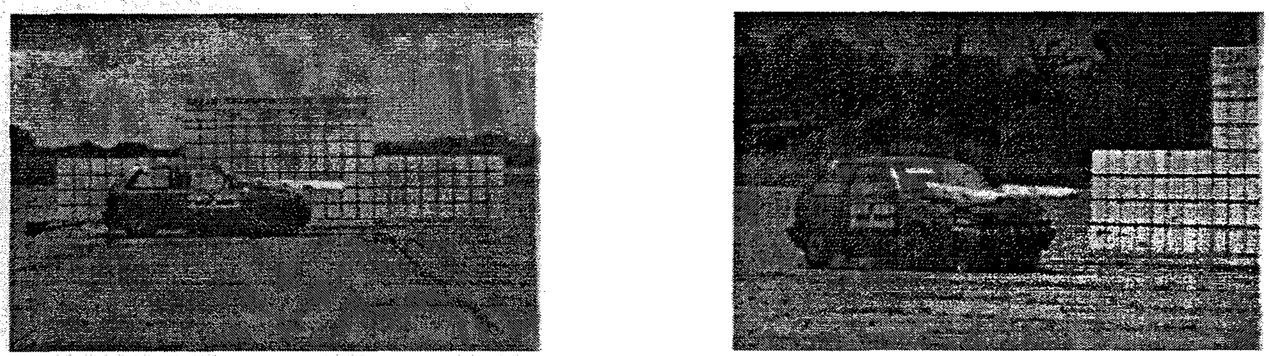


0.017 s

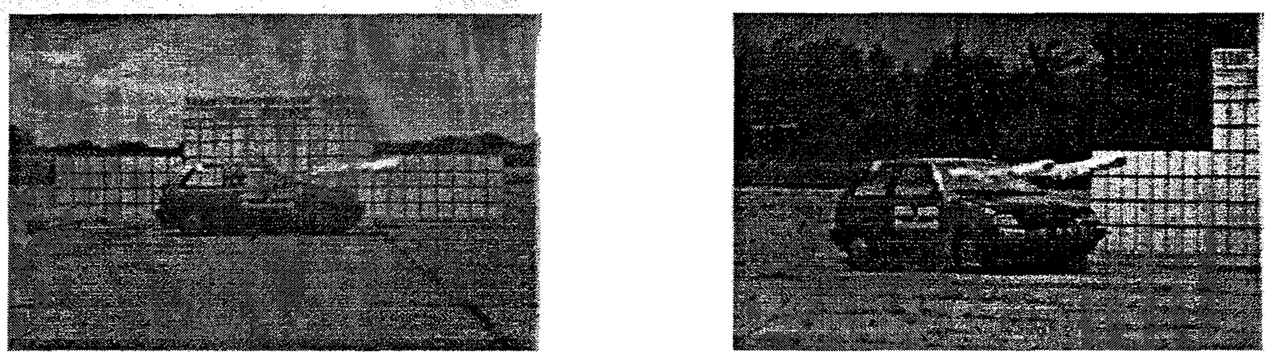
0.035 s

0.052 s

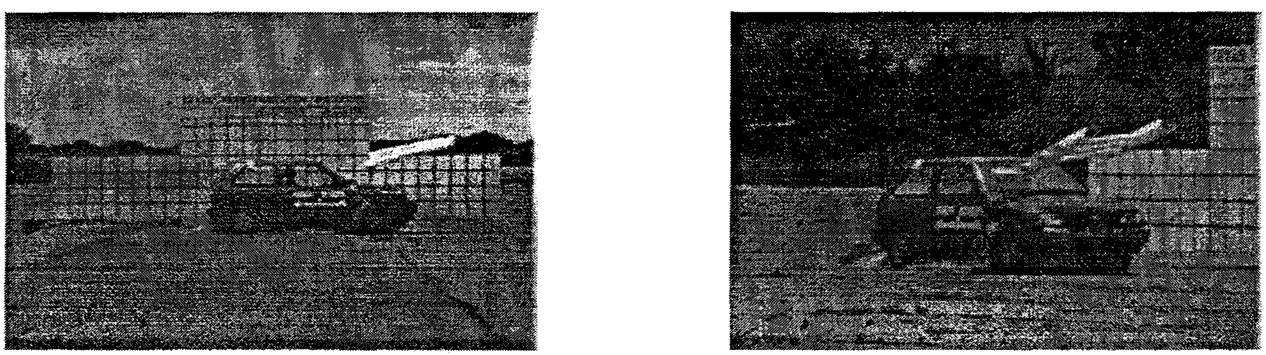
Figure 59. Sequential Photographs for Test No. 453790-2.



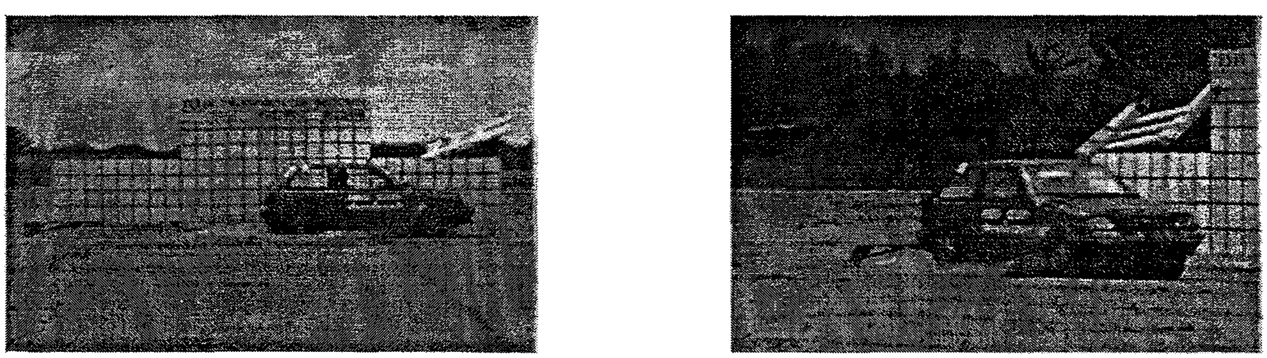
0.069 s



0.104 s



0.138 s



0.173 s

Figure 59. Sequential Photographs for Test No. 453790-2 (continued)

As Figure 58 shows, the barricade separated from the base upon impact. Debris and sand were strewn along the path of the vehicle in an area 6 m wide by 54 m long. Figure 58 also shows damage to the vehicle. The bumper was pushed up slightly, and the headlight on the driver's side was loose. The hood was dented on each corner, and there were three scratches along the hood.

A brief summary of the results of this test is presented in Figure 60. The vertical supports of the barricade separated from the base upon impact and made contact with the hood, but did not penetrate the occupant compartment. Debris from the barricade was thrown along an area 6 m wide by 54 m long. Most fragments were not large enough or heavy enough to pose potential hazard to oncoming traffic in adjacent lanes; however, the vertical supports may pose a slight hazard to workers in the area. The vehicle sustained minor damage to the bumper and hood. The longitudinal occupant impact velocity was 0.8 m/s, and the highest 10-msec average ridedown acceleration was -0.2 g. There was no lateral occupant contact. The 50-msec average accelerations were -1.9 g in the longitudinal direction and -0.3 g in the lateral direction. The vehicle exited the immediate test site in a relatively smooth, stable manner and showed no potential for intrusion into adjacent traffic lanes.

In summary, the plastic Type III barricade by Tex-Mex Barricade was judged to have met all evaluation criteria set forth in NCHRP Report 350.

4.2.5 Hollow Core Recycled Plastic Material with Wooden Base (Test No. 453790-4)

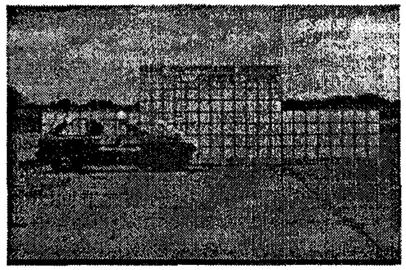
Figure 61 shows a schematic of the Type III barricade fabricated from hollow core recycled plastic material with a wooden base. The construction was similar to that of the Type III wooden barricade. The test vehicle was a 1988 Chevrolet Sprint, as shown in Figure 62. Dimensions and information on the vehicle are given in Appendix Figure 96. The test vehicle impacted the barricade head-on with the centerline of the vehicle aligned with the centerline of the barricade, traveling at a speed of 101.9 km/h.

At 10 msec after impact, the braces for the vertical supports broke away, and at 15 msec, the vertical supports and rail elements separated from the base as a single unit. The top of the vertical supports contacted the wipers in the windshield area at 47 msec. The vehicle lost contact with the barricade at 87 msec, traveling at a speed of 93.5 km/h. Prior to brake application, the vehicle was tracking straight-forward. The vehicle subsequently came to rest 76 m down and 1.5 m to the left of the point of impact. Figure 63 shows sequential photographs of the test period.

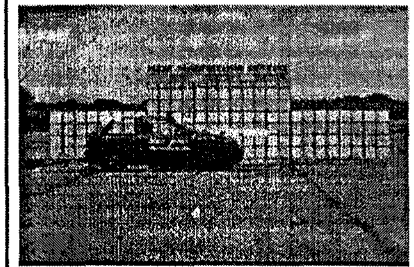
As Figure 62 shows, the hollow core recycled plastic vertical supports and rail elements separated from the wooden base upon impact. Debris and sand were strewn along the path of the vehicle in an area 17 m wide by 77 m long. Figure 62 also shows damage to the vehicle. The bumper and hood of the vehicle were scratched. No penetration or intrusion of the occupant compartment occurred. There was no measurable crush to the exterior of the vehicle.

Figure 64 presents a brief summary of the results of this test. The hollow core plastic vertical supports and rail elements separated from the wooden base and made contact with the

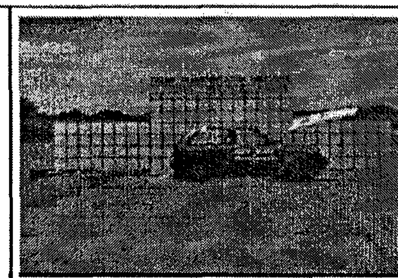
0.000 s



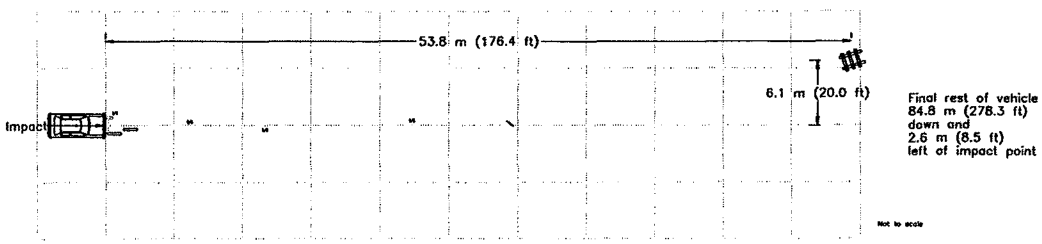
0.035 s

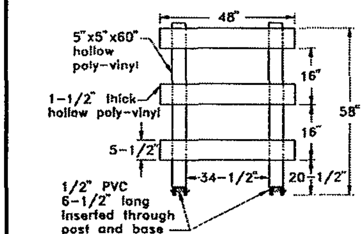


0.069 s



0.138 s





General Information	
Test Agency	Texas Transportation Institute
Test No.	453790-2
Date	08/23/94
Test Article	
Type	Type III Barricade
Name or Manufacturer	Tex-Mex Barricade
Installation Length (m)	1.2 (4.0 ft)
Size and/or dimension and material of key elements	Poly-vinyl material
Soil Type and Condition	on Pavement, dry
Test Vehicle	
Type	Production
Designation	820C
Model	1988 Chevrolet Sprint
Mass (kg) Curb	719 (1584 lb)
Test Inertial	820 (1806 lb)
Dummy	75 (165 lb)
Gross Static	897 (1976 lb)

Impact Conditions	
Speed (km/h)	100.3 (62.4 mi/h)
Angle (deg)	0
Exit Conditions	
Speed (km/h)	96.3 (59.8 mi/h)
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	0.8 (2.5 ft/s)
y-direction	No Contact
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-0.2
y-direction	No Contact
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Average (g's)	
x-direction	-1.9
y-direction	-0.3
z-direction	0.9

Test Article Deflections (m)	
Thrown Forward	53.8 (176.4 ft)
Thrown Laterally	6.1 (20.0 ft)
Vehicle Damage	
Exterior	
VDS	12FD1
CDC	12FDEW1
Interior	
OCDI	FS0000000
Maximum Exterior Vehicle Crush (mm)	Nil (scratched)
Max. Occ. Compart. Deformation (mm)	0 (0 in)
Post-Impact Behavior	
Max. Roll Angle (deg)	-2.6
Max. Pitch Angle (deg)	1.2
Max. Yaw Angle (deg)	-2.4

Figure 60. Summary of Results for Test No. 453790-2

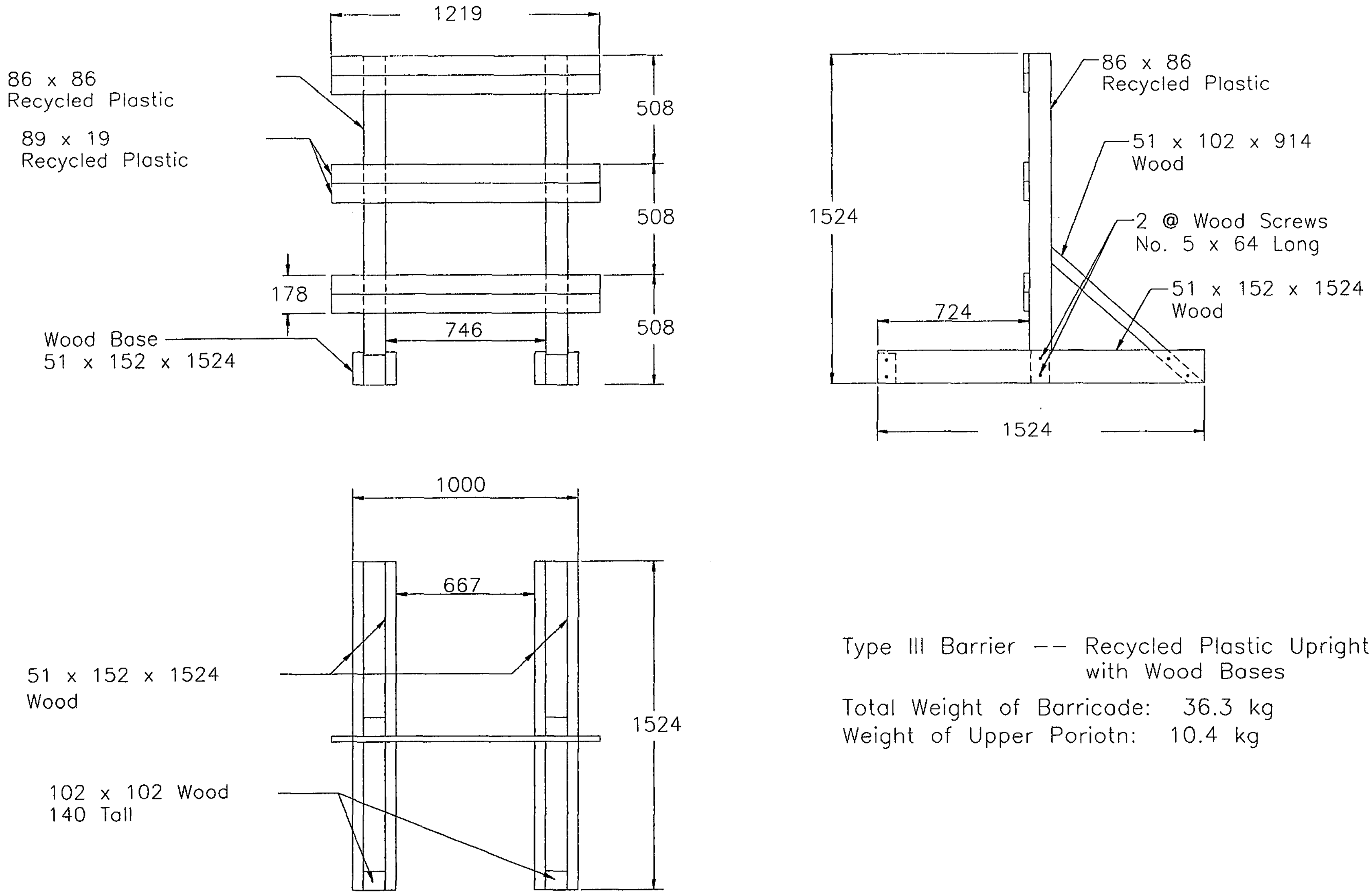


Figure 61. Schematic of Type III Barricade Fabricated from Hollow Core Recycled Plastic Material with Wooden Base (Test No. 453790-4)

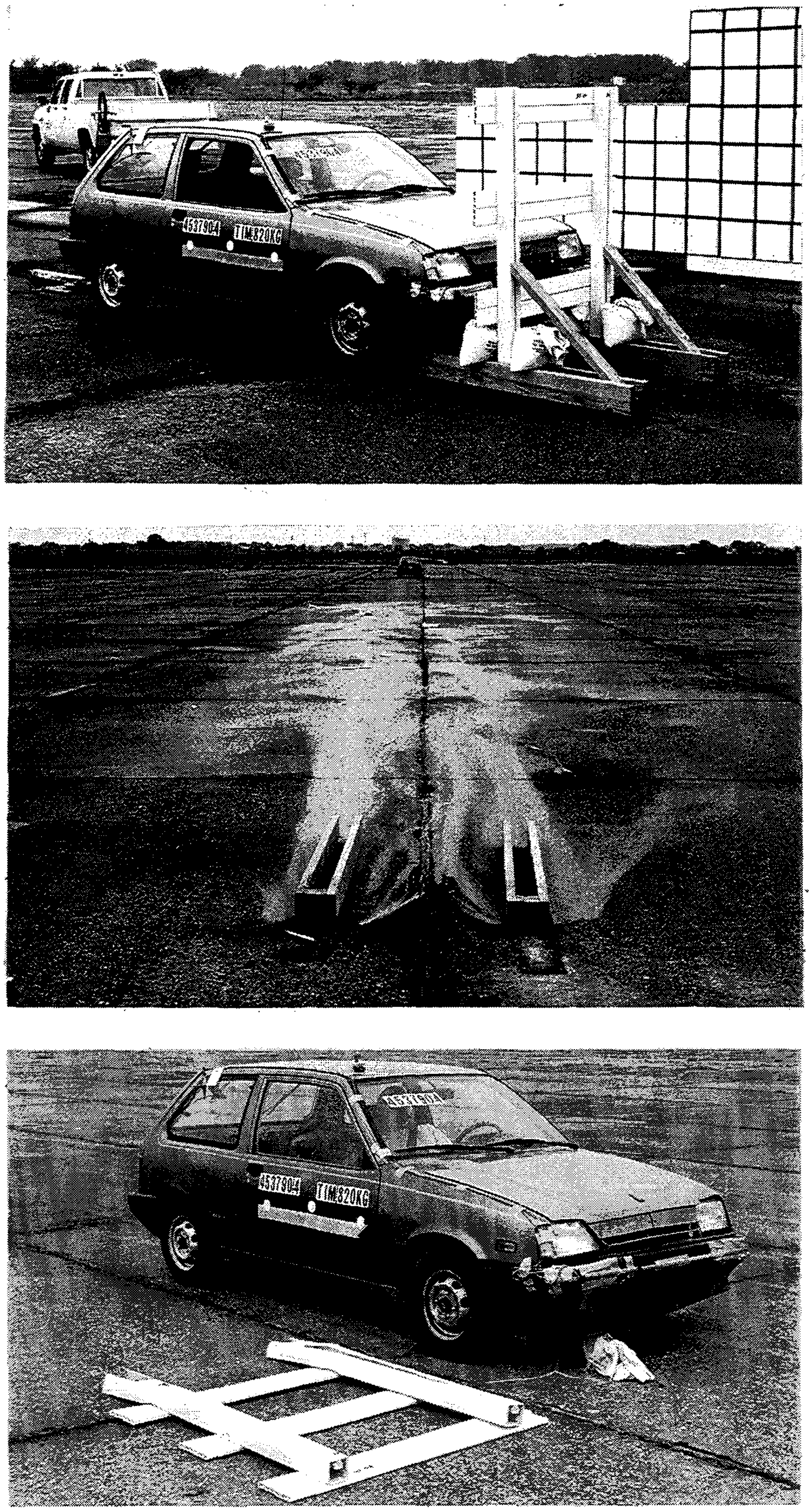
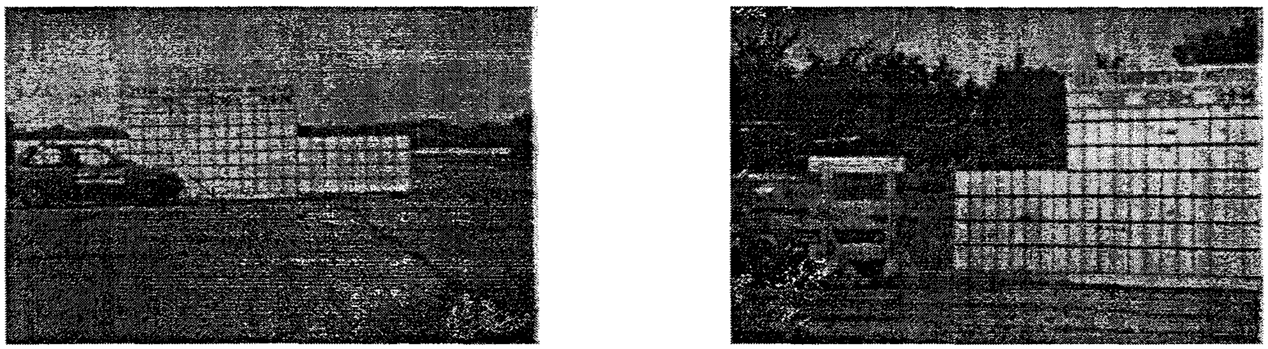


Figure 62. Vehicle and Barricade for Test No. 453790-4

0.000 s



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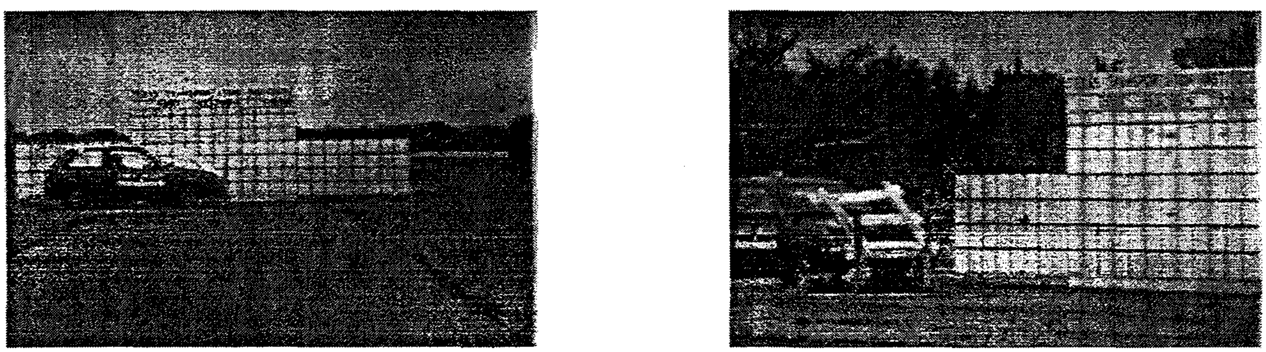
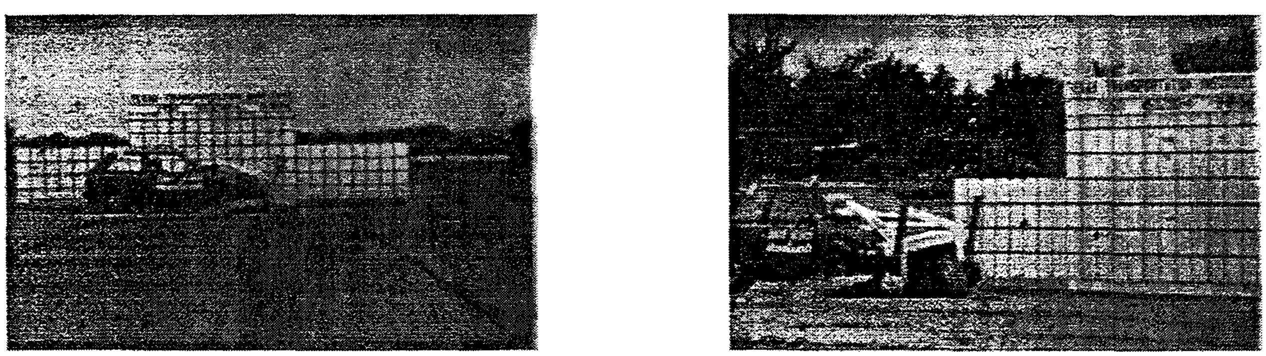


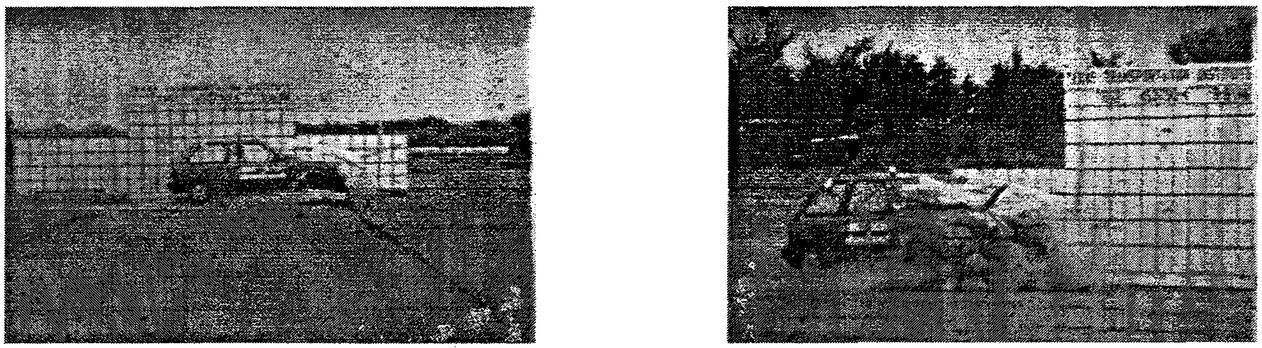
0.057 s



0.087 s

Figure 63. Sequential Photographs for Test No. 453790-4

0.114 s



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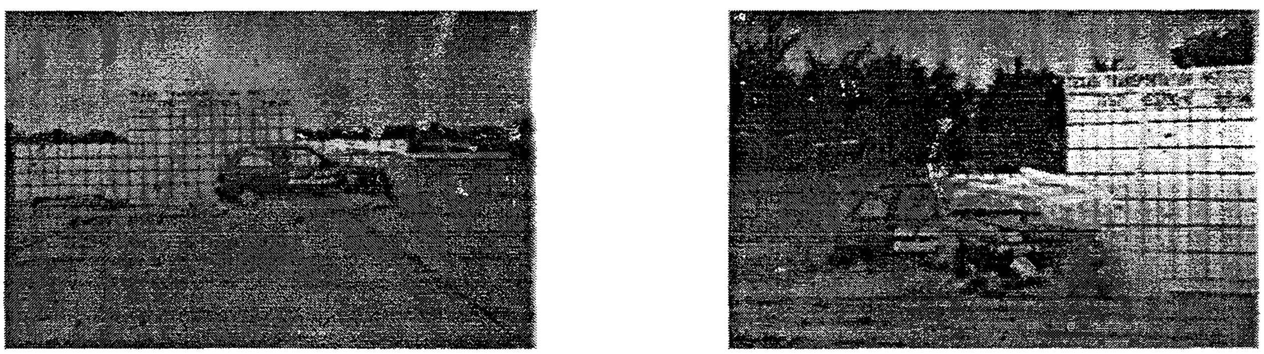
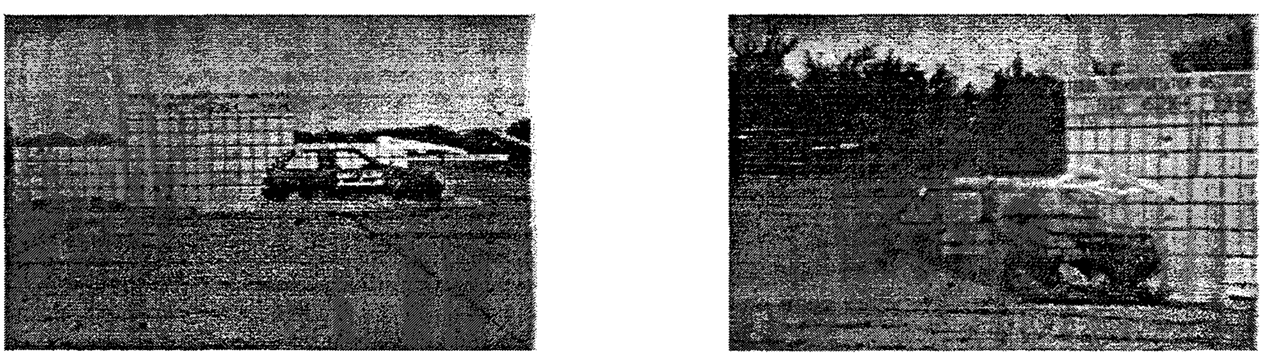
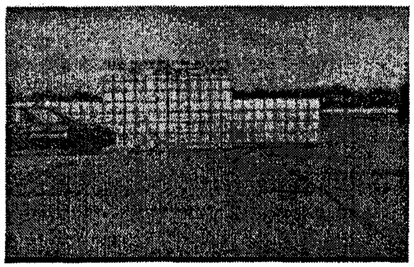


0.188 s

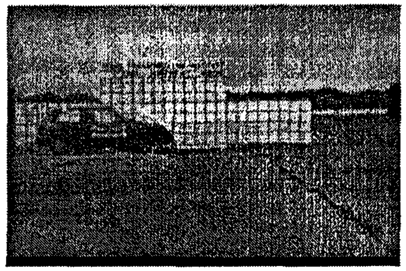


0.225 s

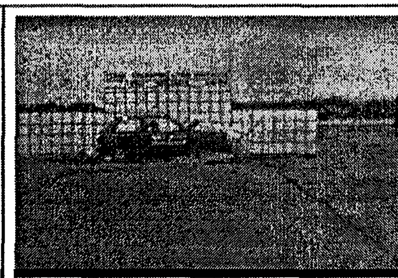
Figure 63. Sequential Photographs for Test No. 453790-4 (continued)



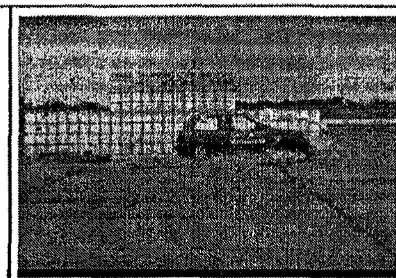
0.000 s



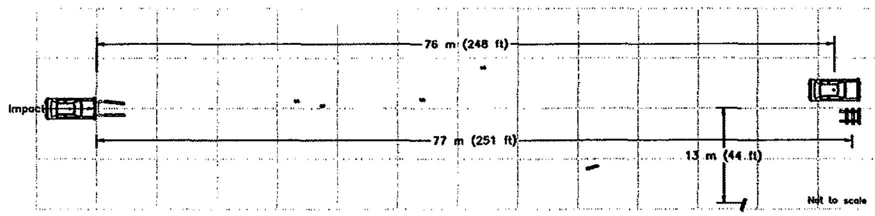
0.057 s

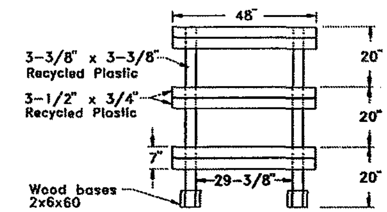


0.114 s



0.188 s





General Information	
Test Agency	Texas Transportation Institute
Test No.	453790-4
Date	09/08/94
Test Article	
Type	Type III Barricade
Name or Manufacturer	
Installation Length (m)	1.2 m (4.0 ft)
Size and/or dimension and material of key elements	Recycled Plastic upright with wood base
Soil Type and Condition .	on Pavement, dry
Test Vehicle	
Type	Production
Designation	820C
Model	1988 Chevrolet Sprint
Mass (kg) Curb	719 (1583 lb)
Test Inertial	820 (1806 lb)
Dummy ..	75 (165 lb)
Gross Static	897 (1976 lb)

Impact Conditions	
Speed (km/h)	101.9 (63.3 mi/h)
Angle (deg)	0
Exit Conditions	
Speed (km/h)	93.5 (58.1 mi/h)
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	1.6 (5.3 ft/s)
y-direction	No Contact
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	0.4
y-direction	No Contact
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Average (g's)	
x-direction	-3.3
y-direction	-0.3
z-direction	-1.7

Test Article Deflections (m)	
Thrown Forward	76.5 (251.0 ft)
Thrown Laterally	13.6 (44.5 ft)
Vehicle Damage	
Exterior	
VDS	12FD1
CDC	12FDEW1
Interior	
OCDI	FS0000000
Maximum Exterior Vehicle Crush (mm) ..	0 (scratched)
Max. Occ. Compart. Deformation (mm) ...	0 (0 in)
Post-Impact Behavior	
Max. Roll Angle (deg) ..	-3.8
Max. Pitch Angle (deg) .	2.6
Max. Yaw Angle (deg) .	3.3

Figure 64. Summary of Results for Test No. 453790-4

hood and windshield of the vehicle, but did not penetrate the occupant compartment. Debris from the barricade was thrown along an area 17 m wide by 77 m long. The plastic vertical supports and wooden braces rode along with the vehicle. The wooden base remained near the point of impact and most of the remaining fragments were not large enough to pose potential hazard to oncoming traffic in adjacent lanes or to workers in the area. Damage to the vehicle included scratches to the bumper and hood. The plastic vertical supports, which separated from the wooden base, contacted the windshield area, but there was no penetration or intrusion into the occupant compartment. The longitudinal occupant impact velocity was 1.6 m/s, and the highest 10-msec average ridedown acceleration was 0.4 g. There was no lateral occupant contact. The 50-msec average accelerations were -3.3 g in the longitudinal direction and -0.3 g in the lateral direction. The vehicle exited the immediate test site in a relatively smooth, stable manner and showed no potential for intrusion into adjacent traffic lanes.

In summary, the Type III barricade fabricated from hollow core recycled plastic material with wooden base was judged to have met all evaluation criteria set forth in NCHRP Report 350.

4.2.6 End-on Test of Hollow Core Recycled Plastic Material with Solid Recycled Plastic Base, Wet Soil Condition (Test No. 453880-3)

Figure 65 shows a schematic of the Type III barricade fabricated from hollow core recycled plastic material with a base constructed of solid recycled plastic material. The construction was similar to that of the barricade tested in test no. 453790-4 except the base was fabricated from solid recycled plastic material instead of wood. The test was conducted under wet soil condition, i.e., the barricade was placed on wet soil instead of a concrete pavement surface. The test vehicle was a 1989 Chevrolet Sprint, as shown in Figure 66. Appendix Figure 90 gives dimensions and information on the vehicle. The test vehicle impacted the barricade end-on with the centerline of the vehicle aligned with the centerline of the barricade, traveling at a speed of 101.1 km/h.

At 6 msec after impact, the lower rail element separated from the right vertical support. The vehicle contacted the left vertical support at 10 msec. At 15 msec, the middle rail element separated from the left vertical support, and the top rail element twisted. The lower edge of the middle rail element contacted the hood of the vehicle at 19 msec. The vehicle contacted the right vertical support at 39 msec, and the top rail element contacted the hood. At 41 msec, the middle rail element contacted the windshield with no resulting damage. Shortly thereafter, the rail elements separated from the right vertical support, and the debris rode along with the vehicle. At 221 msec, the vehicle cleared the test site traveling at a speed of 95.4 km/h. Prior to brake application, the vehicle was tracking straightforward. The vehicle subsequently came to rest 114 m down and 1.8 m to the right of the point of impact. Figure 67 shows sequential photographs of the test period.

As Figure 66 shows, the hollow core recycled plastic vertical supports and rail elements separated from the base fabricated from solid recycled plastic upon impact and subsequently shattered. Debris and sand were strewn along the path of the vehicle in an area 9.9 m wide by

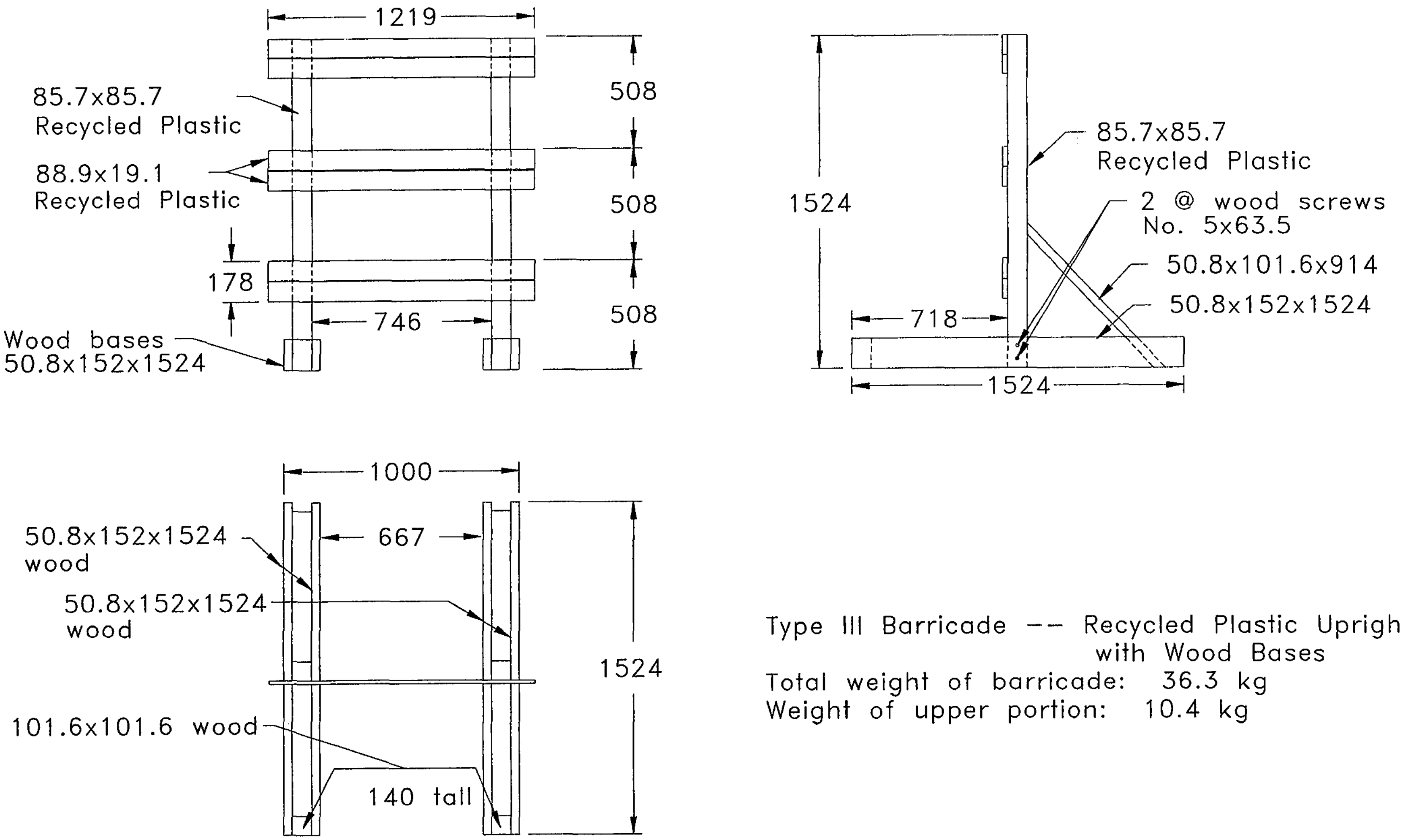


Figure 65. Schematic of Type III Barricade Fabricated from Hollow Core Recycled Plastic Material with Wooden Base (Test No. 453880-3)

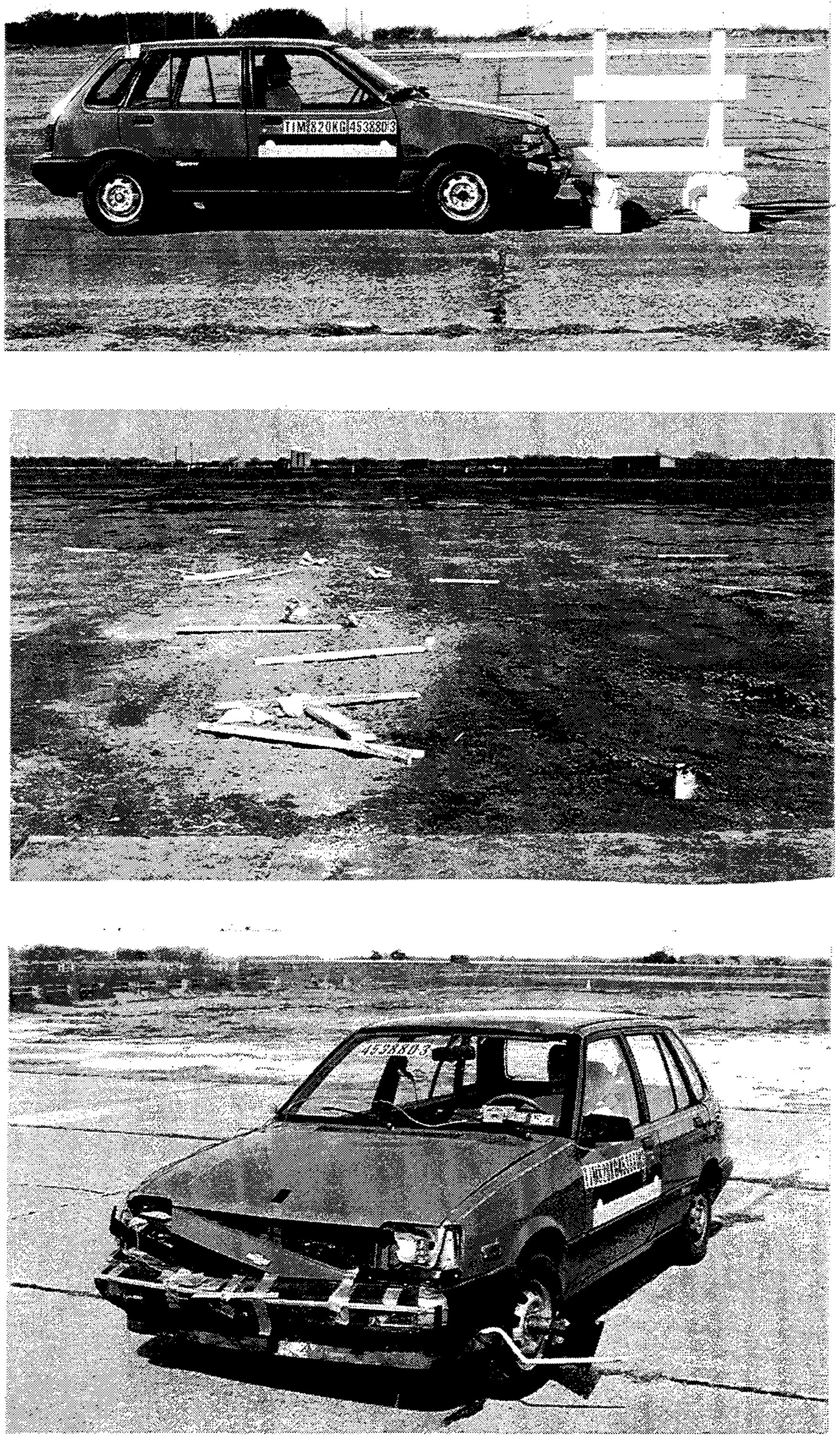
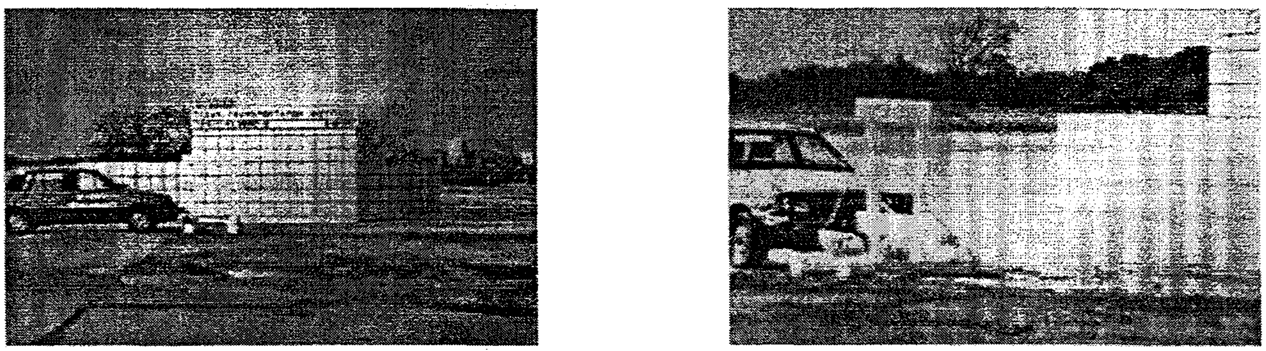


Figure 66. Vehicle and Barricade for Test No. 453880-3



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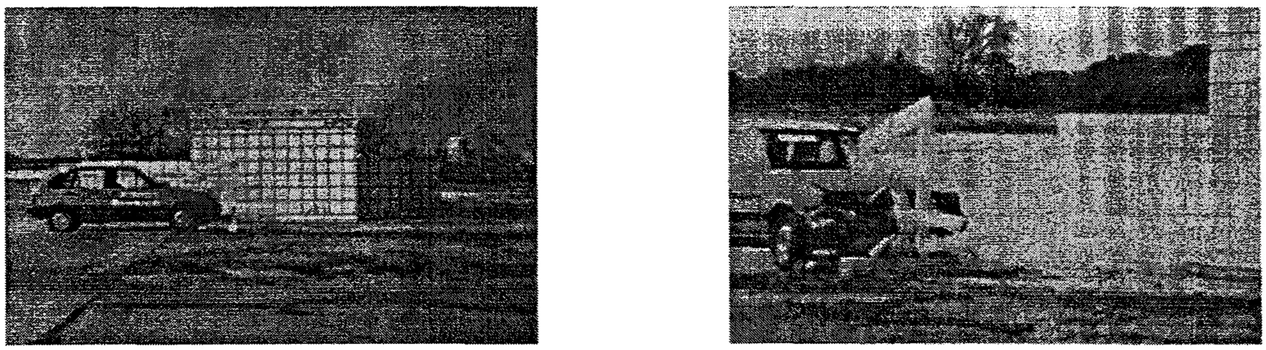
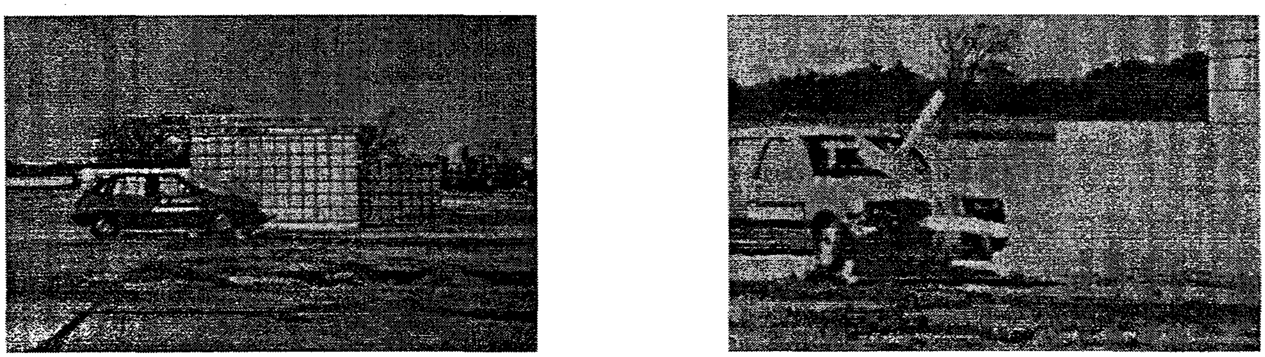
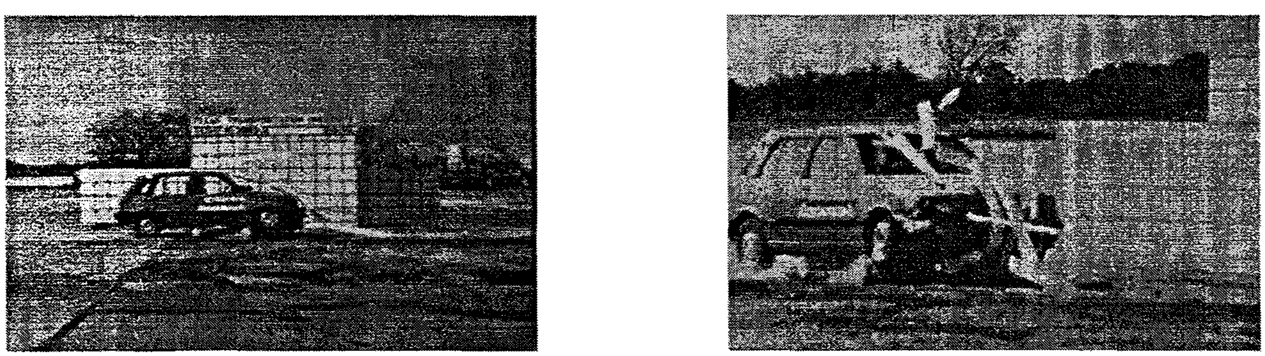


0.029 s



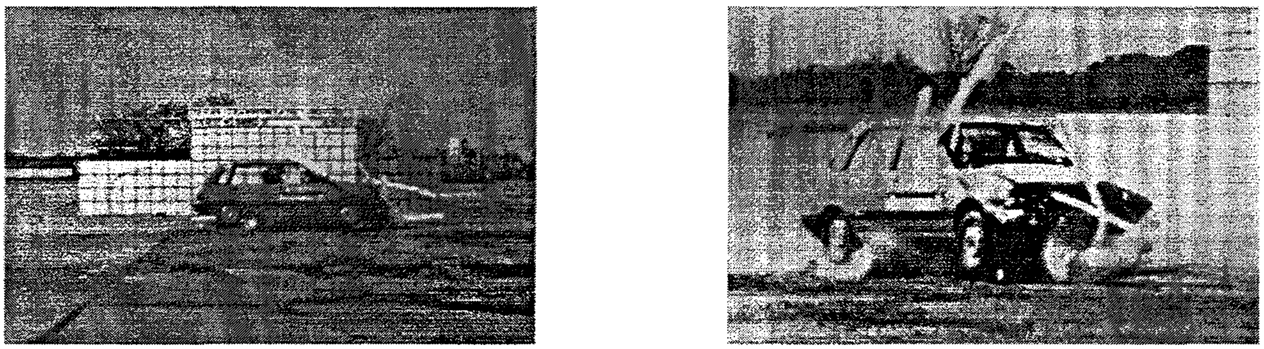
0.059 s



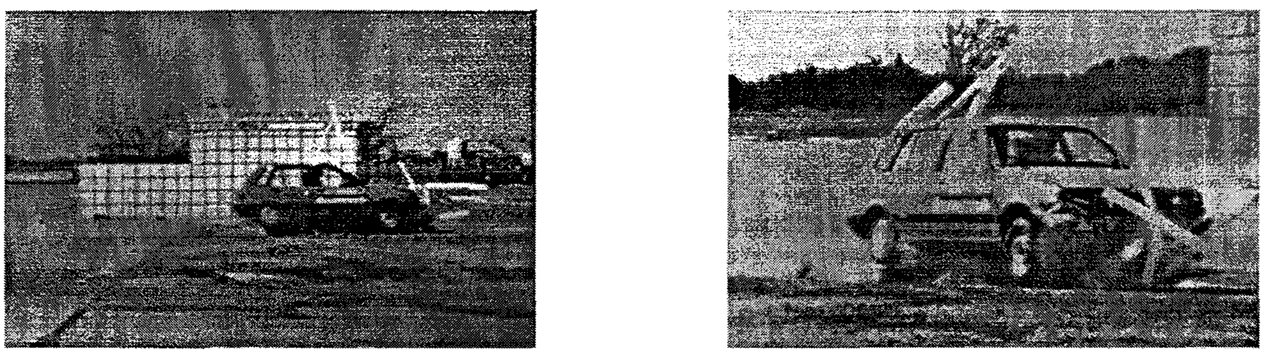
0.091 s

Figure 67. Sequential Photographs for Test No. 453880-3

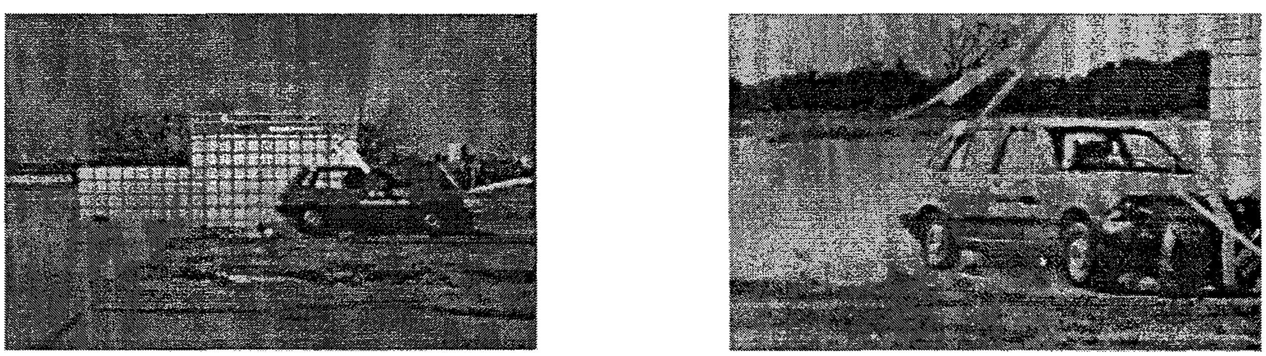
0.120 s



0.150 s



0.179 s



0.211 s

Figure 67. Sequential Photographs for Test No. 453880-3 (continued)

48 m long. Figure 66 shows damage to the vehicle. The damage to the vehicle included the bumper, grill, and scratches on the hood. The right rear tire was flat.

A brief summary of the results of this test is presented in Figure 68. The hollow core recycled plastic vertical supports and rail elements separated from the solid recycled plastic base upon impact. The broken segments made contact with the hood and the windshield, but did not penetrate the occupant compartment. Sand and fragments of the barricade were scattered along an area 9.9 m wide by 48 m long. Most fragments were not large enough to pose potential hazard to oncoming traffic in adjacent lanes or to workers in the area. The vehicle sustained minor damage to the bumper, grill and hood. The longitudinal occupant impact velocity was 1.7 m/s and the highest 10-msec average ridedown acceleration was 3.4 g. There was no lateral occupant contact. The 50-msec average accelerations were -2.6 g in the longitudinal direction and -0.6 g in the lateral direction. The vehicle exited the immediate test site in a relatively smooth, stable manner and showed no potential for intrusion into adjacent traffic lanes.

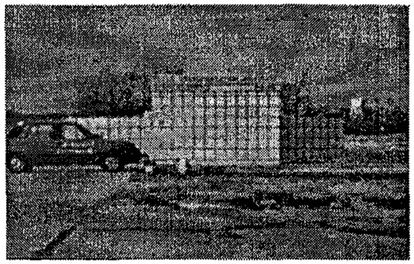
In summary, the Type III barricade fabricated from hollow core recycled plastic material with a base constructed of solid recycled plastic material tested with wet soil condition was also judged to have met all evaluation criteria set forth in NCHRP Report 350.

4.2.7 Solid Recycled Plastic Material (Test No. 453790-5)

Figure 69 shows a schematic of the Type III barricade fabricated from solid recycled plastic material. The construction was similar to that of the Type III wooden barricade. The test vehicle was a 1988 Chevrolet Sprint, as shown in Figure 70. Dimensions and information on the vehicle are given in Appendix Figure 96. The test vehicle impacted the barricade head-on with the centerline of the vehicle aligned with the centerline of the barricade, traveling at a speed of 100.6 km/h.

At 5 msec after impact, the barricade shattered. At 47 msec, the fractured vertical support impacted and penetrated the windshield. The segment then went up over the vehicle and touched the roof. The vehicle lost contact with the barricade at 176 msec, traveling at a speed of 93.6 km/h. Prior to brake application, the vehicle was tracking straightforward. The vehicle subsequently came to rest 93 m down and 1.2 m to the left of the point of impact. Figure 71 shows sequential photographs of the test period.

As Figure 70 shows, the solid recycled plastic barricade shattered upon impact. Debris and sand were strewn along the path of the vehicle in an area 14.5 m wide by 63 m long. Figure 70 also shows damage to the vehicle. The bumper, grill, and hood of the vehicle were dented and scratched. The left side A-post was dented, the windshield was broken, and the roof was dented. Maximum exterior crush to the front of the vehicle at bumper height was 80 mm. Maximum intrusion into the occupant compartment (measured from high-speed film) was 259 mm near the head area of the driver. The maximum residual deformation into the occupant compartment was 61 mm.



0.000 s

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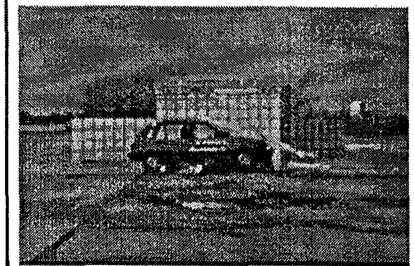
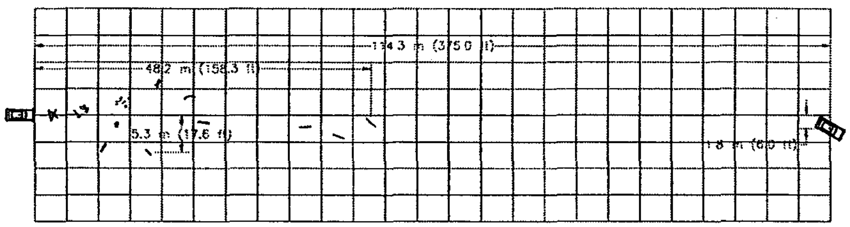
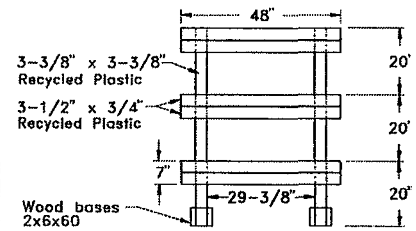


0.120 s

0.179 s





General Information	
Test Agency	Texas Transportation Institute
Test No.	453880-3
Date	02/08/95
Test Article	
Type	Type III Barricade
Name or Manufacturer	Recycled Plastic
Installation Length (m) .	1.2 m (4.0 ft)
Size and/or dimension and material of key elements	Recycled Plastic with wood base
Soil Type and Condition ..	Strong soil, damp
Test Vehicle	
Type	Production
Designation	820C
Model	1989 Chevrolet Sprint
Mass (kg) Curb	713 (1570 lb)
Test Inertial	820 (1806 lb)
Dummy ...	75 (165 lb)
Gross Static	897 (1975 lb)

Impact Conditions	
Speed (km/h)	101.1 (62.9 mi/h)
Angle (deg)	0 (end-on)
Exit Conditions	
Speed (km/h)	95.4 (59.3 mi/h)
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	1.7 (5.8 ft/s)
y-direction	No Contact
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	3.4
y-direction	N/A
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Average (g's)	
x-direction	-2.6
y-direction	-0.6
z-direction	1.5

Test Article Deflections (m)	
Thrown Forward	48.2 (158.3 ft)
Thrown Laterally	5.3 (17.6 ft)
Vehicle Damage	
Exterior	
VDS	12FD1
CDC	12FDEW1
Interior	
OCDI	FS0000000
Maximum Exterior Vehicle Crush (mm) ...	0
Max. Occ. Compart. Deformation (mm)	0
Post-Impact Behavior	
Max. Roll Angle (deg) ...	4.1
Max. Pitch Angle (deg) ..	-2.9
Max. Yaw Angle (deg) ..	-0.6

Figure 68. Summary of Results for Test No. 453880-3

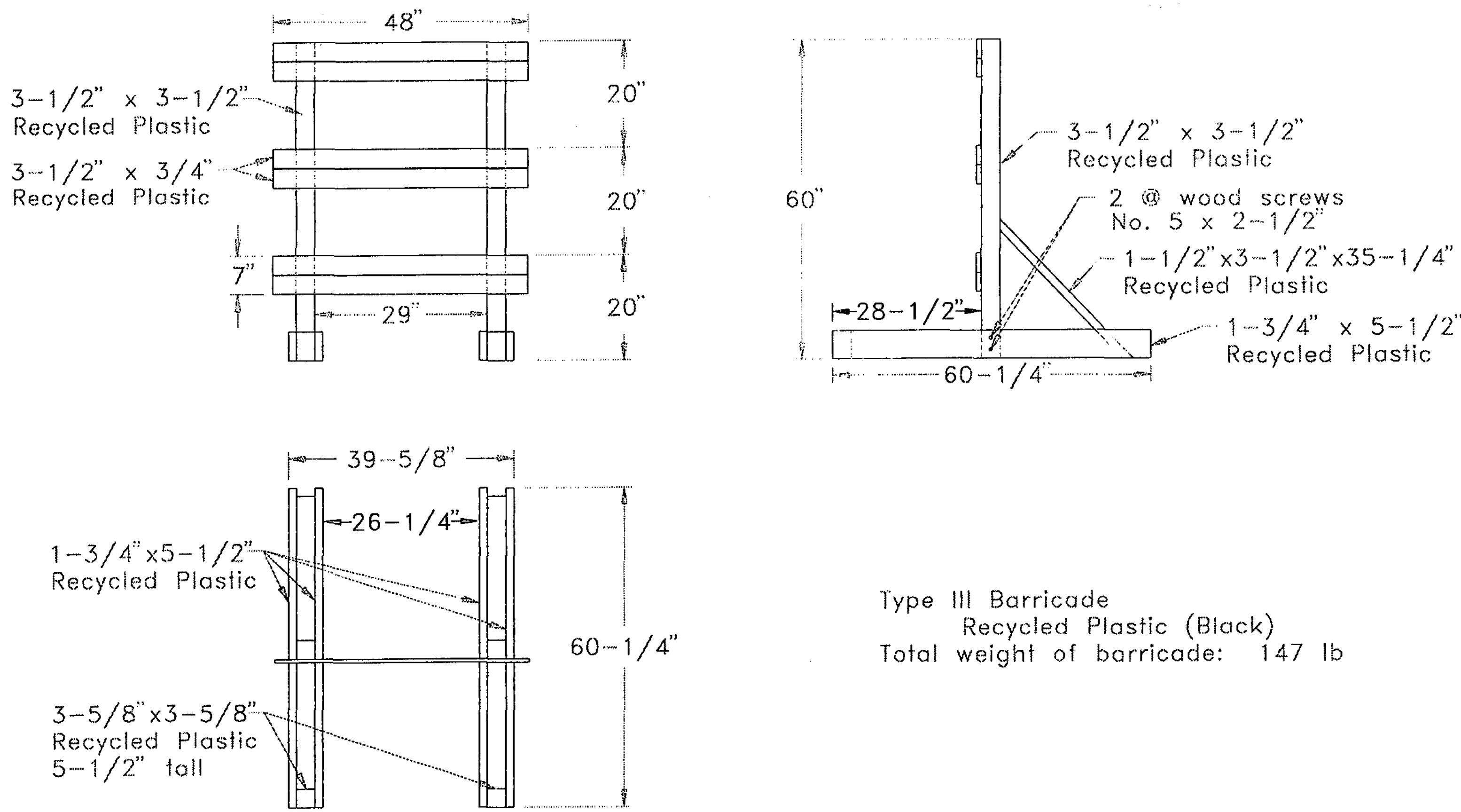


Figure 69. Schematic of Type III Barricade Fabricated from Solid Recycled Plastic Material (Test 453790-5)

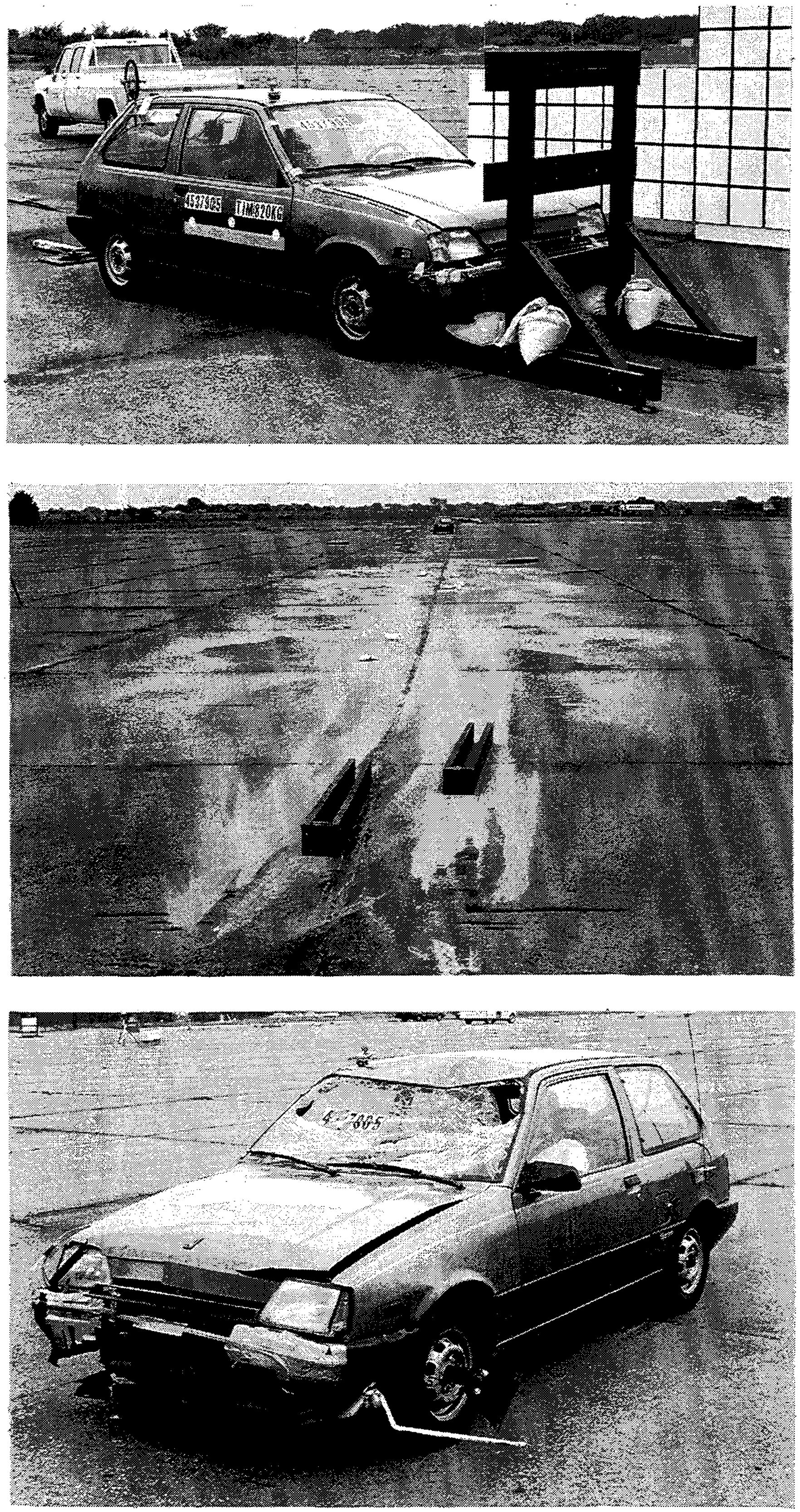
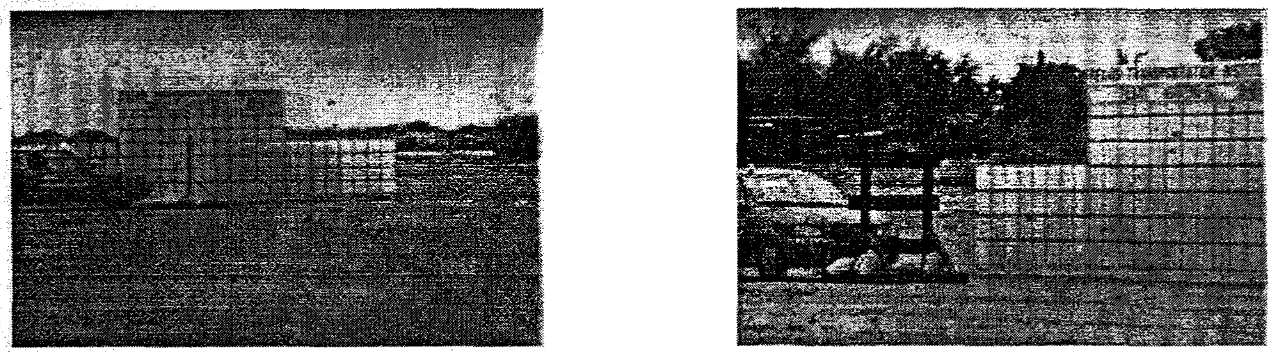


Figure 70. Vehicle and Barricade for Test No. 453790-5



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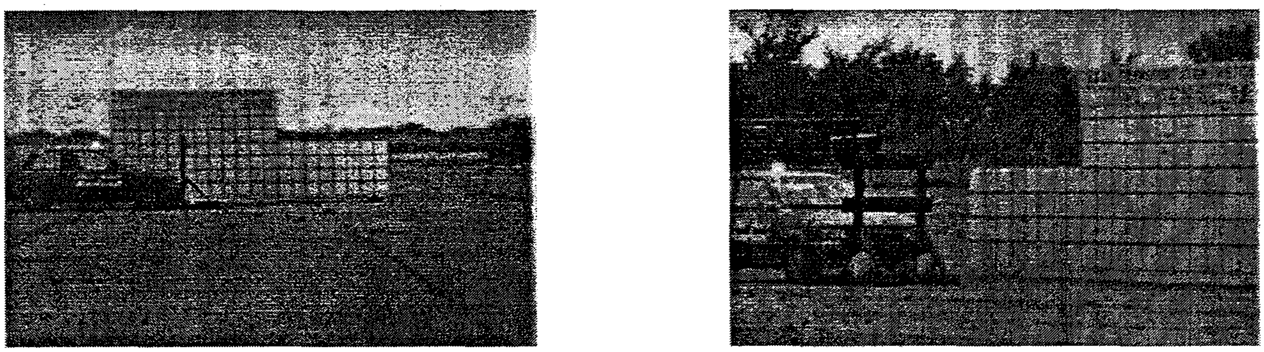

0.027 s

0.055 s

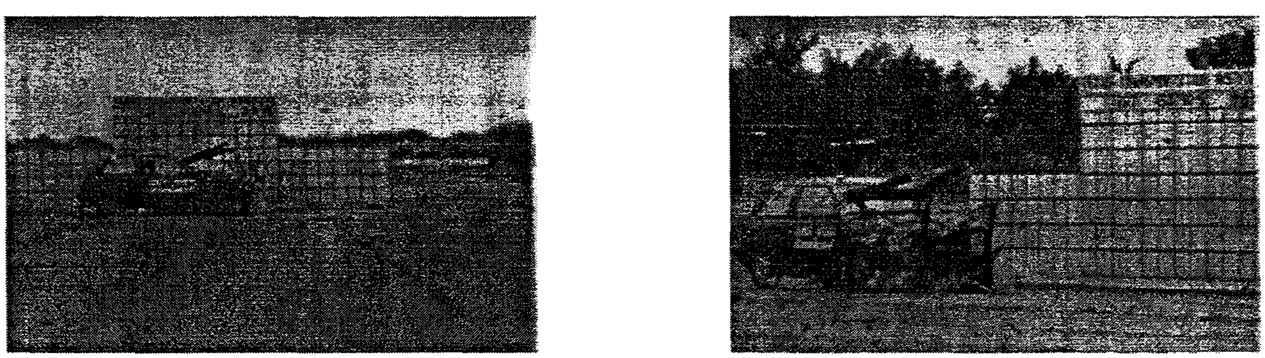

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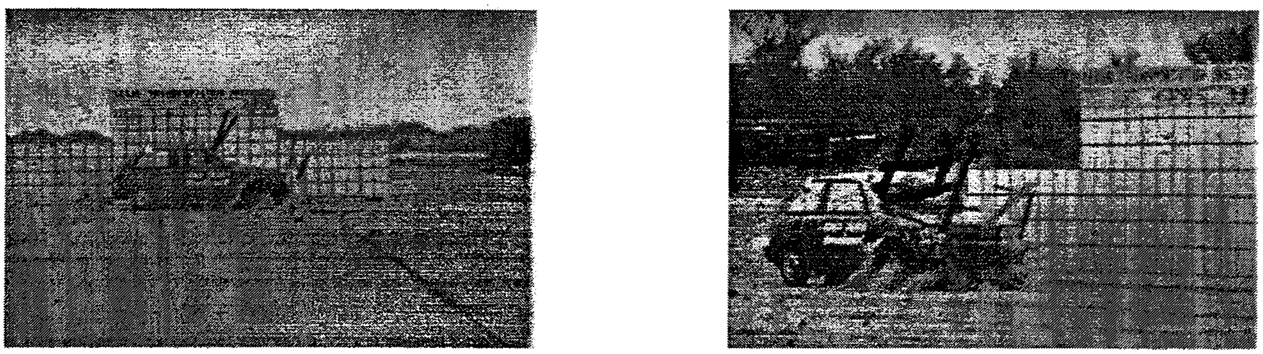
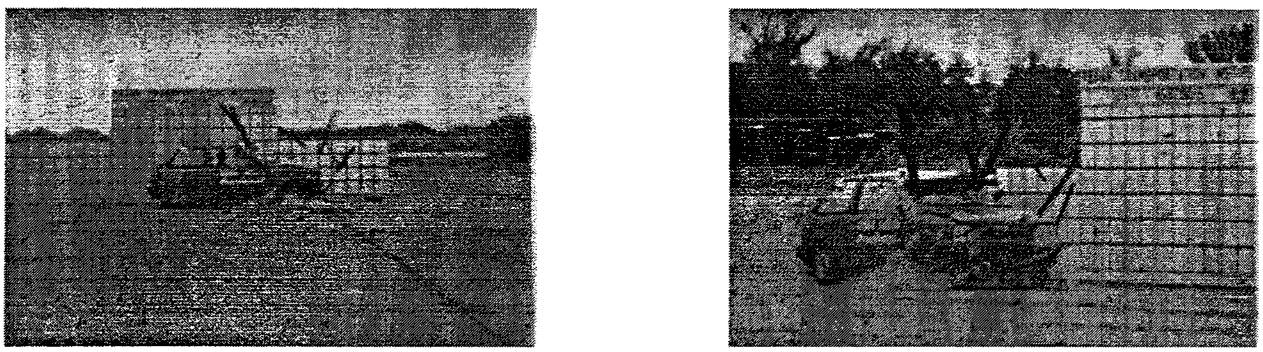
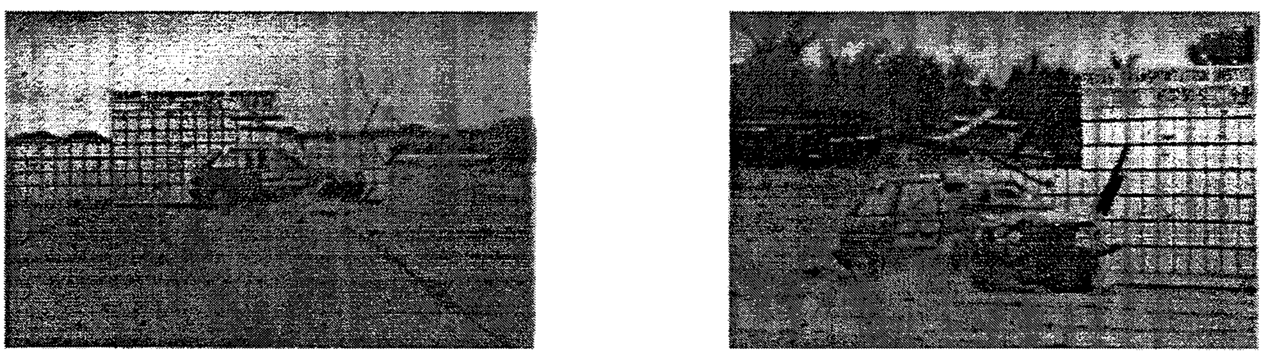
Figure 71. Sequential Photographs for Test No. 453790-5



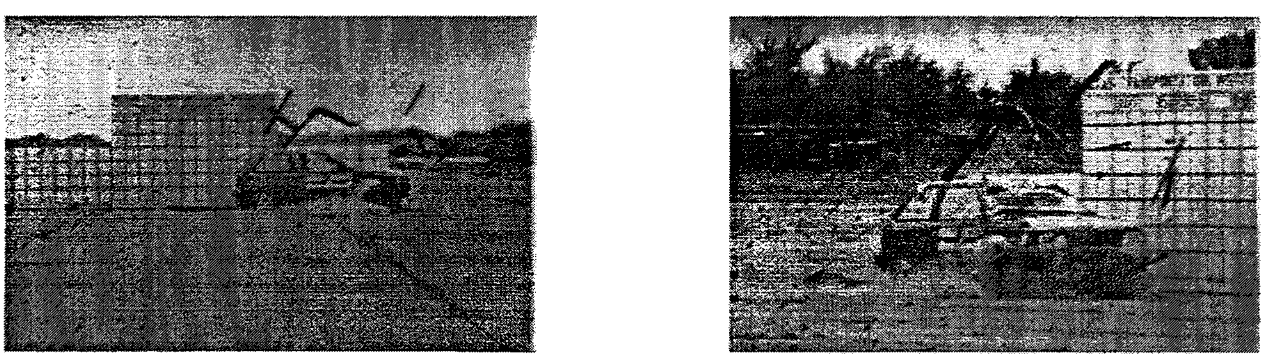
0.109 s



0.136 s



0.169 s



0.203 s

Figure 71. Sequential Photographs for Test No. 453790-5 (continued)

Figure 72 presents a brief summary of the results of this test. The barricade shattered upon impact. A segment of the vertical support made contact with the windshield and penetrated into the occupant compartment. Maximum intrusion into the occupant compartment was 259 mm near the driver's head area. Debris from the barricade was thrown along an area 14.5 m wide by 63 m long. Most of the fragments were not large enough to pose potential hazard to oncoming traffic in adjacent lanes or to workers in the area. Damage to the vehicle included dents and scratches to the bumper and hood and penetration to the windshield area. The longitudinal occupant impact velocity was 2.0 m/s and the highest 10-msec average ridedown acceleration was 0.4 g. Lateral occupant impact velocity was 0.6 m/s, and the highest 10-msec average ridedown acceleration was 0.5 g. The 50-msec average accelerations were -3.9 g in the longitudinal direction and -0.4 g in the lateral direction. The vehicle exited the immediate test site in a relatively smooth, stable manner and showed no potential for intrusion into adjacent traffic lanes.

In summary, the performance of the Type III barricade fabricated from solid recycled plastic material was judged to be unsatisfactory due to penetration of the windshield and the occupant compartment by a segment of the fractured vertical support.

4.3 SIGN PANEL ATTACHMENT MECHANISMS

After alternate barricade designs were developed and successfully crash tested, the next step was to develop and evaluate alternate sign panel attachment mechanisms for barricades fabricated from perforated tubing and hollow core plastic material.

Two alternate sign attachment mechanisms were developed and crash tested for the barricade fabricated from perforated tubing. In the first alternative, shown in Figure 73, the vertical supports for the sign panel are bolted directly to the wooden rail elements. In the second alternative, shown in Figure 74, the vertical supports for the sign panel are bolted to perforated tubing cross members, which are in turn bolted to the perforated tubing vertical supports for the barricade. For the second alternative, the rail elements can be either plastic or wood.

The crash test with the first sign attachment alternative (test no. 453880-5) was judged to be unsatisfactory. The bottom of the sign panel bent backward and shattered the windshield, though there was no penetration into the occupant compartment. Otherwise, the test would have been acceptable. The problem with the bending of the sign panel could be remedied by adding bracing to the sign panel or by attaching the bottom of the sign panel to the top rail element. With this adjustment to the sign panel, this sign attachment mechanism would have performed satisfactorily and would be considered acceptable.

The crash test with the second sign attachment alternative (test no. 453880-7) was successful. However, the fractured vertical supports, the rail elements and the sign panel stayed as a single unit and was thrown forward by the impacting vehicle, raising concern that this may pose a hazard to adjacent traffic and workers in the area. After consultation with TxDOT, it was decided that this sign attachment mechanism is not desirable and should not be considered for implementation.

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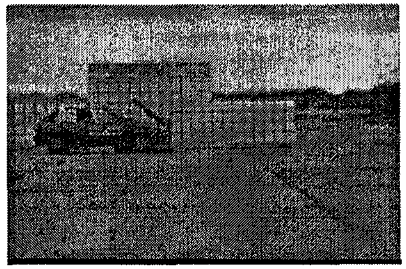

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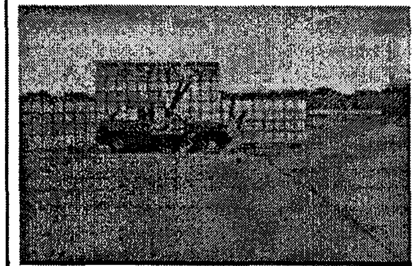
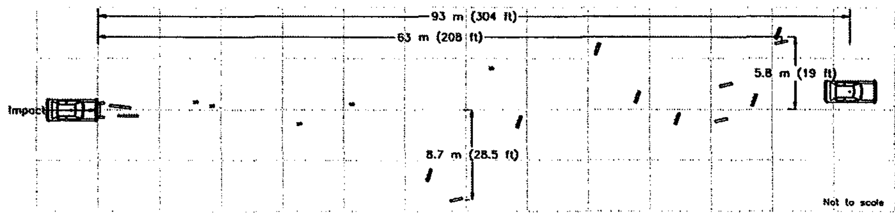
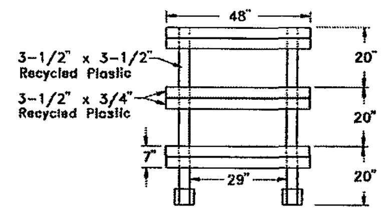


0.109 s

0.169 s





General Information	
Test Agency	Texas Transportation Institute
Test No.	453790-5
Date	09/08/94
Test Article	
Type	Type III Barricade
Name or Manufacturer	
Installation Length (m)	1.2 m (4.0 ft)
Size and/or dimension and material of key elements	Recycled Plastic
Soil Type and Condition .	on Pavement, dry
Test Vehicle	
Type	Production
Designation	820C
Model	1988 Chevrolet Sprint
Mass (kg) Curb	719 (1583 lb)
Test Inertial	820 (1806 lb)
Dummy ..	75 (165 lb)
Gross Static	897 (1976 lb)

Impact Conditions	
Speed (km/h)	100.6 (62.5 mi/h)
Angle (deg)	0
Exit Conditions	
Speed (km/h)	93.6 (58.2 mi/h)
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	2.0 (6.7 ft/s)
y-direction	0.6 (1.9 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	0.4
y-direction	0.5
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Average (g's)	
x-direction	-3.9
y-direction	-0.4
z-direction	-1.3

Test Article Deflections (m)	
Thrown Forward	63.4 (208 ft)
Thrown Laterally	8.7 (28.5 ft)
Vehicle Damage	
Exterior	
VDS	12FD1
CDC	12FDEW1 & 12FDGW7
Interior	
OCDI	FS0000000
Maximum Exterior Vehicle Crush (mm) ..	80 (3.1 in)
Max. Occ. Compart. Deformation (mm) ...	61 (2.4 in)
Post-Impact Behavior	
Max. Roll Angle (deg) ..	-2.0
Max. Pitch Angle (deg) .	2.7
Max. Yaw Angle (deg) .	-0.9

Figure 72. Summary of Results for Test No. 453790-5

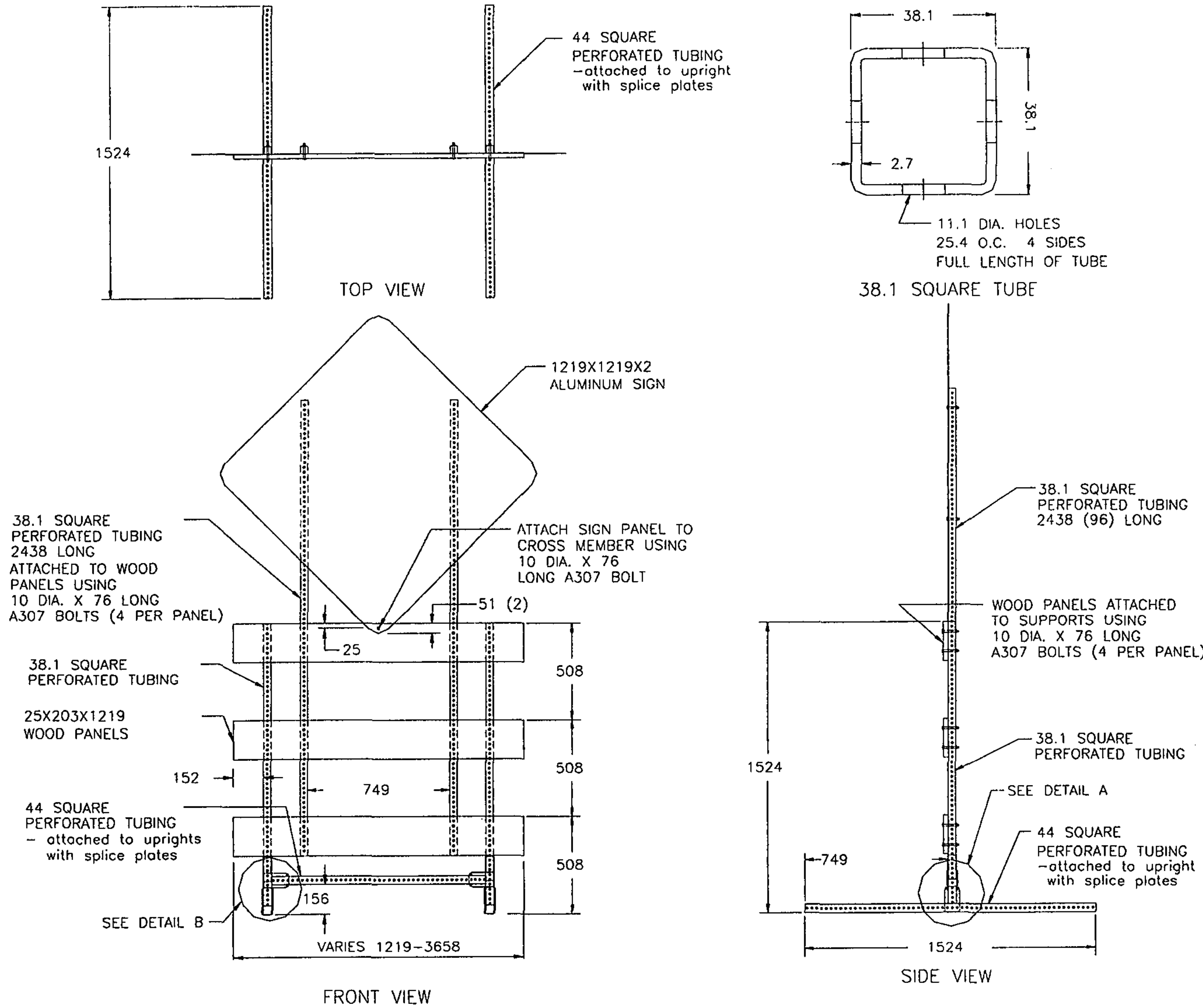


Figure 73. Perforated Steel Tube Type III Barricade with Sign Panel Attached to Wood Panels

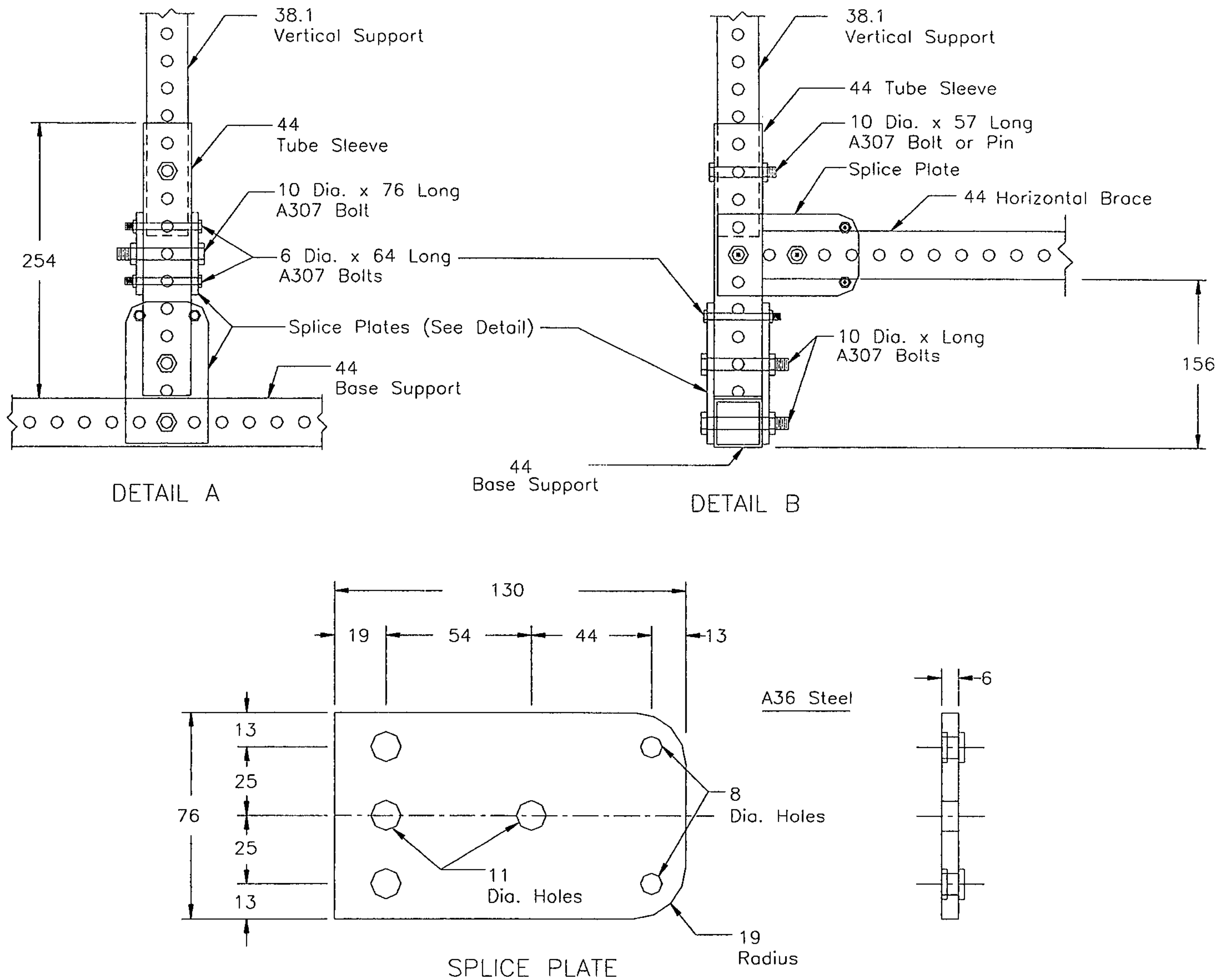


Figure 73. Perforated Steel Tube Type III Barricade with Sign Panel Attached to Wood Panels (continued)

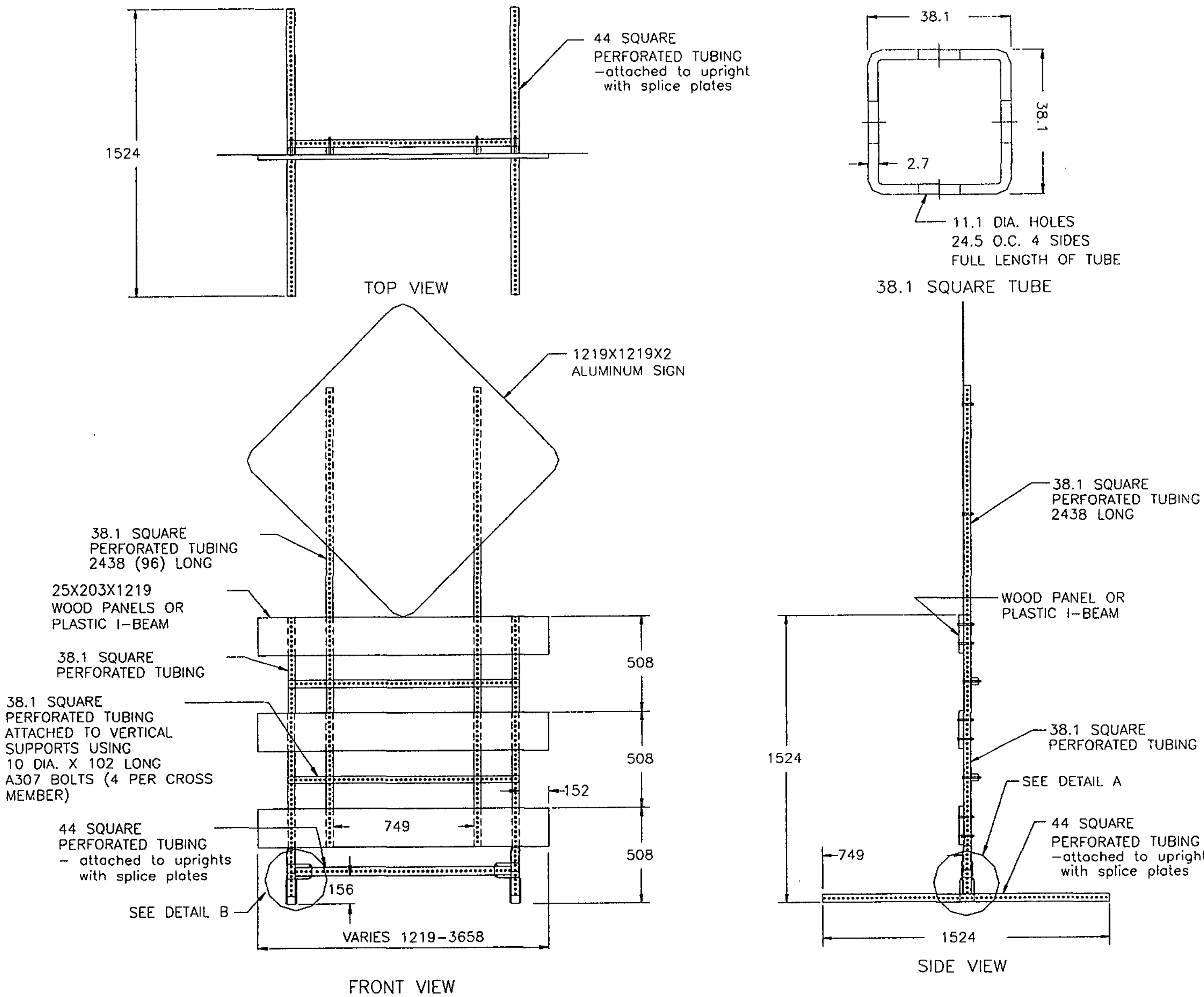


Figure 74. Perforated Steel Tube Type III Barricade with Sign Panel Attached to Perforated Tube Cross Members

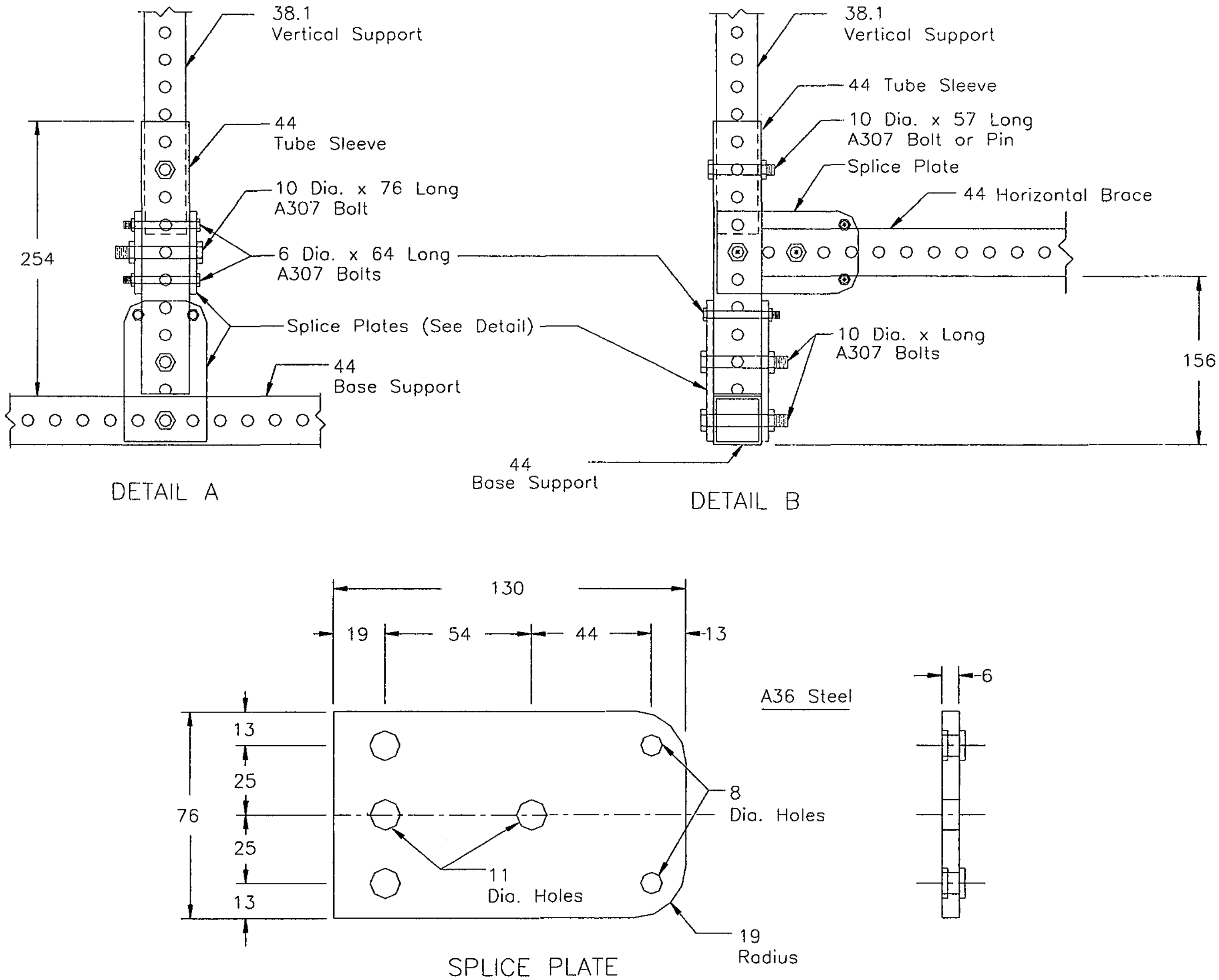


Figure 74. Perforated Steel Tube Type III Barricade with Sign Panel Attached to Perforated Tube Cross Members (continued)

For the barricade fabricated from hollow core recycled plastic material, the vertical supports for the sign panel are attached directly to the plastic rail elements, as shown in Figure 75. Due to the somewhat flexible nature of the plastic rail elements, the vertical supports for the sign panel are extended all the way to ground level for additional support. This sign panel attachment mechanism was crash tested for the barricade fabricated from hollow core recycled plastic material with successful results (test no. 453880-6).

Details of the three crash tests on alternate sign panel attachment mechanisms are presented in the following sections.

4.3.1 Perforated Tubing with Wooden Rail Elements and Sign Panel (Test No. 453880-5)

A Type III barricade with perforated steel tubing and wooden rail elements, similar to that used in test no. 453880-2, was fabricated. An aluminum sign panel was attached to two vertical sign supports, which were in turn bolted to the wooden rail elements. The sign panel was 1219 mm x 1219 mm in size and mounted at a height of 1.52 m from the ground to the bottom of the sign panel. Figure 76 shows a schematic of the barricade with the sign attachment. The test vehicle was a 1988 Ford Festiva, as shown in Figure 77. Dimensions and information on the vehicle are given in Appendix Figure 97. The test vehicle impacted the barricade head-on with the centerline of the vehicle aligned with the centerline of the barricade, traveling at a speed of 100.6 km/h.

As the vehicle impacted the barricade, the bottom rail element began to break and the vertical supports for the barricade began to bend. At 11 msec, the top and center rail elements began to break. At 24 msec, the right vertical support for the sign panel started to separate from the barricade. The right vertical support for the sign panel cleared the bumper and hood at 39 msec, and the left vertical supports for the sign panel and the barricade began to rise at 48 msec. The top of the sign panel contacted the roof at 71 msec. The bottom of the sign panel folded forward and subsequently contacted and penetrated the windshield at 97 msec. At 103 msec, the supports lost contact with the vehicle as it traveled at 86.9 km/h; however, the sign panel remained in contact with the roof. The left vertical support for the sign panel began to separate from the left vertical support of the barricade at 116 msec. At 258 msec, the right vertical support for the barricade began to separate from the base. Prior to brake application, the vehicle was tracking straightforward. The vehicle subsequently came to rest 78 m down and 3.2 m to the right of the point of impact. Figure 78 shows sequential photographs of the test period.

As Figure 77 shows, the barricade and the sign attachment shattered upon impact. Debris and sand were strewn along the path of the vehicle in an area 14.6 m wide and 90.5 m long. Figure 77 also shows damage to the vehicle. There was damage to the hood, roof, and left headlight, but the damage was limited to minor scrapes. The windshield was shattered and deformed into the occupant compartment 51 mm.

Figure 79 presents a brief summary of the results of this test. The barricade and sign panel attachment mechanism shattered upon impact. The bottom corner of the sign panel contacted and shattered the windshield and deformed the windshield into the occupant compartment by 51 mm,

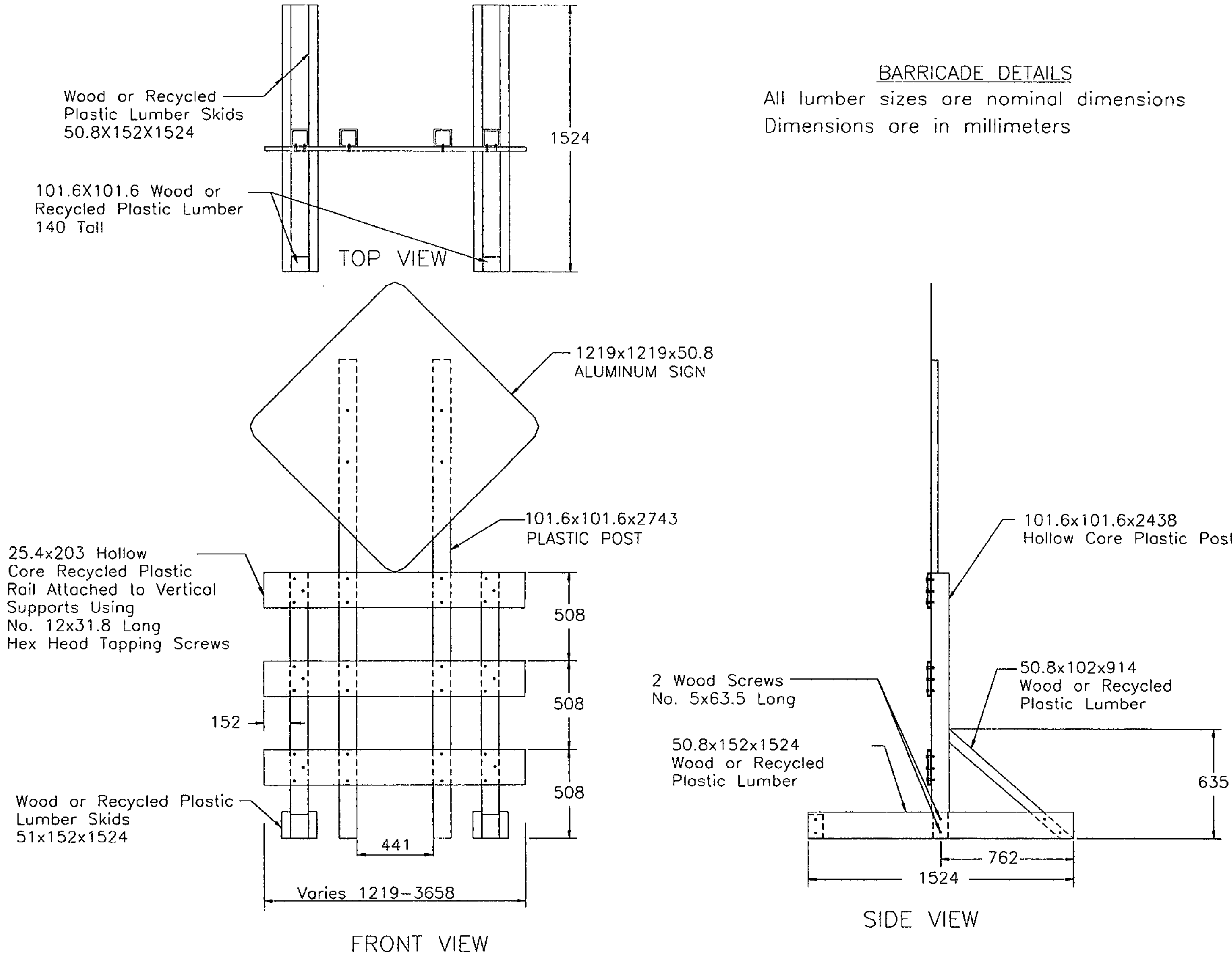


Figure 75. Hollow Core Recycled Plastic Type III Barricade with Sign Panel Attached to Plastic Rail Elements (Test No. 453790-5)

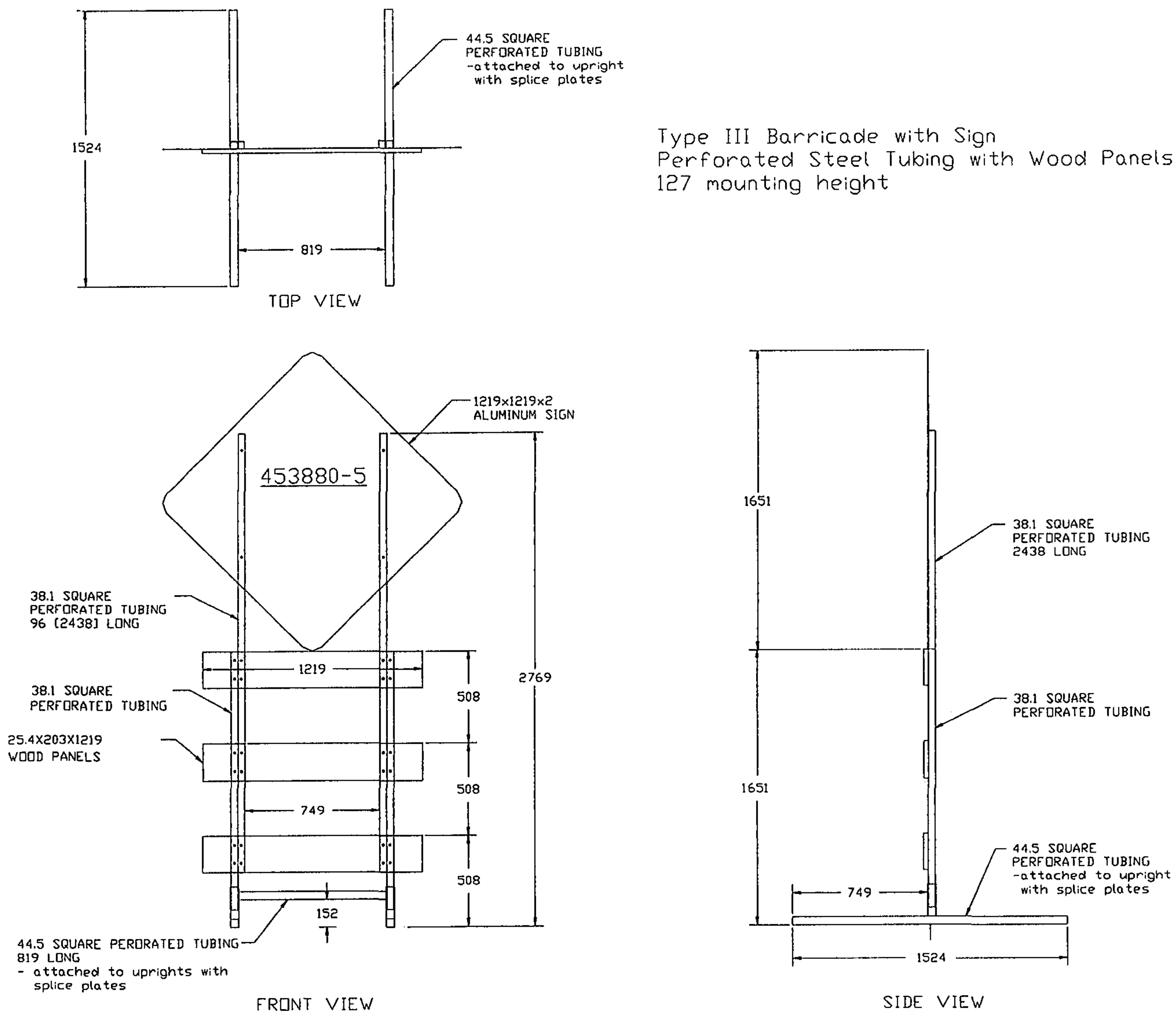
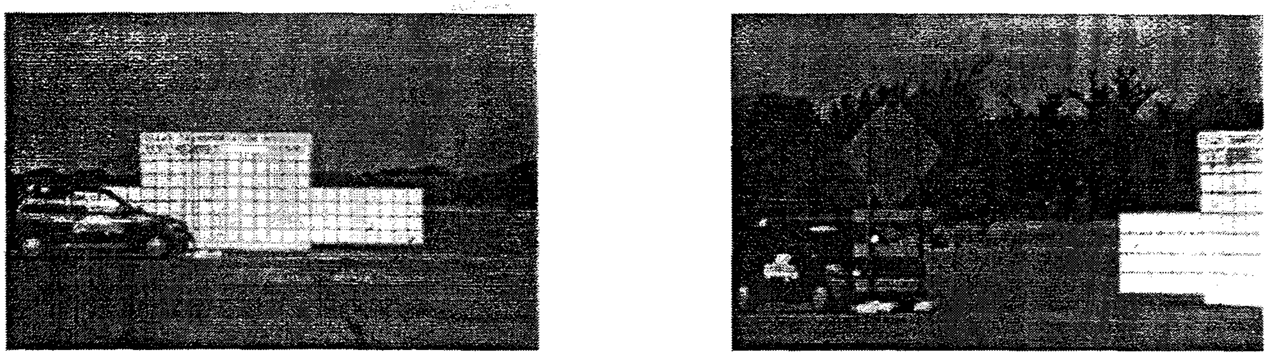
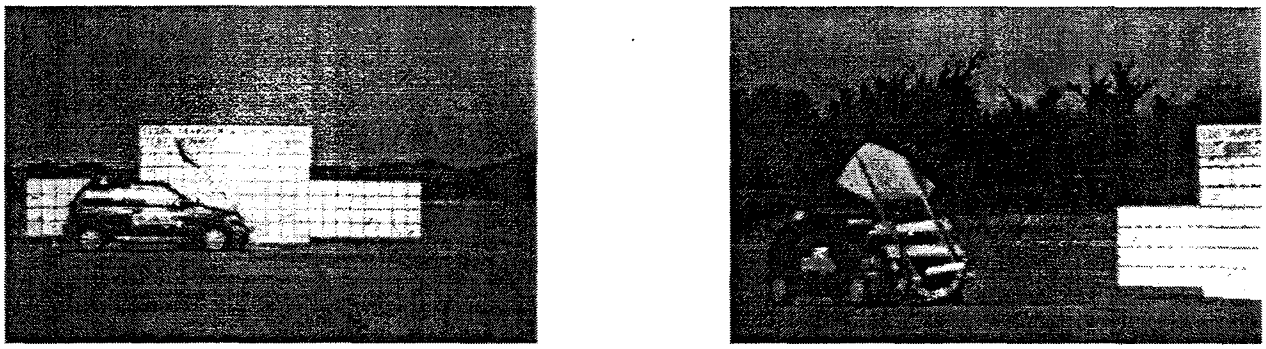


Figure 76. Schematic of Perforated Tubing Type III Barricade with Sign Panel Attached to Wooden Rail Elements (Test No. 453880-5)

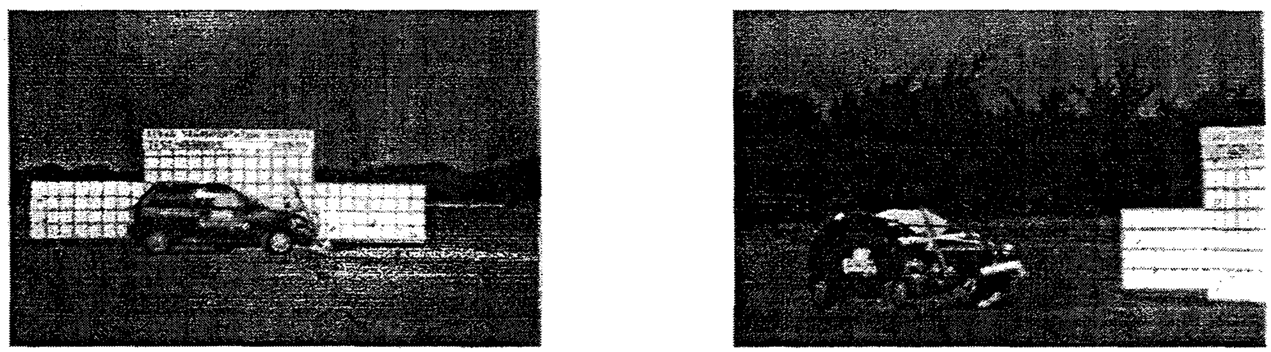
Figure 77. Vehicle and Barricade for Test No. 453880-5



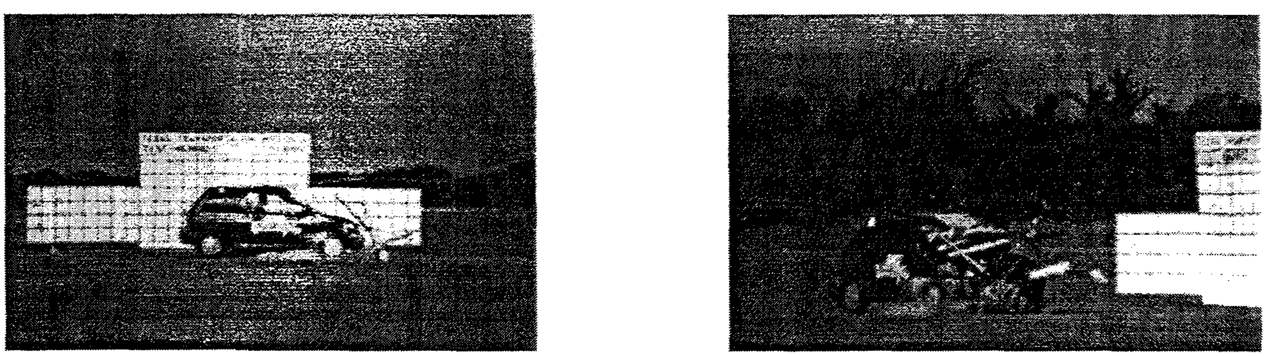
0.000 s



0.042 s

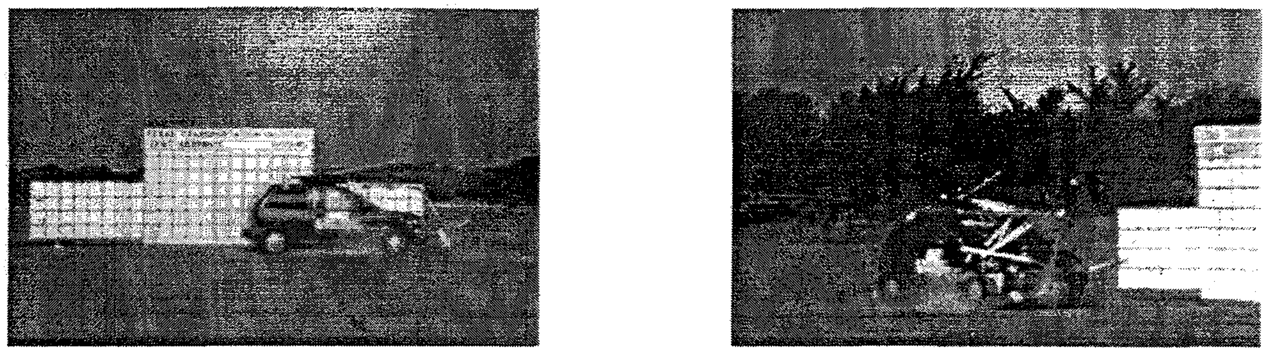


0.086 s

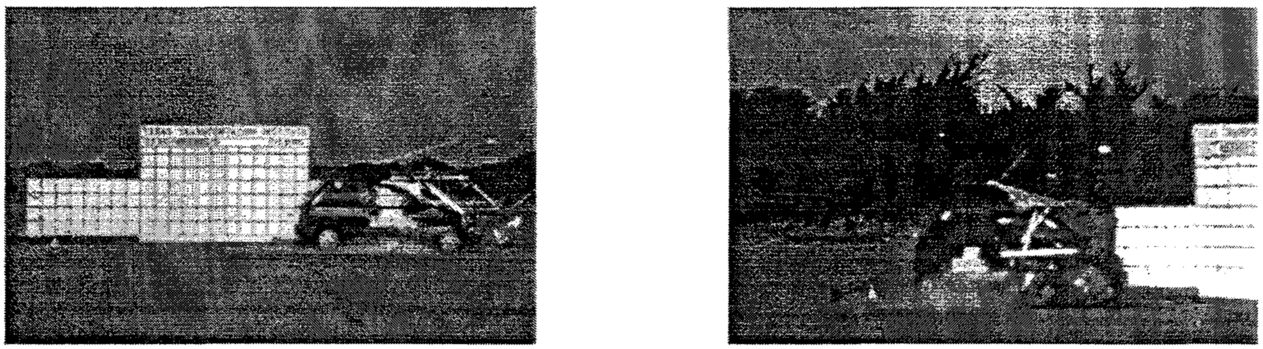


0.128 s

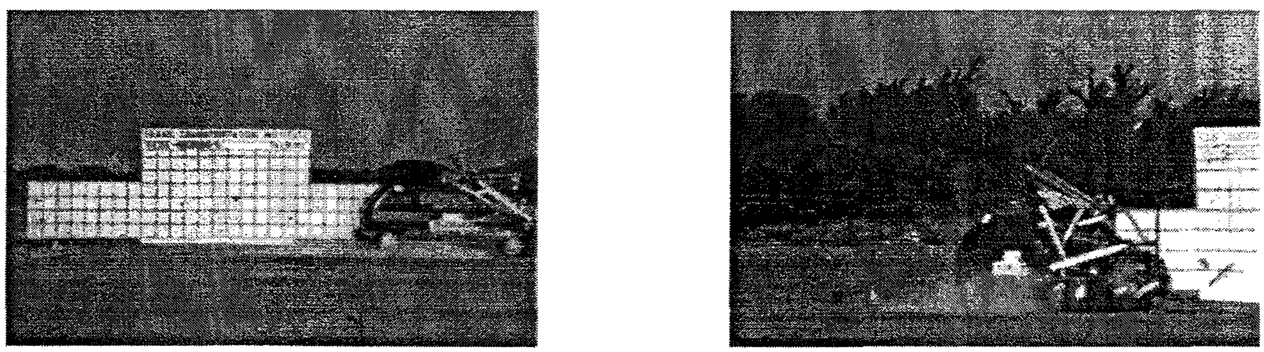
Figure 78. Sequential Photographs for Test No. 453880-5



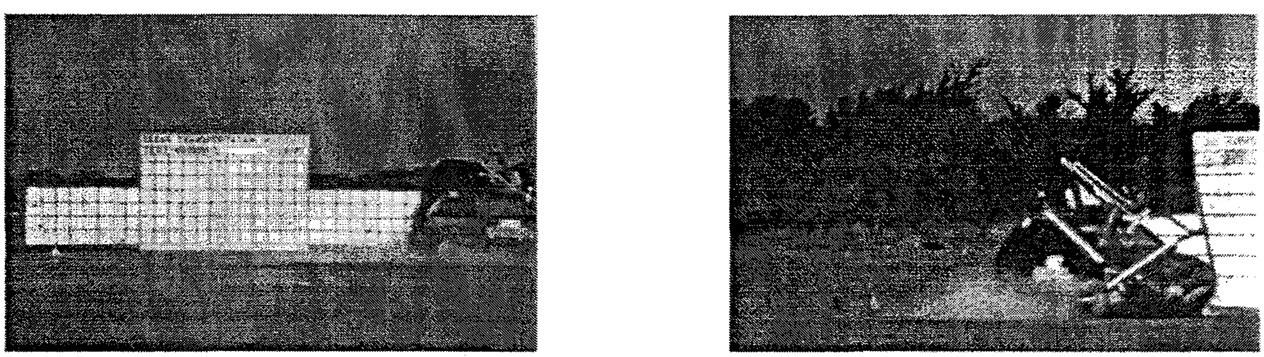
0.172 s



0.214 s

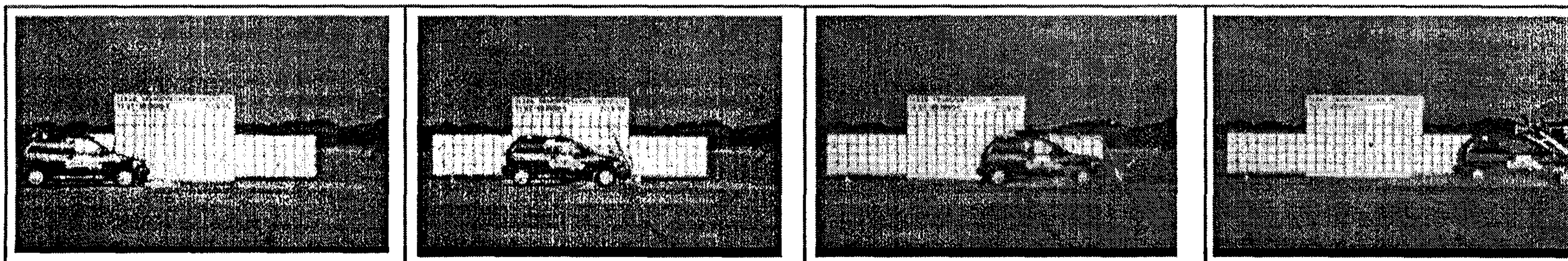


0.258 s

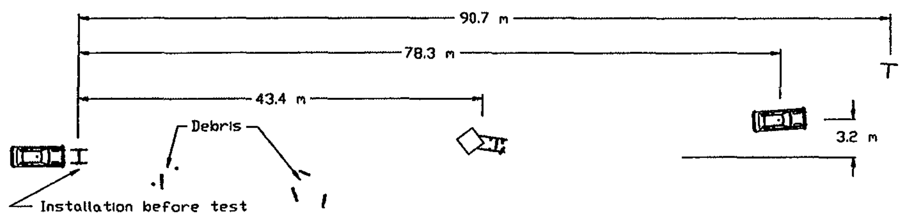


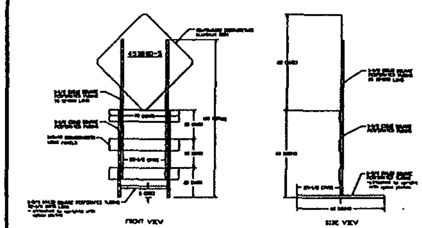
0.300 s

Figure 78. Sequential Photographs for Test No. 453880-5 (continued)



0.000 s	0.086 s	0.172 s	0.258 s





General Information	
Test Agency	Texas Transportation Institute
Test No.	453880-5
Date	07/19/95
Test Article	
Type	Type III Barricade w/sign
Name or Manufacturer	
Installation Height (m)	1.5 (5.0 ft)
Size and/or dimension and material of key elements	Perforated square tubing with wood panels
Soil Type and Condition	Concrete pavement, dry
Test Vehicle	
Type	Production
Designation	820C
Model	1988 Ford Festiva
Mass (kg) Curb	788 (1736 lb)
Test Inertial	820 (1806 lb)
Dummy	75 (165 lb)
Gross Static	896 (1974 lb)

Impact Conditions	
Speed (km/h)	100.6 (62.5 mi/h)
Angle (deg)	0
Exit Conditions	
Speed (km/h)	86.9 (54.0 mi/h)
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	2.3 (7.6 ft/s)
y-direction	No contact
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	0.3
y-direction	N/A
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Average (g's)	
x-direction	-3.8
y-direction	1.7
z-direction	-0.5

Test Article Deflections (m)	
Thrown Forward	90.6 (297.5 ft)
Thrown Laterally	7.6 (25.0 ft)
Vehicle Damage	
Exterior	
VDS	12FD1
CDC	12FDGW6
Interior	
OCDI	FS0100000
Maximum Exterior Vehicle Crush (mm)	51 (2.0 in)
Max. Occ. Compart. Deformation (mm)	51 (2.0 in)
Post-Impact Behavior	
Max. Roll Angle (deg)	-3.6
Max. Pitch Angle (deg)	1.3
Max. Yaw Angle (deg)	2.6

Figure 79. Summary of Results for Test No. 453880-5

but did not penetrate the occupant compartment. Debris from the barricade was thrown along an area 14.6 m wide and 90.5 m long. Most fragments were not large enough to pose potential hazard to oncoming traffic in adjacent lanes or to construction workers in the area. The vehicle sustained minor damage and a shattered windshield. The longitudinal occupant impact velocity was 2.3 m/s, and the highest 10-msec average ridedown acceleration was 0.3 g. There was no contact in the lateral direction. The 50-msec average accelerations were -3.8 g in the longitudinal direction and 1.7 g in the lateral direction. The vehicle exited the immediate test site in a relatively smooth, stable manner and showed no potential for intrusion into adjacent traffic lanes. This crash test was judged to be unsatisfactory due to shattering and deformation of the windshield from contact with the bottom corner of the sign panel. The bending or folding of the bottom corner of the sign panel could potentially be prevented by either providing additional vertical bracing behind the sign panel or lowering the mounting height of the sign panel and bolting the bottom corner of the aluminum panel to the top wooden rail element. With either of these modifications, it is the opinion of the researchers that this sign attachment design would perform satisfactorily for a 1.52-m mounting height in accordance with the guidelines set forth in NCHRP Report 350. Also, based on the results of this test, as well as the test of the skid mounted sign support (Test No. 453360-3), it is the opinion of the researchers that the tested design (shown in Figure 76) will perform satisfactorily for a 2.13-m mounting height without modification. The 2.13-m mounting height should prevent contact of the sign blank with the windshield, thus eliminating the potential hazard associated with the bending or folding of the bottom of the sign panel during impact.

4.3.2 Perforated Tubing with Sign Panel Attached to Cross Members (Test No. 453880-7)

A different sign attachment mechanism was used with a Type III barricade with perforated steel tubing and wooden rail elements in this test. Two cross members fabricated from perforated tubing were bolted to the barricade vertical supports. Two vertical sign supports, also fabricated from perforated tubing, were bolted to the cross members, and an aluminum sign panel was attached to two vertical sign supports. The sign panel was 1219 mm x 1219 mm in size and mounted at a height of 914 mm from the ground to the bottom of the sign panel. Figure 80 shows a schematic of the barricade with the sign attachment. The test vehicle was a 1989 Ford Festiva, as shown in Figure 81. Dimensions and information on the vehicle are given in Appendix Figure 98. The test vehicle impacted the barricade head-on with the centerline of the vehicle aligned with the centerline of the barricade, traveling at a speed of 99.5 km/h.

As the vehicle impacted the barricade, the bottom panel began to break, and the vertical supports began to bend. At 39 msec, the bottom of the sign panel contacted the hood near the windshield. The supports lost contact with the bumper at 47 msec, and the sign panel contacted the windshield at 56 msec. At 130 msec, the sign panel lost contact with the windshield as the vehicle was traveling at 87.0 km/h, and the panel continued to travel in front of the vehicle. Prior to brake application, the vehicle was tracking straightforward. The vehicle subsequently came to rest 91 m down and 9.1 m to the right of the point of impact. Figure 82 shows sequential photographs of the test period.

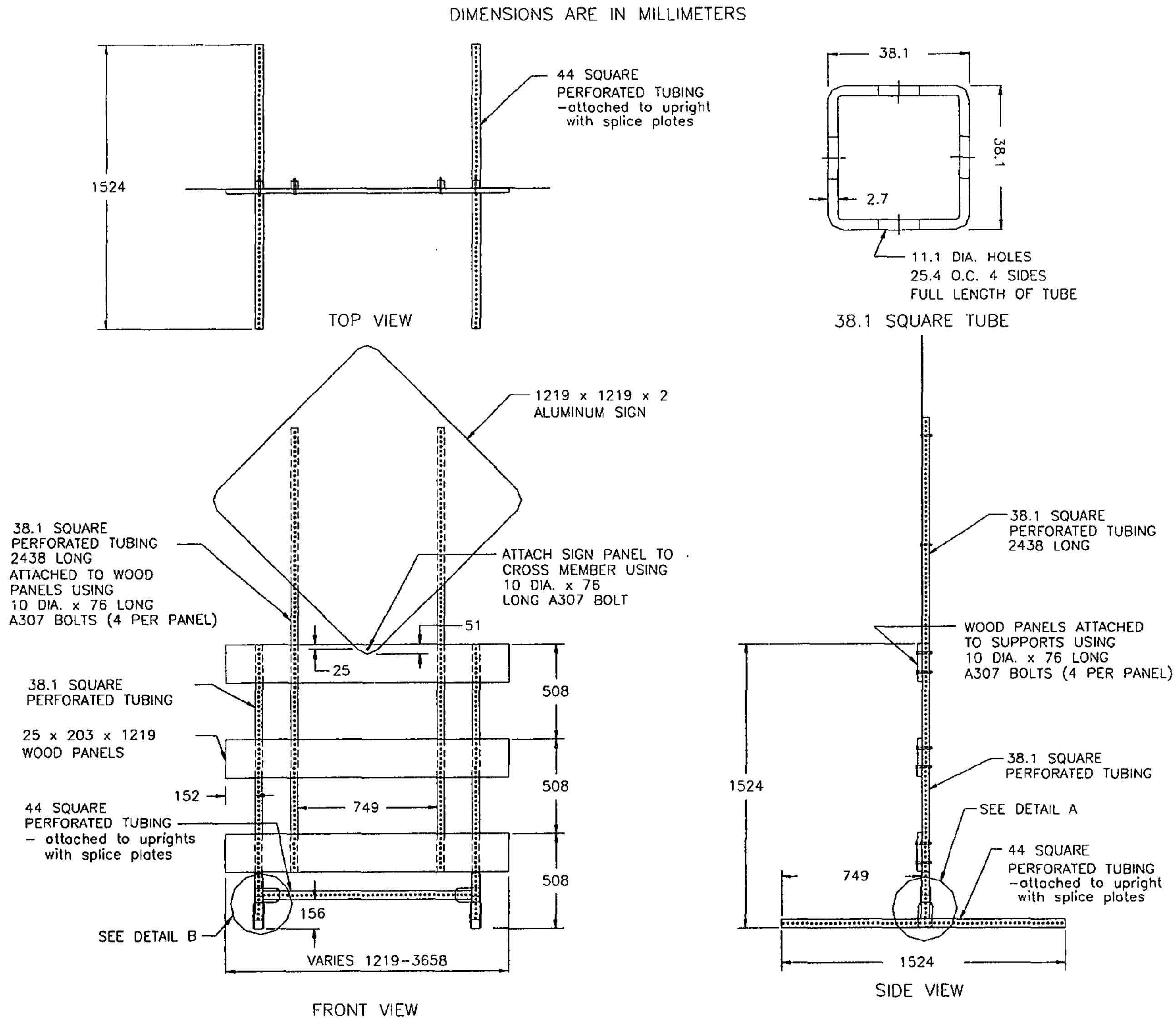


Figure 80. Schematic of Perforated Tubing Type III Barricade with Sign Panel Attached to Cross Members (Test No. 453880-7)

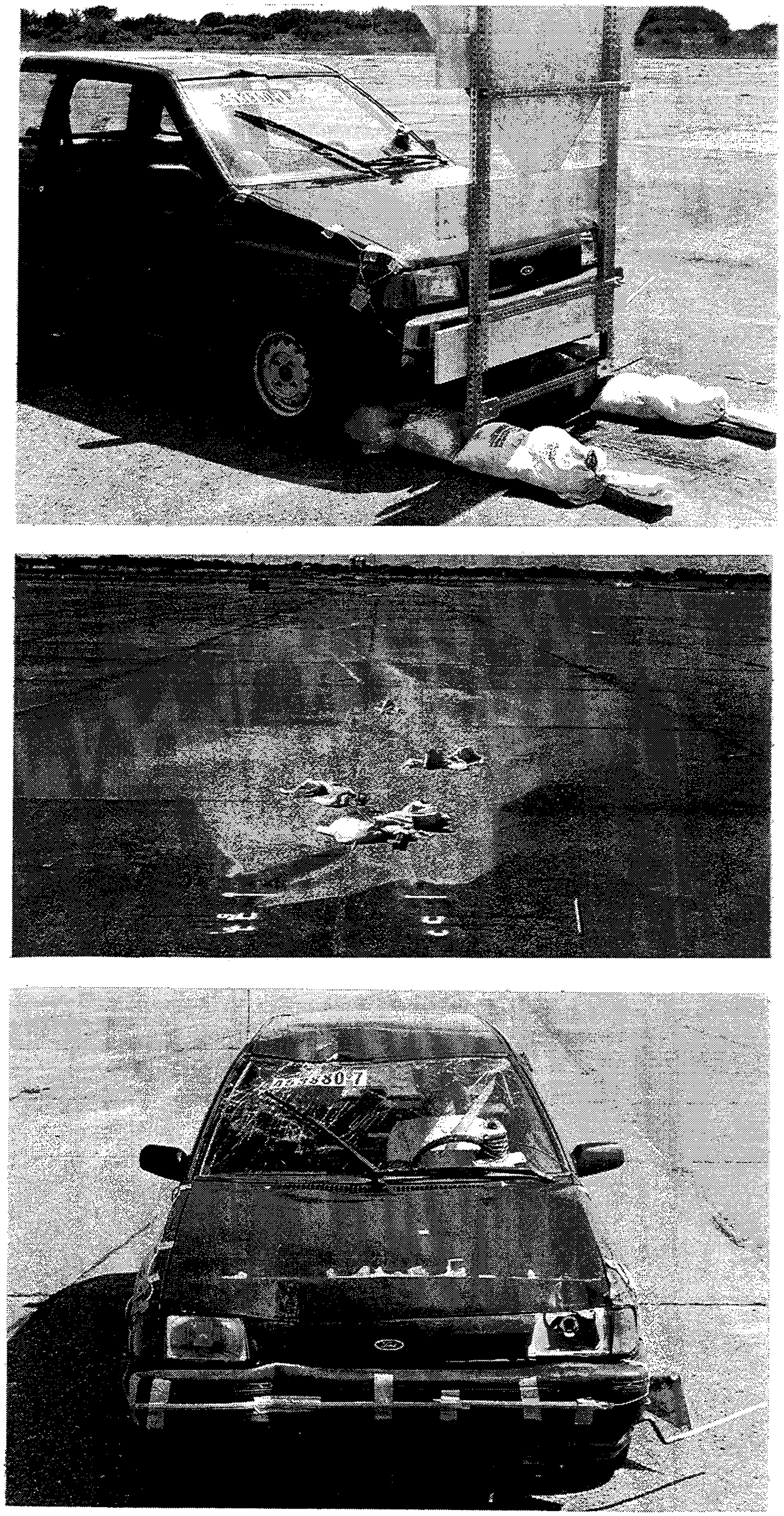
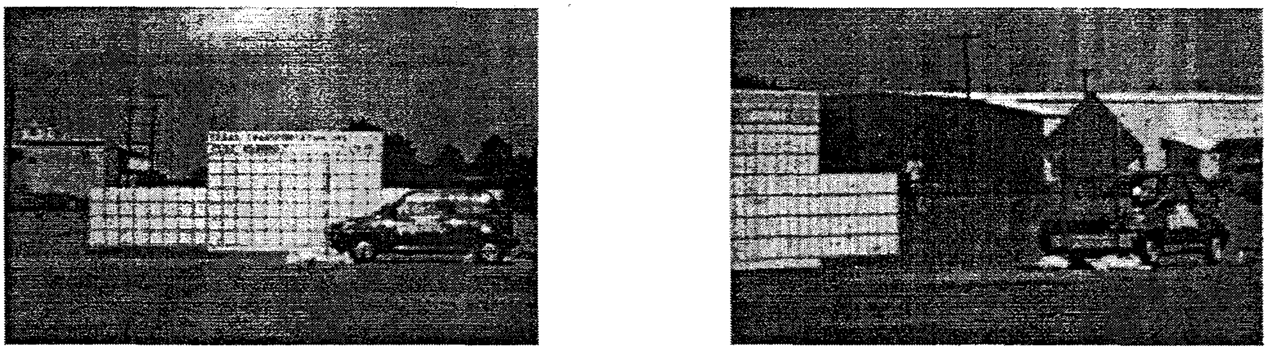
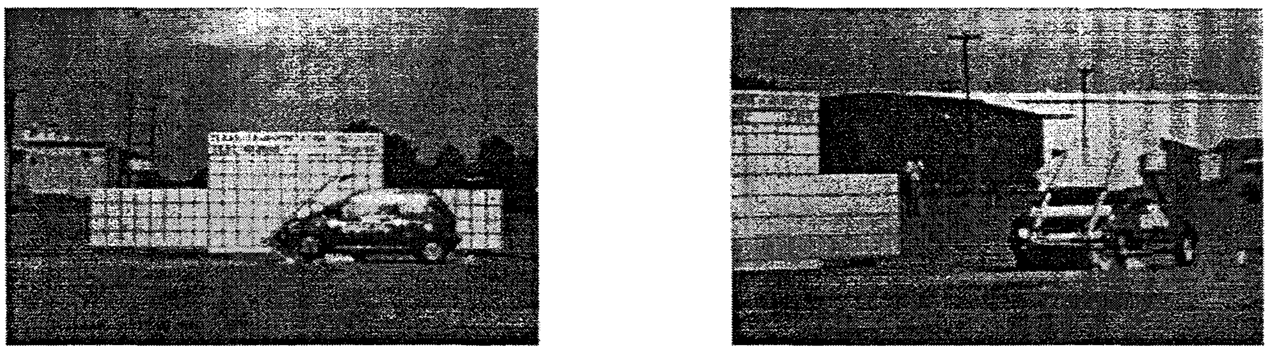


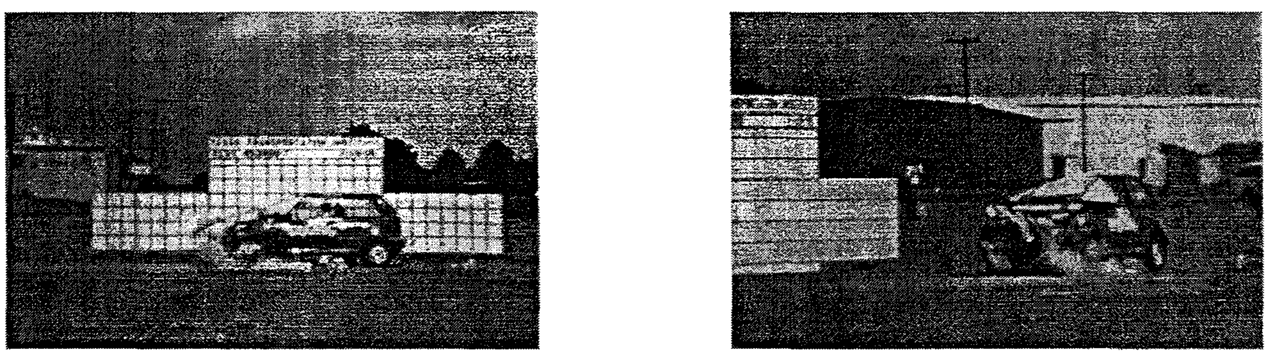
Figure 81. Vehicle and Barricade for Test No. 453880-7



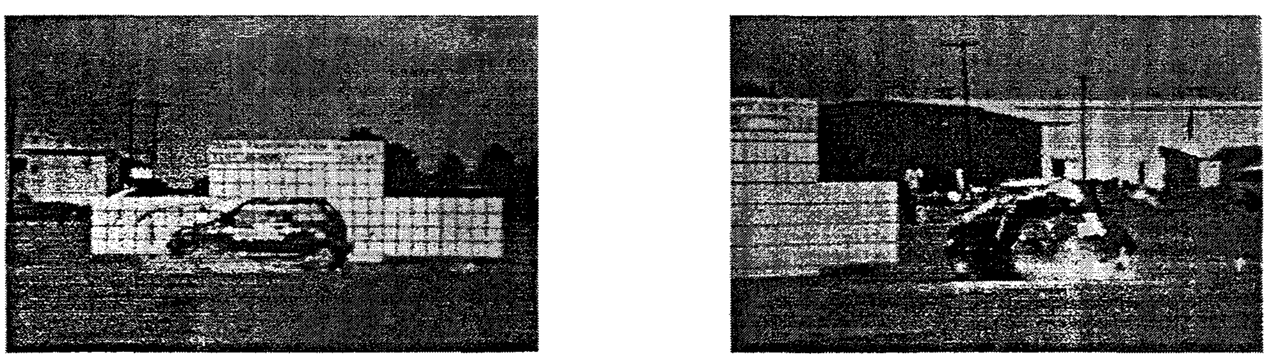
0.000 s



0.039 s

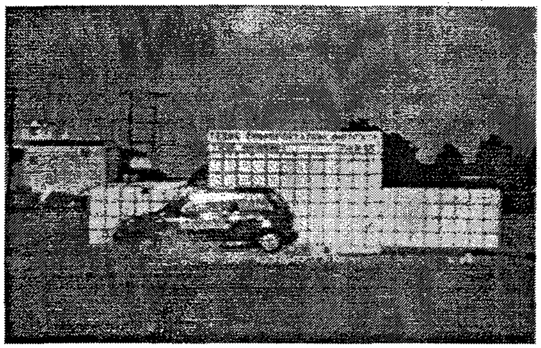
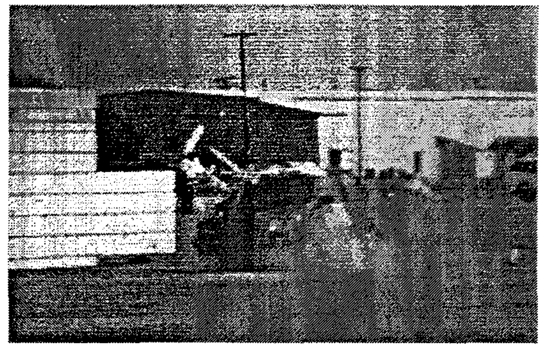


0.079 s

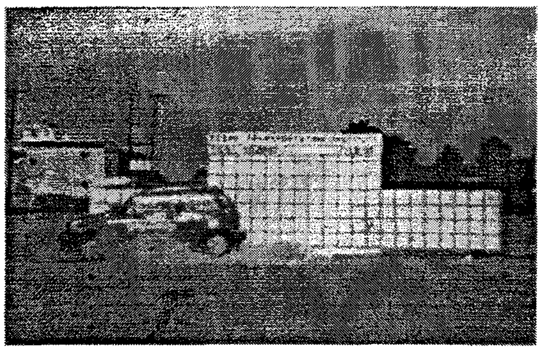
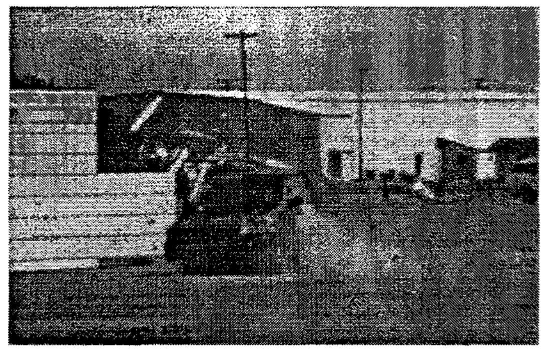


0.118 s

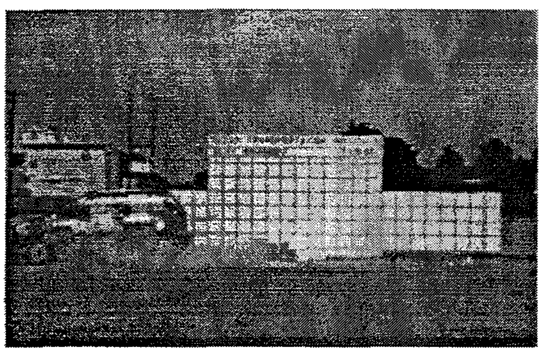
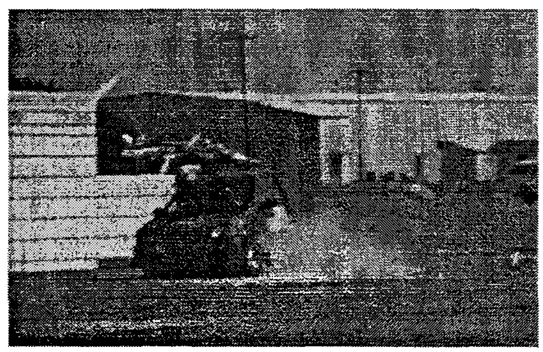
Figure 82. Sequential Photographs for Test No. 453880-7

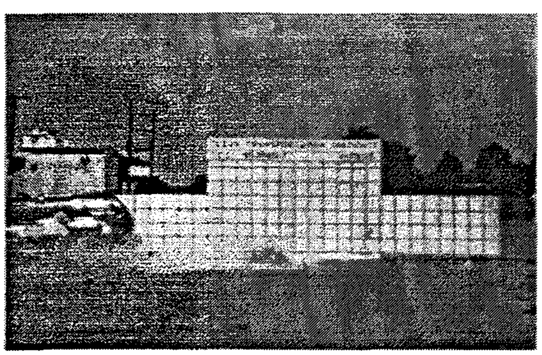
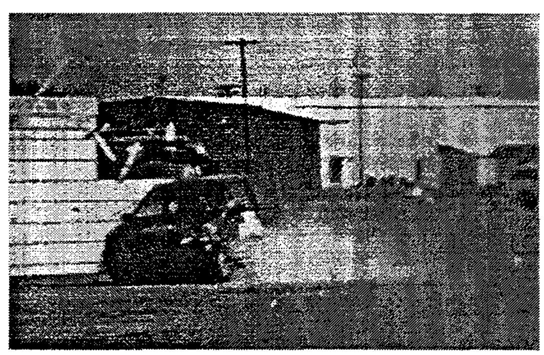
0.157 s

0.196 s

0.236 s

0.275 s

Figure 82. Sequential Photographs for Test No. 453880-7 (continued)

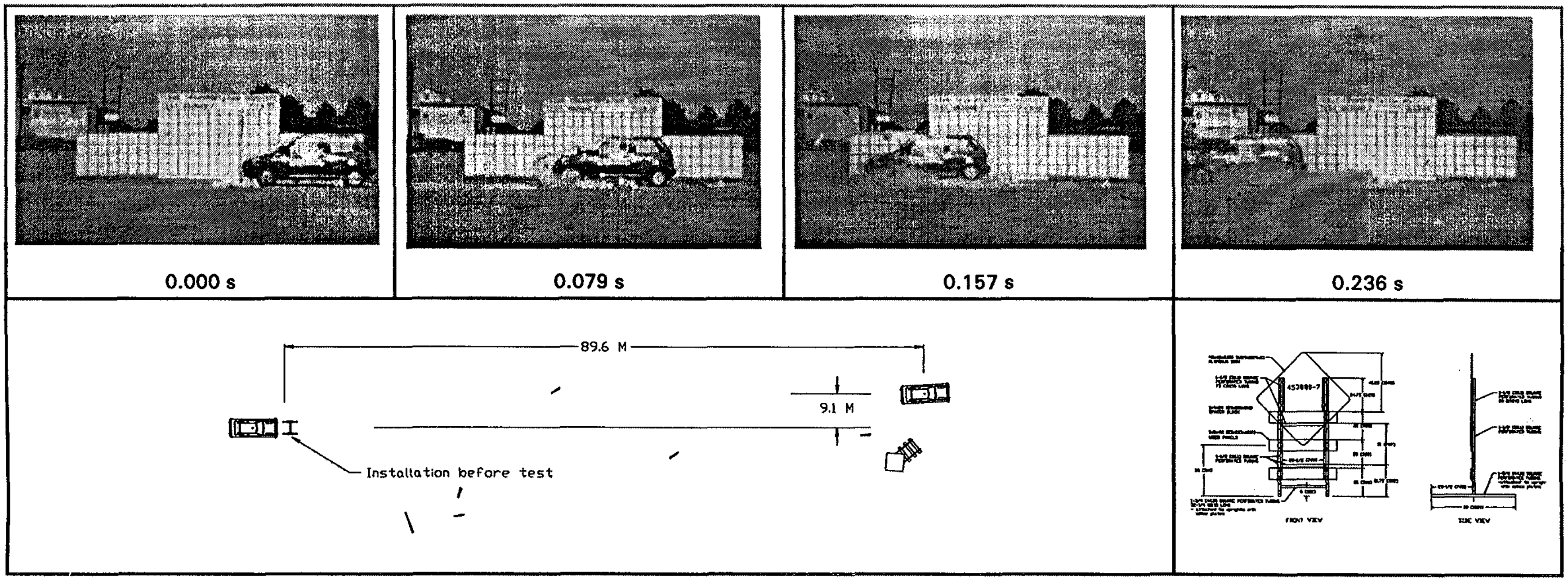
As Figure 81 shows, the vertical supports and the sign attachment separated from the barricade upon impact. Debris and sand were strewn along the path of the vehicle in an area 15.2 m wide and 87.8 m long. Damage to the vehicle is also shown in Figure 81. Maximum crush to the front exterior of the vehicle was not measurable (scrapes only). There was damage to the hood and roof. The windshield was shattered, and the roof was deformed 41mm into the occupant compartment.

Figure 83 presents a brief summary of the results of this test. The vertical supports and the sign panel attachment separated from the barricade upon impact. Broken segments of the barricade made contact with the hood and shattered the windshield and deformed the roof into the occupant compartment by 41 mm, but there was no penetration into the occupant compartment. Debris from the barricade was thrown along an area 15.2 m wide and 87.8 m long. The barricade vertical supports and the sign panel attachment were carried forward by the vehicle as a single unit, and it could pose potential hazard to oncoming traffic in adjacent lanes or to workers in the area, although it remained mostly in the path of the vehicle. The vehicle sustained minor damage to the hood and roof; however, the windshield was shattered. Crush to the center front bumper was not measurable. The longitudinal occupant impact velocity was 2.2 m/s, and the highest 10-msec average ridedown acceleration was 0.3 g. There was no contact in the lateral direction. The 50-msec average accelerations were -3.7 g in the longitudinal direction and 1.7 g in the lateral direction. The vehicle exited the immediate test site in a relatively smooth, stable manner and showed no potential for intrusion into adjacent traffic lanes. This crash test was judged to be successful; however, due to the potential hazard associated with the barricade vertical supports and sign panel attachment being carried forward as a single unit by the impacting vehicle, this sign panel attachment mechanism is not recommended for implementation.

4.3.3 Hollow Core Recycled Plastic Material with Solid Recycled Plastic Base and Sign Panel (Test No. 453880-6)

A Type III barricade was fabricated from hollow core recycled plastic material, similar to that used in test nos. 453790-4 and 453880-3, except that the base was constructed of solid recycled plastic, which had no effect on the impact performance of the barricade. An aluminum sign panel was attached to vertical sign supports also fabricated from hollow core plastic material, which were in turn attached to the rail elements. The sign panel was 1219 mm x 1219 mm in size and mounted at a height of 1.52 m from the ground to the bottom of the sign panel. Figure 84 shows a schematic of the barricade with the sign attachment. The test vehicle was a 1989 Ford Festiva, as shown in Figure 85. Appendix Figure 98 gives dimensions and information on the vehicle. The test vehicle impacted the barricade head-on with the centerline of the vehicle aligned with the centerline of the barricade, traveling at a speed of 98.5 km/h.

As the vehicle impacted the barricade, the base began to separate from the vertical supports, and at 34 msec, the vertical supports slapped the hood. At 49 msec, the vertical supports began to pitch up, and at 89 msec, the sign panel contacted the windshield. The braces separated from the supports at 101 msec. At 126 msec, the sign panel contacted the roof, and the vertical supports for the sign panel separated from those for the barricade. The braces



General Information	
Test Agency	Texas Transportation Institute
Test No.	453880-7
Date	07/19/95
Test Article	
Type	Type III Barricade w/sign
Name or Manufacturer	
Installation Height (m)	0.9 (3.0 ft)
Size and/or dimension and material of key elements	Perforated square tubing with wood panels
Soil Type and Condition	Concrete pavement, dry
Test Vehicle	
Type	Production
Designation	820C
Model	1989 Ford Festiva
Mass (kg) Curb	831 (1830 lb)
Test Inertial	820 (1806 lb)
Dummy	75 (165 lb)
Gross Static	895 (1971 lb)

Impact Conditions	
Speed (km/h)	99.5 (61.8 mi/h)
Angle (deg)	0
Exit Conditions	
Speed (km/h)	87.0 (54.1 mi/h)
Angle (deg)	N/A
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	2.2 (7.1 ft/s)
y-direction	No contact
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	0.3
y-direction	N/A
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Average (g's)	
x-direction	-3.7
y-direction	1.7
z-direction	-0.7

Test Article Deflections (m)	
Thrown Forward	87.8 (288.0 ft)
Thrown Laterally	7.6 (25.0 ft)
Vehicle Damage	
Exterior	
VDS	12FD1
CDC	12FDAW6
Interior	
OCDI	FS0100000
Maximum Exterior Vehicle Crush (mm)	41 (1.6 in)
Max. Occ. Compart. Deformation (mm)	41 (1.6 in)
Post-Impact Behavior	
Max. Roll Angle (deg)	-9.7
Max. Pitch Angle (deg)	-1.7
Max. Yaw Angle (deg)	-6.4

Figure 83. Summary of Results for Test No. 453880-7

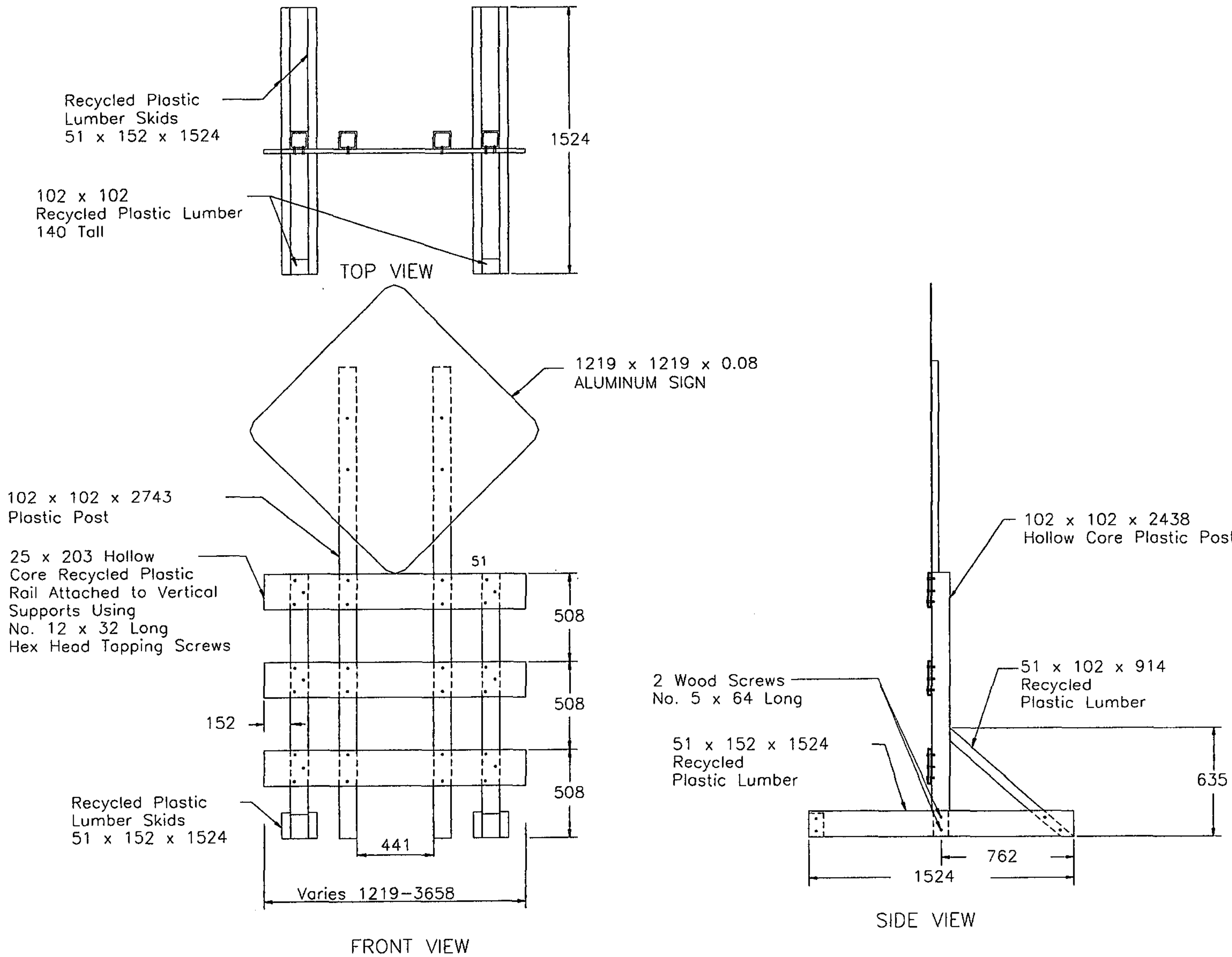


Figure 84. Schematic of Type III Barricade Fabricated from Hollow Core Recycled Plastic Material with Solid Recycled Base and Sign Panel (Test No. 453880-6)

Figure 85. Vehicle and Barricade for Test No. 453880-6

separated from the base at 152 msec. The vehicle lost contact with the barricade at 199 msec, traveling at a speed of 87.2 km/h. Prior to brake application, the vehicle was tracking straight-forward. The vehicle subsequently came to rest 80 m down and 5.7 m to the right of the point of impact. Figure 86 shows sequential photographs of the test period.

As Figure 85 shows, the barricade shattered upon impact. Debris and sand were strewn along the path of the vehicle in an area 13.0 m wide and 83.2 m long. Figure 85 shows damage to the vehicle. Maximum crush to the exterior of the vehicle was 70 mm on the passenger side just above the windshield. There was scrapes on the hood and roof. There was no deformation or intrusion into the occupant compartment.

A brief summary of the results of this test is presented in Figure 87. The barricade shattered upon impact, and broken segments of the barricade made contact with the hood and roof. However, the fragments neither penetrated nor intruded into the occupant compartment. Debris from the barricade was thrown along an area 13.0 m wide and 83.2 m long. Most fragments were not large enough to pose a potential hazard to oncoming traffic in adjacent lanes or to workers in the area. The vehicle sustained minor damage to the hood and roof. Maximum crush was 70 mm. The longitudinal occupant impact velocity was 2.6 m/s, and the highest 10-msec average ridedown acceleration was -3.8 g. There was no contact in the lateral direction. The 50-msec average accelerations were -5.0 g in the longitudinal direction and -2.8 g in the lateral direction. The vehicle exited the immediate test site in a relatively smooth, stable manner and showed no potential for intrusion into adjacent traffic lanes. This crash test was considered satisfactory.

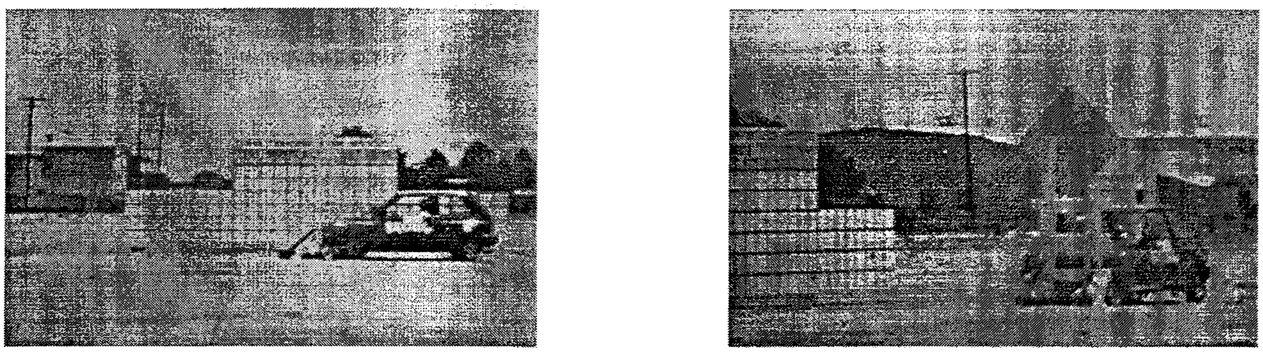
It was observed in the high-speed film that the bottom corner of the aluminum sign panel bent and folded in a manner similar to that observed in a previous test with the perforated tubing using the same 1.52-m mounting height (test no. 453880-5). Therefore, although no intrusion into the occupant compartment was observed in this test, it is the opinion of the researchers that the potential for the corner of the sign panel shattering and penetrating the windshield should be addressed. As with the perforated tubing design, two options are available for eliminating this behavior:

(1) providing an additional vertical brace along the center of the sign, or
(2) slightly lowering the mounting height and attaching the bottom corner of the sign panel to the top cross member of the barricade.

The simpler and more economical of the two modifications is to lower the mounting height by 51 mm and to attach it to the horizontal cross member, as shown in Figure 84. In the opinion of the researchers, modification of the existing hollow core recycled plastic barricade design is not necessary for a 2.13-m mounting height, since the sign panel should not contact the windshield of the impacting vehicle.

4.4 WIND LOAD ANALYSIS

In addition to being crashworthy, a barricade or temporary sign support should have sufficient structural capacity to withstand anticipated service loads. Members of TxDOT's safety review team noted instances in which the 102 mm x 102 mm vertical supports on project limit



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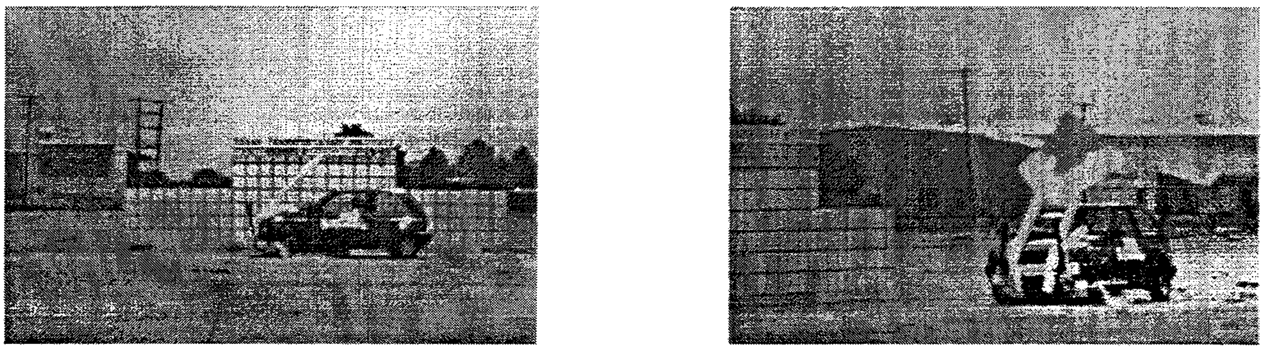

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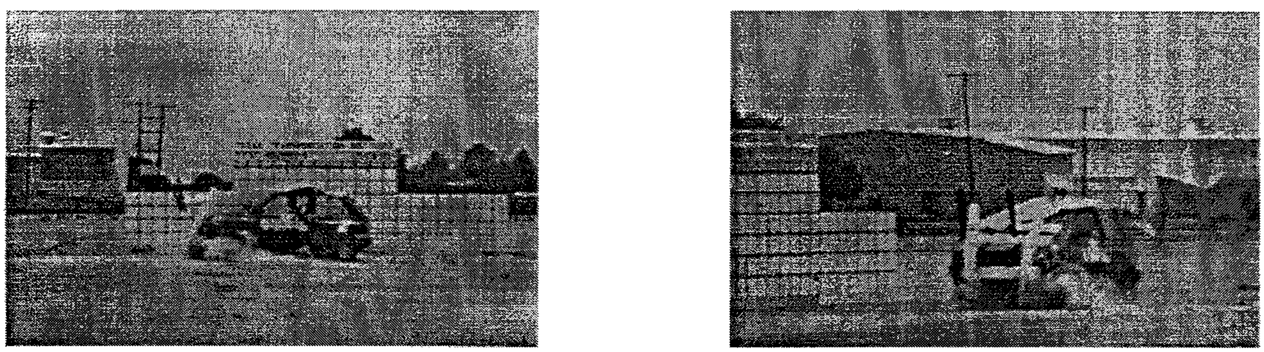

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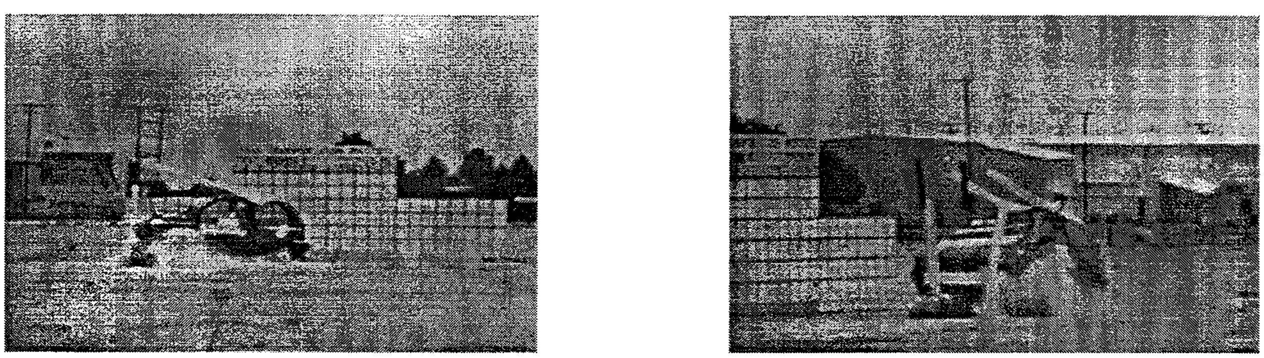
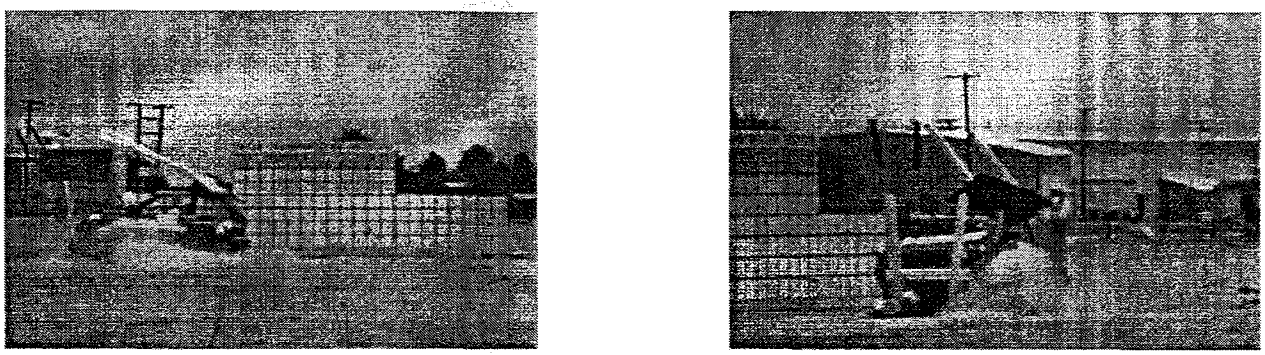


0.148 s

Figure 86. Sequential Photographs for Test No. 453880-6



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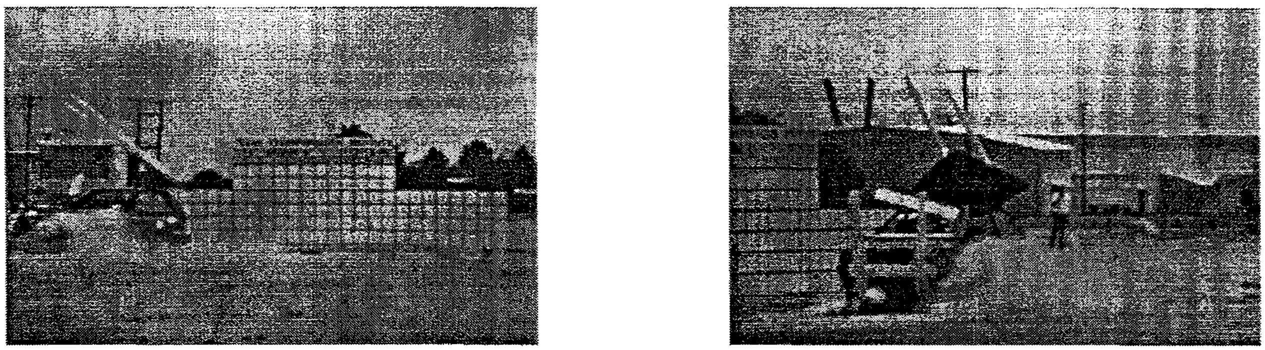

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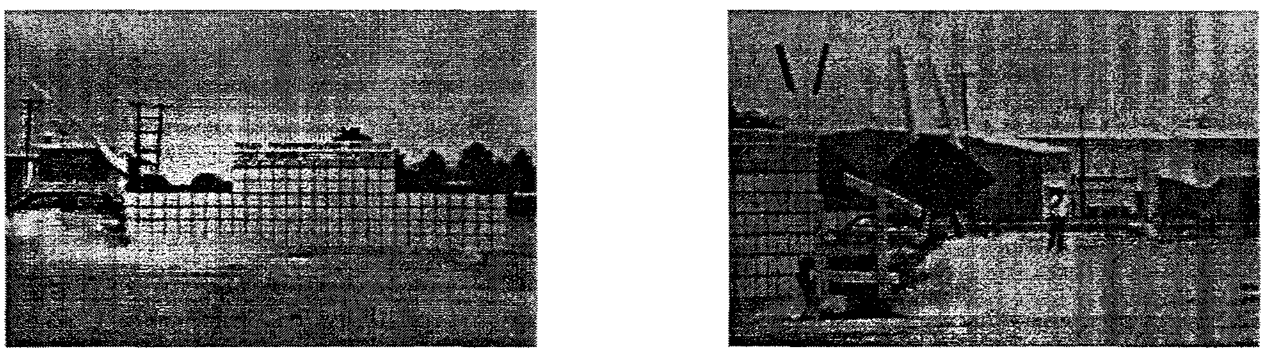

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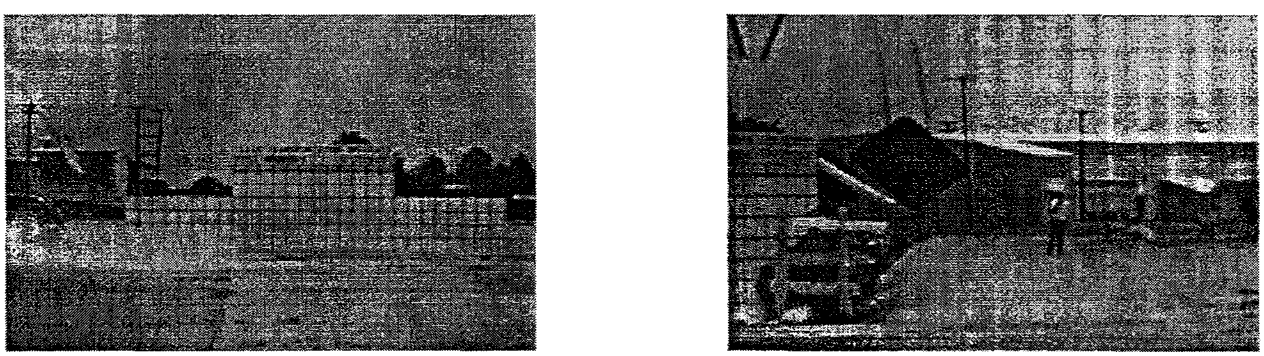
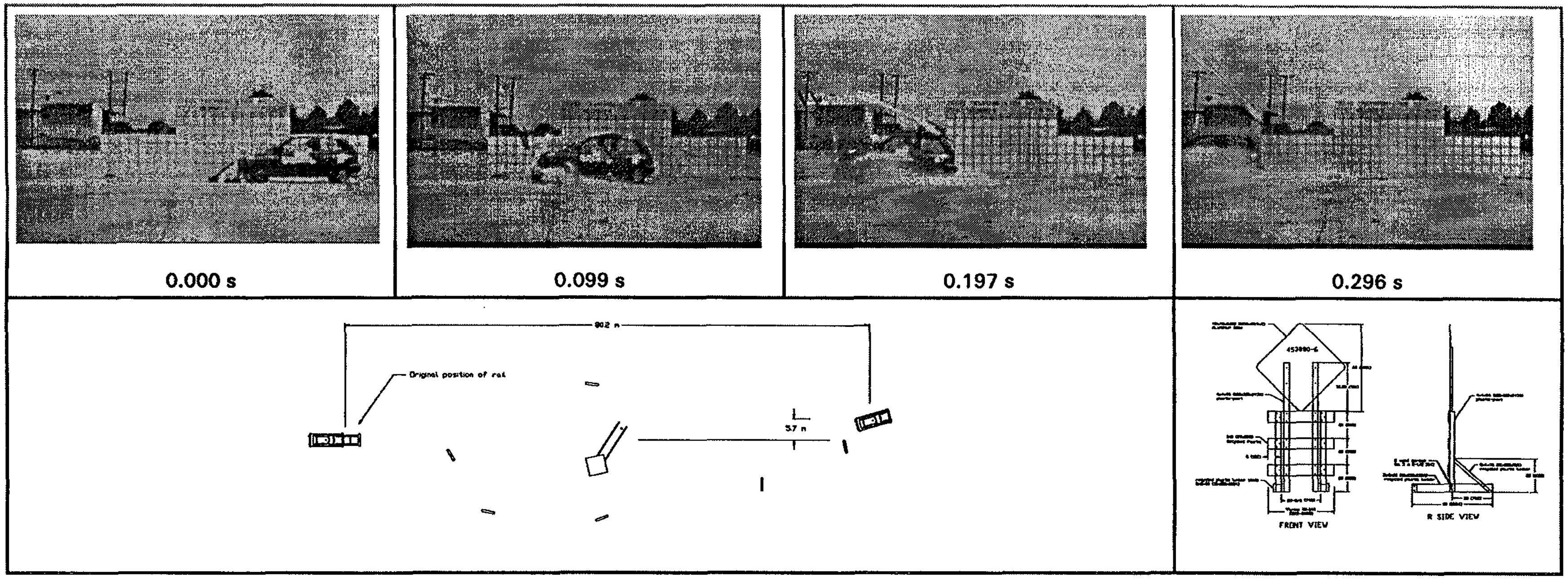


0.345 s

Figure 86. Sequential Photographs for Test No. 453880-6 (continued)



General Information	
Test Agency	Texas Transportation Institute
Test No.	453880-6
Date	07/19/95
Test Article	
Type	Type III Barricade w/sign
Name or Manufacturer	
Installation Height (m)	1.5 (5.0 ft)
Size and/or dimension and material of key elements	Recycled plastic
Soil Type and Condition	Concrete pavement, dry
Test Vehicle	
Type	Production
Designation	820C
Model	1989 Ford Festiva
Mass (kg) Curb	831 (1830 lb)
Test Inertial	820 (1806 lb)
Dummy	75 (165 lb)
Gross Static	895 (1971 lb)

Impact Conditions	
Speed (km/h)	98.5 (61.2 mi/h)
Angle (deg)	0
Exit Conditions	
Speed (km/h)	87.2 (54.2 mi/h)
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	2.6 (8.5 ft/s)
y-direction	No contact
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-3.8
y-direction	N/A
PHD (optional)	
ASI (optional)	
Max. 0.050-sec Average (g's)	
x-direction	-5.0
y-direction	-2.8
z-direction	-0.5

Test Article Deflections (m)	
Thrown Forward	83.2 (273.0 ft)
Thrown Laterally	10.7 (35.0 ft)
Vehicle Damage	
Exterior	
VDS	None applicable
CDC	12FCGN6
Interior	
OCDI	AS0000000
Maximum Exterior Vehicle Crush (mm)	70 (2.8 in)
Max. Occ. Compart. Deformation (mm)	0 (0 in)
Post-Impact Behavior	
Max. Roll Angle (deg)	-3.2
Max. Pitch Angle (deg)	4.6
Max. Yaw Angle (deg)	-1.8

Figure 87. Summary of Results for Test No. 453880-6

barricades had broken during periods of high wind. Additionally, concerns were raised regarding the structural adequacy of the standard temporary wooden sign support structure when supporting a 1219 mm x 1219 mm sign panel mounted at a height of 2.13 m.

Since most roadside sign support structures and temporary traffic control devices are considered to have a relatively short life expectancy, specifications permit them to be designed using wind speeds based on a 10-year mean recurrence interval. Using a 10-year mean recurrence interval, the accepted design wind speed throughout most of Texas is 96.5 km/h. (*12*) Using this wind speed, the associated wind pressure is computed by the following formula:

$$P = 0.0473(1.3V)^2 C_d C_h ,$$

where

P = wind pressure (Pa),
V = wind speed (km/h),
C_d = drag coefficient, and
C_h = height coefficient.

The wind loads on a structure are determined using this calculated wind pressure and the exposed areas of any vertical supports, horizontal panels, and/or sign blanks. Once the loads have been determined, the stresses in the support members can be computed and compared to the allowable stresses. It should be noted that, due to the probabilistic nature and uncertainty of wind load events, the specifications permit a 40% increase in allowable stresses when making these computations.

4.4.1 Temporary Wooden Sign Support System

The wood post sign support system used to support a 1219 mm x 1219 mm warning sign consists of two nominal 102 mm x 102 mm wood posts as detailed in the TxDOT "Barricade and Construction Standards" sheets. These supports may either be embedded in the ground or mounted on wooden skids. Until recently, the warning signs erected on these fixed supports were required to have a mounting height (i.e., the height from the ground to the bottom of the sign panel) of 1.52 m in rural areas and 2.13 m in urban applications. However, the Department has since revised its standards to require a sign panel mounting height of 2.13 m for all fixed sign supports in both rural and urban applications.

As discussed in Section 3.4, the skid-mounted wood post sign support system performed satisfactorily in a full-scale crash test. However, since most existing applications of this system used a 1.52-m mounting height, there was some concern regarding the structural adequacy of the support structure for mounting heights of 2.13 m.

Using a design wind speed of 96.5 km/h, the load on the sign was computed to be 992 N. For a sign mounting height of 2.13 m, the resulting bending moment at the base of the supports is 2972 N-m. Based on the allowable stresses for Grade 2 southern yellow pine, which is a common grade and species of wood, the combined stress ratio (CSR) was determined to be 0.54, which is well below the acceptable value of 1.0. Thus, from the standpoint of structural capacity, the current standard wood post sign support system is considered to be acceptable for use with a 1219 mm x 1219 mm warning sign mounted at a height of 2.13 m.

Using the maximum computed overturning moment for a 2.13-m mounting height, an analysis was conducted to determine the required number of 11.3-kg sand bags required as ballast on the skid-mounted system to prevent overturning during the 96.5 km/h design wind condition. The analysis indicated that a total of 18 bags, equally distributed on the two skids, would be required to withstand the design wind condition. However, if TxDOT and/or contractors are willing to permit a small percentage of blow-downs or overturns, the number of bags can be reduced to a more practical value.

4.4.2 Type III Wooden Barricade with Wooden Sign Panel

As mentioned above, members of TxDOT's safety review team noted several instances in which the 102 mm x 102 mm vertical supports on project limit barricades had broken during periods of high wind. Based on the crash testing described in Section 3.1, the continued use of wooden barricades and sign panels is not recommended. Nonetheless, a wind load analysis on a Type III wooden barricade with sign panel was conducted to provide additional information for use in the evaluation of alternate barricade designs.

As detailed in the TxDOT "Barricade and Construction Standards" sheets, the Type III wooden barricade sign support varies in terms of length, mounting height, and the size of the sign panel. From the standpoint of the wind load analysis, the critical configuration was taken to be a 3.7-m barricade supporting a 1219 mm x 1219 mm warning sign mounted at a height of 1.52 m which, until recently, was the maximum mounting height for barricade sign supports.

Using the exposed areas of both the sign panel and the three horizontal rail faces, the maximum bending moment computed for the Type III barricade sign support was 3618 N-m. Based on the allowable stresses for Grade 2 southern yellow pine, the combined stress ratio (CSR) for the barricade supports was determined to be 0.69, which is well below the acceptable value of 1.0. Thus, from the standpoint of structural capacity, the current Type III wooden barricade sign support system should be capable of withstanding design wind speeds in excess of 96.5 km/h. Thus, the observed failures were likely due to very high winds (i.e. greater than the 96.5 km/h design wind speed) and/or a poor grade or quality of lumber used for the vertical supports.

Using bending moments computed on the basis of a 96.5 km/h design wind speed, the number of 11.3-kg sand bags required as ballast on skid-mounted barricades to prevent overturn was determined. As Table 2 shows, the number of sand bags required varies from 16 to 22 depending on the length of the barricade. If these quantities are impractical and TxDOT and/or contractors are willing to permit a small percentage of blow-downs or overturns, the number of bags can be reduced.

Table 2. Ballast Required for Type III Barricade Sign Support

System Description	Barricade Length m	Moment N-m	No. of 11.3-kg sand bags
Type III Barricade with 1219 mm x 1219 mm sign mounted at 1.52 m	1.2	2780	16
	1.8	2980	18
	2.4	3200	20
	3.7	3620	22

4.4.3 Alternate Type III Barricade Designs

As described in the preceding sections, the two alternate Type III barricade designs that demonstrated satisfactory impact performance during full-scale crash testing are the perforated square steel tubing and the hollow-core recycled plastic. A wind load analysis was conducted on each of these two different support types to determine if they have sufficient structural capacity to withstand the prescribed design wind speed of 96.5 km/h.

The perforated square tubing is manufactured from ASTM A-446 steel which has a yield stress of 227.5 MPa. This gives the 44.5-mm tubing, which is used at the base of the Type III barricade design, a yield moment of 1377 N-m, which is greater than the required moment of 621 N-m for a 3.7-m Type III barricade. Therefore, from a structural analysis standpoint, the perforated steel tube barricade is adequate for lengths up to and including 3.7 m.

However, when used as a sign support for a 1219 mm x 1219 mm warning sign, the analysis indicated that the 44.5-mm tubing is not sufficient to resist the wind loads associated with a 96.5 km/h design wind speed, except for relatively low mounting heights. If it is desired to use this barricade system as a sign support for mounting heights up to and including 2.13 m, the size of the tube sleeve could be increased from 44.5 mm to 50.8 mm and the size of the vertical supports could be correspondingly increased from 38.1 mm to 44.5 mm. This would provide sufficient structural capacity for a 3.7-m barricade supporting a 1219 mm x 1219 mm sign panel mounted at a height of 2.13 m.

It should be noted, however, that unless the proper amount of ballast (see Table 2) is provided at the base of the structure, the barricade will overturn prior to developing the design wind loads. If occasional overturns of this nature are considered acceptable, increasing the structural capacity of the barricade may be unwarranted.

The hollow core recycled plastic Type III barricade is fabricated from recycled HDPE, which has a tensile strength of 27.6 MPa (4000 psi). Although this value is greater than typical values for wood, the hollow section has a smaller section modulus than a solid 102 mm x 102 mm support. The computed allowable moment for the hollow core 102 mm x 102 mm recycled plastic support is approximately 1164 N-m, which is greater than the required moment of 621 N-m for a 3.7-m Type III barricade. Therefore, from a structural analysis standpoint, the hollow core recycled plastic barricade design is suitable for use in lengths up to and including 3.7 m.

However, as with the perforated steel tube design, the analysis indicated that the hollow core 102 mm x 102 mm recycled plastic support is not sufficient to resist the wind loads associated with a 96.5 km/h design wind speed when a 1219 mm x 1219 mm sign panel is attached. If it is desired to use this barricade system as a sign support for mounting heights up to and including 2.13 m, an additional 102 mm x 102 mm member could be added to each vertical support. In other words, two 102 mm x 102 mm posts could be attached to each other and used with the existing skid design to form the equivalent of a 102 mm x 204 mm section. This would provide sufficient structural capacity for a 3.7-m barricade supporting a 1219 mm x 1219 mm sign panel mounted at a height of 2.13 m for the prescribed design wind speed.

Based on the lightweight nature of the hollow core material and the good results of the crash tests conducted on this system, the addition of this extra support member should not affect the impact performance of the system. However, before any changes to the design are considered, several factors should be weighed. First, if proper ballast (see Table 2) is not provided at the base of the structure, the barricade will overturn prior to developing the design wind loads. If this is the case, increasing the structural capacity of the barricade may be unwarranted. Second, in lieu of using barricades as sign supports, temporary wooden sign support systems can be used for the required warning signs. These standard sign support structures have been shown to be adequate from both an impact and structural standpoint.

4.5 SUMMARY

Seven crash tests were conducted on alternate barricade designs without sign attachments and three crash tests were conducted on various sign panel attachment mechanisms. A summary of the findings from the crash tests is as follows:

- A Type III barricade fabricated from perforated tubing was successfully crash tested. The barricade can be used with either plastic or wooden rail elements and on a concrete pavement surface or on a wet soil surface.

- A plastic Type III barricade manufactured by Tex-Mex Barricade was successfully crash tested, indicating the viability of using a lightweight plastic material for fabrication of the barricade.

- A Type III barricade fabricated from hollow core recycled plastic material was successfully crash tested, again indicating the viability of using a lightweight plastic material for fabrication of the barricade. The barricade can be used with bases constructed from wood or a solid recycled plastic material and on a concrete pavement surface or on a wet soil surface.

- The impact performance of a Type III barricade fabricated from solid recycled plastic material was judged to be unsatisfactory. Similar to a wooden barricade, the fractured vertical supports and rail elements rotated upward and into the windshield, resulting in shattering and penetration of the windshield. This confirmed the problem associated with using a heavy material for fabrication of the barricade.

- The test of a Type III barricade fabricated from perforated tubing with wooden rail elements and a sign panel attached to the wooden rail elements was judged to be unsatisfactory. The bottom corner of the aluminum sign panel bent forward upon impact and struck the windshield, resulting in shattering of the windshield, but no intrusion into the occupant compartment. Otherwise, the test would have been considered satisfactory. The problem with the bottom corner of the sign panel bending forward can be remedied by bracing the sign panel or by attaching the bottom corner of the sign panel onto the top rail element.

- A Type III barricade fabricated from hollow core plastic material with a sign panel attached to the plastic rail elements was successfully crash tested, indicating the viability of using a lightweight plastic material for fabrication of the barricade, with or without sign attachment.

- The test of a Type III barricade fabricated from perforated tubing with wooden rail elements and a sign panel attached to cross members fabricated from perforated tubing and bolted to the vertical supports was judged to be satisfactory. However, the fractured vertical supports, the rail elements, and the sign panel attachment mechanism remained as a single unit and was thrown forward by the impacting vehicle, raising concern that this might pose a hazard to adjacent traffic and workers in the area. The use of this sign panel attachment mechanism is therefore not recommended.

V. SUMMARY OF FINDINGS AND RECOMMENDATIONS

Based on the results of the full-scale crash tests, the findings and recommendations are summarized as follows.

5.1 SUMMARY OF FINDINGS

5.1.1 Existing Work Zone Traffic Control Devices

- Existing wooden barricades, with or without sign panel attachments, pose potential hazards to impacting vehicles due to the propensity for the sign panel or the fractured vertical supports to impact and penetrate the windshield.

- A Type III wooden barricade, impacted in an end-on position, performed satisfactorily, which was contrary to the initial concern that the rail elements of the barricade would impact the windshield and penetrate the occupant compartment when impacted in this manner.

- Wooden sign panels, when used with portable sign supports, have the propensity to disengage from the support and impact the windshield of the impacting vehicle and potentially penetrate the occupant compartment. Due to their lightweight nature, plastic/fabric sign panels do not pose such a hazard.

- The crash test with the easel sign support showed the potential for the sign support to rotate and flip up in the air, resulting in the top of the support impacting and penetrating the windshield of the impacting vehicle.

- The GSD sign trailer, with a wooden sign panel, performed satisfactorily in the crash test. The sign panel and the upper vertical supports separated from the trailer and impacted the roof of the impacting vehicle. However, there was no penetration into the occupant compartment.

- A skid-mounted fixed sign support with a wooden sign panel mounted at a height of 1.52 m performed satisfactorily in the crash test. The wooden vertical supports fractured upon impact. The sign panel and the fractured vertical supports impacted the roof of the impacting vehicle, but there was no penetration into the occupant compartment. It is believed that a higher sign mounting height of 2.1 m would perform equally as well or better than the 1.52 m mounting height since the sign panel and fractured vertical supports would more likely rotate over the top of the impacting vehicle.

5.1.2 Alternate Barricade Designs

- A Type III barricade fabricated from perforated tubing was successfully crash tested. The barricade can be used with either plastic or wooden rail elements and is suitable for placement on both a concrete pavement surface and a wet soil surface.

- A plastic Type III barricade manufactured by Tex-Mex Barricade was successfully crash tested, indicating the viability of using a lightweight plastic material for fabrication of the barricade.

- A Type III barricade fabricated from hollow core recycled plastic material was successfully crash tested, again indicating the viability of using a lightweight plastic material for fabrication of the barricade. This barricade can be used with bases constructed from wood or a solid recycled plastic material and is suitable for placement on both a concrete pavement surface and a wet soil surface.

- The impact performance of a Type III barricade fabricated from solid recycled plastic material was judged to be unsatisfactory. Similar to a wooden barricade, the fractured vertical supports and rail elements rotated upward and into the windshield, resulting in shattering and penetration of the windshield. This confirmed the problem associated with using a heavy material for fabrication of the barricade.

- The test of a Type III barricade fabricated from perforated tubing with wooden rail elements and an aluminum sign panel attached to the wooden rail elements was judged to be unsatisfactory. The bottom corner of the aluminum sign panel bent forward upon impact and struck the windshield, resulting in shattering of the windshield, but no intrusion into the occupant compartment. Otherwise, the test would have been considered satisfactory. The problem with the bottom corner of the sign panel bending forward could potentially be remedied by bracing the sign panel or by attaching the bottom corner of the sign panel to the top horizontal rail element.

- A Type III barricade fabricated from hollow core plastic material with an aluminum sign panel attached to the plastic rail elements was successfully crash tested, indicating the viability of using a lightweight plastic material for fabrication of the barricade, with or without sign attachment.

- The test of a Type III barricade fabricated from perforated tubing and wooden rail elements with an aluminum sign panel attached to additional cross members fabricated from perforated tubing was judged to be satisfactory. However, the fractured vertical supports, the rail elements, and the sign panel attachment mechanism remained as a single unit and was thrown forward by the impacting vehicle, raising concern that this might pose a hazard to adjacent traffic and workers in the area. The use of this sign panel attachment mechanism is therefore not recommended.

- Wind load analysis results indicated that the alternate barricade designs have the requisite structural capacity to handle the design wind load conditions. However, in order to be used as sign supports and provide mounting heights up to 2.13 m, some structural changes to the vertical supports may be required.

5.2 RECOMMENDATIONS

- With the demonstrated problem associated with wooden barricades, both with and without sign attachments, the use of wooden barricades in construction zones is not recommended. Alternate barricade designs and sign attachment mechanisms were developed and successfully crash tested in this study. It is therefore recommended that the use of alternate barricade designs using perforated tubing or lightweight plastic material be considered in place of wooden barricades.

- Two sign panel attachment mechanisms for barricades constructed from perforated tubing were developed, one to the rail elements and the other to cross members. The sign panel attachment to rail elements mechanism did not perform satisfactorily. The bottom corner of the sign panel bent forward upon impact and subsequently impacted and shattered the windshield. The performance of the attachment mechanism could potentially be improved by bracing the sign panel or lowering the mounting height and bolting the bottom corner of the sign panel to the top rail element. However, further evaluation is needed to determine if the modified attachment mechanism would perform satisfactorily. The sign panel attachment to cross members mechanism successfully met the crash test evaluation criteria. However, the fractured vertical supports, the rail elements, and the sign panel remained as a single unit and were thrown forward by the impacting vehicle. This could potentially pose a hazard to adjacent traffic and workers in the area. The use of sign panel with barricades constructed from perforated tubing is therefore not recommended until a better attachment mechanism is developed.

- A sign panel attachment mechanism for barricades constructed from hollow core, recycled plastic material was developed and successfully crash tested. However, it was observed that the bottom corner of the sign panel also bent forward upon impact, which could potentially impact and penetrate the windshield. The bending of the bottom corner of the sign panel could be eliminated by bracing the sign panel or lowering the mounting height and bolting the bottom corner of the sign panel to the top rail element. However, further evaluation is needed to determine the performance of the modified attachment mechanism.

- Despite the satisfactory results observed in the end-on test into a 1.22-m long Type III barricade, the researchers believe that, given the geometry of the barricade relative to the front of the vehicle when impacted in an end-on position, a potential hazard still exists. In all likelihood, a longer barricade, e.g., 3.7 m, may not have performed satisfactorily due to the increased weight attributed to the longer horizontal rail elements and the addition of intermediate vertical supports. Additionally, field experience, though anecdotal in nature, indicates the potential for such an occurrence. Thus, it is still recommended that wooden barricades not be placed in such a manner as to expose the barricades to end-on impacts.

- The use of wooden sign panels with portable sign supports is not recommended due to the potential of the sign panel impacting and penetrating the windshield of the impacting vehicle. Due to its light weight, a plastic/fabric type of sign panel does not pose such hazard and is recommended for use with portable sign supports.

- The use of the easel portable sign support is not recommended since the support has the potential to rotate upward and impact and penetrate the windshield of the impacting vehicle.

- The GSD sign trailer, with a wooden sign panel, performed satisfactorily in a head-on test, and its continued use is recommended where warranted.

- A skid-mounted fixed sign support with a wooden sign panel mounted at a height of 1.52 m performed satisfactorily in the crash test. It is believed that a higher sign mounting height of 2.1 m would perform equally as well, if not better. Thus, the continued use of the skid-mounted fixed sign support with sign panel mounting heights of 1.52 m or 2.1 m is recommended.

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APPENDIX A.
DIMENSIONS AND PROPERTIES OF TEST VEHICLES

This appendix provides details on the dimensions and information on the vehicles used for the crash tests performed under this study.

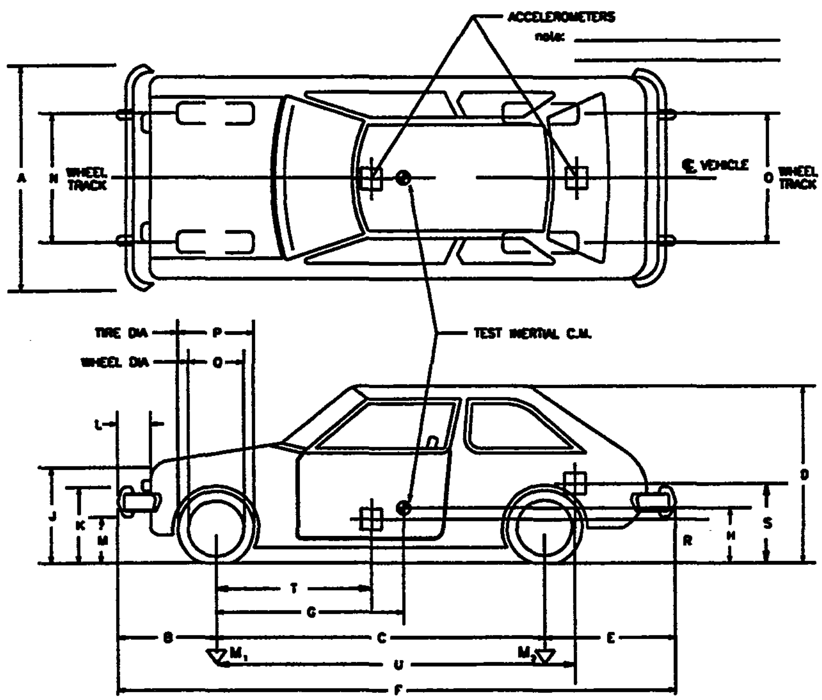
DATE: 05/22/92 TEST NO.: 5336-1 VIN NO.: JHMSR5321BS015220

YEAR: 1981 MAKE: Honda MODEL: Civic

TIRE INFLATION PRESSURE: ______ ODOMETER: ______ TIRE SIZE: 145R13

MASS DISTRIBUTION (kg) LF 264 RF 254 LR 152 RR 147

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: 4 cylinder

ENGINE CID: 1.1 litre

TRANSMISSION TYPE:

_ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: 50th perc male

MASS: 75 kg

SEAT POSITION: Driver

GEOMETRY - (mm)

A 1588	E 724	J 762	N 1372	R 432
B 724	F 3690	K 470	O	S 743
C 2242	G 820.4	L 76	P 552	T 692
D 1340	H	M 343	Q 362	U 2381

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1		518	554
M_2		299	340
M_T		817	894

Figure 88. Vehicle properties for Test No. 453360-1

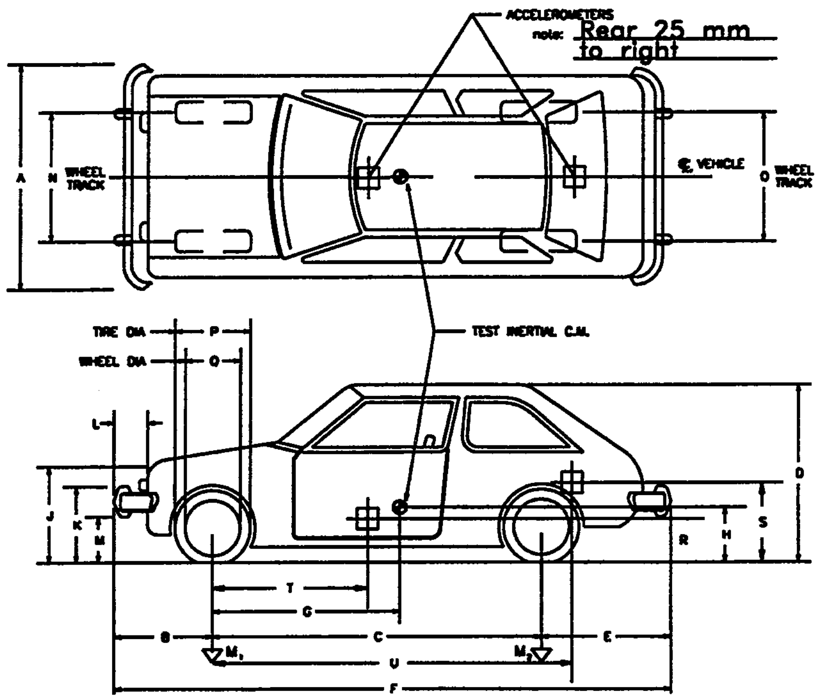
DATE: 09/18/92 TEST NO.: 5336-4 VIN NO.: VX1BA1216GK319727

YEAR: 1986 MAKE: Yugo MODEL: GV

TIRE INFLATION PRESSURE: ______ ODOMETER: 60377 TIRE SIZE: 145R13

MASS DISTRIBUTION (kg) LF 256 RF 239 LR 149 RR 173

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: 4 cylinder

ENGINE CID: 1.1 litre

TRANSMISSION TYPE:

_ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: 50th perc male

MASS: 75 kg

SEAT POSITION: Driver

GEOMETRY - (mm)

A 1530	E 622	J 762	N 1321	R 368
B 673	F 3448	K 470	O	S 660
C 2153	G 848.4	L 76	P 546	T 800
D 1391	H	M 343	Q 362	U 2457

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	543	495	533
M_2	289	322	361
M_T	832	817	894

Figure 89. Vehicle properties for Test No. 453360-4

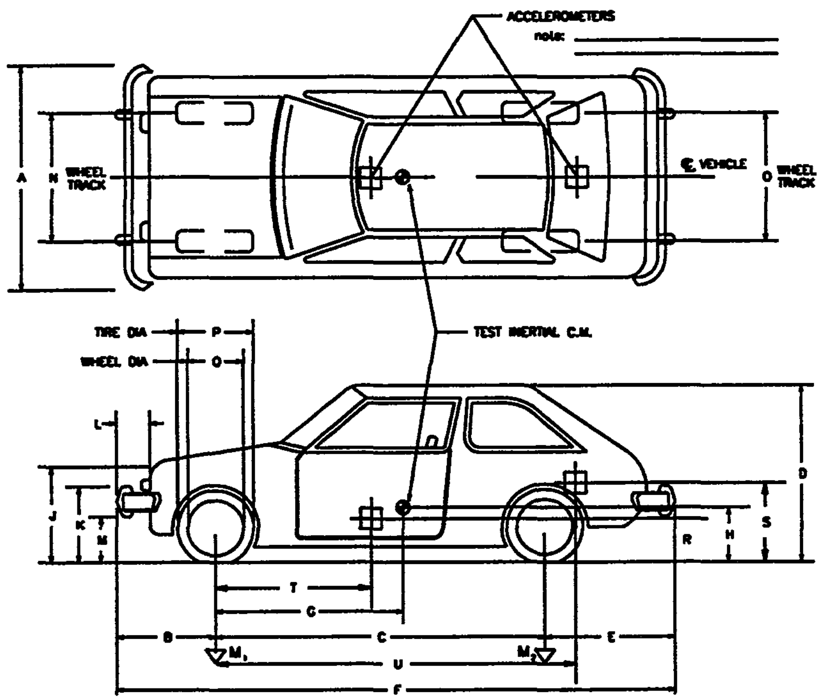
DATE: 02/7&8/95 TEST NO.: 453880-1,2,3,4 VIN NO.: JGMR2152JK761205

YEAR: 1989 MAKE: Chevrolet MODEL: Sprint

TIRE INFLATION PRESSURE: ______ ODOMETER: 05204 TIRE SIZE: 155R12

MASS DISTRIBUTION (kg) LF 242 RF 248 LR 166 RR 164

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: 3 cylinder

ENGINE CID: 1.0 liter

TRANSMISSION TYPE:

_ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: 50th perc male

MASS: 75 kg

SEAT POSITION: Driver

GEOMETRY - (mm)

A	1430	E	640	J	725	N	1330	R	730
B	730	F	3620	K	515	O	1295	S	390
C	2250	G	894.5	L	152	P	550	T	940
D	1315	H		M	400	Q	332	U	2575

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	446	494	530
M_2	273	326	367
M_T	719	820	897

Figure 90. Vehicle properties for Test Nos. 453880-1, 2, 3, and 4

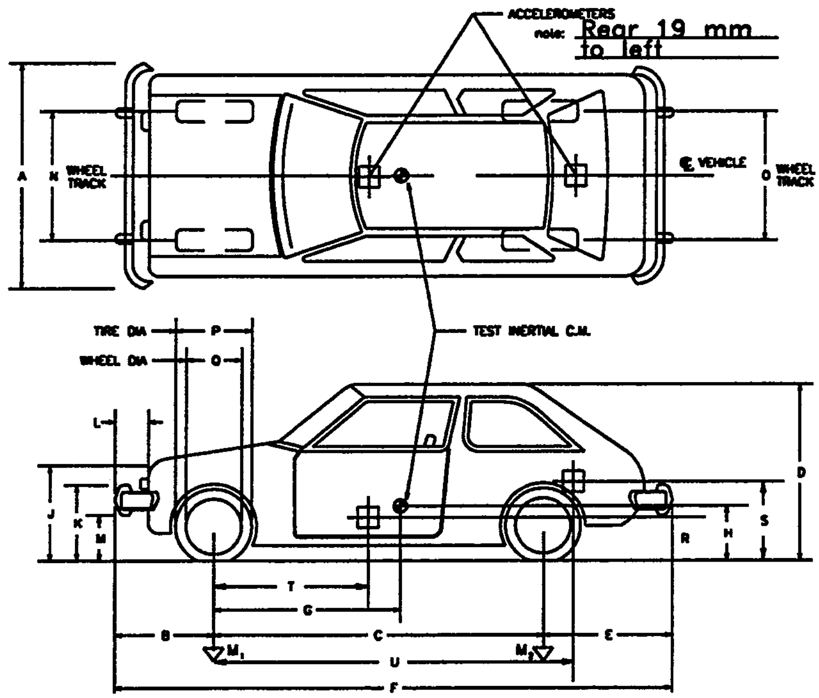
DATE: 09/18/92 TEST NO.: 5336-5 VIN NO.: VX1BB1227KK439776

YEAR: 1989 MAKE: Yugo MODEL: GV

TIRE INFLATION PRESSURE: ______ ODOMETER: 58775 TIRE SIZE: 145R13

MASS DISTRIBUTION (kg) LF 265 RF 239 LR 146 RR 167

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: 4 cylinder

ENGINE CID: 1.1 litre

TRANSMISSION TYPE:

_ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: 50th perc male

MASS: 75 kg

SEAT POSITION: Driver

GEOMETRY - (mm)

A 1518	E 641	J 787	N 1283	R 381
B 673	F 3473	K 502	O	S 667
C 2159	G 825.5	L 89	P 578	T 787
D 1391	H	M 368	Q 362	U 2477

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	544	504	542
M_2	280	313	353
M_T	824	817	894

Figure 91. Vehicle properties for Test No. 453360-5

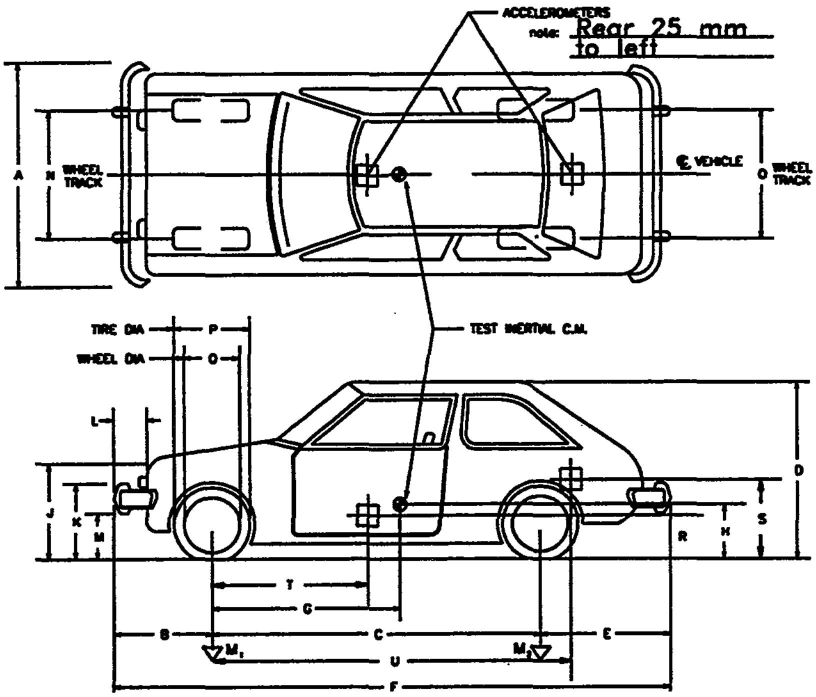
DATE: 08/19/92 TEST NO.: 5336-2 VIN NO.: VX1BA1216JK404378

YEAR: 1988 MAKE: Yugo MODEL: GV

TIRE INFLATION PRESSURE: ______ ODOMETER: 48470 TIRE SIZE: 145R13

MASS DISTRIBUTION (kg) LF 250 RF 252 LR 156 RR 159

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: 4 cylinder

ENGINE CID: 1.1 litre

TRANSMISSION TYPE:

__ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: 50th perc male

MASS: 76 kg

SEAT POSITION: Driver

GEOMETRY - (mm)

A 1518	E 610	J 787	N 1283	R 394
B 699	F 3474	K 514	O	S 692
C 2165	G 833	L 70	P 578	T 813
D 1435	H	M 375	Q 362	U 2419

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	537	502	541
M_2	284	315	352
M_T	817	817	893

Figure 92. Vehicle properties for Test No. 453360-2

DATE: 02/16/93 TEST NO.: 53580-1,2,3 VIN NO.: VX1BA1218HK367960

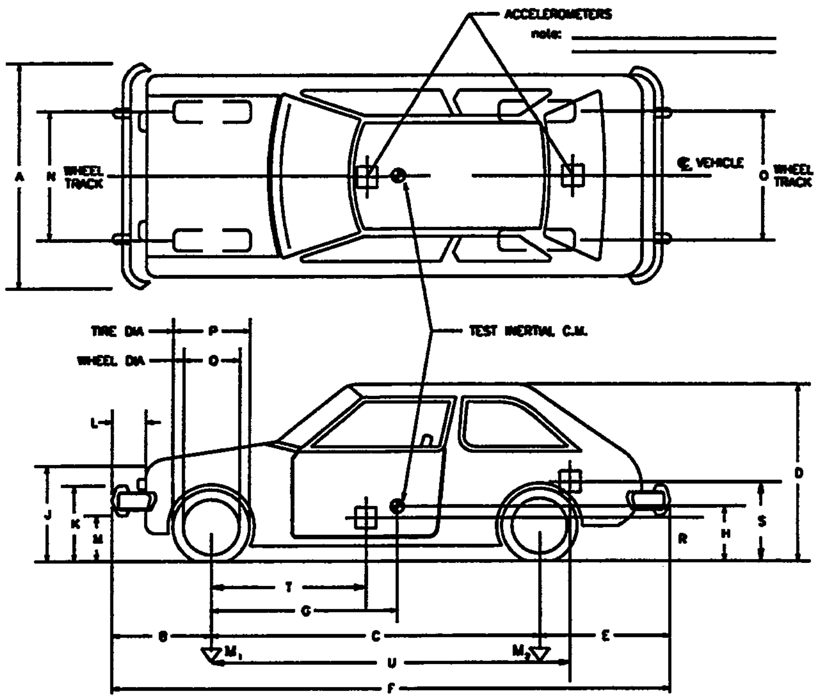
YEAR: 1987 MAKE: Yugo MODEL: GV

TIRE INFLATION PRESSURE: ______ ODOMETER: 62679 TIRE SIZE: P155/80R13

MASS DISTRIBUTION (kg) LF 270 RF 253 LR 143 RR 154

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:

Small dent in rear of vehicle (marked)



ENGINE TYPE: 4 cylinder

ENGINE CID: 1100 cc

TRANSMISSION TYPE:

_ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: 50th perc male

MASS: 72 kg

SEAT POSITION: Driver

GEOMETRY – (mm)

A 1480	E 650	J 785	N 1320	R 385
B 700	F 3495	K 490	O 1260	S 700
C 2145	G 777	L 70	P 560	T 810
D 1405	H	M 355	Q 365	U 2415

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	549	523	557
M_2	271	297	335
M_T	820	820	892

Figure 93. Vehicle Properties for Test Nos. 453580-1, 2, and 3

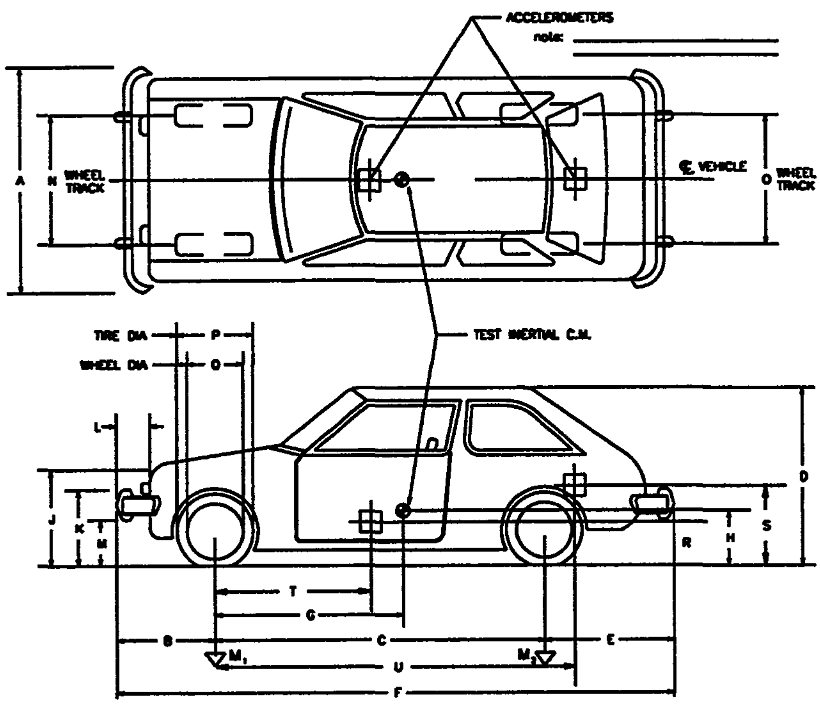
DATE: 08/23/94 TEST NO.: 453790-1,2,3 VIN NO.: JGMR2152JK761205

YEAR: 1988 MAKE: Chevrolet MODEL: Sprint

TIRE INFLATION PRESSURE: ______ ODOMETER: 34449 TIRE SIZE: 155R12

MASS DISTRIBUTION (kg) LF 249 RF 245 LR 164 RR 162

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: 3 cylinder

ENGINE CID: 1.0 liter

TRANSMISSION TYPE:

_ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: 50th perc male

MASS: 75 kg

SEAT POSITION: Driver

GEOMETRY – (mm)

A	1430	E	640	J	725	N	1330	R	730
B	730	F	3620	K	515	O	1295	S	390
C	2250	G	894.5	L	152	P	550	T	940
D	1315	H		M	400	Q	332	U	2575

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	446	494	530
M_2	273	326	367
M_T	719	820	897

Figure 94. Vehicle properties for Test Nos. 453790-1, 2, and 3

DATE: 08/19/92 TEST NO.: 5336-3 VIN NO.: 1GCGC24M5FS104060

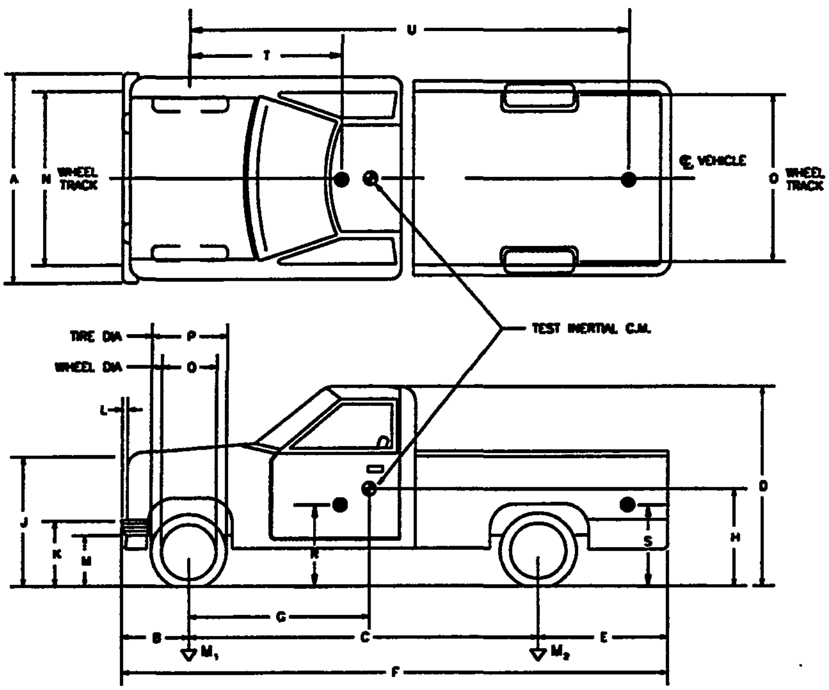
YEAR: 1984 MAKE: Chevrolet MODEL: Custom Deluxe

TIRE INFLATION PRESSURE: ____ ODOMETER: 94710 TIRE SIZE: LT235/85R16

MASS DISTRIBUTION (kg) LF 550 RF 555 LR 474 RR 464

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:

Cracked windshield (marked)



● Denotes accelerometer location.

NOTES: ____

ENGINE TYPE: 8 cyl

ENGINE CID: 5.7 litre

TRANSMISSION TYPE:

_ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: ____

MASS: ____

SEAT POSITION: ____

GEOMETRY - (mm)

A	2013	E	1257	J	1181	N	1676	R	648
B	838	F	5436	K	679	O		S	857
C	3340	G	1534	L	89	P	826	T	1524
D	1842	H		M	445	Q	432	U	1397

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1176	1105	
M_2	945	938	
M_T	2121	2043	

Figure 95. Vehicle Properties for Test No. 453360-3

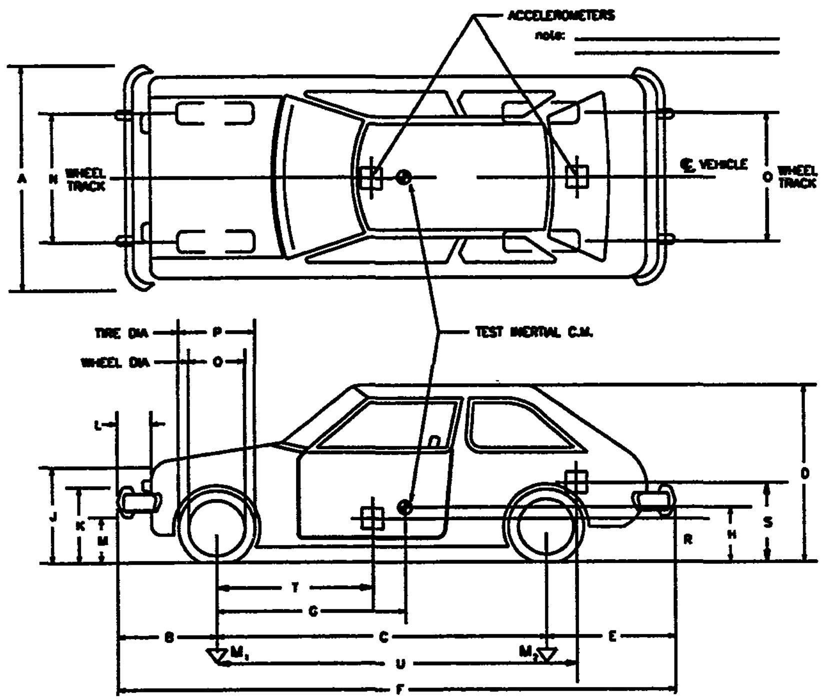
DATE: 09/08/94 TEST NO.: 453790-4 & 5 VIN NO.: JGMR2152JK761205

YEAR: 1988 MAKE: Chevrolet MODEL: Sprint

TIRE INFLATION PRESSURE: ______ ODOMETER: 34455 TIRE SIZE: 155R12

MASS DISTRIBUTION (kg) LF 249 RF 245 LR 164 RR 162

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: 3 cylinder

ENGINE CID: 1.0 liter

TRANSMISSION TYPE:

_ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: 50th perc male

MASS: 75 kg

SEAT POSITION: Driver

GEOMETRY - (mm)

A 1430	E 640	J 725	N 1330	R 730
B 730	F 3620	K 515	O 1295	S 390
C 2250	G 894.5	L 152	P 550	T 940
D 1315	H	M 400	O 332	U 2575

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	446	494	530
M_2	273	326	367
M_T	719	820	897

Figure 96. Vehicle Properties for Test Nos. 453790-4 and 5

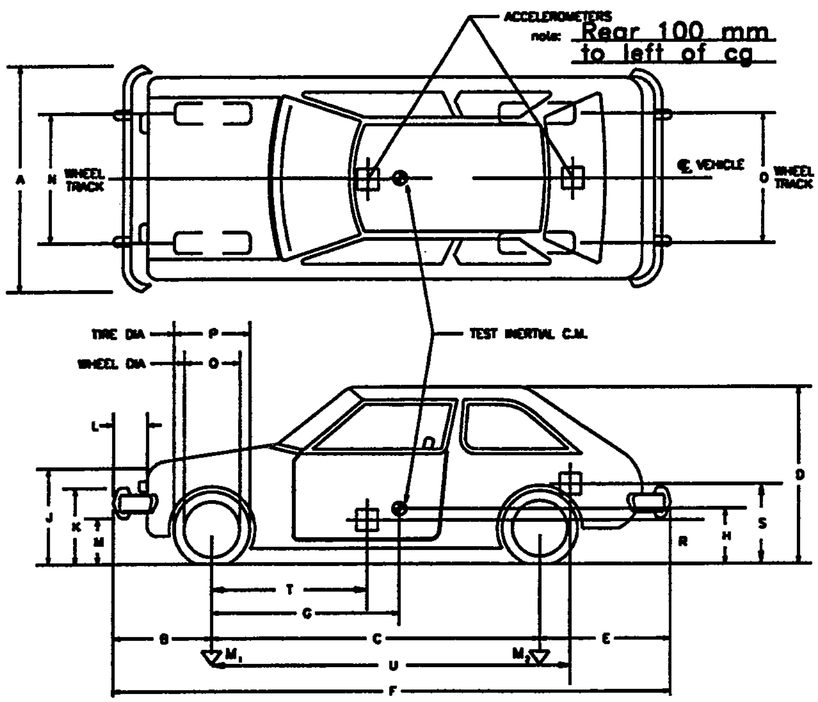
DATE: 07/19/95 TEST NO.: 453880-5 VIN NO.: KNJBT07K2J6167799

YEAR: 1988 MAKE: Ford MODEL: Festiva

TIRE INFLATION PRESSURE: ________ ODOMETER: 152832 TIRE SIZE: 155R12

MASS DISTRIBUTION (kg) LF 269 RF 252 LR 155 RR 144

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: 4 cylinder

ENGINE CID: 1.3 liter

TRANSMISSION TYPE:

_ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: 50th per male

MASS: 75 kg

SEAT POSITION: Driver

GEOMETRY - (mm)

A 1500	E 550	J 740	N 1410	R 400
B 700	F 3520	K 530	O 1395	S 480
C 2270	G 827.7	L 130	P 535	T 880
D 1410	H	M 380	Q 340	U 2510

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	518	521	558
M_2	270	299	338
M_T	788	820	896

Figure 97. Vehicle properties for Test No. 453880-5

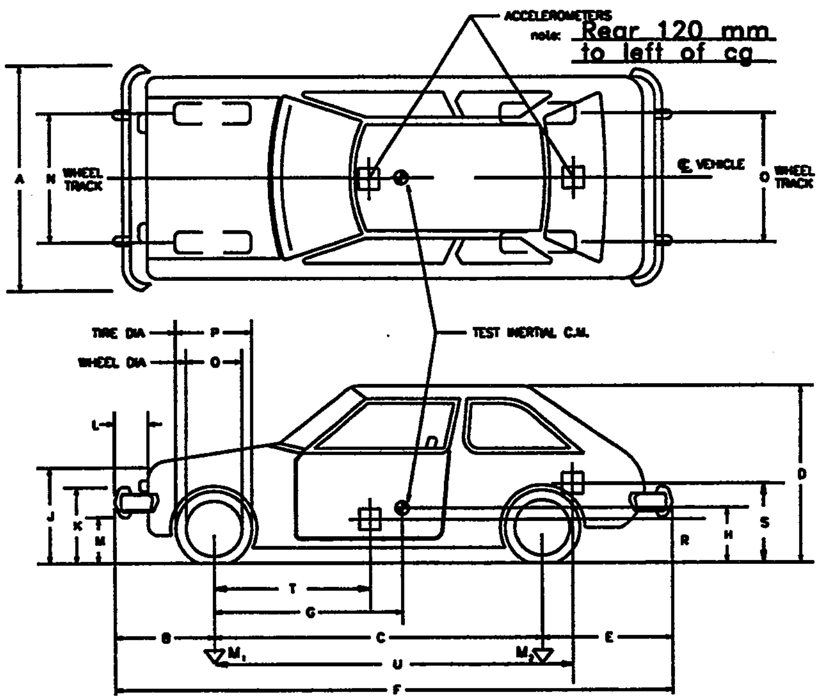
DATE: 07/19/95 TEST NO.: 453880-6 & 7 VIN NO.: KNJBT07K2K6176925

YEAR: 1989 MAKE: Ford MODEL: Festiva

TIRE INFLATION PRESSURE: ______ ODOMETER: 158503 TIRE SIZE: 155R12

MASS DISTRIBUTION (kg) LF 263 RF 253 LR 159 RR 145

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: 4 cylinder

ENGINE CID: 1.3 liter

TRANSMISSION TYPE:

_ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: 50th per male

MASS: 75 kg

SEAT POSITION: Driver

GEOMETRY - (mm)

A 1490	E 590	J 740	N 1385	R 410
B 650	F 3525	K 540	O 1390	S 500
C 2285	G 847.1	L 85	P 540	T 850
D 1460	H	M 390	Q 390	U 2465

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	551	516	552
M_2	280	304	343
M_T	831	820	895

Figure 98. Vehicle properties for Test Nos. 453880-6 and 7

APPENDIX B.
MATERIAL SPECIFICATIONS FOR ALTERNATE BARRICADE DESIGNS

This appendix provides specifications on the perforated tubing and the hollow core, recycled plastic materials used with the alternate barricade designs.

PERFORATED SQUARE STEEL TUBING

Design

The square tubing was formed from 2.7-mm thick steel rolled to size and welded in the corner by high frequency resistance welding and externally scarfed to agree with corner radii. The tubing had 11.1-mm Diameter holes spaced 25.4 mm on center along the center line of each of the four sides.

Material and Finish

The tubing was roll formed from carbon steel conforming to ASTM Specification A-446 with zinc coating designation G-90.

HOLLOW CORE RECYCLED PLASTIC

Upper Unit

The members were extruded from 100 percent high-density polyethylene (HDPE) recycled from post-industrial and post-consumer sources. The product contained appropriate additives to provide UV and heat stabilization to help ensure durability. The HDPE conformed to the following physical and mechanical properties:

Density (ASTM D-792):	0.945-0.955 g/cm^3
Melt Flow Index (ASTM D-1238):	0.1-1.0 g/10 min
Ultra Violet Stabilization:	10% Hindered Amine
Heat Stabilization:	5% Anti-Oxidents
Melting Temperature:	135-149 deg. C
Compressive Strength (ASTM D-198):	85,300 psi
Tensile Strength (ASTM D-638):	4,000 psi
Load Deflection (ASTM D-3043):	2.32 in.
Screw/Nail Withdrawal (ASTM D-143):	1,680 lb
Brittleness (ASTM D-1248):	-55 deg. C
Softening (ASTM D-1525):	128 deg. C
Coef. Of Thermal Expansion (ASTM D-696):	-57.6 cm/cm/deg. C
Tensile Impact Strength (ASTM D-1822):	19334.0 KN·m/m^2

The fabricated vertical supports and horizontal panels were white in color and had a hollow core or hollow profile, which made the members lightweight.

The weight per lineal meter of the vertical supports and horizontal panels were measured to be 1.459 N·m and 1.094 N·m, respectively.

Lower Unit (Base)

The hollow core, recycled plastic upper unit was tested with skids constructed from both wood and recycled plastic lumber. The properties of the recycled plastic lumber should be comparable to standard dimensional lumber of an equivalent size.