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Crash Testing and Analysis of Work Zone Sign Supports

by

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ABSTRACT

A wide variety of traffic controlling devices are used in work zones, some of which are not normally found on the roadside nor in the traveled way outside of the work zones. These devices are used to enhance the safety of the work zones by controlling the traffic through these areas. Due to the placement of the traffic control devices, the devices themselves may be potentially hazardous to both workers and errant vehicles. The impact performance of many work zone traffic control devices is mainly unknown and to date limited crash testing has been conducted, under the criteria of National Cooperative Highway Research Program (NCHRP) Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features*.

The objective of the study was to evaluate and analyze the results of full-scale crash testing of flexible panel work zone sign stands to quantify the features that successful devices shared, as well as common features of those devices that failed salient safety criteria. Parameters considered include sign base and upright properties, sign height, cross-member properties and ancillary details. Results of the analysis point to three fundamental design issues that are problematic, these include 1) combinations of base and upright stiffness and strength that generally lead to significant windshield damage, 2) cross-members that lead to windshield damage in the end-on (90 degree) impact orientation, and 3) appurtenances that have an impact on performance. While there are a significant number of variables that control the performance of a given device, these generalizations offer a basis for evaluation of the fundamental design elements.

Keywords: Crash Testing, Work Zone Safety, Portable Sign Supports

INTRODUCTION

A wide variety of traffic controlling devices are used in work zones, some of which are not normally found on the roadside nor in the traveled way outside of the work zones. These devices are used to enhance the safety of the work zones by controlling the traffic through these areas. Due to the placement of the traffic control devices, the devices themselves may be potentially hazardous to both workers (or bystanders) and 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 must demonstrate acceptable crashworthy performance in order to be used within the roadway on the National Highway System (NHS).

The impact performance of many work zone traffic control devices is mainly unknown and limited crash testing has been conducted in accordance with the guidelines set forth in National Cooperative Highway Research Program (NCHRP) Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features* (2). 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 (3-7). Successful full-scale crash testing on plastic drums, barricades, and portable sign supports has also been previously conducted at the University of Nebraska-Lincoln (8-17). The previous studies have provided some useful information, but there remains unanswered questions regarding the performances of many work zone traffic control devices, which are slightly different from those crash tested.

The objective of the research paper is to evaluate and generalize the design parameters that control the safety performance of portable sign supports. All of the work performed for this evaluation is based on tests that were conducted according to the Test Level 3 (TL-3) criteria set forth in the NCHRP Report No. 350 (2).

EVALUATION CRITERIA

Work zone traffic control devices, such as portable sign supports, must satisfy the requirements provided in NCHRP Report No. 350 to be accepted by FHWA for use on NHS construction projects or as a replacement for existing designs not meeting current safety standards. According to FHWA's Submission Guidelines attached to the July 1997 memorandum, *Action: Identifying Acceptable Highway Safety Features* (18), work zone traffic control devices are Category 2 devices, which are not expected to produce significant change in vehicular velocity, but may penetrate a windshield, injure a worker, or cause vehicle instability when driven over or lodged under a vehicle.

According to Test Level 3 (TL-3) of NCHRP Report No. 350 and FHWA's Submission Guidelines for acceptable Category 2 devices, work zone traffic control devices must be subjected to two full-scale vehicle crash tests: (1) an 820-kg small car impacting at a speed of 35.0 km/hr and at an angle of 0 degrees; and (2) an 820-kg small car impacting at a speed of 100.0 km/hr and at an angle of 0 degrees. The low-speed test is intended to evaluate the breakaway, fracture, or yielding mechanism of the device and occupant risk factors whereas the high-speed test is intended to evaluate vehicular stability, test article trajectory, and occupant risk factors. Since most work zone traffic control devices have a relatively small mass (less than 45 kg), the high-speed crash test is more critical due to the propensity of the test article to penetrate into the occupant compartment. Therefore, the 820-kg small car crash test, impacting at a speed of 35.0 km/hr and at an angle of 0 degrees, was deemed unnecessary for this project. However, these devices are often situated on the roadway where an impact could occur at other angle orientations, such as at 90 degrees at an intersecting roadway. Thus, it has become generally recognized that an additional test should be performed on such devices at the target speed of 100.0 km/hr and at a target impact angle of 90 degrees.

Evaluation criteria for full-scale vehicle crash testing are based on three appraisal areas: (1) structural adequacy; (2) occupant risk; and (3) vehicle trajectory after collision. Criteria for structural adequacy are intended to evaluate the ability of the work zone traffic control device to break away, fracture, or yield in a predictable manner. Occupant risk evaluates the degree of hazard to occupants in the impacting vehicle, including windshield damage. Vehicle trajectory after collision is a measure of the potential for the post-impact trajectory of the vehicle to cause subsequent multi-vehicle accidents, thereby subjecting occupants of other vehicles to undue hazards or to subject the occupants of the impacting vehicle to secondary collisions with other fixed objects. The full-scale vehicle crash tests were conducted and reported in accordance with the procedures provided in NCHRP Report No. 350 and for Category 2 devices.

Windshield damage is a major area of concern when evaluating the safety performance of a work zone traffic control device. The windshield should not be shattered nor damaged in a way that visibility is significantly obstructed. Minor chipping and cracking of the windshield is acceptable. Significant loss of visibility due to extensive “spider web” cracking at key regions of the windshield would deem the performance of the device unsatisfactory. Both layers of glass should not be fractured nor indented with the potential for the test article to penetrate the windshield. An example of satisfactory and unsatisfactory windshield cracking is shown in Figure 1.

GENERAL PERFORMANCE EVALUATION

Based on the results of over 100 full-scale crash test evaluations on portable sign supports, some general observations can be made with respect to the following: (1) the vertical position, failure type, and release time of the sign stand’s fracture point, breakaway mechanism, or yielding hinge; (2) the stiffness and material of the vertical and horizontal crossbrace members; (3) the material of the flag staffs; and (4) the attachment mechanism between the flag assembly and the vertical crossbrace member. Observations pertaining to the extent of the damage encountered by the vehicle as well as the possible hazards to the adjacent traffic and work zone crews can also be made.

Stands with excessive stub lengths remaining after impact can potentially catch on the undercarriage of the vehicle and drag along under the vehicle with heavy contact. This can lead to further fracture of the legs, and the potential for floorboard occupant compartment intrusion. Stands with shorter stub heights will allow the vehicle to pass over more easily or travel with the vehicle with little contact between the stand and the vehicle’s undercarriage.

A mast that fractures instead of bends (or yields) reduces the amount of flex developed in the sign panel and mast. This relatively quick release of the mast from the stand allows the sign panel and mast to fall upon the vehicle with little additional force than what was developed through the impact. On the other hand, when the mast bends, the sign panel and mast develop an additional load due to the lower part of the mast flexing away from the vehicle. When the mast is unloaded, the sign panel and mast have the tendency to "whip" downward onto the vehicle. In addition, a mast that bends rather than fractures typically has a very slow release time (if one at all) from the stand, which adds to the amount of flex in the sign panel and mast.

It is more likely that the sign panel and flag assembly will impact the windshield when the mast bends or has a delayed fracture, resulting in a slow release. However, if the mast fractures quickly, the probability that the mast and sign panel contact the roof is increased if the mast length is less than 2.3 m. When the mast fractures quickly, there is also the possibility of no contact between the mast/sign panel configuration and the vehicle. Conversely, the hood or windshield is likely to be impacted by the sign panel and flag assembly when the mast bends and does not release from the stand until much later.

Sign panels, with flexible vertical and horizontal members, can potentially develop excessive flex in the members and strike the vehicle with a concentrated impact force. However, it is noted that this phenomenon is partially dependent on the mast's release time from the stand. Sign panels with rigid vertical members, spanning the full length of the sign panel and those which released quickly from the stand, were found to develop minimal flex in the vertical member and were most likely to impact the vehicle's roof. This was found to be true whether the rigid vertical member also functioned as the vertical crossbrace, or whether it was coupled with a flexible, fiberglass vertical member.

Sign panels with rigid vertical members spanning only the lower quarter of the sign panel can potentially develop excessive flex in the vertical member and impact the windshield, even for varying sizes of vertical and horizontal flexible members. Sign panels, containing rigid vertical members spanning only the lower half of the sign and horizontal members with a thickness larger than 4.8 mm, were shown to develop additional flex in the vertical members and cause windshield damage. The use of rigid horizontal members in combination with vertical members has the potential for the rigid horizontal crossbrace members to penetrate the windshield when oriented end-on to the vehicle.

A flexible horizontal member, with a 4.8 mm thickness, generally has enough flexibility to reduce the potential for windshield penetration in an end-on orientation, but provides adequate rigidity to reduce the flex in the sign panel when impacted head-on. However, for an end-on impact, it may be possible that the sign panel and mast rotate, allowing the top of the sign panel and/or mast to potentially impact the windshield and roof. The performance of the flexible horizontal member in an end-on orientation is not only dependent upon the amount of flexibility in the member but also the sign panel's release time from the stand. If the release time is slow, the potential for the horizontal member to impact the windshield is increased.

The material used for the flag staffs included round wooden-dowels and flat, rectangular-shape fiberglass bars. Wooden-doweled staffs generally do not flex significantly, while fiberglass staffs provide much more flexibility. Typically, wooden-doweled staffs bridge across the metal trim and roof, thereby not allowing the metal flag holder to contact the windshield. Remaining pieces of wooden-doweled staffs that have fractured in the metal flag holder have been shown to cause damage to the windshield, especially in an end-on orientation. The metal holder for the wooden-doweled staffs has also revealed the potential for the holder to strike and dent the vehicle's roof and windshield.

The more flexible, fiberglass staffs and the bolted attachment assembly at the top of the vertical member are also prone to striking the windshield while the upper vertical crossbrace member is unloaded. In addition, this fiberglass staffed flag assembly has been shown to cause severe denting on the vehicle's roof and hood.

The location and extent of damage to a vehicle by the flags and flag holder is also dependent on the length of the mast and how quickly the mast fractures or releases form the stand. The probability of the metal flag holder impacting the roof is increased when the mast length is greater than 2.3 m. With a longer mast length and quick release of the mast, there is also the possibility of no contact between the metal flag holder and the vehicle. There was also the potential of the sign panel to impact the windshield when flags were not attached to the top of the sign panel.

Finally, it was evident that the debris from the portable sign supports tended to be thrown along the path of the impacting vehicle. The relative hazard posed to the adjacent traffic and work zone crews located adjacent to the sign supports is somewhat subjective in nature. Depending on the specific site conditions at which these devices are being used, the sign support debris was determined to be less of a hazard to adjacent traffic and work zone crews than the moving vehicle itself.

PARAMETER DEVELOPMENT

The comparison made using generalized properties of the major sign components included only the sign support systems that contained a sign locking mechanism of either a screwlock or a stablock design as shown in Figure 2. For all the systems evaluated, the aluminum vertical tubing ranged in size from 30 to 45 mm square with wall thickness between 1.4 and 2.6 mm. The comparison was performed for both the head-on (0 degree) and end-on (90 degree) orientations.

The parameters considered were the height to the bottom of the sign panel, base stiffness (spring), and section modulus at bumper height. The height to the bottom of the sign panel was placed in one of two categories: (1) low, which included heights up to 500 mm above the ground; and (2) high, which included heights greater than 500 mm above the ground. Examples of each height category are shown in Figure 3.

Base stiffness was also divided into two categories: (1) stiff; and (2) non-stiff. For the head-on orientation, stiff was used to describe the rigid base types and non-stiff was used to describe spring base types (i.e., torsional spring, extension spring, double upright coil spring, and single upright coil spring). For the end-on orientation, stiff was used to describe base types which were essentially rigid in the 90 degree orientation (i.e., rigid, torsional spring, extension spring, and double upright coil spring) and non-stiff was used for base types which still performed like a spring in the 90 degree orientation (i.e., single upright coil spring). Examples of the base types are shown in Figure 4.

Bumper height stiffness was used to describe the section modulus of the mast and/or sign panel vertical crossbrace at the bumper height. The stiffness was divided into three categories: (1) stiff; (2) non-stiff; and (3) combination. Examples of each category are shown in Figure 5.

The stiff grouping included the systems that had an aluminum mast spanning the height of the sign panel and also the sign panels that had an aluminum vertical crossbrace member. The sizes of The non-stiff grouping included systems that did not have an aluminum vertical crossbrace member or mast. The "combination" grouping contained those systems with an aluminum vertical tubing connected to the base and the sign panel, but the sign panel contained a fiberglass vertical crossbrace member.

Systems Oriented Head-on

The head-on (0 degree) impact evaluation results are shown in Table 1. A system with a low height, a stiff base, and was non-stiff at the bumper height would probably perform satisfactorily in the head-on orientation. A system would also probably perform satisfactorily in the head-on direction if it was low in height with a non-stiff base and was stiff at the bumper height.

In comparing the systems that were low in height with a non-stiff base and were non-stiff at the bumper height, the flag system was found to make a difference in the performance of the sign support system. A system containing wood or short (660 mm long) fiberglass flag staffs performed satisfactorily. The system that performed unsatisfactorily contained long (760 mm long) fiberglass flag staffs. It should be noted that the only difference between these systems was the length of the flag staffs. Therefore, a system with a low height, a non-stiff base, and was non-stiff at the bumper height would appear to perform satisfactorily as long as the flag staffs at the top of the sign panel were short (approximately 660 mm long). The short flag staff design parameter would help reduce the amount of flex that the top of the sign panel could encounter.

For systems that were low in height with a "combination" bumper height stiffness, the stiffness of the base made a difference on the performance of the sign support system. If the system had a stiff base, it would probably perform unsatisfactorily. On the other hand, a system with a non-stiff base stiffness would probably perform satisfactorily. With a non-stiff base, the upper portion of the system is allowed to rotate thereby increasing its momentum and causing a quicker fracture of the system's upper portion. Therefore, a system with a low height, a non-stiff base, and a "combination" bumper height stiffness would probably perform satisfactorily in the head-on orientation unlike a system with a low height, a stiff base, and a "combination" bumper height stiffness.

The systems evaluated with a high height all contained a non-stiff base and were stiff at the bumper height. The difference between these systems was the number of mast pieces. The system with three sections of mast performed unsatisfactorily due to the mast connections being weak and consequently breaking into pieces and impacting the windshield. The systems with only two sections of mast performed satisfactorily in regards to windshield damage due to the mast remaining intact and rotating above the vehicle without contacting the windshield. One of the systems with two sections of mast performed unsatisfactorily due to floorboard penetration. This system was then redesigned to reduce the height of the base from 430 mm to 365 mm and it performed satisfactorily. Therefore, a system with a high height, a non-stiff base, and a stiff bumper height stiffness would probably perform satisfactorily in the head-on orientation as long as the mast had only two sections and the height of the base is less than 375 mm.

Systems Oriented End-on

The number of systems impacted in the end-on orientation was much less than the number of head-on impacts. Many systems were not tested in the end-on orientation unless they were successful in the head-on orientation. Therefore, this led to a limited amount of system performance available for analysis as shown in Table 2.

A system with a low height, a stiff base, and a non-stiff bumper height stiffness would probably perform satisfactorily in the end-on orientation. A system with a low height, a non-stiff base, and either a stiff or non-stiff bumper height stiffness would also probably perform satisfactorily in the end-on orientation. It should be noted that these three general system configurations only had one system tested in the end-on orientation, therefore it may be difficult to determine if these results would be the same for other systems with the same general configurations.

As for systems with low heights, stiff bases, and stiff bumper height stiffness, the system's performances in the end-on orientation were varied. When comparing parameters to determine their varied performances, it was found that the horizontal crossbrace member material, as shown in Figure 6, and the flag staff material were different. One system contained an aluminum horizontal crossbrace member and wooden flag staffs and performed unsatisfactorily because the horizontal crossbrace member penetrated the windshield. Another system contained a fiberglass horizontal crossbrace member and wooden flag staffs and performed unsatisfactorily because the wooden flag system holder impacted and penetrated the windshield. The system that performed satisfactorily contained a fiberglass horizontal crossbrace member and fiberglass flag staffs. Therefore, it would appear that a system with a low height, a stiff base, and a stiff bumper height stiffness would probably perform satisfactorily in the end-on orientation if the sign panel contains a fiberglass horizontal crossbrace member and fiberglass flag staffs.

Consequently, slight differences in system design details can potentially lead to very different results especially between different manufacturers. Therefore, extreme care should be taken when attempting to categorize various products for one or more manufacturers.

SUMMARY AND CONCLUSIONS

For the portable signs systems included in this study, acceptable performance was garnered through either a quick release of the sign from the base in the case of stiff base connections or a flexible base that allowed the sign to pivot away from the vehicle immediately after impact. This prevented the sign panel and upright from pivoting on the bumper of the vehicle and striking the windshield. In the case of signs with flexible bases, all of the tests were successful. Again, the same principals applied, with the flexible base allowing the sign to rotate away from the vehicle at impact. The performance of signs impacted in the end-on (90 degree) orientation was predicated on the structural rigidity of the cross-member used to support the sign itself. Flexible cross-members with relatively low cross-sectional areas performed acceptably. Details of these various signs played a vital role. For example, flags mounted above the sign were shown to negatively impact performance in certain instances, and sign bases were shown to have the potential to penetrate the vehicle. These details need to be carefully considered in design.

These general guidelines can be extrapolated to recent experiences with rigid panel signs, which to date have been generally less successful. Again the connection mechanism has proven critical, especially with the lower height signs. If the sign does not release quickly, the rigid panel has a very high propensity to rotate into the windshield, precipitating a failure due to penetration or significant cracking. Because the center-of-gravity for these devices is low, this rotation is difficult to control relative to the flexible signs discussed herein. Additionally, tests performed at an end-on (90 degree) orientation have shown the sign panel itself has sufficient strength to penetrate the windshield. This to date has been the failure mechanism of many of the stands evaluated.

For rigid panel signs with higher mounting heights, the parameters discussed in regard to flexible signs apply. For the most part, impact of the rigid panel occurs on the top of the vehicle and does not affect the windshield.

While it is desirable to identify features that lead to acceptable safety performance, extensive testing has shown that small changes in design can significantly affect performance. For portable sign supports, such as those included in this study, similar devices may be capable of meeting the performance requirements from NCHRP Report No. 350. However, the impact performance of sign supports can only be verified through the use of full-scale vehicle crash testing. It should be noted that relatively small design changes might affect performance; thus, full-scale testing may be necessary when considering design changes in existing approved devices.

DISCLAIMER

The contents of this paper reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration nor Dicke Tool Company. This paper does not constitute a standard, specification, or regulation.

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FIGURE 1 Windshield damage: pass and fail, respectively

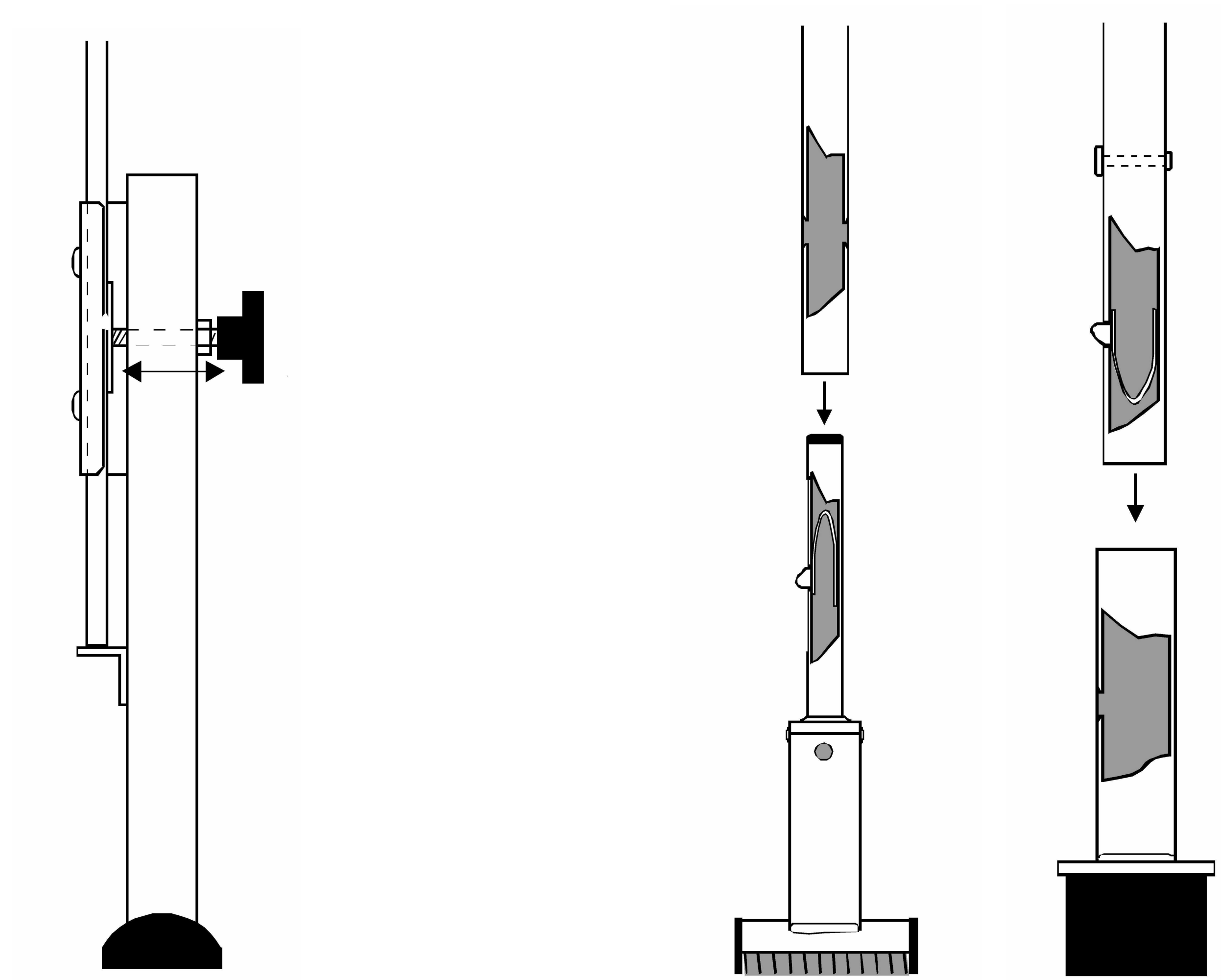

FIGURE 2 Sign lock mechanism: screwlock and stablock

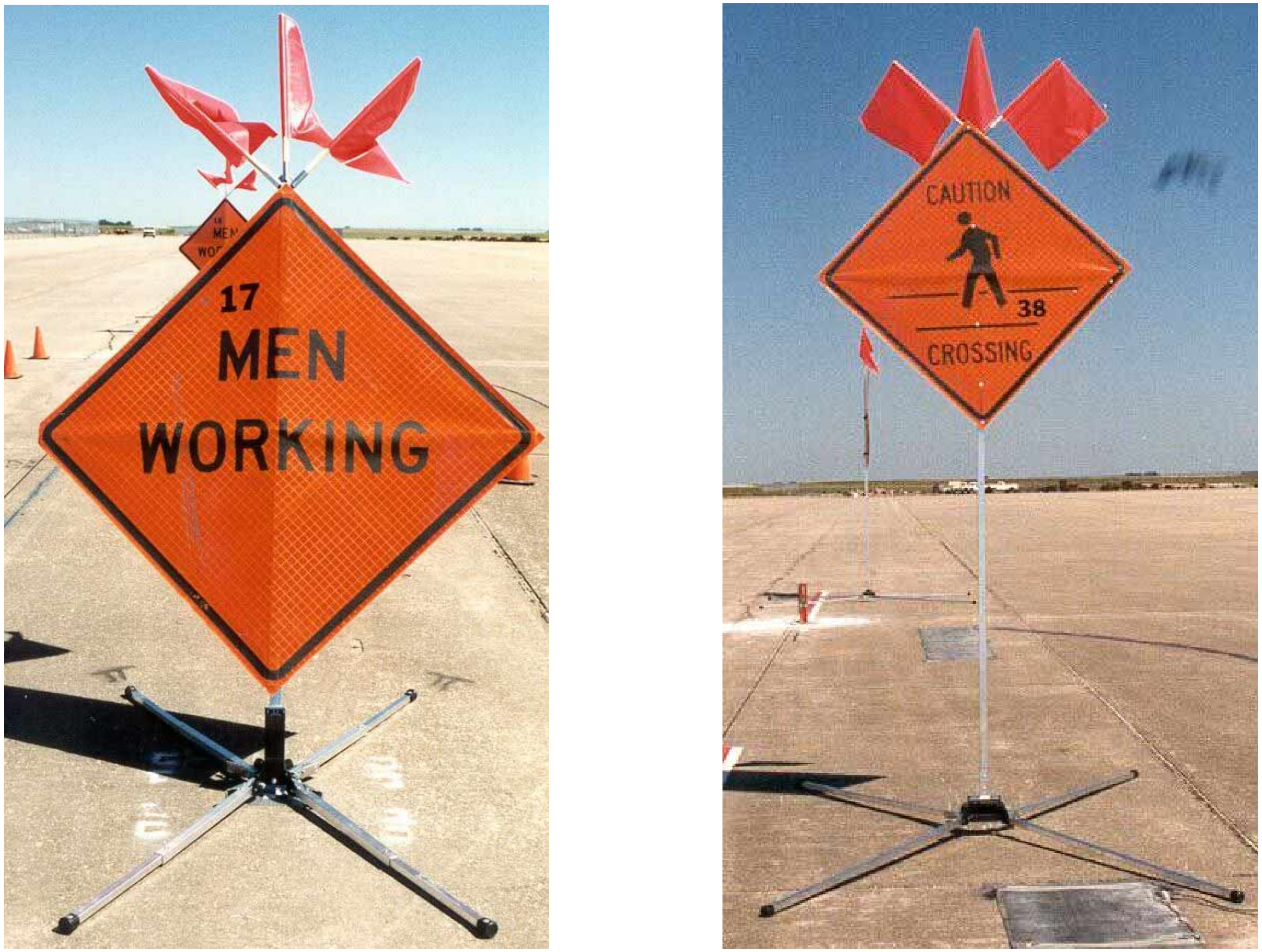

FIGURE 3 Heights to bottom of the sign panel: low and high, respectively

FIGURE 4 Base types: rigid, torsion spring, extension spring, single upright coil spring, and double upright coil spring

FIGURE 5 Bumper height stiffness: stiff, non-stiff, and combination

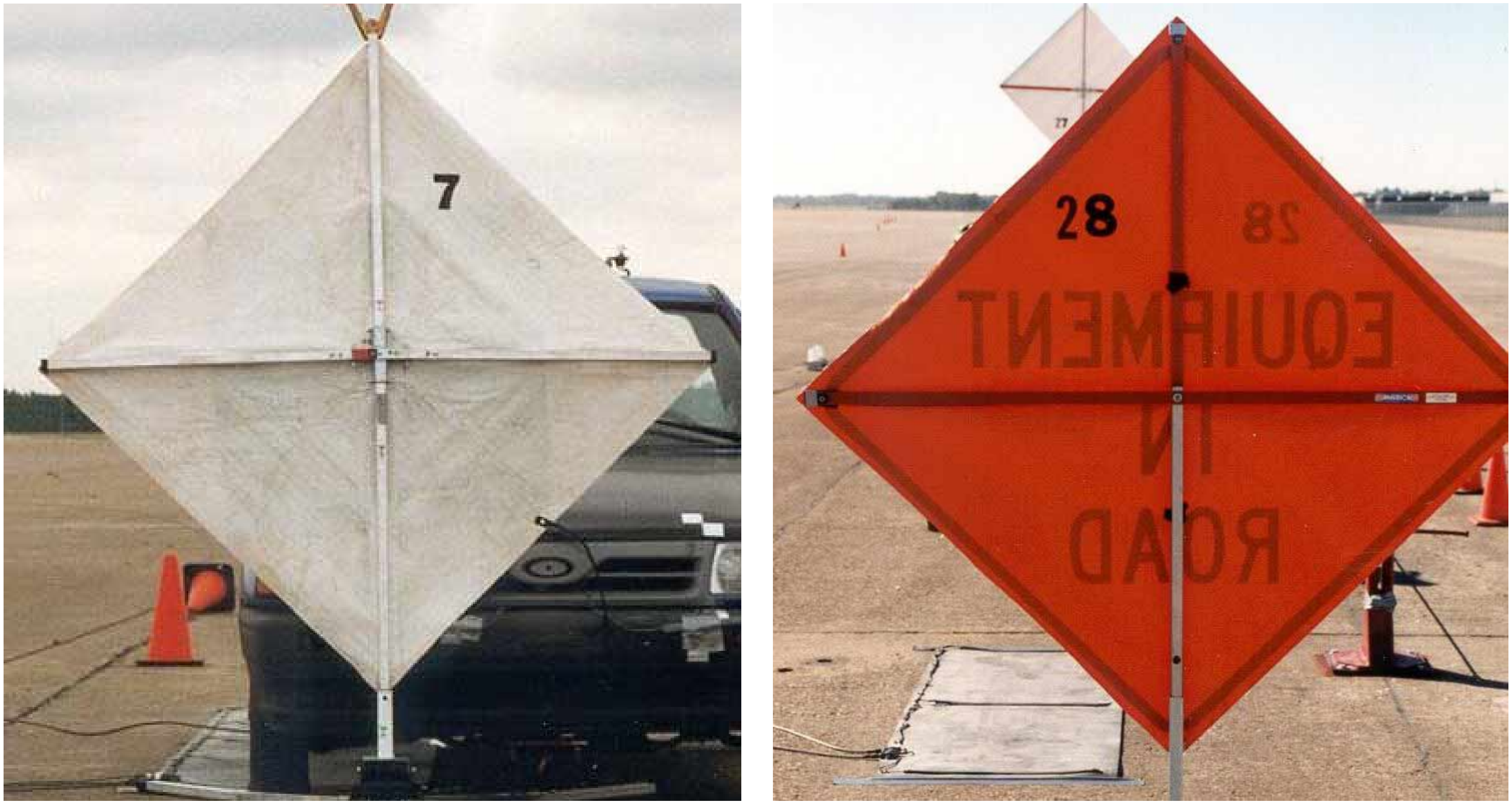

FIGURE 6 Material of horizontal crossbrace members: aluminum and fiberglass, respectively

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TABLE 1 General parameter comparison – head-on impact

System No.[1]	Height to Bottom of Sign Panel (low or high)	Base Stiffness (stiff or non-stiff)	Bumper Height Stiffness (stiff, non-stiff, or combination)	Pass or Fail
5	Low	Stiff	non-stiff	Pass
26	Low	Stiff	non-stiff	Pass
11	low	Stiff	combination	Fail
16	low	Stiff	combination	Fail
25	low	Stiff	combination	Fail
28	low	Stiff	combination	Fail
7	low	non-stiff	stiff	Pass
13	low	non-stiff	stiff	Pass
17	low	non-stiff	stiff	Pass
19	low	non-stiff	stiff	Pass
20	low	non-stiff	stiff	Pass
21	low	non-stiff	stiff	Pass
14	low	non-stiff	non –stiff	Fail
15	low	non-stiff	non-stiff	Pass
24	low	non-stiff	non-stiff	Pass
35	low	non-stiff	non-stiff	Pass
23	low	non-stiff	combination	Pass
22	high	non-stiff	stiff	Fail
27	high	non-stiff	stiff	Fail
34	high	non-stiff	stiff	Pass

[1] Corresponds to the system numbers in the recently published MwRSF reports (9,10,12,15,17)

TABLE 2 General parameter comparison – end-on impact

System No.[1]	Height to Bottom of Sign Panel (low or high)	Base Stiffness (stiff or non-stiff)	Bumper Height Stiffness (stiff, non-stiff, or combination)	Horizontal Crossbrace	Pass or Fail
8	low	stiff	stiff	25.40 mm sqr aluminum	Fail
30	low	stiff	stiff	5.25 mm thick fiberglass	Fail
44	low	stiff	stiff	4.88 mm thick fiberglass	Pass
6	low	stiff	non-stiff	4.76 mm thick fiberglass	Pass
48	low	non-stiff	stiff	4.89 mm thick fiberglass	Pass
45	low	non-stiff	non-stiff	4.84 mm thick fiberglass	Pass

[1] Corresponds to the system numbers in the recently published MwRSF reports (9,10,12,15,17)