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U-POST INVESTIGATION

NJ DOT PROJECT 7758

by

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16. Abstract

The New Jersey Department of Transportation has conducted twenty-six full scale crash tests on steel and aluminum U-posts. Thirteen of the tests involved steel U-posts and thirteen involved aluminum U-posts. The sign installations contained from one to four posts for both the steel and aluminum tests.

The tests were conducted on the four pound per foot steel sections and the four and eight pound per foot equivalent aluminum sections with both 2,000 pound and 4,500 pound vehicles; the impact speed ranged from 20 to 45 mph, and the impact angle ranged from 0° (head-on) to 20° in accordance with Federal Highway Administration test conditions.

Results of our dynamic testing indicate that simultaneously impacting more than one 4 pound per foot steel U-post, or more than three aluminum U-posts produces conditions which do not satisfy present Federal Highway Administration critieria (1968 tentative criteria). The testing has also indicated that the use of aluminum bolts for the signpost connection yields less severe speed changes than stainless steel bolts, when only a partial number of posts are impacted by the vehicle.

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II. INTRODUCTION

Many small and intermediate size highway signs in use today are supported by relatively small section steel channels, commonly referred to as U-posts. Because of lower post loads from smaller signs, larger more substantial supports are not necessary. Research has produced various methods of providing a breakaway feature to ensure the safety of larger supports, and has shown that breakaway installations effectively reduce injury in vehicle crash situations.

However, there have been no concentrated efforts to determine safe limitations for U-post installations. This generally less expensive installation may become a hazard if too many posts are required to support a single sign.

U-posts were presumed to yield at the ground line upon impact, allowing the vehicle to pass over the posts. We call this action "bendaway," as opposed to "breakaway" where the post detaches from its base and allows the vehicle to pass underneath.

Steel channel U-posts are provided in sections weighing from two to four pounds per foot. In addition, they can be bolted back to back to form sections weighing up to eight pounds per foot. Aluminum channel U-posts have recently become available in sections whose cross section strengths are equivalent to either four, six or eight pounds per foot steel sections.

The Federal Highway Administration advises the use of vehicle momentum change as the basic criteria for determining the relative safety of sign installations. According to this criteria, a support system producing a momentum change in excess of 1,100 pound-seconds during impact ceases

I. SUMMARY AND CONCLUSIONS

Small channel shaped sign supports, designed to bend at the base on impact, are commonly used in New Jersey and other states. Previous research into the safety of these posts has been mostly limited to verifying this "bendaway" action on impact with single post installations.

Steel channels, which are most widely used, vary in size from two to four pounds per foot sections and are used for supporting highway delineators and highway signs up to about 60 square feet in area.

An aluminum version of these posts, in limited sizes, has recently become available.

Results of our dynamic testing indicate that simultaneously impacting more than one 4 pound per foot steel U-post, or more than three aluminum U-posts produces conditions which do not satisfy present Federal Highway Administration criteria (1968 tentative criteria). The testing has also indicated that the use of aluminum bolts for the signpost connection yields less severe speed changes than stainless steel bolts when only a partial number of posts are impacted by the vehicle.

In all, twenty-six full-scale crash tests were conducted. Thirteen of these tests involved steel U-post supports and thirteen involved aluminum U-posts. The sign installations contained from one to four posts for both the steel and aluminum tests.

The tests were conducted on the four pound per foot steel sections and the four and eight pound per foot equivalent aluminum sections with both 2,000 pound and 4,500 pound vehicles; the impact speed ranged from 20 to 45 mph, and the impact angle ranged from 0° (head-on) to 20° in accordance with Federal Highway Administration test conditions.

to be a safe roadside installation. Research, currently underway with the University of Cincinnati and unavailable for consideration in this study, is investigating the possibility of using a set of criteria combining the time duration of vehicle occupant impact with the windshield and the speed change of the vehicle.

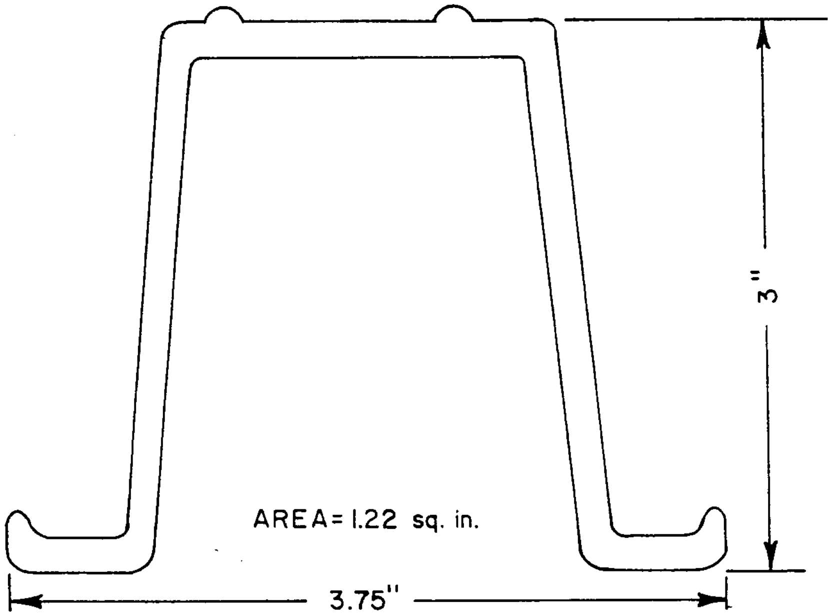
The Federal Highway Administration further advises that dynamic tests be run under varied conditions to ensure that the most critical situations would be tested. The three conditions are: (1) a 2,000 pound vehicle traveling between 20 and 25 mph, impacting the test sign at a 0° angle of incidence (measured from the perpendicular to the sign face), (2) a 2,000 pound vehicle traveling between 35 and 45 mph, impacting at a 20° angle of incidence, and (3) a 4,500 pound vehicle traveling between 40 and 45 mph, impacting at a 10° angle of incidence.

III. STUDY PROCEDURES

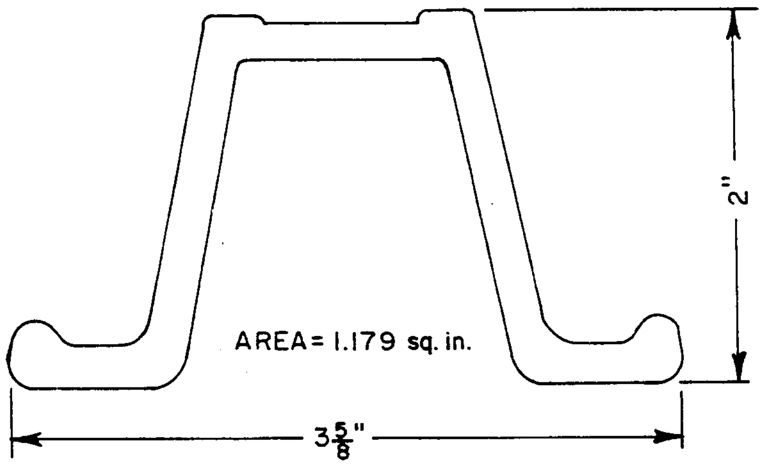
Posts Tested

The four pound per foot steel U-post section is the most commonly used, when more than one post is required to support a sign. The four pound section is used almost exclusively for multi-post installations of intermediate sign sizes on New Jersey highways. For this reason, all the steel posts tested were four pound per foot sections. With one exception, all the aluminum posts tested were equivalent in strength to the four pound per foot steel posts. This exception was an aluminum "X" section designed to be equivalent in strength to an eight pound per foot steel piggyback section (see Figures 1 and 2). The equivalent steel strength in an aluminum post is achieved by its increased cross section depth producing a section modulus nearly double that of the steel post, compensating for the higher allowable stress of the steel post.

TYPICAL SHAPES



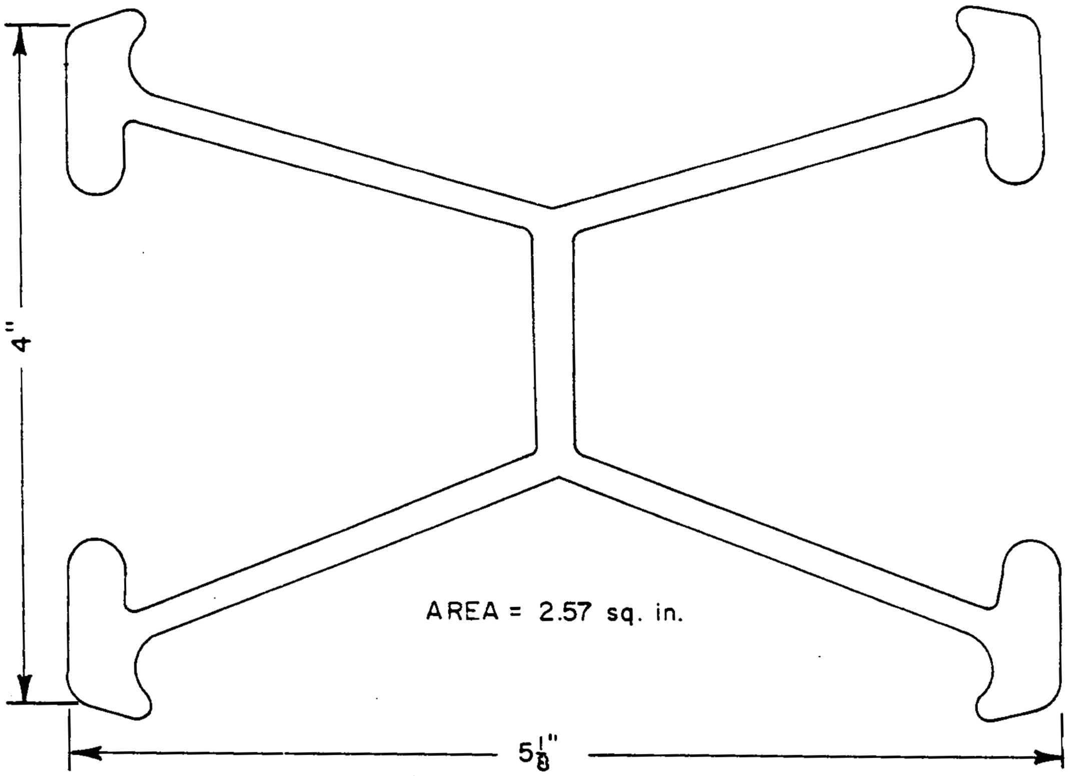
ALUMINUM POST EQUIVALENT OF 4 lb./ft. STEEL POST



4 lb./ft. STEEL

FIGURE 1

TYPICAL SHAPE



Aluminum Post Equivalent Of 8 lb./ft. Piggy Back Steel Post

FIGURE 2

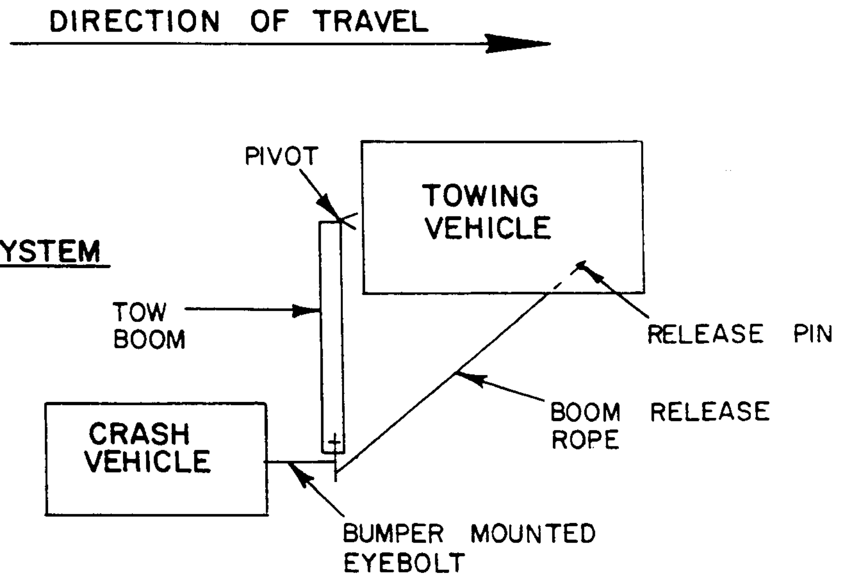
The initial testing was designed to find the maximum number of four pound per foot steel U-posts that could be simultaneously impacted below the momentum criteria limits specified by the Federal Highway Administration. Three sign installations were erected: a two, three and four-posted sign. The posts were spaced at one foot to facilitate the impacting of all the posts simultaneously and test the most severe condition. One foot is also the minimum spacing that would be used in field installations.

<u>Crash and Tow Vehicle System</u>

A suitable test site was selected and a system for towing and guiding crash vehicles was developed. The system used was basically the same as the method used by the University of Cincinnati in their full-scale field testing.

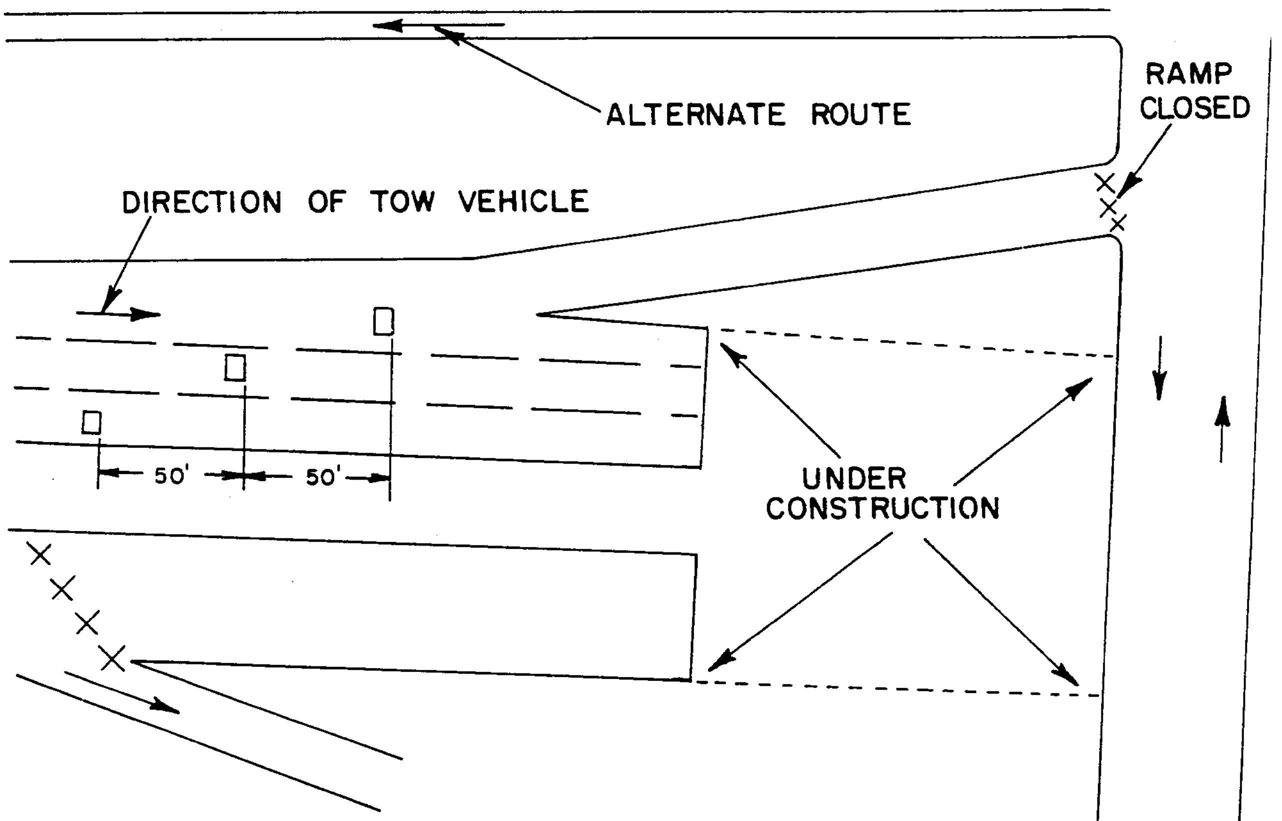
The crash vehicle was mounted with a bar bolted through the center of the front bumper extending out eight inches or more (see Figure 3). An eye was welded to the protruding end of this bar. A 1/2-ton pickup truck was used as the towing vehicle. This truck was fitted with a boom which was mounted on the rear bumper by means of a pintle type hitch. The free end of the boom was suspended by a wire rope from the center of the stiffened tailgate. The boom was an eight inch deep aluminum I-beam. A steel pin was mounted on the outboard end of the boom and bolted so as to allow a 60° rotation toward the rear. This system allowed the crash vehicle to be offset to the right of the towing vehicle approximately 12 feet on centers. With this system, no steering or speed control equipment was necessary on board the crash vehicle.

The pin on the boom was slipped through the eye of the bumper mounted bolt and restrained from rotation by a wire rope attached to a release pin mounted on the chassis under the towing vehicle's passenger seat. This



CRASH VEHICLE TOW SYSTEM

FIGURE 3



TEST SITE

FIGURE 4

release pin extended vertically through the floor into the cab of the tow vehicle. Pulling this pin and accelerating the tow vehicle allowed the pin on the boom to disengage from the eye bolt on the crash vehicle. This released the crash vehicle from the control of the tow vehicle.

A pair of wire ropes was initially used to connect the boom pin to the crash vehicle and later, chains were used. Neither functioned as well as the eye bolt.

Recording Equipment

Each crash vehicle was prepared with test equipment and brought to proper test weight.

The test equipment included: (1) accelerometers mounted directly behind the front seat for measuring longitudinal and lateral "G" forces, (2) a recorder to provide a permanent trace of the accelerometer data, (3) an electrically operated screw jack for brake application, (4) a 12 volt D.C. battery, and (5) a receiver with servo operated switches for remote control of all equipment. A radio transmitter, operated from near the test sign installation, was used to activate the on board test equipment.

The tests were monitored by two television cameras and two 16mm movie cameras. The television cameras were located to show a pan view and a fixed side view of each test. In later tests, the fixed view was head-on from behind the sign. This was made possible by a truck with a roof mounted remote camera using a telescopic lens. One 16mm camera provided a pan view of each test, while the other was fixed at 90° to provide a data source for impact information. The latter 16mm camera recorded data at 60 frames per second. Tape switches were located six feet apart, seven feet in front of the test sign with one on the sign-post itself, to monitor the crash vehicle speed.

Test Site

The test site was a section of southbound Interstate Route 95, adjacent to a section under construction. Entering traffic was rerouted to a nearby interchange on the test dates. Tests were conducted in a northbound direction and the on-ramp was used as an escape route for the towing vehicle.

The macadam roadway course was removed from a small area in each of the three roadway lanes offset from each other at 50 foot intervals (Figure 4). Then the subbase and shale, if encountered, was removed to a depth of three to four feet and filled with a shoulder material to within a foot of the surface. The top foot was filled with a cold patch material and smoothed, so vehicles would not hit any bumps. The posts for each sign installation were driven three to four feet into this base using a pneumatic driven jackhammer or sledgehammer.

IV. RESULTS

Table 1 gives the results of the 26 tests conducted. From the 16mm film, a frame by frame plot of a fixed point on each crash vehicle was drawn for vehicle speed. These plots were used to determine all data except peak "G" readings, which were taken from the accelerometer trace. See Figures 9, 10 and 11 in the Appendix for typical plots with accelerometer traces superimposed. In a few tests, either the 16mm camera or the accelerometer failed to supply accurate data, subsequently, data from the operating source are reported. In most cases, test conditions were duplicated to verify the data.

Figure 5 shows the momentum change as computed for each test, post type and the number of posts impacted.

The method used to compute momentum change was: $M = V \times Mass$

Where, M = change of momentum in lb.-sec.,

V = change in speed for the duration of impact in ft./sec., and

Mass = weight of the crash vehicle in pounds divided by 32.2 ft./sec.^{2}.

Figure 6 shows the peak G's recorded for the various tests and post types.

Figure 7 shows the relationship of impact duration to the materials and number of posts impacted.

A description of each test installation and the conditions of impact are in the Appendix.

Tabulations of the chemical and physical properties of the post materials are also found in the Appendix in Tables 2 through 5.

V. DISCUSSION

Order of Testing

The plan for the order of testing was to impact steel post installations of two, three, four and then five-posted signs (refer to Study Procedures). However, the crash vehicle overturned while impacting the four-post installation, hence, the test on a five-post sign was not attempted. Further, it was necessary to use five different 2,000 pound crash vehicles to complete the first 7 steel post tests.

The erratic behavior of the steel posts, which frequently sheared at the bumper line, did not yield, and tended to cause considerable damage to the underside of the crash vehicle, prompted the change to aluminum posts for the next six tests (Tests 8 through 13).

SUMMARY OF RESULTS

STEEL POSTS						
No. of Impacted	Notes	No.	mph	lb-sec	G	Impact sec
1 of 3	e	#1	5.3	495	5.0	[illegible]
1 of 3	f	#5	10.0	1450	7	.284
1 of 1		#14	6.0	640	5.0	[illegible]
2 of 2		#3	14.6	1320	7.4	.210
2 of 2		#17	11.6	1120	6.6	.228
3 of 3	g	#6	10.5	970	6	[illegible]
3 of 3		#16	15.5	1500	8.7	.198
4 of 4	k	#2	21.8	2030	23	[illegible]
4 of 4		#7	22.8	2100	10	.196

No. of Impacted						
[illegible]						
1 of 4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1 of 1						
[illegible]						
2 of 3	[illegible]	[illegible]	[illegible]			
[illegible]						
3 of 3		[illegible]	[illegible]			
3 of 3		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3 of 3	[illegible]	[illegible]	[illegible]			
[illegible]		#13	15.9	1440	6.9	.277

All data was taken from the 16 ... [illegible]

a. Data during impact only.
b. The accelerometer was used to record peak "G" data; the film data was used when the accelerometer was not working.
c. Test condition - 20^{0} angle of impact, 35-45 mph, 2000 lb. vehicle.
d. " " - 10^{0} " " " , 40-45 " , 4500 lb. "

All other tests- 0^{0} " " " , 20-25 " , 2000 lb. " .

e. Post broke away from sign panel during impact.
f. Post did not break away from sign panel during impact.
g. Left post was not attached to sign panel and was yielded at bumper height prior to impact.
h. Power to accelerometer lost during impact.
i. No film to corroborate accelerometer data.
j. Post equivalent to 8 lb/ft steel piggyback.
k. Vehicle overturned during impact.

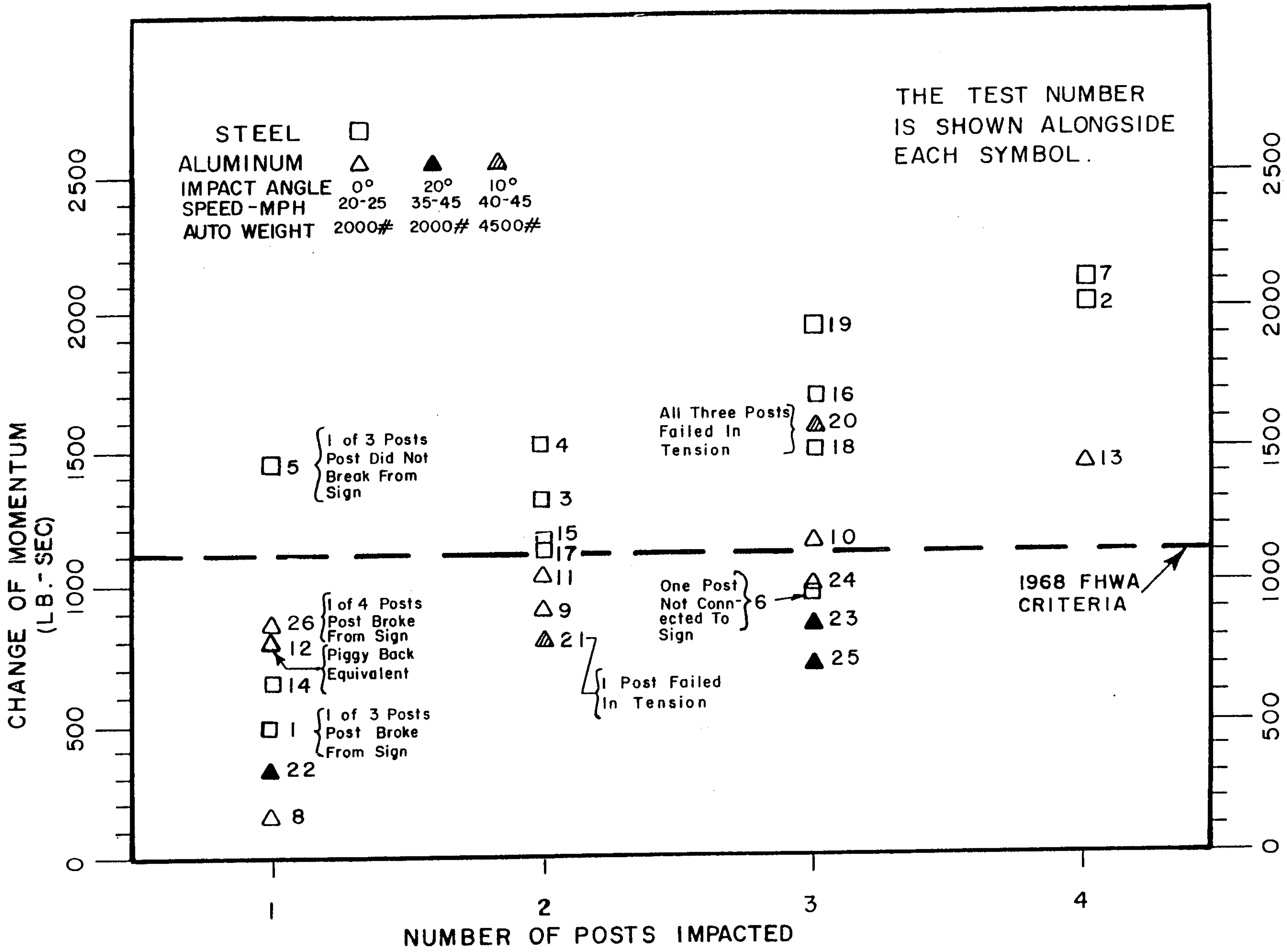

THE TEST NUMBER IS SHOWN ALONGSIDE EACH SYMBOL.
STEEL
ALUMINUM
IMPACT ANGLE 0° 20° 10°
SPEED-MPH 20-25 35-45 40-45
AUTO WEIGHT 2000# 2000# 4500#
CHANGE OF MOMENTUM (LB.-SEC)
NUMBER OF POSTS IMPACTED
1 of 3 Posts Post Did Not Break From Sign
1 of 4 Posts Post Broke From Sign
Piggy Back Equivalent
1 of 3 Posts Post Broke From Sign
1 Post Failed In Tension
All Three Posts Failed In Tension
One Post Not Connected To Sign
1968 FHWA CRITERIA
0
500
1000
1500
2000
2500
1
2
3
4
5
26
12
14
1
22
8
4
3
15
17
11
9
21
19
16
20
18
10
24
6
23
25
7
2
13

FIGURE 5

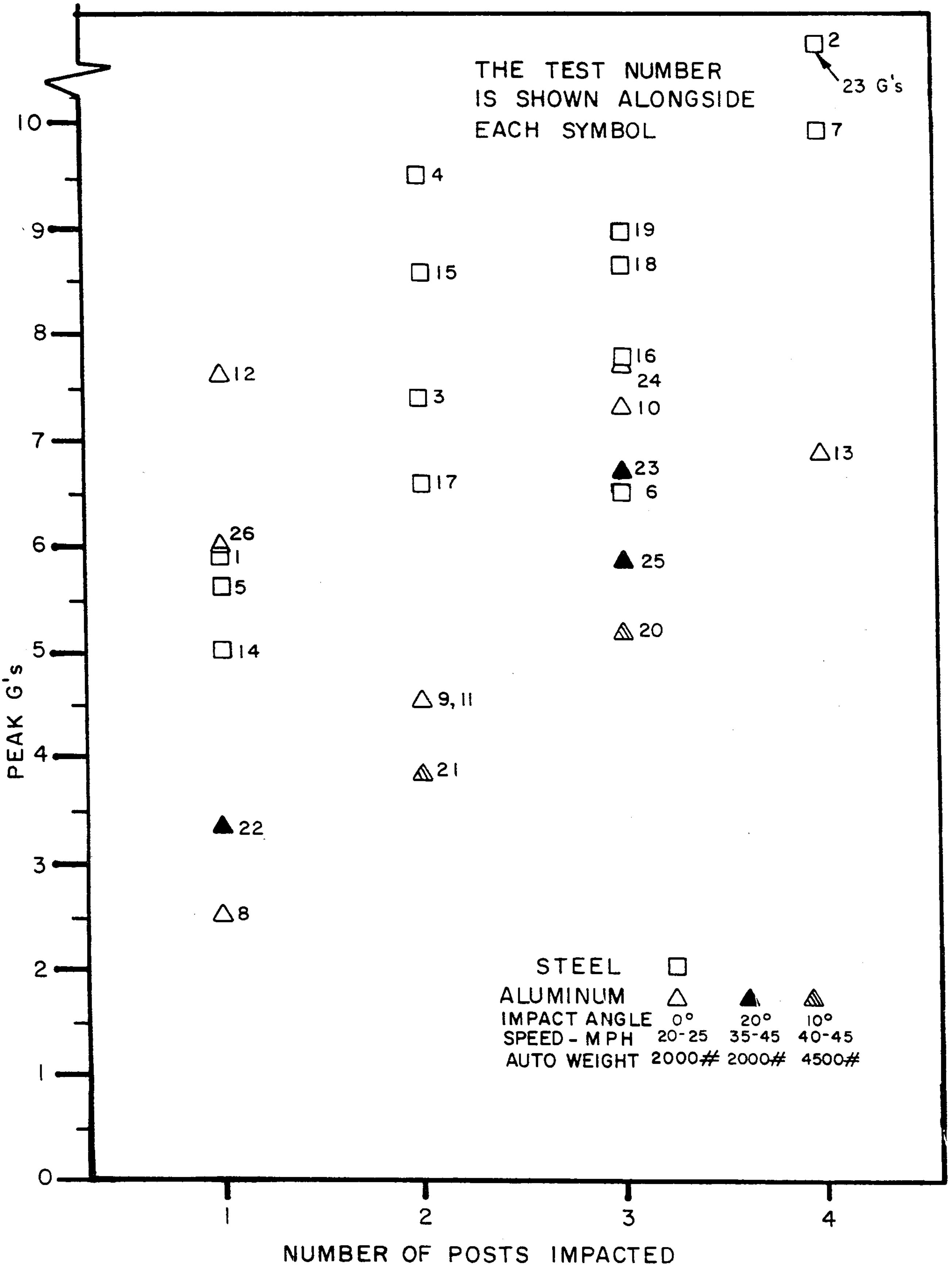
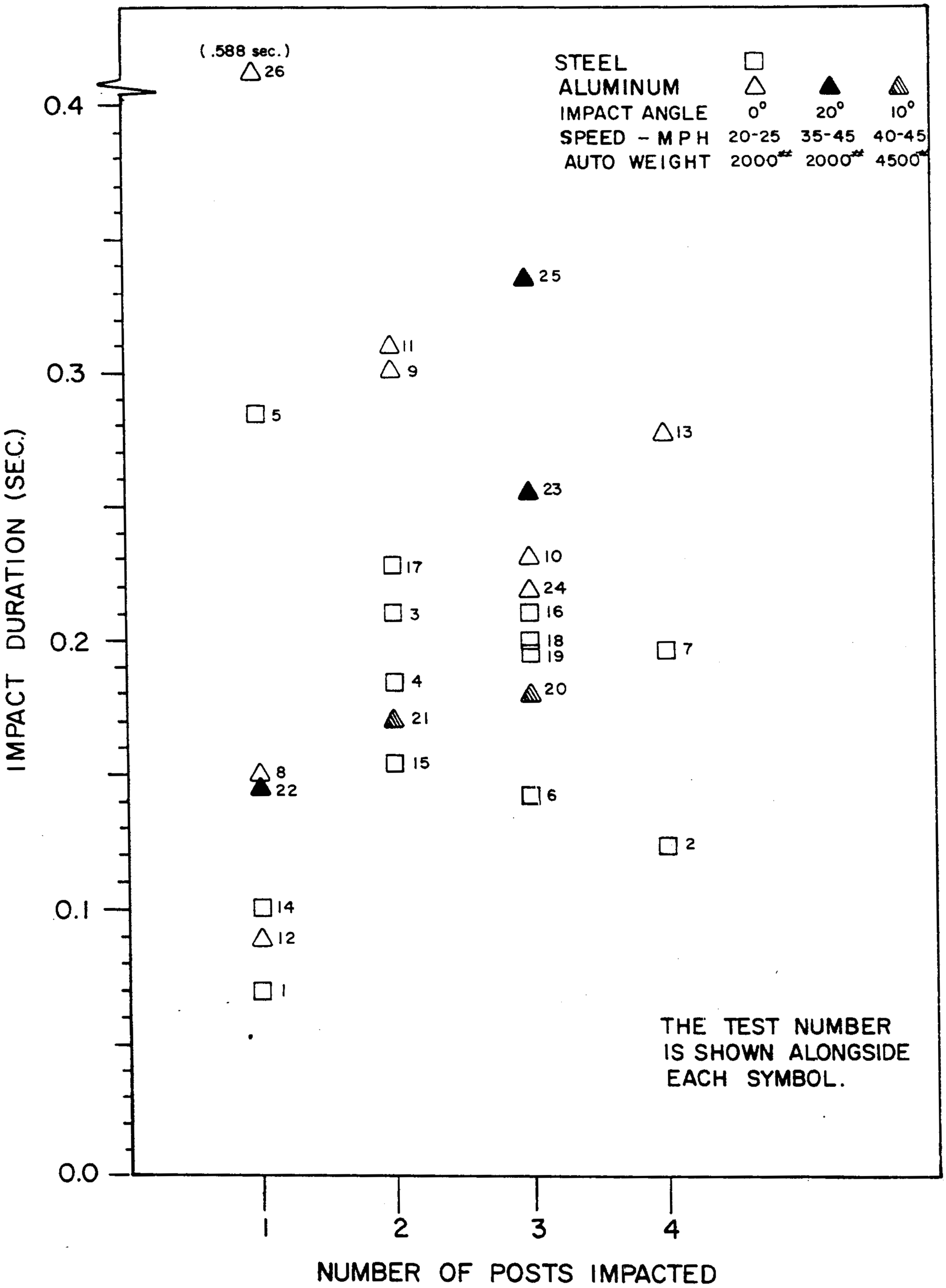

THE TEST NUMBER
IS SHOWN ALONGSIDE
EACH SYMBOL
23 G's
PEAK G's
0
1
2
3
4
5
6
7
8
9
10
NUMBER OF POSTS IMPACTED
2
7
4
19
15
18
16
24
12
3
10
13
23
17
6
26
1
25
5
20
14
9, 11
21
22
8
STEEL
ALUMINUM
IMPACT ANGLE 0° 20° 10°
SPEED - MPH 20-25 35-45 40-45
AUTO WEIGHT 2000# 2000# 4500#

FIGURE 6



(.588 sec.)
STEEL
ALUMINUM
IMPACT ANGLE 0° 20° 10°
SPEED - MPH 20-25 35-45 40-45
AUTO WEIGHT 2000** 2000** 4500**
IMPACT DURATION (SEC.)
0.4
0.3
0.2
0.1
0.0
26
25
11
9
5
13
23
10
17
24
3
16
18
19
7
4
20
21
8
22
15
6
2
14
12
1
THE TEST NUMBER IS SHOWN ALONGSIDE EACH SYMBOL.
1
2
3
4
NUMBER OF POSTS IMPACTED

FIGURE 7

Subsequent to the six aluminum tests, a steel of higher plasticity was sought from the New Jersey Department of Transportation Maintenance Yard and from a steel supplier. Tests 14 through 19 were conducted on these posts to complete our testing of steel U-posts.

Tests 8 through 13 were conducted on aluminum posts and only one 2,000 pound vehicle was used for all the tests -- so minimal was the vehicle damage. Even after impacting four posts (Test 13), the vehicle was considered usable for further tests with one minor repair -- freeing the hood latch from the grille work.

The preliminary results of these 19 tests (13 with steel and 6 with aluminum) indicated that the aluminum posts gave consistently better results than the steel samples tested. Therefore, the last seven tests (Tests 20 through 26) were conducted with aluminum posts. Five of these seven tests were designed to give information on increased speeds and angles of impact. The other two tests were designed to duplicate previous post impact conditions. In addition, the post spacing was increased to that which would be found in actual installations for some of these latter tests.

Peak "G" Force

The symbol "G" refers to the constant acceleration due to gravity (32.2 ft./sec./sec.). For a vehicle that decelerates at 128.8 ft./sec./sec., there would be a negative "G" force exerted on the vehicle of four G's.

There are three factors to consider with deceleration forces: the actual peak G reading, the time duration of the G reading and the onset rate.

Research conducted by Mr. J. P. Stapp over a period of four years, and later work by others resulted in a composite graph indicating that the human body can tolerate 40 G's in deceleration for up to 40 milliseconds without injury. Additional work by New York State concluded that a 10 G deceleration lasting longer than 50 milliseconds may produce injury to a human body.

The onset rate has also been investigated by Mr. Stapp and he suggested a 1,000 G per second value as a tolerable rate. The Federal Highway Administration suggests the use of 500 G's per second as a more conservative value.

In our study, the only other measure of deceleration (besides the accelerometer tracing) is the speed change and calculated deceleration from frame to frame on the 16mm film. From a review of the study films, it is safe to assume that maximum deceleration took place over a period of 17.5 milliseconds (time between 16mm frames). The more conservative onset rate of 500 G's per second would permit a peak G force of approximately 8.7.

A review of Table 1 indicates that only four tests resulted in G forces exceeding 8.7, and three of these were less than 10 peak G's. These latter G readings are far below the allowable peaks suggested by Mr. Stapp.

Momentum Change

The change in momentum is directly a function of the weight of the vehicle and the change in speed of the vehicle during impact. It is obvious that the speed parameter is more than minimally affected by certain factors. Those factors most readily defined are the post material and the number of posts impacted.

Less obvious, but important conditions which also have a substantial effect on the speed change are: the angle of impact, the type bolts used for the signpost connection and the imbedment of the posts (refer to Item 2 in the Bibliography).

Of the posts tested, there appears to be two distinct regions for the ranges of momentum change. Although this is not obvious from Figure 5, Figure 8 highlights this feature in a plot of momentum change and duration of impact. The variation of momentum change in Figure 8 (for each material type) is mainly a function of the number of posts simultaneously impacted, while the variation in the duration of impact is mainly a function of the conditions of impact (e.g., an impact of a partial number of posts of an installation, or an angle impact).

Most of the data samples of Figure 8 are for the 2,000 pound vehicle. The 4,500 pound vehicle was only used to satisfy the Federal Highway Administration test conditions, since it was hazardous towing this vehicle at 45 mph. Hence, only the comparison of Tests 20 and 21 can be made for the heavier vehicle. Although Test 20 yielded a very high momentum change, the low "peak G" and speed change puts this test in the acceptable region (less than 8.5 G's) of the other impacts of three aluminum posts.

Aluminum Versus Steel Bolts

The comparison of aluminum and steel bolts is empirically possible when the crash vehicle impacts a partial number of posts of a test installation. If the impacted post (or posts) does not separate from the sign (i.e., the bolts don't fail), the sign acts as a structural member tying all the posts together. The effective resistance to the impacting vehicle is then greater than the number of posts impacted when a partial number

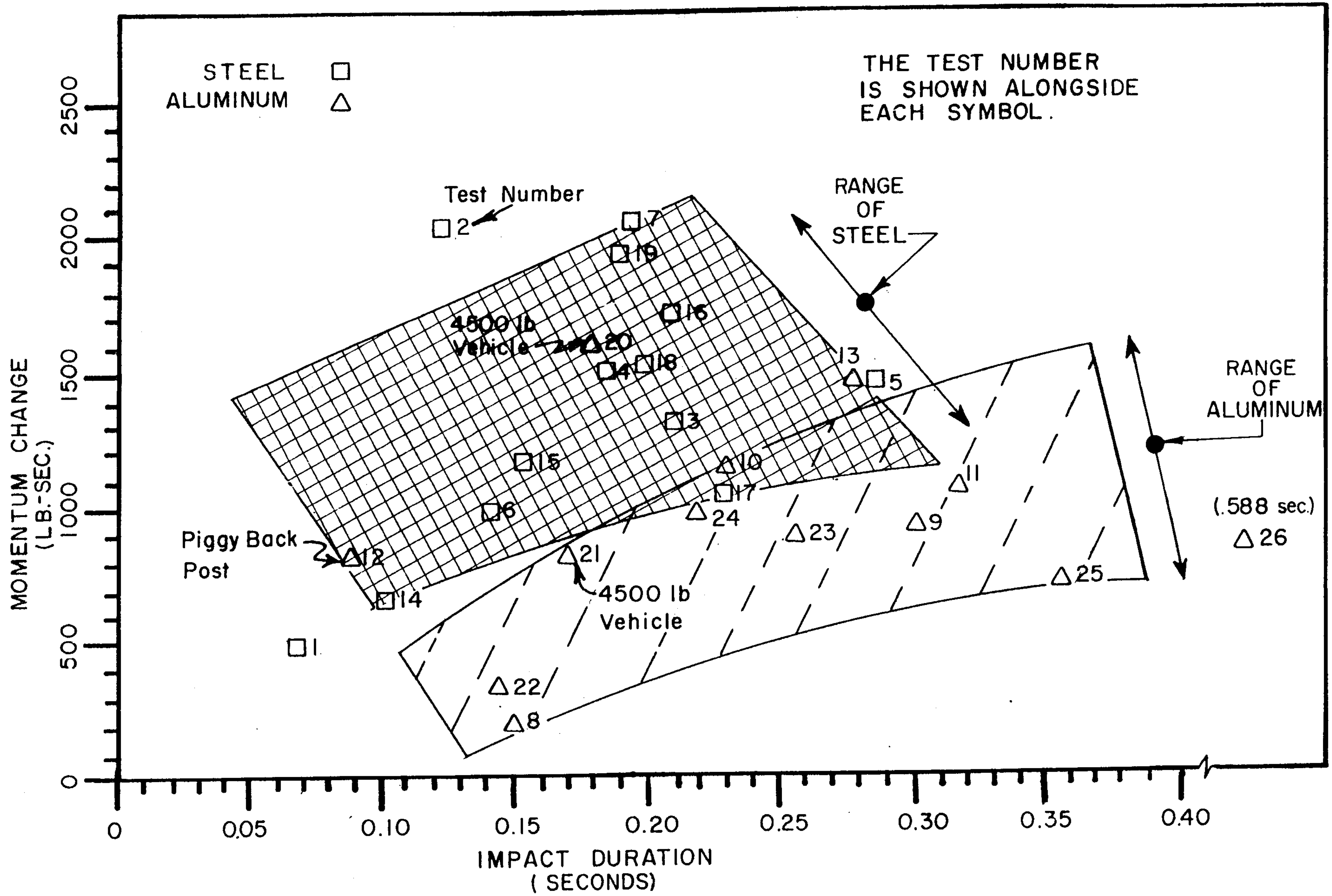

STEEL
ALUMINUM
THE TEST NUMBER IS SHOWN ALONGSIDE EACH SYMBOL.
Test Number
RANGE OF STEEL
RANGE OF ALUMINUM
4500 lb Vehicle
4500 lb Vehicle
Piggy Back Post
(.588 sec.)
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
MOMENTUM CHANGE (LB-SEC.)
0
500
1000
1500
2000
2500
IMPACT DURATION (SECONDS)
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40

FIGURE 8

of posts is impacted. There were five tests where less than all the posts of a multi-post installation were impacted (Tests 1, 5, 21, 22 and 26).

Two steel bolts per post, with washers at the sign face, were used to attach the posts to the sign panel in three of these tests: Nos. 1, 5 and 26. Only one post was impacted in each of these three tests. In all, only two of the six bolts involved broke immediately upon impact, both on the same post. The post was the one impacted in Test No. 1, a steel post test. The post yielded at the base and allowed the car to pass easily. As a result, the momentum change was very low.

In Test No. 5, impact conditions were identical. However, the bolts did not break. Consequently, the post did not yield at all, severe damage was done to the vehicle, and the resulting momentum change was excessively high for a one post impact. The effect of the bolts remaining intact was to offer, to some extent, the resistance of the other two posts to the impacting vehicle.

In Test No. 26, aluminum posts were used to support a 4' x 8' sign and the posts were spaced at two feet, rather than at one foot as in Tests No. 1 and 5. Steel bolts with washers at the sign face were again employed. The bottom bolt did not break immediately and, consequently, the post failed in tension near the base. The top bolt never broke and the post, which hooked on the front end of the test vehicle, failed again in tension where the base of the sign panel was bolted. The momentum change was again high for a one post impact. Again, the resistance of more than one post was felt by the impacting vehicle.

From the description of Tests No. 1, 5 and 26, the advantage of the post bolts breaking upon impact can be clearly seen, regardless of post material, when less than all the posts of an installation are impacted.

To emphasize this point, Tests No. 21 and 22 were also impacts of less than all the posts of a multi-post installation. However, aluminum bolts were used. Both tests were run under higher speed conditions than in Tests 1, 5 and 26. Test No. 21 was with a 4,500 pound vehicle and Test No. 22 was with a 2,000 pound vehicle. In each test, both bolts on each post impacted broke immediately, and the sign remained attached, as in Tests 1, 5 and 26, to the remaining posts. The momentum change for Test No. 21 was the lowest recorded for a two-post test, and only one test produced a lower momentum change for a one-post impact than Test No. 22.

Although limited test results are available on steel and aluminum bolts, the benefits of the aluminum bolts appear to outweigh those of the steel on partial post impacts. The main benefit being the ability of the post to disconnect from the sign (with the use of aluminum bolts), thus not giving the resistance of all posts to the impacting vehicle.

The only disadvantage to using aluminum bolts is that on some vehicle impacts the sign may be disconnected from the posts and hit the vehicle's windshield.

Chemical and Physical Properties of Materials

The New Jersey Department of Transportation specification for the U-post stipulates that rail steel must be supplied for all construction jobs. Chemical properties are not defined in the specification, except to indicate a high carbon content, nor are heat treating procedures. Only the minimum physical limits for tensile and yield strengths are stated -- 80,000 psi and 60,000 psi, respectively.

With this background, testing commenced without the benefit of chemical and physical analyses. The posts used in the first seven tests were thought to be rail steel, but a subsequent chemical analysis of one post showed it to be in the billet range. Consequently, more extensive sampling was made of the steel posts used in the subsequent six steel post tests.

Extensive sampling of the initially tested steel posts (Tests 1 through 7) is not available. However, the physical and chemical ranges can be visually compared (Table 2 and 3) to those properties for the steel used in Tests 14 through 19. A glaring difference in ultimate strengths is seen for the posts used in Tests 17 and 18, but this difference is not evident in the momentum change (Table 1). Essentially, there appears to be two groups of steels, on the basis of the sampled ultimate strengths. The chemical analyses would indicate that there are four groups of steel: Tests 1 through 7, Tests 14 through 16, Tests 17 and 18 and Test 19.

If we were to combine those steels with similar physical and chemical properties, there would be four possible groups. A more accurate interpretation of the chemical tests may indicate that every post used in the steel tests would show it to have unique chemical properties.

An examination of Table 1 for the two-post impacts for steel shows two tests to be borderline with the Federal Highway Administration momentum criteria. The four impact tests conducted on the two-post steel installations indicate no similarity in either the physical or chemical properties of the posts used. Hence, it would be difficult to write a specification on steel posts to guarantee a steel which will meet the Federal Highway Administration criteria.

In effect, the intermixing of the properties does not allow us to group the steels into two areas, as we had thought -- low plastic and high plastic. If the steels have to be dynamically tested before grouping them in the plastic range, a specification stipulating this procedure could result in a very costly product. Besides, the two-post installation of an expected higher plastic steel does not meet the Federal Highway Administration criteria (Test No. 17).

Prior to conducting the last series of six steel post tests, the extremely high momentum changes of the first seven steel post tests, even while impacting only two steel posts, led us to seek materials of higher plasticity for testing. For this reason, six tests were conducted on aluminum posts, whose ultimate strengths were approximately one-third that of the steel.

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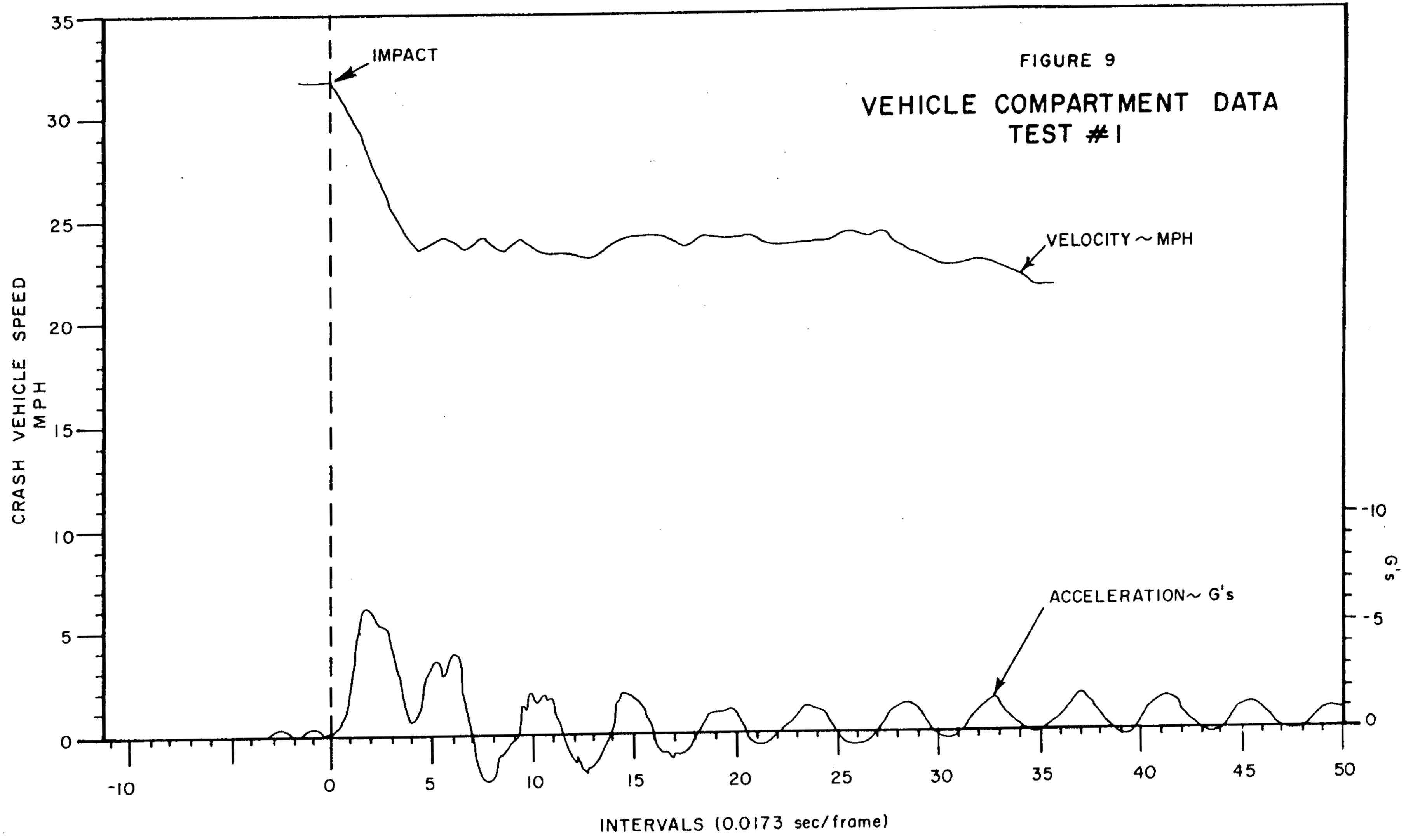
3. "Design Criteria for Breakaway Sign Supports," T. C. Edwards, T. J. Hirsch, P. M. Olson, T.T.I., Highway Research Board Record Number 222.
4. "Designing Fail-Safe Structures for Highway Safety," Public Roads, Volume 36, Number 6, February 1971, F. J. Tamanini, Chief, Structures and Applied Mechanics Division.
5. "Design of Sign Supports and Structures," Highway Research Board Record Number 346, 1971.
6. "Development of Design Criteria for Safer Luminaire Supports," NCHRP Report Number 77, 1969.
7. "Development of Safer Roadside Structures and Protective Systems," Highway Research Board Record Number 259.
8. "Full-Scale Dynamic Testing of the New Jersey Breakaway Sign Structure," N. E. Shoemaker, CAL Report Number VJ-2955-V-1, Cornell Aeronautical Laboratory, Inc., September 1970.
9. "Guardrails, Barriers and Sign Supports," Highway Research Board Record Number 174.
10. "Rib-Bak Four Sign Post," Pollak, (Catalog by the Pollak Steel Company), 1965.

APPENDIX

FIGURE 9

VEHICLE COMPARTMENT DATA TEST #1



B-229-1

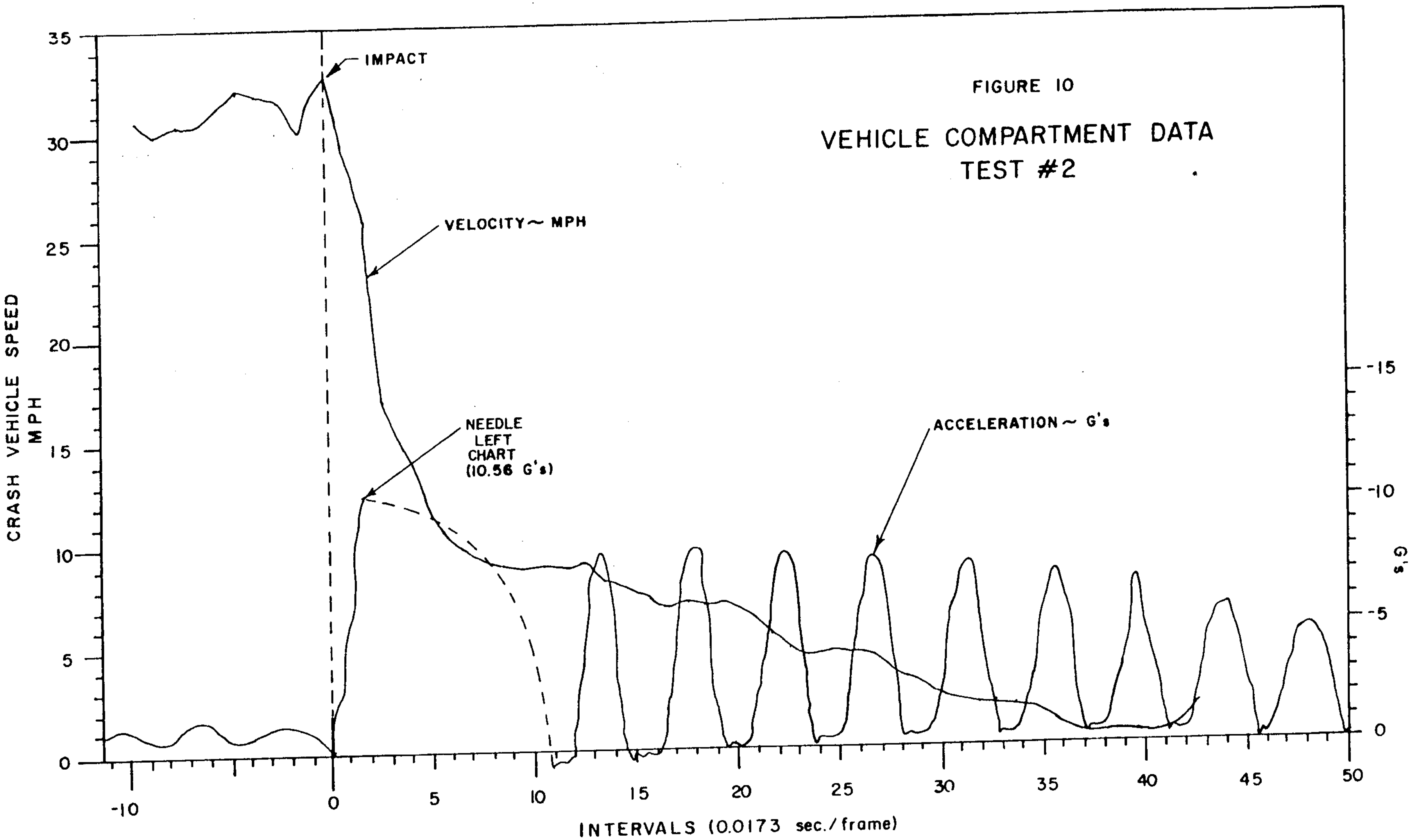


FIGURE 10
VEHICLE COMPARTMENT DATA
TEST #2
IMPACT
VELOCITY ~ MPH
NEEDLE LEFT CHART (10.56 G's)
ACCELERATION ~ G's
CRASH VEHICLE SPEED MPH
G's
INTERVALS (0.0173 sec./frame)
35
30
25
20
15
10
5
0
-10
0
5
10
15
20
25
30
35
40
45
50
-15
-10
-5
0

B-229-2

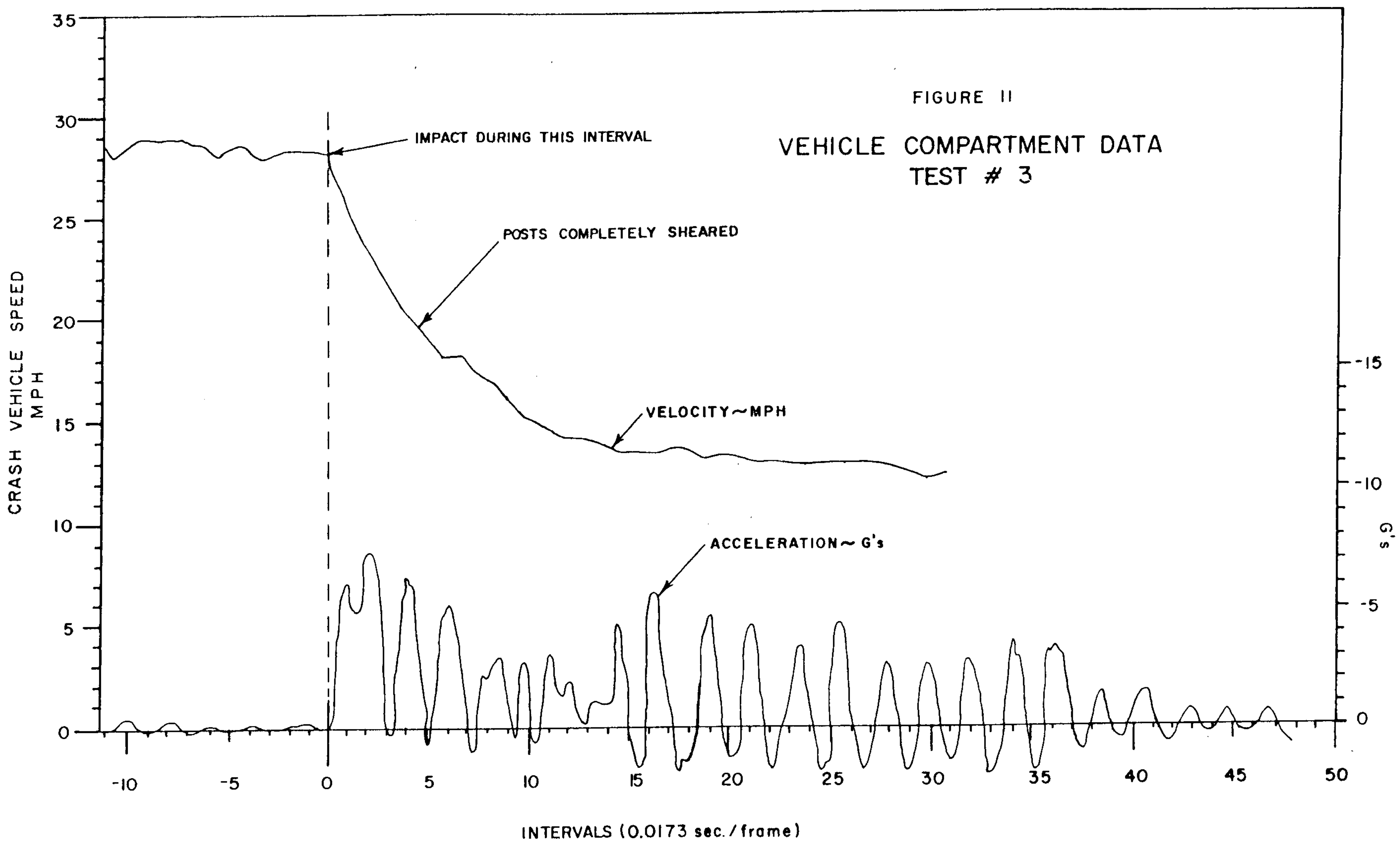


FIGURE II

VEHICLE COMPARTMENT DATA
TEST # 3

B-229-3

TEST NUMBER 1

Sign	-	4' x 6' sheet aluminum panel
Support	-	4 lb./ft. steel; three posts at one foot spacing; Sample No. 046459 and/or Sample No. 8 may have been used in this test.
Attachment of Sign to Post	-	Steel bolts and washers
Impact Angle	-	0° (measured perpendicular to sign face)
Vehicle	-	1961 Comet, 2020 pounds
Speed at Impact	-	30 mph

Only one post of the three-post installation was struck by the crash vehicle. The crash vehicle went to its left after release from the tow vehicle and struck the left U-post with the right end of the front bumper. The bumper bent back allowing the fender to be crumpled and the post impacted the right front wheel, breaking the tie rod.

The bolts which attached the sign panel to the post popped on impact, and the post yielded at the base. The sign remained attached to the other two posts.

TEST NUMBER 2

Sign	-	4' x 6' sheet aluminum panel
Support	-	4 lb./ft. steel; four posts at one foot spacing; Sample No. 046459 and/or Sample No. 8 may have been used in this test.
Attachment of Sign to Post	-	Steel bolts and washers
Impact Angle	-	0° (measured perpendicular to sign face)
Vehicle	-	1961 Comet, 2045 pounds
Speed at Impact	-	31 mph

All four posts were struck. The front right side of the crash vehicle's bumper was bent backward and the rest of the bumper was mangled. The right front fender was crumpled and the right front corner of the hood was bent in. The car overturned during impact and landed on its left side.

The two left posts sheared about 18 inches above the ground. The other two posts yielded about 30° and 45° at the base, causing some post buckling. The sign rotated clockwise but remained attached to all posts.

TEST NUMBER 3

Sign	-	4' x 6' sheet aluminum panel
Support	-	4 lb./ft. steel; two posts at one foot spacing; Sample No. 046459 and/or Sample No. 8 may have been used in this test.
Attachment of Sign to Post	-	Steel bolts without washers
Impact Angle	-	0° (measured perpendicular to sign face)
Vehicle	-	1963 Ford Falcon, 1990 pounds
Speed at Impact	-	29 mph

Both posts were hit, and the bumper was pushed in about one foot at the center. Minor damage was done to the sheet metal of the hood. Both posts sheared at bumper level, and the upper portions of the posts remained attached to the sign panel and carried forward.

TEST NUMBER 4

Sign	-	4' x 6' sheet aluminum panel
Support	-	4 lb./ft. steel; two posts at one foot spacing; Sample No. 046459 and/or Sample No. 8 may have been used in this test.
Attachment of Sign to Post	-	Aluminum bolts and washers
Impact Angle	-	0° (measured perpendicular to sign face)
Vehicle	-	1963 Ford Falcon, 1990 pounds
Speed at Impact	-	24 mph

Both posts were hit. The right end of the front bumper was bent and the right front fender was crumpled. The right front corner of the hood was bent and the front end was thrown out of alignment.

The left post sheared at bumper level, the top portion of the post remained attached to the sign panel and carried forward. The right post popped the sign bolts upon impact, yielded to the vehicle and returned to an upright position.

TEST NUMBER 5

Sign	-	4' x 6' sheet aluminum panel
Support	-	4 lb./ft. steel; three posts at one foot spacing; Sample No. 046459 and/or Sample No. 8 may have been used in this test.
Attachment of Sign to Post	-	Steel bolts with washers
Impact Angle	-	0° (measured perpendicular to sign face)
Vehicle	-	1963 Ford Falcon, 1990 pounds
Speed at Impact	-	24 mph

Only one post of the three-post installation was struck by the crash vehicle. The crash vehicle went to its left after it was released by the tow vehicle and struck the left U-post with the right end of the front bumper which bent backward.

The post did not yield and remained attached to the sign panel. This sent the right side of the Falcon into the air. The post ripped off the fender at the mounting bolts and tore the right front door panel back as the post slid down the passenger side of the car.

All three posts remained in position. Minor deformation was incurred by the left post and the other two remained straight and undeformed.

TEST NUMBER 6

Sign	-	4' x 6' sheet aluminum panel
Support	-	4 lb./ft. steel; three posts at one foot spacing; Sample No. 046459 and/or Sample No. 8 may have been used in this test.
Attachment of Sign to Post	-	Steel bolts with washers
Impact Angle	-	0° (measured perpendicular to sign face)
Vehicle	-	1961 Comet, 2020 pounds
Speed at Impact	-	26 mph

The crash vehicle struck all three posts. The center of the front bumper and hood were bent backward. The left post detached from the sign panel, yielded and bent away at the ground line. The center and right posts sheared at bumper level and, with the sign panel attached, carried forward.

A secondary impact with the sign panel shattered the windshield. The rear passenger floor pan was impaled on the posts and the gas tank was buckled by the two sheared post stubs.

TEST NUMBER 7

Sign	-	4' x 6' sheet aluminum panel
Support	-	4 lb./ft. steel; four posts at one foot spacing; Sample No. 046459 and/or Sample No. 8 may have been used in this test.
Attachment of Sign to Post	-	Steel bolts without washers
Impact Angle	-	0° (measured perpendicular to sign face)
Vehicle	-	1961 Comet, 2020 pounds
Speed at Impact	-	23 mph

All four posts were struck. The same crash vehicle that was used in Test Number 6 was reused. The right front fender was crumpled and the hood was pushed in. The car impacted the posts squarely, bounced to the left and sheared the far left post. The car's front bumper came to rest on the lower portion of the sheared left post.

The sign panel remained attached to all four posts. The two center posts were bent only slightly at the bumper line and the right post was not deformed at all.

TEST NUMBER 8

Sign	-	30" x 30" sheet aluminum panel
Support	-	Aluminum post equivalent to 4 lb./ft. steel section; one post; Sample No. 11B-AL.-A.
Attachment of Sign to Post	-	Aluminum bolts without washers
Impact Angle	-	0° (measured perpendicular to sign face)
Vehicle	-	1964 Ford Falcon, 1992 pounds
Speed at Impact	-	17 mph

The crash vehicle struck the post with the right side of the front bumper and the bumper was skewed one inch back on the right side. No other vehicle damage could be detected.

The post yielded at the ground line, some reverse curvature was induced at the bumper line and the car passed over the post.

The sign panel became detached from the post when the sign impacted the ground as the post bent down. The panel was thrown into the air, bounced off the right fender and door landing 18.5 feet from the impact point.

TEST NUMBER 9

Sign	-	4' x 6' sheet aluminum panel
Support	-	Aluminum posts equivalent to 4 lb./ft. steel posts; two posts at a spacing of one foot; Samples No. 13B, 14B-AL.-A.
Attachment of Sign to Post	-	Aluminum bolts without washers
Impact Angle	-	0° (measured perpendicular to sign face)
Vehicle	-	1964 Ford Falcon, 1992 pounds
Speed at Impact	-	19 mph

Both posts were hit and the center of the bumper was bent inward 2.5 inches at the point of impact. The hood was jammed shut and there was minor damage to the grillwork.

Both posts yielded at the ground line. Some reverse curve bending of the posts occurred at the bumper line and the car passed over the posts.

The sign panel remained attached to both posts.

TEST NUMBER 10

Sign	-	4' x 6' sheet aluminum panel
Support	-	Aluminum posts equivalent to 4 lb./ft. steel posts; three posts spaced at one foot; Samples No. 7B, 10B, 12B-AL.-A.
Attachment of Sign to Post	-	Aluminum bolts without washers
Impact Angle	-	0° (measured perpendicular to sign face)
Vehicle	-	1964 Ford Falcon, 1992 pounds
Speed at Impact	-	19 mph

All three posts were hit and the front bumper of the crash vehicle was pushed in five inches. The same vehicle was used in the previous two tests and no repairs were effected after the last two tests.

All three posts yielded at the ground line. Some reverse curve bending occurred at the bumper line and the car passed over the posts.

The sign panel remained attached to all three posts.

TEST NUMBER 11

Sign	-	4' x 6' sheet aluminum panel
Support	-	Aluminum posts equivalent to 4 lb./ft. steel posts; two posts spaced at one foot; Samples No. 1A, 3A-AL.-A.
Attachment of Sign to Post	-	Aluminum bolts without washers
Impact Angle	-	0° (measured perpendicular to sign face)
Vehicle	-	1964 Ford Falcon, 1992 pounds
Speed at Impact	-	22 mph

Both posts were hit. Damage to the front bumper was negligible, but the right front corner of the grille and hood were bent in. Both posts yielded at the ground line. The left post twisted clockwise, the right post twisted counter-clockwise and the right post crossed over the top of the left post. Both posts showed some reverse curve bending at the bumper line. The car passed over the posts.

All four sign bolts popped upon impact. The sign left the posts and landed 24 feet beyond the impact point.

TEST NUMBER 12

Sign	-	30" x 30" sheet aluminum panel
Support	-	One aluminum post equivalent to 8 lb./ft. steel section piggyback post; Sample No. 6-AL.-A.
Attachment of Sign to Post	-	Aluminum bolts without washers
Impact Angle	-	0° (measured perpendicular to sign face)
Vehicle	-	1964 Ford Falcon, 1992 pounds
Speed at Impact	-	21 mph

The same crash vehicle used in Tests No. 8, 9, 10 and 11 was reused. The front bumper hit the post at a point six inches to the right of the center of the vehicle. The bumper was further pushed in against the body brace causing the brace to bend.

The post yielded at the ground line and bent flat to ground level. A slight reverse curve of the post was noted at the bumper line. The car stopped just at the top end of the post when the brakes were applied.

The sign bolts ripped through the sign face upon impact and the sign was thrown 26 feet beyond the impact point.

TEST NUMBER 13

Sign	-	4' x 6' sheet aluminum panel
Support	-	Aluminum posts equivalent to 4 lb./ft. steel posts; four posts spaced at one foot; Samples No. 4A, 5A, 6A-AL.-A.
Attachment of Sign to Post	-	Aluminum bolts without washers
Impact Angle	-	0° (measured perpendicular to sign face)
Vehicle	-	1964 Ford Falcon, 1992 pounds
Speed at Impact	-	19 mph

This crash vehicle was used in the five previous tests. The crash vehicle hit all four posts. The left post hit the left corner of the front bumper causing the bumper to be pushed backward. Further damage was incurred to the hood and left fender. All four posts remained attached to the sign panel and yielded at the ground line. The vehicle came to a stop before passing beyond the posts.

TEST NUMBER 14

Sign	-	30" x 30" sheet aluminum panel
Support	-	4 lb./ft. steel; one post; Sample No. 046457.
Attachment of Sign to Post	-	Aluminum bolts without washers
Impact Angle	-	0° (measured perpendicular to sign face)
Vehicle	-	1963 Ford Falcon, 2022 pounds
Speed at Impact	-	22 mph

The crash vehicle struck the post near the center of the bumper causing a bumper indentation of 3-1/2 inches.

The post bent away at the ground line. The sign remained attached to the post and the car passed over both.

TEST NUMBER 15

Sign	-	4' x 6' sheet aluminum panel
Support	-	4 lb./ft. steel; two posts at one foot spacing; Samples No. 046453 and 046458.
Attachment of Sign to Post	-	Aluminum bolts without washers
Impact Angle	-	0° (measured perpendicular to sign face)
Vehicle	-	1963 Ford Falcon, 2022 pounds
Speed at Impact	-	23 mph

The crash vehicle impacted both posts near the center of the bumper, causing a total indentation to the bumper of four inches. The left post sheared about 23 inches above the ground. The right post bolts broke from the sign on impact and the post bent away. The sign panel and top piece of the left post traveled 19 feet forward.

The front end of the Falcon climbed 4.8 feet into the air upon impact. The stub of the sheared left post impacted the floor pan under the rear seat when the Falcon came down and the vehicle's forward movement dragged the undercarriage over the post stub. This caused buckling of the floor pan and gas tank and a small dent to the rear bumper. Minor dents were noted on the hood and fenders and a shock absorber bolt was broken.

TEST NUMBER 16

Sign	-	4' x 6' sheet aluminum panel
Support	-	4 lb./ft. steel; three posts at one foot spacing; Samples No. 046455, 046456 and 046454.
Attachment of Sign to Post	-	Aluminum bolts without washers
Impact Angle	-	0° (measured perpendicular to sign face)
Vehicle	-	1963 Ford Falcon, 2022 pounds
Speed at Impact	-	21 mph

The crash vehicle struck all three posts sending the car 5.4 feet in the air. The left and center posts sheared on impact; the right post bent back only 30° and prevented the Falcon from traveling any farther. The Falcon came down, landing on the sheared stub of the left post. The stub was driven up behind the grille and would have destroyed the left headlight, had there been one.

The bumper was driven solidly against the cross frame member in the center of the Falcon. The sign bolts broke from the right and center posts sending the center and left pieces of sheared post, with the sign panel, 9.5 feet beyond the point of impact.

TEST NUMBER 17

Sign	-	4' x 6' sheet aluminum panel
Support	-	4 lb./ft. steel, two posts at one foot spacing; Samples No. 050472 and 050473.
Attachment of Sign to Post	-	Aluminum bolts without washers
Impact Angle	-	0° (measured perpendicular to sign face)
Vehicle	-	1963 Ford Fairlane, 2120 pounds
Speed at Impact	-	27 mph

Both posts were impacted. The bumper was indented 1/2-inch and two small dents were left on the hood where the posts hit.

Both posts bent away allowing the crash vehicle to pass over them. The sign detached from the posts and traveled 32.5 feet forward.

TEST NUMBER 18

Sign	-	4' x 6' sheet aluminum panel
Support	-	4 lb./ft. steel; three posts at one foot spacing; Samples No. 050475, 050471 and 050474.
Attachment of Sign to Post	-	Aluminum bolts without washers
Impact Angle	-	0° (measured perpendicular to sign face)
Vehicle	-	1963 Ford Fairlane, 2120 pounds
Speed at Impact	-	21 mph

The crash vehicle had been used in Test Number 17. The three posts were impacted at the center of the bumper. The tow cable connector on the front bumper contacted the center post and was bent down, ripping the bumper in torsion. The bumper was pushed in five inches by the impact.

All three posts yielded, although the vehicle did not have enough momentum to carry it past the installation.

The sign remained attached by only one bolt, which was on the right post.

TEST NUMBER 19

Sign	-	4' x 6' sheet aluminum panel
Support	-	4 lb./ft. steel; three posts at one foot spacing; Samples No. 050470, 050469 and 050468.
Attachment of Sign to Post	-	Aluminum bolts without washers
Impact Angle	-	0° (measured perpendicular to sign face)
Vehicle	-	1963 Ford Fairlane, 2120 pounds
Speed at Impact	-	23 mph

This crash vehicle had been used in Tests No. 17 and 18. Impact of the three posts was centered on the bumper. The tow cable connector impacted the center post. The bumper had been straightened somewhat before the test. The car was raised into the air more than 2.5 feet by the impact. Both outside posts sheared and the center post bent back about 30°, stopping the forward movement of the vehicle while in mid-air.

The crash vehicle came down and was suspended four inches off the ground when the sheared post stubs became lodged behind the bumper. The hood and grille were pushed in and the bumper was again flattened against the frame.

The sign became detached from all three posts and was thrown 27 feet forward. The sheared tops of the outside posts landed 12 feet from the impact point.

TEST NUMBER 20

Sign	-	4' x 6' sheet aluminum panel
Support	-	Aluminum posts equivalent to 4 lb./ft. steel; three posts at two foot spacing; Samples No. 9F, 16B and 5F-AL.-B posts.
Attachment of Sign to Post	-	Aluminum bolts without washers
Impact Angle	-	10° (measured perpendicular to sign face)
Vehicle	-	1964 Ford Station Wagon, 4507 pounds
Speed at Impact	-	43 mph

This was the first attempt at a high-speed test with a full size crash vehicle. All three posts impacted within the width of the hood leaving minor indentations and bending the hood and grille slightly. The bumper was also pushed back slightly.

Initially, all three posts yielded at the ground line upon impact. An extreme reverse curvature of the posts resulted. The posts detached from the sign panel and were broken at the bumper line in tension. The freed sign panel came flat against the windshield and the entire surface of the windshield was cracked, but no glass pieces were dislodged.

The three posts carried about ten feet beyond the sign panel landing 107.5 feet from the impact location.

The vehicle engine was running during the test because the steering was power assisted. The car was backed up and run under its own power for Test No. 21.

TEST NUMBER 21

Sign	-	4' x 6' sheet aluminum panel
Support	-	Aluminum sections equivalent to 4 lb./ft. steel posts; three posts at two foot spacing; Samples No. 18B, 19F, 1F-AL.-B.
Attachment of Sign to Post	-	Aluminum bolts without washers
Impact Angle	-	10° (measured perpendicular to sign face)
Vehicle	-	1964 Ford Station Wagon, 4507 pounds
Speed at Impact	-	41 mph

This test was run with the same crash vehicle that was used in Test No. 20. The steering arm had been faulty prior to Test No. 21 and needed reconnecting before the test. No further work was done except to replace the left front tire which went flat when the tire hit a curb during Test No. 20.

This test was intended to duplicate the conditions of Test No. 20. However, only the left two posts were impacted when the car drifted to the left after release. Further high-speed runs with this car were not attempted.

The two left posts were impacted within the width of the hood and dents similar to those incurred in Test No. 20 were noted. Both posts yielded at the ground line and detached from the sign panel. The left post bent down, while the center post failed in tension at the bumper line and carried 90 feet. The sign remained attached to the remaining post by the upper bolt. This post did not show any signs of deformation.

The steering arm came loose again, but the vehicle was otherwise able to move under its own power.

TEST NUMBER 22

Sign	-	4' x 6' sheet aluminum panel
Support	-	Aluminum posts equivalent to 4 lb./ft. steel posts; three posts at two foot spacing; Samples No. 7F, 15F and 10B-AL.-B.
Attachment of Sign to Post	-	Aluminum bolts without washers
Impact Angle	-	20° (measured perpendicular to sign face)
Vehicle	-	1963 Ford Falcon, 1960 pounds
Speed at Impact	-	32 mph

The crash vehicle veered to the right when the tow-truck boom contacted the left front wheel of the crash vehicle after release. Consequently, only the far right post was impacted.

At the high angle of incidence, the post twisted 90° as it yielded at the ground line and became detached from the sign. Subsequently, tension failure occurred at the bumper line and the post landed some 16 feet from the impact point.

The post impacted the bumper in front of the left headlight leaving a small dent in the bumper. There were no marks on the fender and the headlight remained intact.

The post stub was removed and a new post driven solidly and attached to the sign panel for Test No. 23.

TEST NUMBER 23

Sign	-	4' x 6' sheet aluminum panel
Support	-	Aluminum posts equivalent to 4 lb./ft. steel posts; three posts at two foot spacing; Samples No. 7F, 15F and 1F-AL.-B.
Attachment of Sign to Post	-	Aluminum bolts without washers
Impact Angle	-	20° (measured perpendicular to sign face)
Vehicle	-	1963 Ford Falcon, 1960 pounds
Speed at Impact	-	35 mph

This test was a repeat of Test No. 22 and all three posts were impacted. The left-hand post was impacted by the left end of the bumper and the post twisted and bent outward to the left. It then slid down the left side of the Falcon and the left front fender was buckled in the process.

The other two posts yielded at the base, detached from the sign panel and allowed the vehicle to pass over them. Minor hood and grille damage was noted and the bumper was pushed in 1-1/4 inches in the center. After the test, the hood was banged out to permit opening and closing it.

The sign panel came down into the windshield, one corner dropping first. This caused the windshield to be totally shattered scattering glass all over the vehicle's interior. The sign panel landed 68 feet beyond the impact point.

TEST NUMBER 24

Sign	-	4' x 6' sheet aluminum panel
Support	-	Aluminum posts equivalent to 4 lb./ft. steel posts; three posts at one foot spacing; Samples No. 23, 22 and 21-AL.-B.
Attachment of Sign to Post	-	Aluminum bolts without washers
Impact Angle	-	0° (measured perpendicular to sign face)
Vehicle	-	1963 Ford Falcon, 1960 pounds
Speed at Impact	-	27 mph

The same crash vehicle used in Tests No. 22 and 23 was reused.

All three posts were impacted and they all yielded at the ground line. The sign remained attached to only the center post which broke in tension near the ground line. The post and sign were sent 43 feet forward. The two outer posts twisted, but remained in place and allowed the crash vehicle to pass over.

The left end of the front bumper was pushed back causing crumpling of the left front fender and demolition of the left headlight. The hood was again freed after the test.

TEST NUMBER 25

Sign	-	4' x 6' sheet aluminum panel
Support	-	Aluminum posts equivalent to 4 lb./ft. steel posts; three posts at two foot spacing; Samples No. 20B, 4B and 14B-AL.-B.
Attachment of Sign to Post	-	Steel bolts with washers
Impact Angle	-	20° (measured perpendicular to sign face)
Vehicle	-	1963 Ford Falcon, 1960 pounds
Speed at Impact	-	37 mph

The same Falcon used in Tests No. 22, 23 and 24 was reused.

All three posts were impacted. The right post, the first hit, yielded at the ground line, twisted violently and failed in tension. The center post was impacted next and twisted as the left post was impacted.

As the right post was broken in tension, the sign panel, which was still attached to the left and center post, was dragged to the ground and rotated nearly 180°. This action caused the left post to cross over the center post since none of the steel bolts detached from the sign panel. Pushing back of the left side of the front bumper and fender was minimal and the vehicle was used in the final test without repair.

TEST NUMBER 26

Sign	-	4' x 8' sheet aluminum panel
Support	-	Aluminum posts equivalent to 4 lb./ft. steel posts; four posts at two foot spacing; Samples No. 24, 25, 26 and 2B-AL.-B.
Attachment of Sign to Post	-	Steel bolts with washers
Impact Angle	-	0° (measured perpendicular to sign face)
Vehicle	-	1963 Ford Falcon, 1960 pounds
Speed at Impact	-	23 mph

The posts in this test were spaced at two feet to minimize the chance of hitting all four posts simultaneously. The car angled off after release and only struck the far right-hand post.

The post yielded both at the ground and at the bumper upon impact. The bolt at the bottom of the sign did not break. The post also bent at the bottom of the sign face. The left front wheel of the crash vehicle lifted into the air.

The right post then failed in tension at the ground line but remained hooked around the front end. The bottom bolt on the sign face then broke, bending the sign panel at the top bolt. This continued tension straightened the upper section of the sheared right post and it failed, in tension, where the post had been bent at the bottom of the sign face. The other three posts were bent back at angles up to 30°.

Damage to the vehicle was slight.

TABLE 2

NEW JERSEY DEPARTMENT OF TRANSPORTATION

LABORATORY TEST RESULTS

4 LB./FT. STEEL POST SAMPLES

TENSILE ANALYSIS

Sample Number	Area In.^{2}	Elongation %	Load Lbs.	Ultimate Strength Psi	Remarks
046453	.036	20	4820	133,885	Test #15
046454	.036	20	4560	126,663	Test #16
046455	.036	20	4860	134,996	Test #16
046456	.036	20	4760	132,219	Test #16
046457	.036	20	4820	133,885	Test #14
046458	.036	20	4640	128,885	Test #15
046459	.036	15	4960	137,774	
8	.125	12	1551	124,409	Tests #1 to 7

CHEMICAL ANALYSIS

Sample Number	Silicon %	Manganese %	Sulfur %	Carbon %	Phosphorus %
046453	---	1.38	0.050	0.53	0.012
046459	0.18	1.37	---	0.46	0.04

TABLE 3

NEW JERSEY DEPARTMENT OF TRANSPORTATION

LABORATORY TEST RESULTS

4 LB./FT. STEEL POST SAMPLES

TENSILE ANALYSIS

Sample Number	Elongation %	Ultimate Strength Psi	Remarks
050468	20	137,610	Test #19
050469	20	146,460	Test #19
050470	20	144,615	Test #19
050471	30	103,030	Test #18
050472	30	104,610	Test #17
050473	30	99,125	Test #17
050474	20	103,030	Test #18
050475	25	102,090	Test #18

CHEMICAL ANALYSIS

Sample Number	Silicon %	Manganese %	Sulfur %	Carbon %	Phosphorus %
050468	0.28	1.10	0.060	0.61	0.036
050475	0.16	0.96	0.039	0.40	0.038

TABLE 4

MAGNODE PRODUCTS, INC.

LABORATORY TEST RESULTS

ALUMINUM ALLOY 6061-T6M SAMPLES (1-14)-AL-A

4 LB./FT. & 8 LB./FT. EQUIVALENT SECTIONS

Sample Number	Yield Strength Ksi	Ultimate Strength Ksi	Elongation %	Remarks
1A	32.8	40.0	17.0	Test #11
3A	31.8	40.4	16.0	Test #11
4A	35.3	44.7	15.0	Test #13
5A	33.8	44.0	17.0	Test #13
6A	35.9	45.5	17.0	Test #13
7B	45.2	47.6	8.0	Test #10
10B	47.0	47.7	9.0	Test #10
11B	42.5	44.3	7.0	Test #8
12B	47.1	49.0	5.5	Test #10
13B	39.2	45.5	8.5	Test #9
14B	45.3	46.4	8.5	Test #9
6	38.9	40.9	10.5	Test #12

TABLE 5

MAGNODE PRODUCTS, INC.

LABORATORY TEST RESULTS

ALUMINUM ALLOY 6061-T6M SAMPLES (1-20)-AL-B

4 LB./FT. EQUIVALENT SECTIONS

Sample Number	Yield Strength Ksi	Ultimate Strength Ksi	Elongation %	Remarks
1F	40.8	47.7	10.0	Test #21,23
2B	41.4	49.0	12.0	Test #26
4B	48.0	49.0	12.5	Test #25
5F	40.4	42.7	9.0	Test #20
7F	44.1	45.6	10.0	Test #22,23
9F	45.4	46.5	11.0	Test #20
10B	47.6	49.4	11.0	Test #22
14B	50.1	51.5	10.0	Test #25
15F	47.4	48.5	10.0	Test #22,23
16B	48.0	49.5	10.0	Test #20
18B	44.6	48.9	9.0	Test #21
19F	45.1	46.3	9.0	Test #21
20B	47.1	49.0	8.5	Test #25