Paper No. 980627

CRASH TESTING AND EVALUATION OF WORK ZONE TRAFFIC CONTROL DEVICES

by

King K. Mak
Phone: 210-698-2068
Fax: 210-698-2068
e-mail: king@tti3a.tamu.edu
Texas Transportation Institute
The Texas A&M University System
College Station, TX 77843-3135

Roger P. Bligh
Phone: 409-845-4377
Fax: 409-845-6554
e-mail: rbligh@ttiadmin.tamu.edu
Texas Transportation Institute
The Texas A&M University System
College Station, TX 77843-3135

and

Lewis R. Rhodes, Jr.
Phone: 512-416-3330
Fax: 512-416-3161
Texas Department of Transportation
11th and Brazos
Austin, TX 78701

PRESENTED AT

THE 77th ANNUAL MEETING
TRANSPORTATION RESEARCH BOARD
WASHINGTON, D.C.

JANUARY 1998

TEXAS TRANSPORTATION INSTITUTE
THE TEXAS A&M UNIVERSITY SYSTEM

INTRODUCTION

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. Thus, the Federal Highway Administration (FHWA) and the Manual on Uniform Traffic Control Devices (MUTCD) (*1*) require that work zone traffic control devices be crashworthy themselves.

The impact performance of many work zone traffic control devices is mostly unknown and little, if any, crash testing has been conducted in accordance with guidelines set forth in National Cooperative Highway Research Program (NCHRP) Report 350. (*2*) The Texas Department of Transportation (TxDOT), through its research program, has sponsored a number of studies in recent years to develop safer traffic control devices for use in maintenance and construction work zones. Many of these research projects were developed by TxDOT's Traffic Operations Division through a partnering relationship with the Associated General Contractors (AGC) of Texas and the Texas Chapter of the American Traffic Safety Services Association (ATSSA). These studies, conducted at the Texas Transportation Institute (TTI), assessed the impact performance of various work zone traffic control devices, including plastic drums and sign substrates, temporary and portable sign supports, plastic cones, vertical panels and barricades. (*3-9*)

The results, findings, conclusions and recommendations from these studies on the impact performance of various work zone traffic control devices are presented in two papers due to the large volume of materials. This paper covers temporary and portable sign supports, plastic drums, sign substrates for use with plastic drums, traffic cones, and vertical panels, while a second paper covers barricades.

STUDY APPROACH

Test Articles

The following work zone traffic control devices were crash tested and evaluated under the studies:

- Temporary sign support,
- Portable sign supports,
- Plastic drums,
- Sign substrates for use with plastic drums,
- Two-piece traffic cones, and
- Vertical panels.

Brief descriptions of these work zone traffic control devices are presented as follows.

<u>Temporary Sign Support</u>

Figure 1 shows a schematic of the TxDOT wooden temporary sign support crash tested and evaluated. The TxDOT skid-mounted sign support is designed to support a 12.7 mm (½ in.) thick, 1219 mm × 1219 mm (48 in. × 48 in.) plywood sign panel, consists of two nominal 102 mm × 102 mm (4 in. × 4 in.) wood supports mounted on wooden skids constructed from nominal 51 mm × 152 mm (2 in. × 6 in.) lumber. Wood braces are used between the supports and from the supports to the skids to stabilize the system.

Until recently, the sign panels 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 (5 ft) in rural areas and 2.13 m (7 ft) in urban applications. The standards have since been revised to have a mounting height of 2.13 m (7 ft) for both urban and rural applications. At the time of the head-on crash test, the 1.52 m (5 ft) mounting height was still in effect and was selected for the purpose of crash testing. The rationale for using the lower mounting height was that it would be more critical with a higher potential for impacting and penetrating the windshield of the test vehicle. However, by the time of the end-on (from the side) crash test, the standards have been revised to a mounting height of 2.13 m (7 ft) for both urban and rural applications. Thus, the sign support was crash tested at the 2.13 m (7 ft) mounting height for the end-on test.

<u>Portable Sign Supports</u>

Four different designs of portable sign supports with various sign panel substrates and mounting heights were crash tested and evaluated in the studies:

- A spring-loaded portable sign support with a 12.7 mm (½ in.) thick, 1219 mm × 1219 mm (48 in. × 48 in.) plywood sign panel mounted at a height of 305 mm (1 ft),
- A spring-loaded portable sign support with a 1219 mm × 1219 mm (48 in. × 48 in.) plastic/fabric sign panel mounted at heights of 305 mm (1 ft) and 710 mm (2 ft),
- A 32 mm × 32 mm (1-1/4 in. × 1-1/4 in.) tubular steel frame portable sign support (manufactured by TrafFix) with a 1219 mm × 1219 mm (48 in. × 48 in.) plastic/fabric sign panel mounted at a height of 305 mm (1 ft),
- An easel portable sign support, fabricated from 32 mm × 32 mm (1-1/4 in. × 1-1/4 in.) steel angles, with a 1219 mm × 1219 mm (48 in. × 48 in.) plastic/fabric sign panel mounted at a height of 305 mm (1 ft), and

- A wooden A-frame portable sign support with a 12.7 mm (½ in.) thick, 1219 mm × 1219 mm (48 in. × 48 in.) plywood sign panel mounted at a height of 305 mm (1 ft),

The spring-loaded, tubular steel, and easel portable sign supports were purchased commercially, photographs of which are shown in Figure 2. The wooden A-frame portable sign support was fabricated by a contractor in accordance with TxDOT standards, a schematic of which is shown as Figure 3.

<u>Plastic Drums</u>

Nine models of plastic drums were provided from five different manufacturers for evaluation, including:

- TrafFix HDPE and LDPE models,
- Flex-O-Lite HDPE and LDPE models,
- Service & Materials BOUNCER model,
- Plastic Safety Systems HDPE and LDPE models, and
- Radiator Specialty HD 8 and LD 10 models.

The plastic drum models consist of a drum body that snaps onto a base, which may consist of: (a) a plain base ballasted with sandbags, (b) a container that can be filled with sand to the desired weight, (c) a molded rubber base, and (d) a cutout from truck tire sidewall. Figure 4 shows photographs of selected plastic drum models with the four different types of bases.

<u>Sign Substrates for Plastic Drums</u>

A number of different sign substrates for use with plastic drums were evaluated, including:

- Plywood (12.7 mm or 0.5 in thick),
- Aluminum (2 mm or 0.080 in thick) made from virgin or recycled material,
- Plastic (6-mm or 1/4 in. thick) and polyethylene (3.1 mm or 0.125 in. thick),
- Fiberglass (3.1 mm or 0.125 in. thick),
- Fiber reinforced plastic (FRP) (3.1 to 3.8 mm or 0.125 to 0.15 in. thick) made from virgin or recycled material,
- Polycarbonate (0.152 in or 4 mm thick), and
- Fiber reinforced polycarbonate (4 mm or 0.158 in. thick).

The sign substrates, with the exception of plywood, were obtained commercially. All the sign panels were of the standard size, 610 mm × 460 mm (24 in. × 18 in.) except the fiber reinforced polycarbonate sign panel that measured only 550 mm × 380 mm (21.7 in × 15 in). Most of the sign panels tested did not have the reflective sheeting which should not have any effect on the impact performance of the sign panels. The sign panels were attached to the top of plastic drums with two 13 mm × 25 mm bolts. It is interesting to note that there are some slight differences in the spacing of the bolt holes among the various plastic drum manufacturers. It was necessary to field drill the bolt holes on the sign panels to fit the specific drum used with the test.

<u>Two-Piece Traffic Cones</u>

Two-piece traffic cones supplied by two manufacturers, Bent Manufacturing and TrafFix, were crash tested to evaluate their impact performance. The two-piece traffic consisted of a cone body and a weighted base which slips over the cone body. Photographs of a two-piece traffic cone are shown in Figure 5. It has been observed in the field that the two-piece traffic cone is sometimes used with two weighted bases to keep the cone from toppling over from air current generated by passing traffic. Thus, a two-piece traffic cone with two weighted bases were also crash tested to assess if the additional base would adversely affect the impact performance of the traffic cone.

Vertical Panels

The vertical panels were fabricated from 12.6 mm (½ in.) thick plywood with dimensions of 203 mm × 610 mm (8 in. × 24 in.) and mounted on three different types of supports: (1) nominal 51 mm × 102 mm (2 in. × 4 in.) wooden post, (2) 1.8 kg/m (1.2 lb/ft) channel delineator post, and (2) 38 mm × 38 mm (1.5 in. × 1.5 in.) steel angle. The supports were all 1.5 m (5 ft) in length, 610 mm (2 ft) of which were embedded in soil. The three vertical panels, each with a different support, were installed in a straight line and spaced 2.4 m (8 ft) apart so that all three vertical panels could be impacted in a single crash test. Photographs of the test installation are shown inn Figure 6.

Test Conditions

Table 1 summarizes the test conditions for each of the work zone traffic control devices, including *NCHRP Report 350* test designation, test vehicle, impact speed, and impact configuration. Most of the crash tests conducted on the work zone traffic control devices corresponded to test designation 3-71 of *NCHRP Report 350*, i.e., an 820-kg passenger car impacting the test article head-on at a nominal impact speed of 100 km/h. However, there are a few exceptions as follows:

1. A 2000-kg pickup truck was used for the head-on test with the wooden temporary sign support. A pickup truck was considered a more critical test vehicle than the small passenger car due to the geometry of the sign support in relation to the vehicle.
2. The wooden temporary sign support was also crash tested in an end-on configuration, i.e., from the side, with a small passenger car. The rationale for this test was that temporary sign supports are often used at intersections where the support might be impacted from the side.
3. In addition to the head-on tests (*NCHRP Report 350* test designation 3-71), the plastic drums were also tested in a glancing configuration in which the right front tire of the 820C test vehicle was aligned with the center of the plastic drum. The purpose of these glancing tests was to evaluate the effect on vehicle stability when the test vehicle ran over the base of the plastic drum.

Test Procedures

The test procedures were generally in accordance with guidelines set forth in *NCHRP Report 350*. Note that some crash tests were conducted prior to the publication and adoption of *NCHRP Report 350*. The test vehicles were fully instrumented in earlier crash tests, i.e., with a triaxial accelerometer to measure accelerations in the longitudinal, lateral, and vertical directions and rate transducers to measure the roll, pitch, and yaw rates. However, it became evident after a few tests that the accelerations and vehicle dynamics were so minor (basically in the noise level) that it would be a waste of time and effort to instrument the vehicle. Thus, the vehicles in later tests were not instrumented.

Also, the test vehicles in earlier crash tests were directed into the test article using a cable reverse tow and guidance system. Due to the relative benign impact behavior for some the traffic control devices, such as plastic drums with or without sign panels and two-piece traffic cones, it was decided to use a live driver for these tests to reduce the turnaround time between tests. The driver was restrained with a five-point seat belt and wore a helmet for protection. Furthermore, A wire mesh was installed behind the windshield to prevent any intrusion or penetration into the occupant compartment.

The evaluation criteria used to assess the impact performance of work zone traffic control devices are generally in accordance with guidelines set forth in *NCHRP Report 350*, as follows:

1. Occupant risk, measured in terms of occupant impact velocity (limit - 12 m/s) and ridedown acceleration (limit - 20 g's). As mentioned above, it became evident from earlier tests that the occupant impact velocity and ridedown acceleration experienced by the vehicles in tests with these work zone traffic control devices are so far below the limits that occupant risk is not of any concern. Thus, the test vehicles were not instrumented and occupant risk factors not determined in later tests.
2. Occupant compartment integrity. There should not be any penetration or intrusion of the occupant compartment. The windshield should not be shattered or damaged to the extent that it obstructs the vision of the driver.
3. Debris from the test article should not pose any potential hazard to the vehicle occupants or workers in the immediate vicinity.
4. Vehicle should remain stable throughout impact sequence, i.e., both during and after the impact.

STUDY RESULTS AND FINDINGS

The results and findings from the crash tests on the various work zone traffic control devices are summarized in this section.

Temporary Sign Support

In the head-on test with the TxDOT wooden temporary sign support, the vertical supports fractured at bumper height. The sign panel and pieces of the support went up and over the hood of the pickup truck and a broken segment of the support struck the roof near the rear of the cab, but did not intrude or penetrate into the occupant compartment. In the end-on crash test, the vertical supports fractured sequentially and the first support contacted and dented the roof of the vehicle just above the windshield. The supports and the sign panel then rotated off the back of the vehicle. Both crash tests were judged to have met all evaluation criteria set forth in *NCHRP Report 350* and the impact performance of the TxDOT wooden temporary sign support was considered satisfactory.

Portable Sign Supports

For the test of the spring-loaded portable sign support with a plywood sign panel mounted at a height of 305 mm (1 ft), the bracket holding the sign panel broke upon impact, allowing the sign panel and a segment of the support to impact and penetrate the windshield. The bracket and sign panel subsequently went over the top of the vehicle while the base of the portable sign support hung up on the undercarriage of the vehicle. The impact performance of the spring-loaded portable sign support with a plywood sign panel was judged to be unsatisfactory due to penetration of the windshield.

The spring-loaded portable sign support was retested with a plastic/fabric sign panel mounted at heights of 305 mm (1 ft) and 710 mm (2 ft). In both tests, the plastic/fabric sign panel and upper support arm went over the vehicle and showed no potential for intruding into the occupant compartment. The spring-loaded portable sign support with the plastic/fabric sign panel was judged to have met all evaluation criteria set forth in *NCHRP Report 350* for both mounting heights of 305 mm (1 ft) and 710 mm (2 ft).

In the crash test of the tubular steel frame portable sign support with a plastic/fabric sign panel mounted at a height of 305 mm (1 ft), the upper portion of the sign support separated from base and the sign panel and plastic reinforcement straps contacted the windshield. However, due to the light weight of the sign panel and plastic reinforcement straps, there was no damage to the windshield. The tubular steel portable sign support with plastic/fabric sign panel mounted at a height of 305 mm (1 ft) was judged to have satisfactory impact performance, meeting all evaluation criteria set forth in *NCHRP Report 350*.

In the test of the easel portable sign support with a plastic/fabric sign panel mounted at a height of 305 mm (1 ft), the front legs of the support were bent at bumper height and the sign panel was released from the support. The easel support then rotated into and penetrated the windshield. The impact performance of the easel portable sign support was judged to be unsatisfactory due to penetration of the windshield and the potential risk of severe injury to the occupants.

In the crash test of the wooden A-frame portable sign support with a plywood sign panel mounted at a height of 305 mm (1 ft), the A-frame folded up and three of the four supports were fractured. The top of the A-frame rotated into the windshield, which was shattered and pushed inward. The impact performance of the A-frame portable sign support with plywood sign panel was judged to be unsatisfactory due to penetration of the windshield and the potential risk of severe injury to the occupants.

Plastic Drums

Results of the crash tests indicate that the impact performance of plastic drums met with the evaluation criteria set forth in the *NCHRP Report 350* guidelines and are judged to be satisfactory.

1. Occupant risk in terms of occupant impact velocity and ridedown acceleration is insignificant, i.e., impacts with plastic drums do not impart any significant force or deceleration to the vehicle to pose any hazard of injury to the occupants. Damage to the vehicles was mostly superficial, i.e., scrapes and scratches, and that the vehicles could be reused in multiple tests. In fact, the level of occupant risk is so low that a live driver was used in many tests to reduce turnaround time between tests.
2. Occupant compartment integrity was maintained in all the tests. There was no penetration or intrusion of the occupant compartment, no shattering of windshield or vision obstruction to the driver due to damage to windshield.
3. Debris from the plastic drums did not pose any potential hazard to the vehicle occupants or workers in the immediate vicinity. The drum body, after separating from the base, would stay with the vehicle until the vehicle slowed down or would go up and over the vehicle. The drum body does not pose a hazard due to its light weight and the large surface area. Weighted bases, such as sand-filled containers or rubber bases, typically stay close to the point of impact. Plain bases ballasted with sandbags are more messy since the sandbags are typically cut by the undercarriage of the vehicle and sand would be scattered in the vicinity of the impact. However, neither pose any hazardous conditions.
4. Vehicles typically remain stable throughout the impact sequence even in impacts where the tires of the vehicles would run over the weighted bases or sandbags.
5. If warning lights are to be used with the plastic drums, they should be rigidly attached to the plastic drums to minimize the potential of the lights separating and impacting the windshield of the impacting vehicles.

Sign Substrates for Plastic Drums

Results of the crash tests indicate that the impact performance of sign substrates mounted on plastic drums was satisfactory for some sign substrates, meeting the evaluation criteria set forth in the *NCHRP Report 350* guidelines, while other sign substrates failed to perform satisfactorily. Some general observations on the crash tests are as follows:

1. Occupant risk in terms of occupant impact velocity and ridedown acceleration is insignificant, as with the plastic drums. The addition of a sign panel on top of the plastic drum do not impart any significant force or deceleration to the vehicle to pose any hazard of injury to the occupants. Damage to the vehicles was slightly higher for the sign substrate tests than that for plastic drums alone. The sign panel tended to slap hard on the hood. However, the damage was still superficial in nature, i.e., scrapes and scratches. A live driver was used in the tests to reduce turnaround time between tests and the test vehicle was used in multiple tests.

2. Occupant compartment integrity was not maintained in some tests. The unsatisfactory impact performance of some sign substrates was mainly due to the shattering of windshields and the potential for penetration or intrusion into the occupant compartment. The wire mesh shield installed in the test vehicle prevented any actual penetration or intrusion into the occupant compartment; nevertheless, the potential was present.
3. Debris was present in some sign substrate tests, which could potentially pose hazard to workers in the immediate vicinity. The plastic and polycarbonate sign substrates, particularly the polycarbonate sign substrate, shattered upon impact. Some broken pieces were sufficiently large to pose potential hazard to workers in the immediate vicinity.
4. Vehicles typically remain stable throughout the impact sequence.

More detailed discussions of the crash test results for the individual sign substrates are summarized as follows.

Plywood. The 12.7 mm (0.5 in.) thick plywood sign substrate shattered the windshield and its impact performance was judged to be unsatisfactory.

Aluminum. The 2 mm (0.080 in.) thick aluminum sign substrate was used in three crash tests. Two of the tests were judged to be satisfactory, but the windshield was shattered in the third test which was unexpected. This raised some questions about the suitability of using the aluminum sign substrate and this matter is under further investigation.

Plastic. Two different plastic sign substrates were tested. The 6 mm (1/4 in.) thick plastic sign panel was broken in the test, but the impact performance was otherwise satisfactory. The 3.1 mm (0.125 in.) thick polyethylene plastic sign panel performed satisfactorily, but the panel was considered too flexible to be acceptable. The sign panel flexed and did not remain vertical even without any significant wind loading, which poses a problem to the legibility of the sign.

Fiberglass. The 3.1 mm (0.125 in.) thick fiberglass sign substrate performed satisfactorily in the crash tests.

Fiber Reinforced Plastic (FRP). Fiber reinforced plastic (FRP) sign substrates (3.1 to 3.8 mm or 0.125 to 0.15 in. thick), manufactured from virgin or recycled materials, performed satisfactorily in the crash tests.

Polycarbonate. Polycarbonate sign substrates from three manufacturers were tested. One polycarbonate sign substrate performed satisfactorily. Another polycarbonate sign substrate, with the trade name of Medex, shattered the windshield of the test vehicle and its impact performance was judged to be unsatisfactory. A third polycarbonate sign substrate, 4 mm (0.152 in.) thick, slapped the hood of the vehicle and shattered upon impact with large fragments scattered over a relatively wide area along the path of the vehicle and could have posed a potential hazard to workers in the immediate area. Due to the brittle nature of the polycarbonate sign substrate, its use is not recommended.

Fiber Reinforced Polycarbonate. The 4 mm (0.158 in.) thick fiber reinforced polycarbonate sign substrate performed satisfactorily. However, the sign panel was undersized. The nominal weight of a standard size panel would have weighed 1.56 kg, which is heavier than most of the other sign substrates tested. It is unsure what effect the smaller panel size might have on the impact performance of this sign substrate.

Two-Piece Traffic Cones

In tests with two-piece traffic cones, the cone body readily separated from the base and traveled with the vehicle. The cone body sustained only minor scrapes and there was no damage to the vehicle. The weighted base moved from its original position, but did not pose any potential hazard to the driver or workers in the immediate vicinity of the traffic cone. The tests were judged to have met all evaluation criteria set forth in *NCHRP Report 350*.

In the test of a two-piece traffic cone with two weighted bases, the cone body again readily pulled out of the bases and traveled with the vehicle. The bottom base was moved slightly while the top base rolled for some distance, but did not pose any potential hazard to the driver or workers in the immediate vicinity of the traffic cone. The cone body was only scraped and there was no damage to the vehicle. The test was judged to have met all evaluation criteria set forth in *NCHRP Report 350*. The use of two weighted bases does not appear to adversely affect the impact performance of the two-piece traffic cone.

Vertical Panels

The three different supports for the vertical panels, i.e., nominal 51 mm × 102 mm (2 in. × 4 in.) wooden post, 1.8 kg/m (1.2 lb/ft) channel delineator post, and 38 mm × 38 mm (1.5 in. × 1.5 in.) steel angle, all performed satisfactorily in the crash test.

SUMMARY

This paper presents the results of a series of studies conducted at the Texas Transportation Institute for the Texas Department of Transportation to assess the impact performance of various work zone traffic control devices, including plastic drums and sign substrates, temporary and portable sign supports, plastic cones, and vertical panels. Most of the work zone traffic control devices satisfactorily met the evaluation criteria set forth in *NCHRP Report 350* and are recommended for field implementation. However, the following devices failed to perform satisfactorily and are not recommended for field applications, including the:

- Easel portable sign support,
- Wooden A-frame portable sign support,
- Use of plywood sign panels for portable sign supports, and
- Use of plywood and polycarbonate sign substrate for plastic drums.

Results from these studies are being incorporated into the TxDOT Barricade and Construction Standard sheets for use in work zones. These standard sheets are used in construction and maintenance contracts and are considered standards for maintenance operations conducted by TxDOT. Demonstration projects are planned that will incorporate the proposed standards in several construction contracts, which will assist TxDOT in implementing the new standards during the summer of 1998.

DISCLAIMER

ACKNOWLEDGMENT

This study was sponsored by the Texas Department of Transportation (TxDOT), in cooperation with the Federal Highway Administration (FHWA) and their support are deeply appreciated. Other personnel from TxDOT and Mr. Bob Musselman of the Federal Highway Administration (FHWA) also provided information and direction on the studies, and their assistance is gratefully acknowledged.

REFERENCES

1. Part VI of the Manual on Uniform Traffic Control Devices (MUTCD), entitled, “Standards and Guides for Traffic Controls for Street and Highway Construction, Maintenance, Utility and Incident Management Operations,” 1988 Edition, Revision 3, September, 1993.
2. Ross, H.E. Jr., D.L. Sicking, R.A. Zimmer, and J.D. Michie, “Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances,” NCHRP Report 350, National Cooperative Highway Research Program, Transportation Research Board, Washington, D. C., March 1993.
3. Mak, K.K., R.P. Bligh, and W.L. Menges, “Evaluation of Sign Substrates For Use with Plastic Drums,” Research Report 2924-3F, Prepared for Texas Department of Transportation, Austin, Texas, October, 1996.
4. Mak, K.K., R.P. Bligh, and W.L. Menges, “Evaluation of Work Zone Barricades and Temporary Sign Supports,” Research Report No. 5388-1F, Prepared for Texas Department of Transportation, Austin, Texas, February 1996.
5. Mak, K.K., and R.A. Zimmer, “Evaluation of Plastic Drum Specifications,” Research Report No. 2924-2F, Prepared for Texas Department of Transportation, Austin, Texas, September 1995.
6. Mak, K.K., R.A. Zimmer, and W.L. Campise, "Testing and Evaluation of Work Zone Traffic Control Devices," Research report 1938-1F, prepared for Texas State Department of Highways and Public Transportation, Austin, Texas, November 1991.
7. Mak, K.K., and W.L. Campise, "Testing and Evaluation of Work Zone Traffic Control Devices," Research report 1917-1F, prepared for Texas State Department of Highways and Public Transportation, Austin, Texas, October 1990.
8. Mak, K.K., and W.L. Campise, "Testing and Evaluation of Traffic Control Devices for Use in Work Zones," Final report, TTI Project No. 9850B, prepared for Texas State Department of Highways and Public Transportation, Austin, Texas, January 1990.
9. “Design, Evaluate, and Test Work Zone Sign Supports and Barricades,” TTI Project No. 439107, sponsored by the Texas Department of Transportation, in progress.

TABLE 1 Impact Conditions

Test Article	NCHRP 350 Designation	Test Vehicle	Impact Speed (km/h)	Impact Configuration
Temporary Sign Support	N/A	2000P	100	Head-on, Center of Vehicle Aligned with Center of Device
	N/A	820C	100	End-on, Center of Vehicle Aligned with Side of Device
Portable Sign Supports	3-71	820C	100	Head-on, Center of Vehicle Aligned with Center of Device
Plastic Drums	3-71	820C	100	Head-on, Center of Vehicle Aligned with Center of Device
	N/A	820C	100	Head-on, Right Front Tire of Vehicle Aligned with Center of Device
Sign Substrates on Plastic Drums	3-71	820C	100	Head-on, Center of Vehicle Aligned with Center of Device
Two-Piece Traffic Cones	3-71	820C	100	Head-on, Center of Vehicle Aligned with Center of Device
Vertical Panels	3-71	820C	100	Head-on, Center of Vehicle Aligned with Center of Device

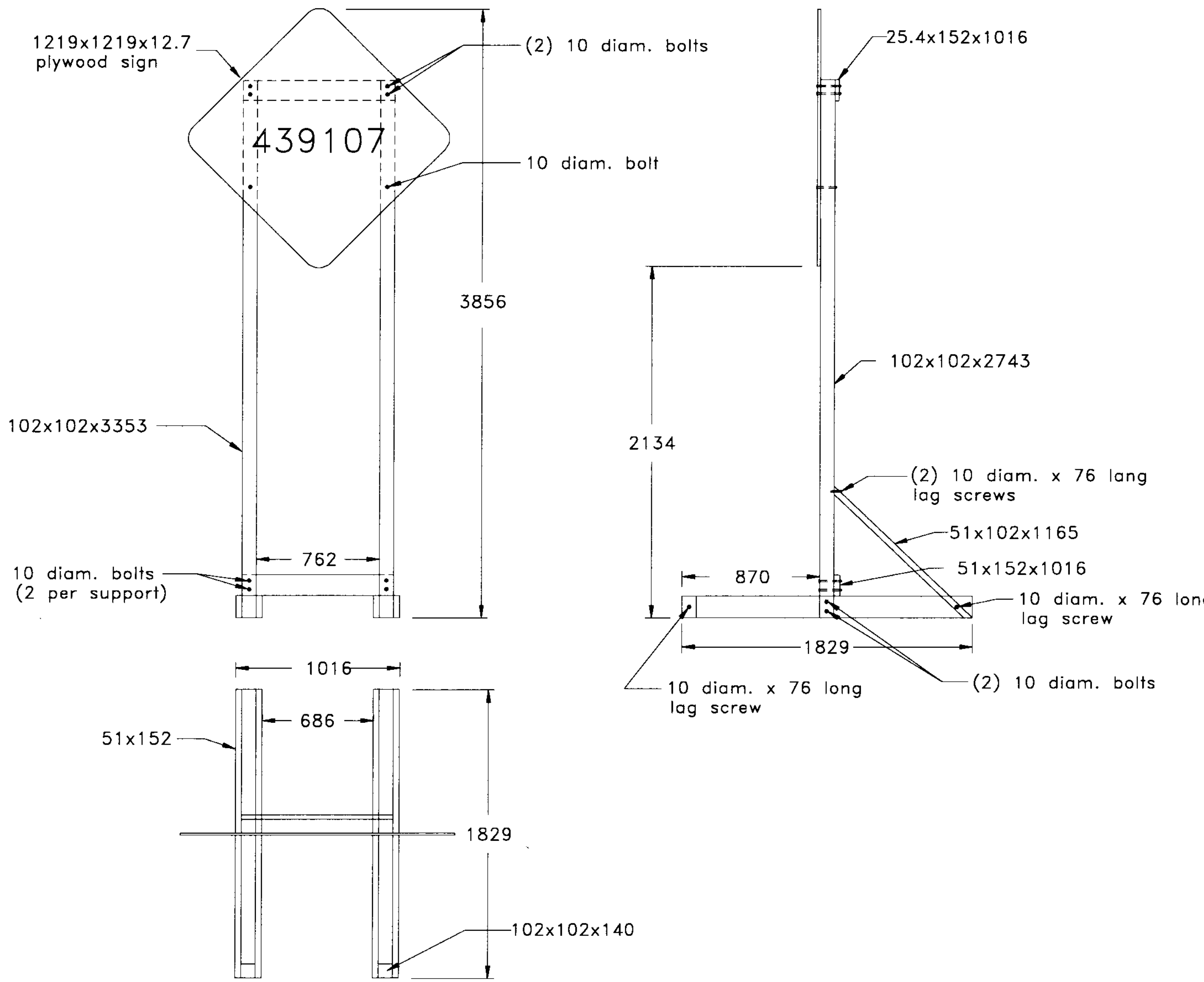

FIGURE 1 Schematic of the TxDOT skid-mounted sign support

FIGURE 2 Photographs of purchased portable sign supports

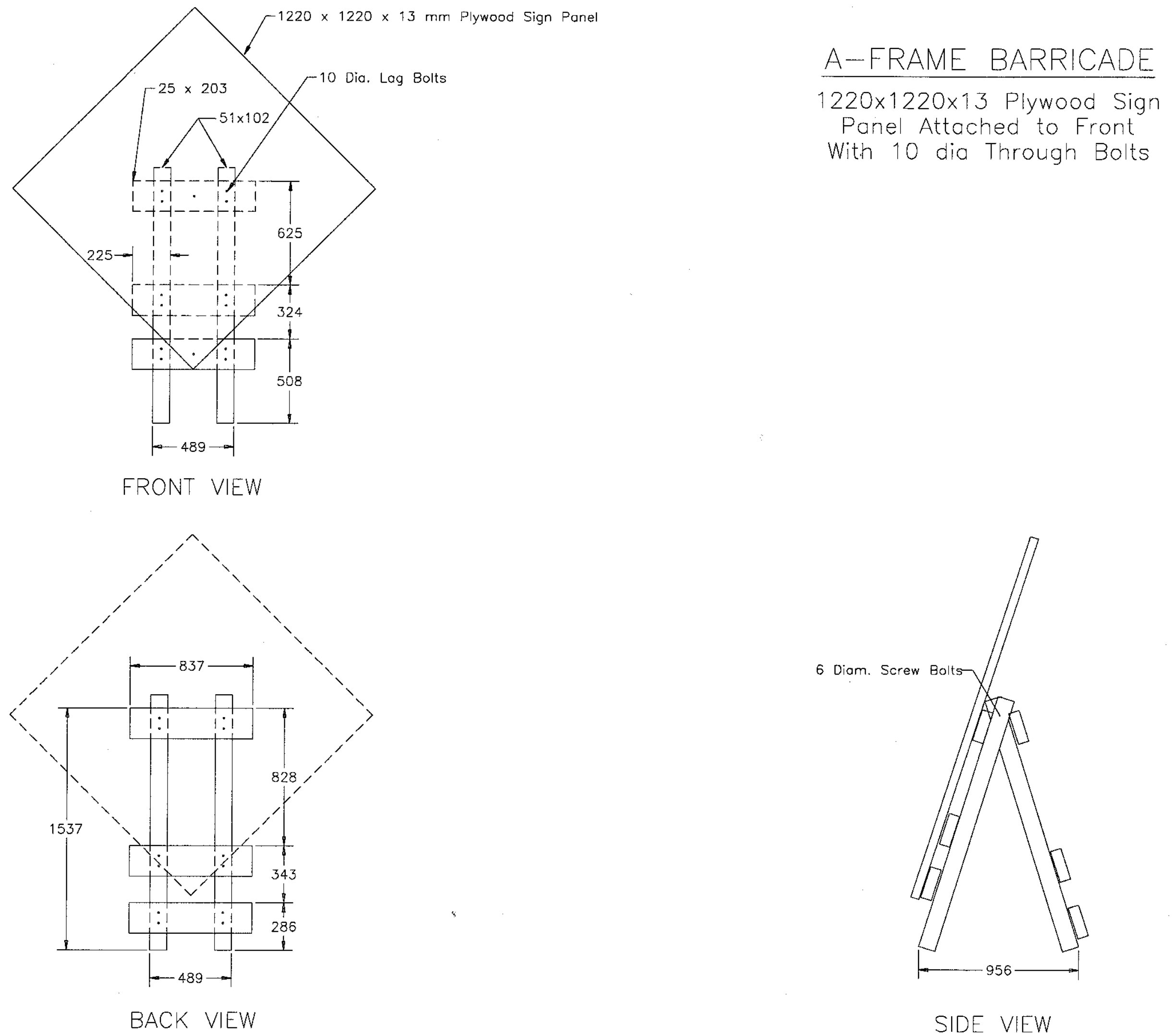

FIGURE 3 Schematic of wooden A-frame portable sign support

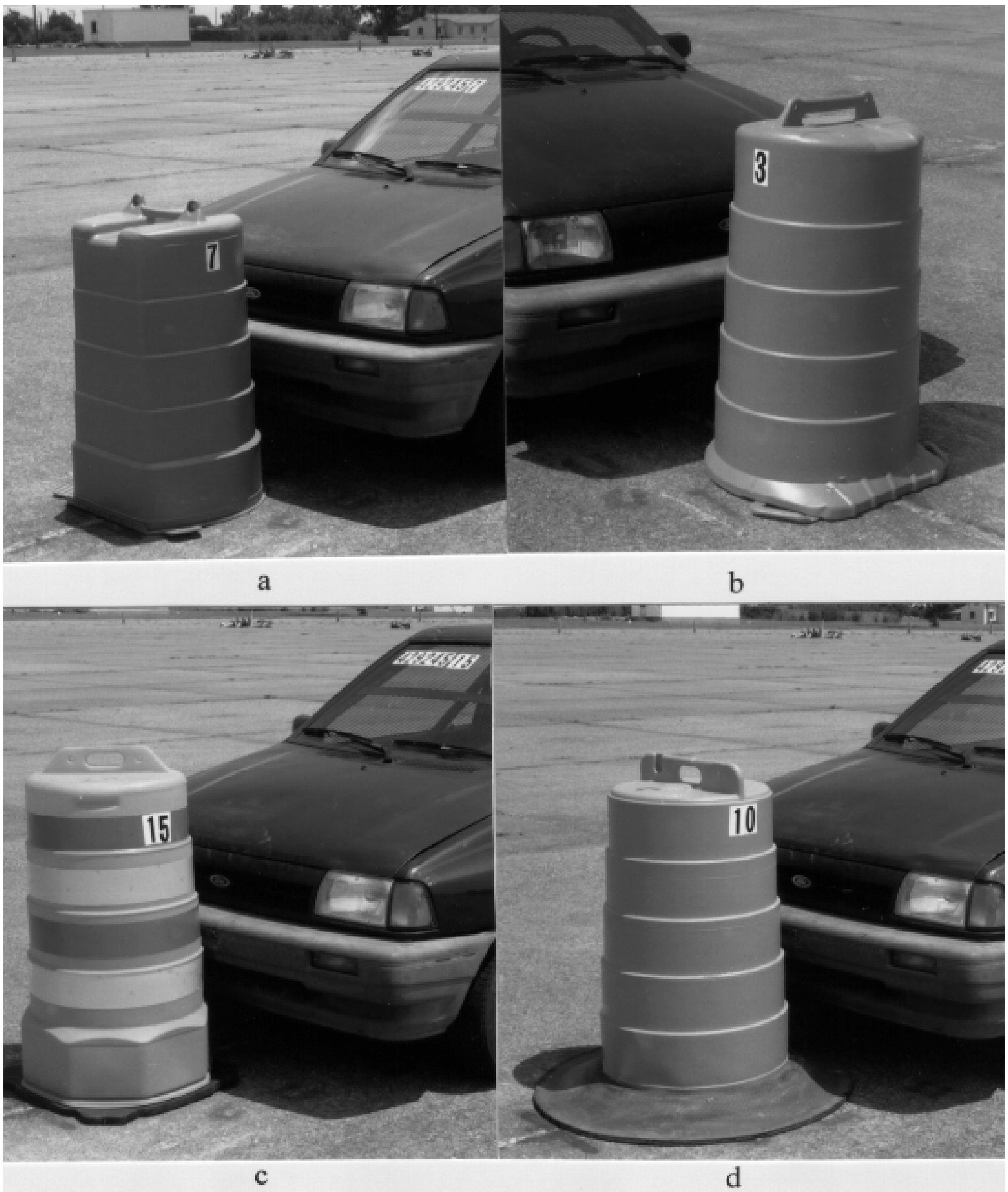

FIGURE 4 Photographs of plastic drum models with different bases

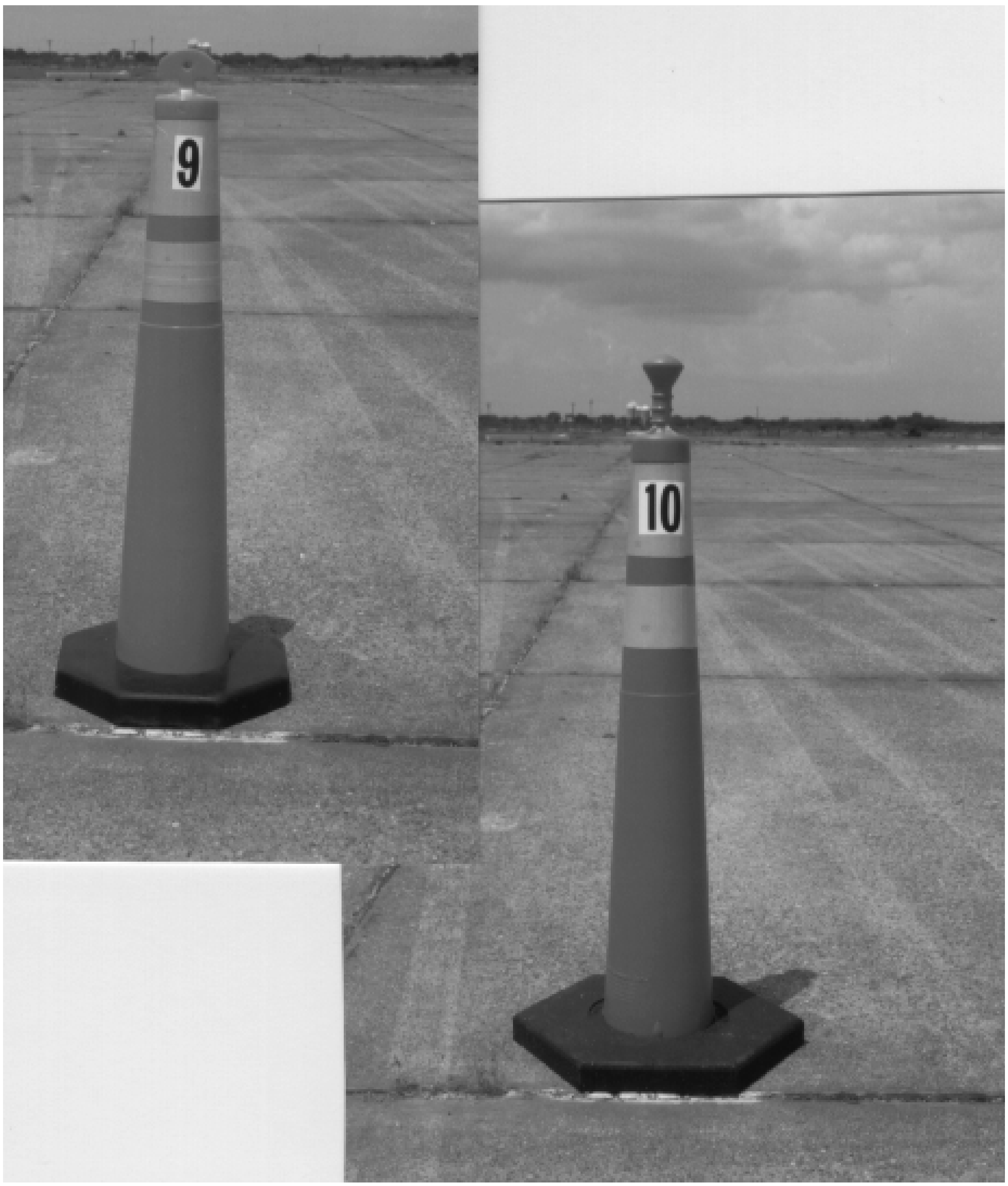

FIGURE 5 Photographs of two-piece traffic cone

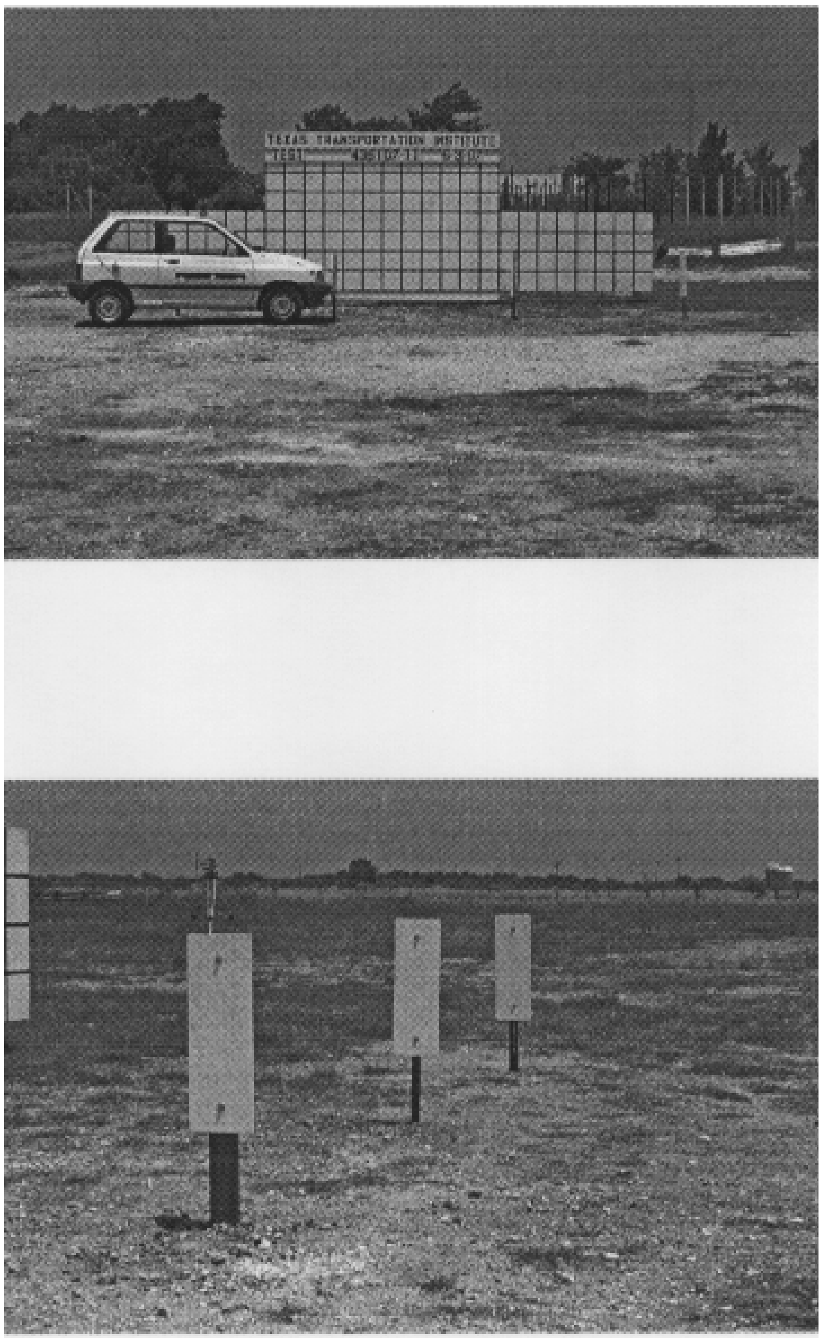

FIGURE 6 Vertical panels test installation

LIST OF TABLES

LIST OF FIGURES