Effect of Vehicle Collision With Aluminum Roadside Sign Structures Mounted on Frangible Bases

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Roadside sign structures are usually located adjacent to a traffic lane and because of their location give rise to a safety hazard. Numerous collisions with these structures have been reported and in many instances serious injury or fatalities have occurred.

This paper presents the results of the mathematical simulation of vehicle collision with single and dual support aluminum roadside sign structures mounted on frangible bases. The study was performed with the aid of a mathematical model verified by a full-scale crash test and analyzed sign and sign support configurations that are typical of roadside sign structures proposed by the state of Maine. The equations of motion predicting the response of the system were solved numerically and a computer was used to obtain the results. Some findings of the study reveal that low-speed collisions (15-20 mph) normally cause the support to hit the windshield area of the vehicle; medium-speed collisions (30-45 mph) with the single support structure cause the support to strike the top or trunk area of the vehicle; and medium- and high-speed collisions with the dual support structure cause the post to clear the vehicle.

•AN EFFICIENT modern highway requires having roadway signs that relay information to the motorist in a clear and concise manner, and current highway design concepts for multilane facilities have resulted in the installation of sign supports near the edge of the traffic lane. Because of their location, these signs constitute a safety hazard, and collisions with these signs have caused fatalities.

An obvious solution to the problem is relocation of the support. This approach is usually not feasible, and the engineer must resort to other means to alleviate the dilemma. A design that has already shown considerable merit is the slip base type breakaway support that, upon impact, disengages the post from the foundation. This generally accepted design limits impact forces, but regard must be given to the possibility that the structure may fall on the vehicle and create a hazardous situation for the occupants.

The purpose of this investigation was to evaluate the crash-dynamic behavior of various aluminum sign structure configurations mounted on frangible bases having different impact characteristics. The base force-deformation behavior was obtained from laboratory tests performed by the Texas Transportation Institute, and the results used in the study are presented in the Appendix. The dynamic response of the vehicle and the structure was obtained with the aid of a mathematical model. Typical results are presented in Tables 3 through 10 in the Appendix.

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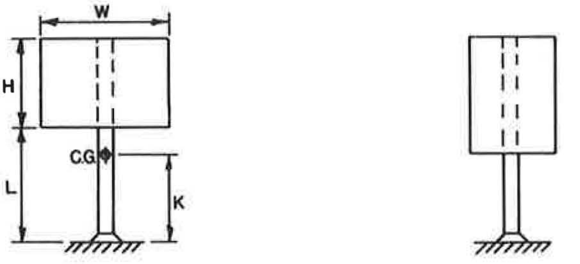
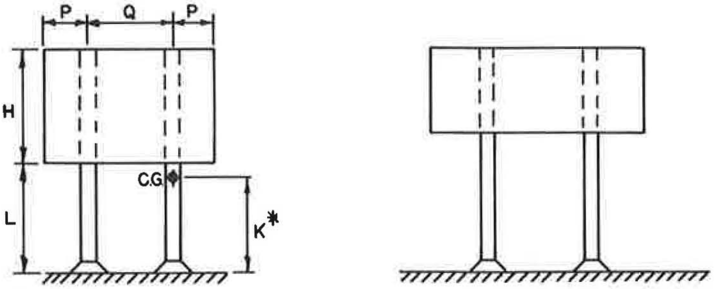


SIGN 1A

SIGN 1B

SIGN	1A	1B
W (FT.)	6.0	4.0
H (FT.)	5.0	10.0
L (FT.)	7.0	6.0
WEIGHT (LBS.)	93.2	124.0



SIGN 1C

SIGN 1D

*FOR IDEALIZED SIGN (FIG.2)

SIGN	1C	1D
P (FT.)	2.0	2.5
Q (FT.)	6.0	8.0
H (FT.)	9.0	6.0
L (FT.)	7.0	7.0
WEIGHT* (LBS.)	111.6	93.0

Figure 1. Sign configurations used in study.

DESCRIPTION OF SIGN STRUCTURE

The aluminum signs and sign support configurations evaluated in this study are typical of roadside sign structures proposed by the state of Maine. These structures are shown in Figures 1 and 2. The complete post and sign description is given in Table 2 in the Appendix.

In the mathematical simulation it was assumed that the frangible bases deform by the amounts indicated in Figures 3 through 6. These deformations were obtained from accelerometer test data and represent the distance the impacting ram used in the base fracture test moved after initial contact with the base. This force-deformation ideal-

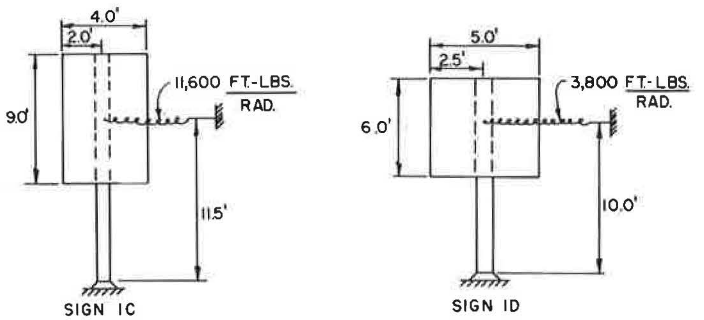


Figure 2. Idealizations of signs 1C and 1D.

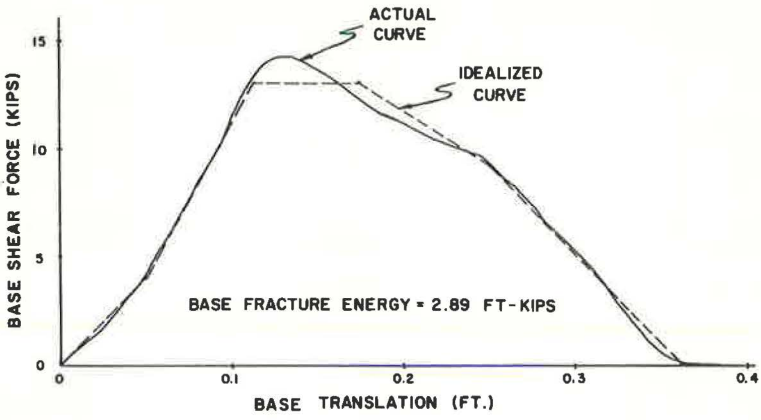


Figure 3. Base fracture energy curve for 6 x $^3/_{16}$-in. post.

ization makes the peak forces encountered in the larger bases quite sizeable since the energy for all bases must be dissipated for a relatively small value of base deformation. The idealized curves also shown in Figures 3 through 6 represent the same base fracture energy as the experimental curves and were necessary to obtain the input to the computer coding, which assumes a piecewise linear variation of base shear force.

MATHEMATICAL SIMULATION

Two mathematical models were employed in the study. The model that yields the dynamic response of the single support structure assumes four degrees of freedom and is basically a planar version of the three-dimensional model that was employed in the analysis of luminaire support structures (1). This more recent model was coded in order to reduce the computer time associated with the solution of a problem. A Runge-Kutta numerical integration scheme (2) has also been added, making the program more efficient.

The model used to predict the behavior of the dual support structure assumes two degrees of freedom and idealizes the structure as being hinged at the center of the sign

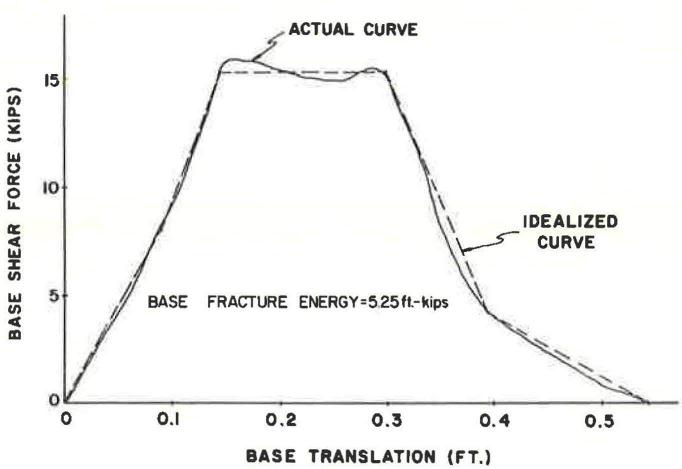


Figure 4. Base fracture energy curve for 8 x $^1/_4$-in. post.

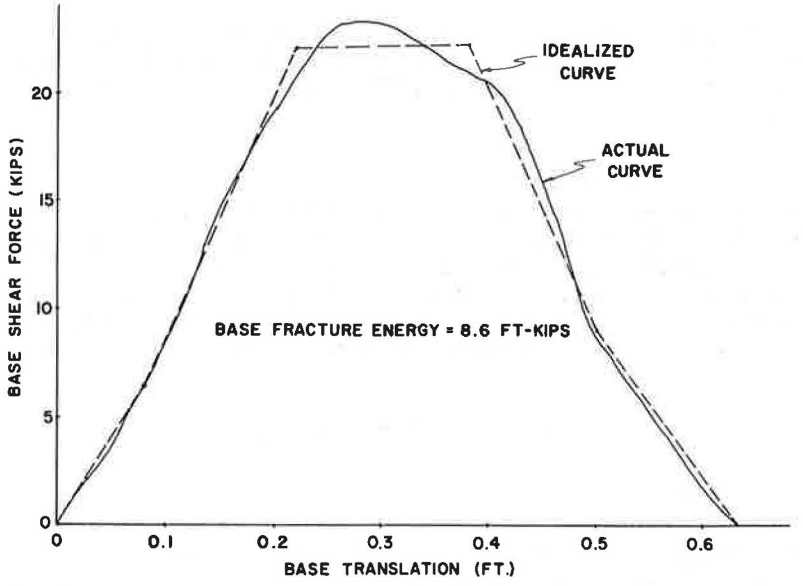


Figure 5. Base fracture energy curve for 10 x $^1/_4$-in. post.

and capable of having only a rotation about this point. The effects of the sign and of the support that is not impacted are lumped into a torsional spring constant, as shown in Figure 2.

The vehicle is represented as a single-degree-of-freedom spring-mass system having a spring of variable stiffness. The rigid mass and its velocity simulate the momentum

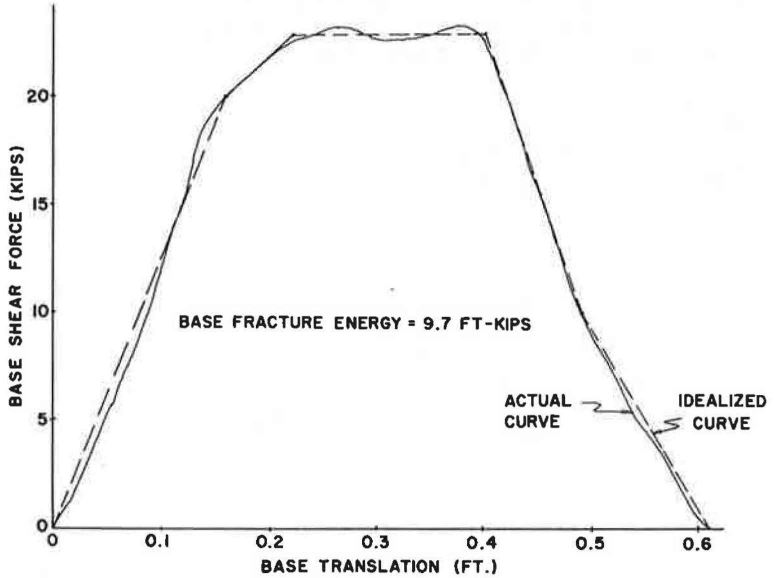


Figure 6. Base fracture energy curve for 12 x $^1/_4$-in. post.

of the vehicle and the energy absorbed is determined from the spring force-deformation relationship. In the study it was assumed that the spring constant was a function of the vehicle weight. The collisions were considered to take place for a vehicle approach angle of zero.

Verification of Mathematical Model

To verify the mathematical models, a full-scale crash test was performed at the Texas Transportation Institute Research Annex. The test employed a 1959 Ford sedan weighing 3,550 lb and sign 1A. The impact velocity was 29 mph.

Table 1 and Figure 7 present a comparison of model and crash test results and indicate good agreement. It is anticipated that the model will predict results very satisfactorily for most cases where the peak force encountered in fracturing the base is not extremely large.

DISCUSSION OF RESULTS

Single Support Structures

The study revealed that for impacting velocities up to 45 mph, the single support structure does not clear the vehicle. Sign 1B, being taller and having a higher mass-center position than sign 1A, has a greater tendency to clear the vehicle and will probably do so at the higher velocities. Figure 8 shows the response of sign 1B when it is subjected to a 45-mph collision. Collisions by the lightweight (2,500-lb) vehicles traveling at slow speeds (15 mph or less) may be considered hazardous as they cause the support structure to strike the windshield area of the vehicle in a majority of the cases. This is because at the slower speeds the post has a greater tendency to translate and ride the front of the vehicle before falling on it. The effect is more pronounced for collisions with the supports mounted on bases having a high base fracture energy.

The results further revealed that a lightweight vehicle traveling at speeds below 15 mph may be stopped when it collides with supports mounted on bases having fracture energies of 10 ft-kips or greater. This large change in velocity may have a severe effect on the vehicle occupants, and such collisions could be interpreted as hazardous.

Collisions that cause the signpost to strike the top of the vehicle will normally not be hazardous unless the structure is quite massive or the contact is made near the windshield area. If contact is initially made in the windshield area, then it is conceivable that, depending on the rotation of the post, a secondary impact with the hood or windshield by some other point on the post could occur.

Dual Support Structures

The results of the study of dual support structures disclose that, for the cases investigated, only the slow-moving vehicle encounters a secondary collision with the post.

TABLE 1

COMPARISON OF MODEL AND CRASH TEST RESULTS

Test	Initial Velocity (mph)	Change in Velocity (mph)	Post-Vehicle Contact Time (sec)	Average Vehicle Deceleration (g)	Remarks
Full-scale crash	29.0	2.7	0.084	1.47	Signpost rotates 105 deg and hits top of vehicle 10.75 ft from front bumper. Total time of event is 0.338 sec.
Mathematical model	29.0	2.5	0.084	1.33	Signpost rotates 105 deg and hits top of vehicle 10.25 ft from front bumper. Total time of event is 0.318 sec.

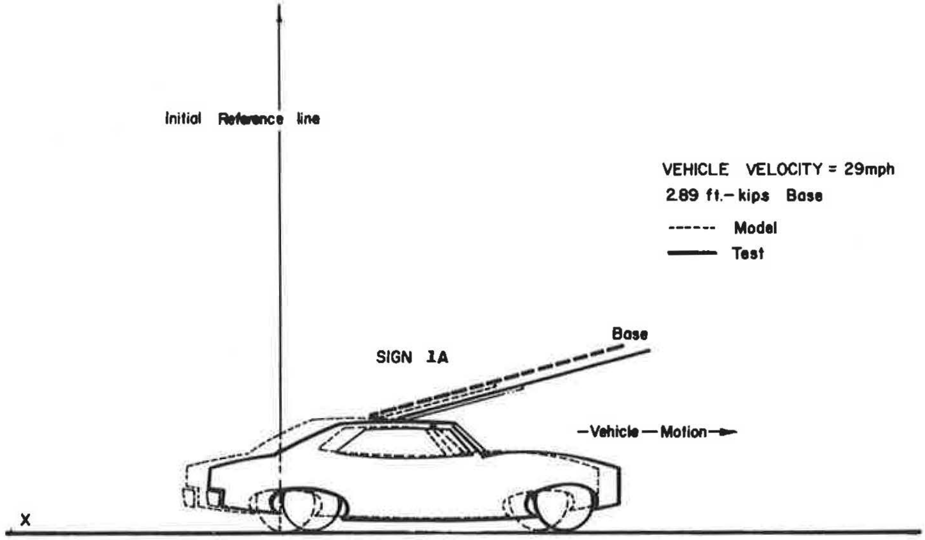


Figure 7. Comparison of model and crash test results, sign 1A.

This secondary collision occurs in the area of the windshield of the vehicle and may be interpreted as hazardous. The deceleration rates and velocity changes at these slow speeds are less than those obtained for the single support structures impacted at the same velocity. This is due to the dual support structure idealization and the high position of the assumed center of rotation.

Collisions at the higher vehicle velocities cause the post to clear the vehicle. This is due to the large angular velocity that is acquired by the relatively light support as a result of the vehicular impact. The response of sign 1C following impact by a medium-sized vehicle at various velocities is shown in Figure 9.

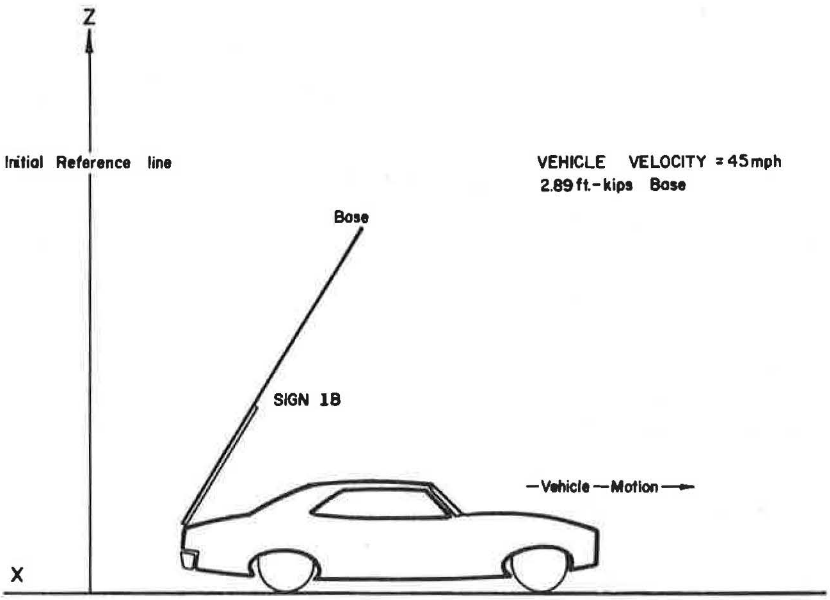


Figure 8. Typical impact response of sign 1B.

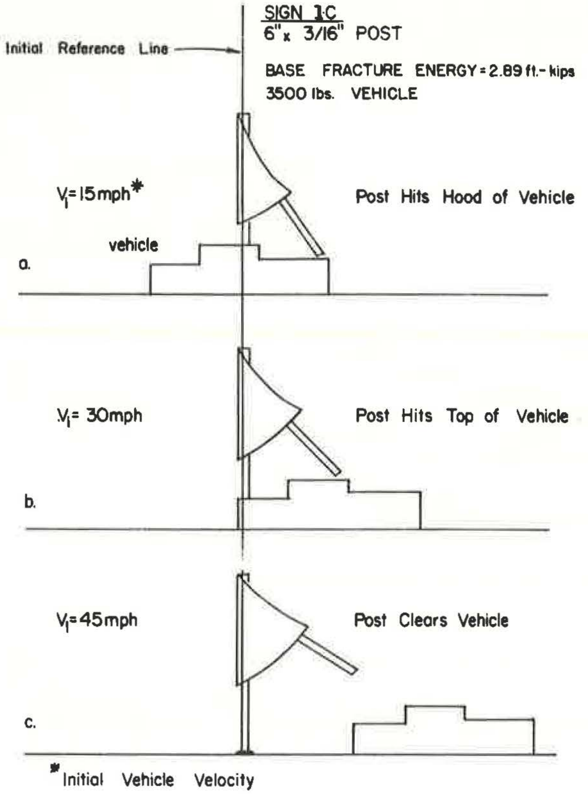


Figure 9. Typical impact response of sign 1C.

Comparison

The results given in the tables in the Appendix show that the impact behavior of signs 1A and 1B is very similar. The higher center of mass of sign 1A gives it more of a tendency to rotate and, as a result, the rotation angle of the structure is greater when it rotates and strikes the vehicle. In general, it can be said that lowering of the center of mass of the structure will give the support more of a tendency to translate and will increase the vehicular change in velocity.

Signs 1C and 1D behave in much the same manner. The stiffer torsional spring assumed for sign 1C gives the structure a greater rotational stiffness and its effect becomes more pronounced for collisions of light vehicles with supports requiring the larger base fracture energies. In the case of a heavier vehicle impacting at a low velocity, the stiffer torsional spring of sign 1C causes the support to encounter a secondary collision in the hood or windshield area, whereas sign 1D has its support strike the top of the vehicle.

A comparison of the single and dual support structures indicates that greater vehicular velocity changes and deceleration rates will be experienced when similar collisions involve the sign employing the single support. This can be partially attributed to the different sign geometric and inertia properties and the constraints imposed on the idealized structure. They produce the effect of causing the single support to stay in longer contact with the vehicle, thus accounting for the larger velocity changes.

GENERAL CONCLUSIONS

The general conclusions stated here are based on the cases investigated and a criterion that uses a vehicular velocity change of 11 mph as one that causes passenger injury (3).

In single support structures, the following conclusions may be stated:

1. Collisions by vehicles traveling up to 45 mph cause the supports investigated to strike the vehicle.
2. Collisions of lightweight vehicles traveling at speeds of approximately 15 mph may cause a hazardous condition (one that could cause passenger injury) when they impact the large-diameter support posts. This is based on vehicular velocity changes of approximately 11 mph.
3. Medium- and high-speed collisions will cause the support to strike the top or trunk areas of the vehicle. These cases are not usually hazardous.

In dual support structures, the following conclusions may be reached:

1. For the cases investigated, velocity changes remain below the criteria established for a hazardous condition.

2. Low-speed collisions (15-20 mph) will normally give rise to a secondary collision in the vicinity of the hood or windshield area. These collisions are not necessarily hazardous, however, as the post will not come through the windshield after the secondary collision takes place.
3. Medium- and high-speed collisions cause the post to clear the vehicle and the vehicular velocity changes remain within tolerable limits.

It should be emphasized that the assumption of the post and sign remaining fastened together during impact has been made. If the connections are not rigid enough, it is possible for the post and the sign to detach and possibly create an additional hazard as secondary collisions with both the post and sign would be encountered.

ACKNOWLEDGMENTS

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Appendix

On the following pages, Table 2 gives the properties of the signposts, and Tables 3 through 10 give the results for the 4 signs with base fracture energies of 2.89 and 9.7 ft-kips.

TABLE 2. POST PROPERTIES FOR SIGNS USED IN STUDY

SIGN 1A

Post	6" x 3/16"[c]	8" x 1/4"	10" x 1/4"	12" x 1/4"
Post Height (ft)	12.0	12.0	12.0	12.0
Post Weight (lbs)	52.5	93.1	110.3	132.9
K[a] (ft)	8.2	7.7	7.6	7.4
Base Fracture Energy (ft-kip)	2.89	5.25	8.6	9.7

SIGN 1B

Post	6" x 3/16"	8" x 1/4"	10" x 1/4"	12" x 1/4"
Post Height (ft)	16.0	16.0	16.0	16.0
Post Weight (lbs)	70.0	124.1	147.1	177.2
K[a] (ft)	9.9	9.5	9.4	9.2
Base Fracture Energy (ft-kip)	2.89	5.25	8.6	9.7

SIGN 1C

Post	6" x 3/16"	8" x 1/4"	10" x 1/4"	12" x 1/4"
Post Height (ft)	16.0	16.0	16.0	16.0
Post Weight (lbs)	70.0	124.1	147.1	177.2
K[b] (ft)	11.5	11.5	11.5	11.5
Base Fracture Energy (ft-kip)	2.89	5.25	8.6	9.7

SIGN 1D

Post	6" x 3/16"	8" x 1/4"	10" x 1/4"	12" x 1/4"
Post Height (ft)	13.0	13.0	13.0	13.0
Post Weight (lbs)	56.9	101.0	119.5	144.0
K[b] (ft)	10.0	10.0	10.0	10.0
Base Fracture Energy (ft-kip)	2.89	5.25	8.6	9.7

[a]For center of gravity of post and sign (Fig. 1)

[b]For assumed center of rotation of idealized structure (Fig. 2)

[c]Pipe diameter and wall thickness, respectively

TABLE 3. RESULTS FOR SIGN 1A WITH BASE FRACTURE ENERGY OF 2.89 FT-KIPS

Vehicle Weight (lbs)	Initial Vehicle Velocity (mph)	Change in Vehicle Velocity (mph)	Duration of Collision (sec)	Average Vehicle Deceleration (G's)	Remarks
2500	15	5.0	0.121	1.9	Post hits top of vehicle. L = 6.8 ft[a]
2500	30	2.9	0.091	1.4	Post hits top of vehicle. L = 10.9 ft
2500	45	2.3	0.080	1.3	Post hits top of vehicle. L = 12.6 ft
3500	15	3.4	0.124	1.3	Post hits top of vehicle. L = 7 ft
3500	30	2.5	0.084	1.3	Post hits top of vehicle. L = 10.4 ft
3500	45	2.1	0.069	1.4	Post hits top of vehicle. L = 12.2 ft
5000	15	1.9	0.098	0.9	Post hits top of vehicle. L = 7.3 ft
5000	30	1.3	0.072	0.8	Post hits top of vehicle. L = 10.5 ft
5000	45	1.1	0.066	0.7	Post hits top of vehicle. L = 12.4 ft

(a) L is the distance from front bumper of vehicle to point where support hits

TABLE 4. RESULTS FOR SIGN 1B WITH BASE FRACTURE ENERGY OF 2.89 FT-KIPS

Vehicle Weight (lbs)	Initial Vehicle Velocity (mph)	Change in Vehicle Velocity (mph)	Duration of Collision (sec)	Average Vehicle Deceleration (G's)	Remarks
2500	15	5.5	0.129	1.9	Post hits top of vehicle. L = 9.8 ft[a]
2500	30	3.1	0.086	1.7	Post hits trunk area of vehicle.
2500	45	2.6	0.084	1.4	Post hits trunk area of vehicle.
3500	15	3.8	0.131	1.2	Post hits top of vehicle. L = 10.2 ft
3500	30	2.7	0.092	1.3	Post hits trunk area of vehicle.
3500	45	2.1	0.079	1.2	Post hits trunk area of vehicle.
5000	15	1.9	0.104	0.8	Post hits top of vehicle. L = 10.7 ft
5000	30	1.3	0.076	0.7	Post hits trunk area of vehicle.
5000	45	1.2	0.074	0.7	Post hits trunk area of vehicle.

(a) L is the distance from front bumper of vehicle to point where support hits

TABLE 5. RESULTS FOR SIGN 1C WITH BASE FRACTURE ENERGY OF 2.89 FT-KIPS

Vehicle Weight (lbs)	Initial Vehicle Velocity (mph)	Change in Vehicle Velocity (mph)	Duration of Collision (sec)	Average Vehicle Deceleration (G's)	Remarks
2500	15	3.2	0.116	1.3	Post hits hood area of vehicle.
2500	30	2.0	0.075	1.2	Post hits windshield area of vehicle.
2500	45	2.3	0.075	1.4	Post has cleared the vehicle.
3500	15	2.3	0.120	0.9	Post hits hood area of vehicle.
3500	30	1.5	0.081	0.8	Post hits top of vehicle.
3500	45	1.7	0.071	1.1	Post has cleared the vehicle.
5000	15	1.6	0.094	0.8	Post hits hood area of vehicle.
5000	30	1.1	0.069	0.7	Post hits top of vehicle.
5000	45	1.2	0.067	0.8	Post has cleared the vehicle.

TABLE 6. RESULTS FOR SIGN 1D WITH BASE FRACTURE ENERGY OF 2.89 FT-KIPS

Vehicle Weight (lbs)	Initial Vehicle Velocity (mph)	Change in Vehicle Velocity (mph)	Duration of Collision (sec)	Average Vehicle Deceleration (G's)	Remarks
2500	15	2.9	0.109	1.2	Post hits windshield area of vehicle.
2500	30	1.8	0.082	1.0	Post has cleared the vehicle.
2500	45	1.7	0.072	1.1	Post has cleared the vehicle.
3500	15	2.0	0.112	0.8	Post hits windshield area of vehicle.
3500	30	1.3	0.076	0.8	Post has cleared the vehicle.
3500	45	1.2	0.062	0.9	Post has cleared the vehicle.
5000	15	1.5	0.088	0.8	Post hits windshield area of vehicle.
5000	30	0.9	0.065	0.6	Post has cleared the vehicle.
5000	45	0.9	0.060	0.7	Post has cleared the vehicle.

TABLE 7. RESULTS FOR SIGN 1A WITH BASE FRACTURE ENERGY OF 9.7 FT-KIPS

Vehicle Weight (lbs)	Initial Vehicle Velocity (mph)	Change in Vehicle Velocity (mph)	Duration of Collision (sec)	Average Vehicle Deceleration (G's)	Remarks
2500	15	9.2	0.153	2.7	Post hits windshield area of vehicle.
2500	30	7.0	0.057	5.6	Post hits windshield area of vehicle.
2500	45	6.8	0.044	7.0	Post hits top of vehicle. L = 7.0 ft[a]
3500	15	7.7	0.136	2.6	Post hits windshield area of vehicle.
3500	30	5.1	0.057	4.0	Post hits top of vehicle. L = 7.0 ft
3500	45	4.7	0.040	5.4	Post hits top of vehicle. L = 7.6 ft
5000	15	6.0	0.150	1.8	Post hits top of vehicle. L = 7.0 ft
5000	30	3.7	0.058	2.9	Post hits top of vehicle. L = 9.0 ft
5000	45	3.8	0.038	4.6	Post hits top of vehicle. L = 10.0 ft

(a) L is the distance from front bumper of vehicle to point where support hits

TABLE 8. RESULTS FOR SIGN 1B WITH BASE FRACTURE ENERGY OF 9.7 FT-KIPS

Vehicle Weight (lbs)	Initial Vehicle Velocity (mph)	Change in Vehicle Velocity (mph)	Duration of Collision (sec)	Average Vehicle Deceleration (G's)	Remarks
2500	15	10.0	0.168	2.7	Post hits windshield area of vehicle.
2500	30	7.5	0.059	5.8	Post hits top of vehicle. L = 7.5 ft[a]
2500	45	7.4	0.046	7.4	Post hits top of vehicle. L = 8.5 ft
3500	15	8.5	0.162	2.4	Post hits windshield area of vehicle.
3500	30	5.8	0.058	4.5	Post hits top of vehicle. L = 11.0 ft
3500	45	5.3	0.042	5.8	Post hits top of vehicle. L = 12.0 ft
5000	15	6.2	0.157	1.8	Post hits top of vehicle. L = 8.0 ft
5000	30	4.2	0.065	2.9	Post hits trunk area of vehicle.
5000	45	4.1	0.040	4.7	Post hits trunk area of vehicle.

(a) L is the distance from front bumper of vehicle to point where support hits

TABLE 9. RESULTS FOR SIGN 1C WITH BASE FRACTURE ENERGY OF 9.7 FT-KIPS

Vehicle Weight (lbs)	Initial Vehicle Velocity (mph)	Change in Vehicle Velocity (mph)	Duration of Collision (sec)	Average Vehicle Deceleration (G's)	Remarks
2500	15	9.5	0.152	2.5	Post hits hood area of vehicle.
2500	30	5.2	0.055	4.3	Post has cleared the vehicle.
2500	45	5.2	0.045	5.3	Post has cleared the vehicle.
3500	15	5.2	0.156	1.5	Post hits hood area of vehicle.
3500	30	3.8	0.053	3.3	Post has cleared the vehicle.
3500	45	3.8	0.040	4.3	Post has cleared the vehicle.
5000	15	3.6	0.144	1.1	Post hits windshield area of vehicle.
5000	30	2.7	0.060	2.0	Post has cleared the vehicle.
5000	45	2.7	0.040	3.1	Post has cleared the vehicle.

TABLE 10. RESULTS FOR SIGN 1D WITH BASE FRACTURE ENERGY OF 9.7 FT-KIPS

Vehicle Weight (lbs)	Initial Vehicle Velocity (mph)	Change in Vehicle Velocity (mph)	Duration of Collision (sec)	Average Vehicle Deceleration (G's)	Remarks
2500	15	7.5	0.136	2.5	Post hits hood area of vehicle.
2500	30	5.2	0.052	4.5	Post has cleared the vehicle.
2500	45	3.6	0.041	4.0	Post has cleared the vehicle.
3500	15	5.1	0.123	1.9	Post hits hood area of vehicle.
3500	30	3.7	0.052	3.2	Post has cleared the vehicle.
3500	45	2.6	0.040	3.0	Post has cleared the vehicle.
5000	15	3.5	0.135	1.2	Post hits windshield area of vehicle.
5000	30	2.6	0.053	2.2	Post has cleared the vehicle.
5000	45	1.8	0.038	2.1	Post has cleared the vehicle.