IMPACT-YIELDING SIGN SUPPORTS

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This paper presents the results of an investigation of the steel-channel sign supports currently used by Ohio and many other states. These steel supports when struck by an automobile were found to yield at the ground line, and the impacting vehicles showed deceleration values well within human tolerance levels. The study included a laboratory simulation of the crash tests, a computer program to extrapolate the results, and a full-scale field testing program. The field testing program included 40 crash tests with velocity, sign type, angle-of-collision incidence, and soil-support conditions as the variables.

•A GREAT deal of research has been conducted on breakaway sign supports (1, 2). Biomedical research has also been conducted to determine the effects of deceleration impact on the human body (3, 4, 5, 6).

Breakaway sign supports have been shown to be effective in reducing injury when very large double-posted signs are used. However, the steel-channel supports used for small and intermediate-size signs had never been investigated. This study was conducted to determine the properties of these smaller size posts. In this work, signs of up to 56 sq ft of sign area were considered.

The breakaway sign support, upon impact, shears off at the base and the post swings up and out of the path of the vehicle. On the other hand the yielding sign support yields at the ground line and swings downward. The vehicle then passes over the post.

OBJECTIVES OF THE STUDY

A study of pictures and accident reports indicated that the steel-channel sign supports currently in use by the State of Ohio yielded on impact, with minimum damage to car and occupants. The objective of this study, therefore, was to determine definitively whether the channel posts are actually yielding sign supports and to provide, where necessary, criteria for redesign for maximum safety.

The steel-channel posts are provided in sections weighing 2, 3, and 4 lb per ft. The 3- and 4-lb sections are bolted back to back to form sections of 6 and 8 lb respectively. Figure 1 shows a typical channel post section. Figure 2 shows the sections bolted back to back to form a "piggyback" or "X" configuration.

Variables considered in the program were: post size, type, and material; sign-marker size and shape; support conditions; vehicle weight; vehicle velocity; angle-of-collision incidence; and sign type (single or double posted).

DESCRIPTION OF THE RESEARCH

The research program was divided into four phases:

1. Preliminary field testing to determine the range of the variables involved;
2. Laboratory testing on a crash simulator;
3. Computer programming to simulate and extrapolate the results; and
4. Field testing to verify the laboratory and computer work.

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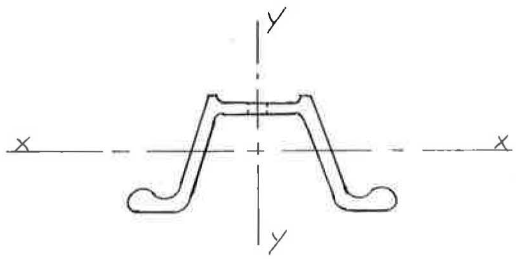

Figure 1. Typical channel section.

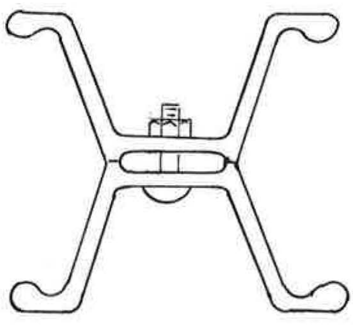

Figure 2. Typical piggyback section.

Preliminary Field Testing

The preliminary field testing consisted of six tests on posts of various sizes. These tests were monitored only by high-speed photography. The purposes of the series were to determine whether the steel post did actually yield under impact and to determine the damage to the impacting vehicle and the amount of deceleration.

The following information was obtained from the preliminary test series. Those tests are identified as 1817-1 through 1817-6 in Table 1.

TABLE 1

RESULTS OF FIELD CRASH TESTS

Test No.	Sign Type	Velocity (mph)	Incidence	Peak g	Average
1817-1	3-lb single	45	Head on	1.18	0.2
1817-2	4-lb single	45	Head on	4.26	1.33
1817-3	6-lb single	45	Head on	5.84	2.50
1817-4	8-lb single	45	Head on	5.12	1.86
1817-5	3-lb double	45	Head on	Est. 1.0	Poor film
1817-6	6-lb double	45	Head on	6.60	2.78
1817-7	2-lb single	10	Head on	Not recorded	
1817-8	2-lb single	20	Head on	Not recorded	
1817-9	2-lb single	30	Head on	Not recorded	
1817-10	2-lb single	40	Head on	Not recorded	
1817-11	3-lb single	10	Head on	1.66	0.30
1817-12	3-lb single	20	Head on	0.91	0.08
1817-13	3-lb single	30	Head on	3.45	1.15
1817-14	3-lb single	40	Head on	6.22	3.42
1817-15	3-lb single	10	45 deg	0.84	0.11
1817-16	3-lb single	20	45 deg	2.10	0.50
1817-17	3-lb single	30	45 deg	2.66	0.74
1817-18	3-lb single	40	45 deg	3.20	1.0
1817-19	4-lb single	10	Head on	0.54	0.08
1817-20	4-lb single	20	Head on	2.11	0.60
1817-21	4-lb single	30	Head on	1.86	0.53
1817-22	4-lb single	40	Head on	2.90	1.18
1817-23	8-lb single[a]	45	Head on	9.28	2.25
1817-24	6-lb single	30	Head on	2.54	0.59
1817-25	8-lb single	45	Head on	8.76	3.11
1817-26	6-lb double	30	Head on	4.12	1.64
1817-27	8-lb double	30	Head on	5.88	1.73
1817-28	6-lb double	30	Head on	7.56	2.71
1817-29	8-lb single	30	Head on	7.40	2.60
1817-30	8-lb double	45	Head on	8.86	3.10
1817-31	8-lb single[a]	50	Head on	6.50	1.16
1817-32	6-lb single[a]	50	Head on	4.12	1.18
1817-33	4-lb single	30	45 deg	3.06	0.74
1817-34	6-lb double	45	45 deg	5.65	Not reported
1817-35	6-lb single[a]	45	45 deg	7.15	2.1
1817-36	8-lb double	30	45 deg	3.88	0.97
1817-37	8-lb double	45	Head on	4.02	1.73
1817-38	6-lb double	45	Head on	3.96	1.64
1817-39	6-lb single	30	45 deg	4.20	1.06
1817-40	8-lb double[a]	40	Head on	8.40	2.28

[a]Concrete embedment.

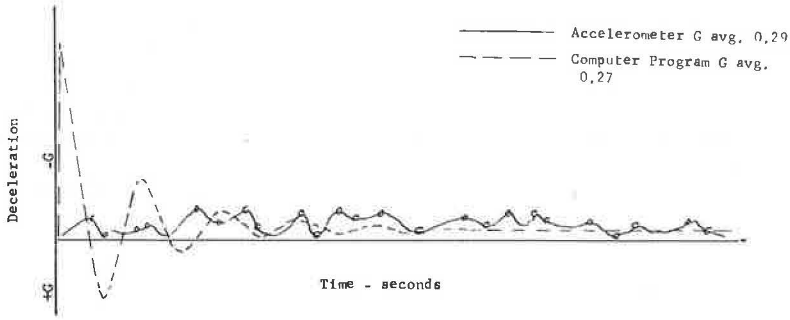

Figure 3. Laboratory test sand embedment.

1. The steel posts were found to be yielding posts when struck head-on at high velocity.
2. Deceleration values were found to be of a magnitude which could be measured by strain-gage accelerometers. The deceleration values were well within human tolerance levels.
3. Damage to the impacting vehicle was not serious. Only one test vehicle was used for all six preliminary tests.

Laboratory Testing Program

Research agencies throughout the country have used various types of simulators for studying impact behavior. The pendulum is the most widely used device, but hydraulic sleds have also been used.

The simulator used in this project was simply a scaled-down field test. The impacting vehicle was a small Fiat and the posts were usually the two-pound sections. The posts were set in a replaceable soil box and the compaction of the soil was carefully controlled.

The impacting vehicle was powered by a falling weight. The weight was a 1½-ton roller from a nearby steel mill, hoisted by winch to the top of the tower. As the weight was raised, the Fiat was pulled backward by a system of cables and pulleys until reaching the rear end of its track, when a hook on the back bumper tripped automatically, which released the mill weight sending the Fiat forward into the sign support. At the completion of each test, the complete soil box, including the deformed post, was lifted out of its pit and a fresh soil box hoisted into position. Spare soil boxes permitted the preparation of one post installation while another test was in progress.

Data collection in the laboratory simulation was exactly the same as for the full-scale field tests. Each test was recorded on high-speed film and recordings were taken from accelerometers mounted in the test vehicle.

Figure 3 shows the correlation between the laboratory tests and the computer simulation.

Computer Simulation

The computer program to describe the collision is basically a force, mass, acceleration equation. The post, the sign marker, and the supporting medium are idealized as shown in Figure 4. The complete system is then handled by the finite-element method, coupled with a step-by-step integration procedure. The precision of the results obtained is, of course, a function of the degree of precision of the input data. Apart from the specific terms in the equation itself, the number of time steps used becomes the prime factor in determining the precision of the results.

The basic matrix equation for the simulation is

$$\{P\}_t = [M] \cdot \{\ddot{\delta}\}_t + [C] \cdot \{\dot{\delta}\}_t + [K] \cdot \{\delta\}_t$$

where

$\{P\}_t$ = a vector of forces applied at the node points. Their value must be found by solving the dynamic interaction between the vehicle and the sign post.

$[M]$ = the mass matrix. The mass of the system is idealized as small masses lumped at the discrete node points. In a planar situation, there are displacement components in both the X and Y directions, and consequently the size of the mass matrix is twice the number of discrete node points in the system.

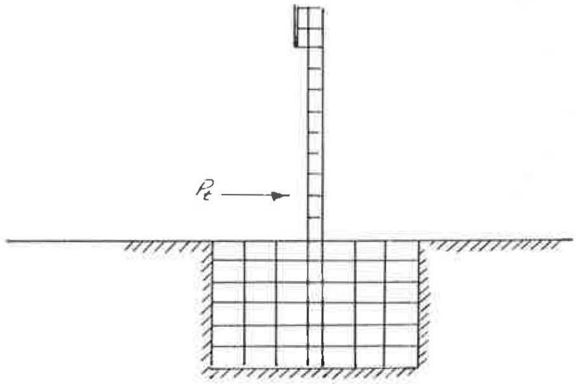

Figure 4. Idealized post.

$\{\ddot{\delta}\}_t$ = the accelerator vector. In simple terms this acceleration is the answer being sought. The acceleration varies with the time and furnishes a curve that yields both peak and average values of deceleration.

$[C]$ = the damping matrix. It is assumed to be proportional to the mass stiffness matrices in the following form: $[C] = \alpha \cdot M + \beta \cdot K$ in which α and β are constants related to the internal damping capacity of the system.

$\{\dot{\delta}\}_t$ = the velocity vector, which of course varies with time as the vehicle passes over the sign support.

$[K]$ = the stiffness matrix of the system. This matrix is formed in the same manner as the mass matrix, except that the individual stiffnesses, rather than the masses of the finite elements, are considered. The stiffness matrix is, of course, the same size as the mass matrix.

$\{\delta\}_t$ = the displacement vector. This vector also varies with time and furnishes the deflected shape of the sign support during the impacting time interval.

To obtain a suitable degree of precision, the system must be broken up into small elements, which of course increases the number of degrees of freedom of the system. Depending on the number of elements used, the program may involve 120 x 120 matrices, so that computer storage capacity becomes a serious problem.

A basic assumption of the program is that the problem is adequately represented by a two-dimensional system. This assumption was seriously questioned, since the angle-of-collision incidence is an important parameter of the problem. However, the full-size crash tests conclusively proved that the yielding sign posts, even when struck at a severe angle of incidence, twist into the plane of the impacting vehicle and yield as designed. Consequently the investigators feel that the assumption of the two-dimensional analysis is reasonably justified.

Figures 5 and 6 show the correlation between the computer simulation and the full-scale field tests.

Full-Scale Field Testing Program

The field testing program was conducted on a "drag strip" that was leased for this program. The strip was ¾ mile long and 30 ft wide so that several testing sites could be prepared simultaneously.

The crash vehicles in this program were towed up to speed and released. The crash vehicles were all standard-size automobiles. The towing vehicle was a ¾-ton Chevrolet pick-up truck. A 10-ft-long boom, made of 4 x 4 spruce, offset the crash vehicle from the tow truck as shown in Figure 7. The boom was pivoted at the center of the back bumper of the towing vehicle. Two tow ropes reached from the end of the boom

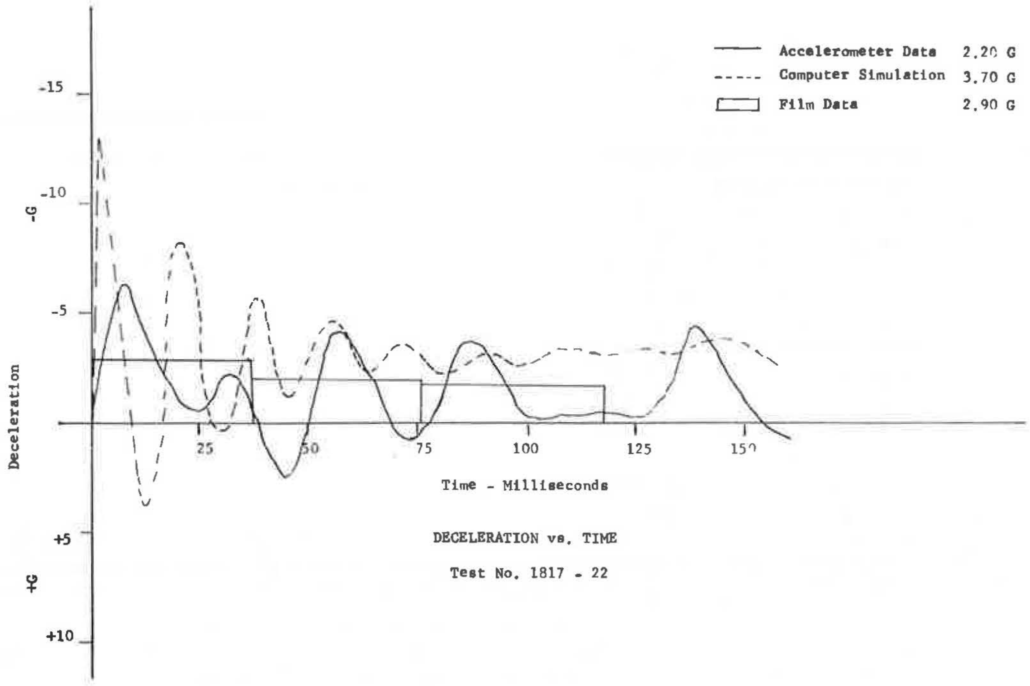

Figure 5. Deceleration versus time. Test no. 1817-22.

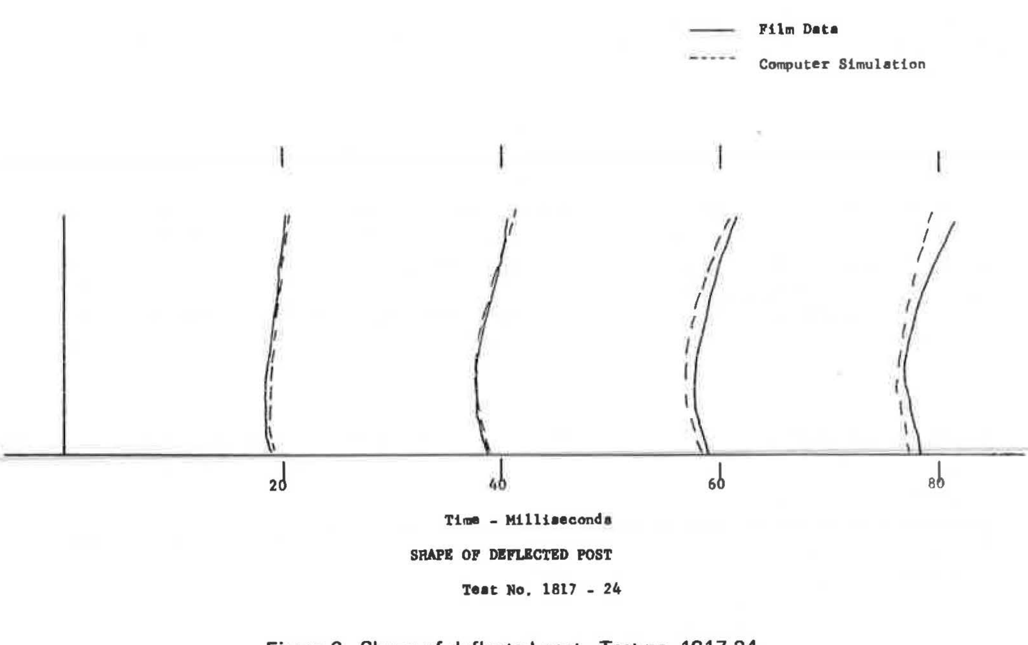

Figure 6. Shape of deflected post. Test no. 1817-24.

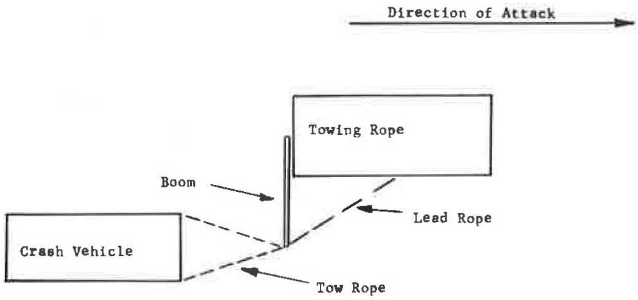

Figure 7. Towing apparatus.

to the crash vehicle. One lead rope attached the end of the boom to a release hook fastened to the frame of the truck. A solenoid controlled by a push button in the cab of the truck activated the release hook. No steering device of any kind was used in the crash vehicle. A steering control was designed and built, but never used, and the crash vehicle was controlled only by the driver of the towing vehicle.

Data Collection

Two systems of measuring deceleration were used. High-speed films were taken of each test and accelerometers were mounted in the test vehicle. Every test was photographed with a high-speed electrically operated camera. This camera operates at approximately 1,000 frames per second (compared to 64 frames per second for the ordinary movie camera). The camera was mounted 60 ft back from the test area on a 6-ft-high wooden platform. Photographic markers were mounted at 10-ft intervals along the edge of the test area, as shown in Figure 8.

At the completion of each series of tests the films were developed and still pictures were made of every 100th frame. This gave a permanent record of the position of the vehicle and the shape of the deflected post at $^1/_{10}$-second intervals. A manually operated film viewer permitted stopping the film at each frame for determining values of deceleration. Assuming a camera speed of 1,000 frames per second each frame of the film then represents one millisecond of elapsed time. Consequently a curve of deceleration versus time could be plotted from the deceleration data obtained from the film record.

The data collection system consisted of two accelerometers mounted in the crash vehicle. Various methods of mounting the accelerometers were considered. Mounting the accelerometers on the frame is probably the most stable arrangement, but the

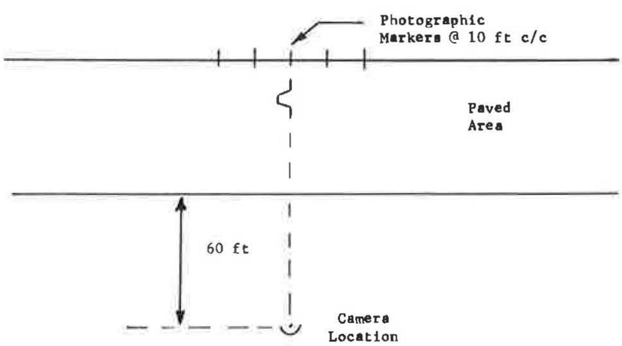

Figure 8. Plot plan showing camera location.

investigators felt that mounting the accelerometers directly in the passenger compartment would record values more representative of the actual shock experienced by the driver. Consequently the two accelerometers, one longitudinal and one transverse, were mounted on either the dash or the floor board of the passenger compartment.

An electronic signal from the accelerometers was picked up and stored on magnetic tape. The tape recorder was powered by an automobile battery and a DC to AC converter. The tape recorder, converter, battery, and a signal amplifier all rode in the crash vehicle. After each series of tests, the tape recorder was played back in the laboratory through a light beam oscillograph and a permanent record of the test was obtained.

RESULTS

In all, 40 full-scale crash tests were conducted. The results were broken down into the primary results (the g values) and the peripheral questions which must also be answered before the yielding sign post can be considered as safe.

Primary Results

Table 1 gives the results of the field-testing program. Two criteria have been used for evaluating these results, the Stapp curve and the 10 g-50 msec criteria set by New York State. Great care must be taken in reporting results in this research area. Both peak values and average values of deceleration are often reported, but the exact definitions of these terms have never been spelled out. Note that both criteria for evaluating decelerations require both a g value and a time interval. For this program, decelerations were computed on the basis of distance traveled after impact. The curves from the photographic data were plotted in 2-ft increments after impact. This, of course, means more laborious computations, since a somewhat different time base is used for each test, depending on impact velocity. However, this type of computation enables each test to be compared to both of the standard criteria. Figure 9 shows a reproduction of the Stapp curves with the values of the peak decelerations superimposed. These peak values were computed for the first 2-ft increment of travel after impact. Figure 10 shows a similar curve with average deceleration values superimposed. In both Figures 9 and 10, tests which yielded a deceleration of less than 1.0 g are not recorded. These figures show quite clearly that no test of the yielding sign post exceeded either of the safety criteria.

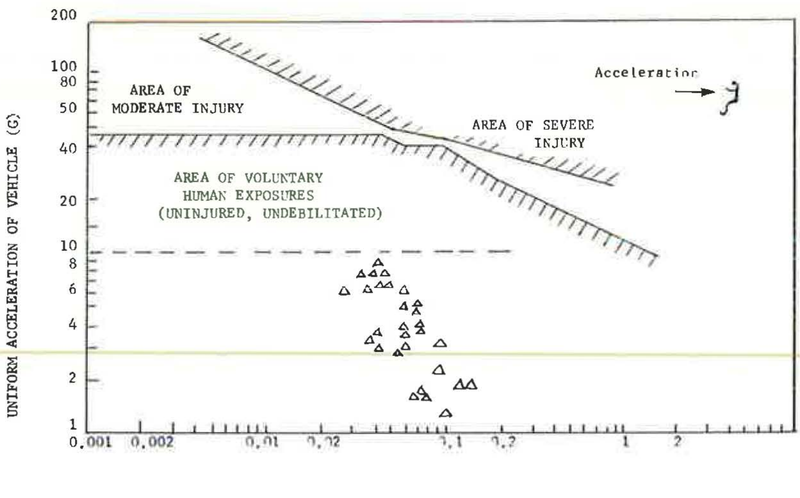

Figure 9. Peak values of deceleration.

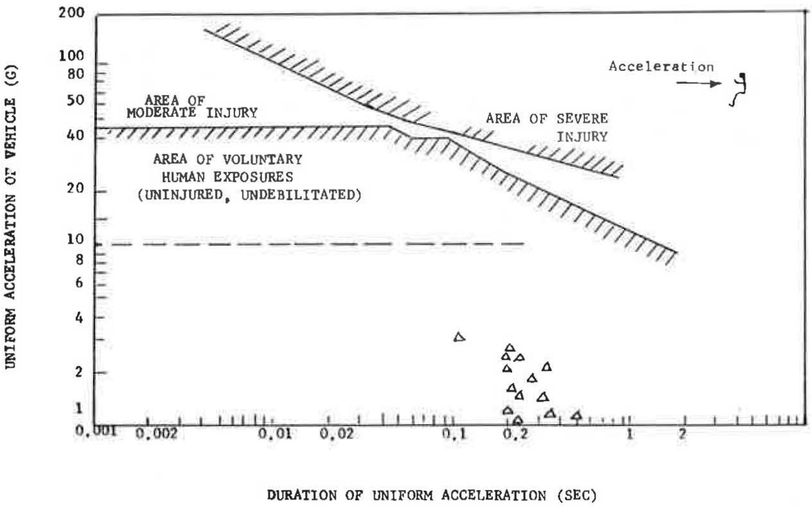

Figure 10. Average values of deceleration.

Secondary Results

In addition to the deceleration values, there are several peripheral questions which must be answered before the yielding sign supports can be considered safe:

1. Does the sign post actually yield as predicted?
2. Is there a reverse curvature of the post which would send the sign marker through the windshield?
3. Does the sign marker fly loose and become a hazard itself?
4. What effect do soil support conditions have on post behavior?

The 2-, 3-, and 4-lb sections, when struck by the automobile, yield at the ground line and the channel section spreads open. There is longitudinal splitting of the post along the bolt holes. At higher velocities (30 mph and up), the post may fail in tension after it has been flattened to the ground. The larger "piggyback" sections fail in a different fashion. These supports consist of two smaller sections bolted back to back (bolts at 16 in. center to center). Upon impact the post bends, thus shearing the bolts and permitting the sections to yield individually. During the crash test, every piggyback section failed as predicted. In the smaller posts, one test showed a shear failure at the bumper line. The rest of the tests showed good yield failures.

No sign marker caused serious damage to the windshield of the impacting vehicles. In only one test did the sign marker strike the windshield. In this one test, which was a double-posted installation struck at a 45-deg angle of incidence, the sign marker struck the windshield a glancing blow and cracked the windshield at the right lower corner. This is on the passenger side of the vehicle.

The flexible supports (2-lb and 3-lb sections) exhibited a reverse curvature when struck at higher velocities (30 mph and up). High-speed films show that the sign support yields at the ground line and bends forward, between the ground line and the bumper of the crash vehicle. Above the bumper line, the sign post, on first impact, bends back toward the vehicle. However, the momentum of the crash vehicle causes it to strike the post a second time and ride over the post, flattening it to the ground.

The method of attachment of the marker to the post naturally affects the behavior of the marker. In the early tests in the series, steel bolts were used to attach the sign marker to the post. Upon impact the steel bolts pulled through the sign marker, permitting the sign marker to fall. However, with the steel bolts there was a tendency for the post to "throw" the sign marker. Most markers landed within 25 ft of the impact site, but one marker landed 40 ft from the point of impact. Midway through the test series, the switch was made to aluminum bolts. When the aluminum bolts were used, the bolts failed on impact and the sign markers fell quite close to the point of impact, generally within a 10-ft radius of the post.

Support conditions (driven post versus concrete) had only a minor effect on the yielding characteristics of the system. The actual crash test showed no appreciable difference in deceleration values between the driven posts and the posts set in concrete. Laboratory tests in a sand foundation showed that, for this type of foundation, both the post and the soil yield, permitting the vehicle to pass over with minimum deceleration.

CONCLUSIONS AND RECOMMENDATIONS

The field tests and the computer simulations clearly indicate that the 2-, 3-, 4-, 6-, and 8-lb steel sign supports currently used by the State of Ohio are yielding sign supports and may be considered safe to use.

The sign markers should be attached to the single-posted signs with aluminum, and not with steel, bolts. The aluminum clips used for the extruded aluminum sign markers on double-posted signs should be investigated further. These clips function well when the sign post is struck head-on or at a low angle of incidence. At high angles of incidence, these clips tend to slide along the sign marker and may present a safety hazard.

No tests were conducted on spliced posts in this research. Further research should be initiated to determine the safety characteristics of the spliced posts.

Both single- and double-posted signs were investigated in this program. No triple-posted signs were checked. These triple-posted signs should be the subject of further research.

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