

Vehicle Impact Tests of Breakaway Wood Supports for Dual-Support Roadside Signs

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Since the late 1960s, the California Department of Transportation has used 6 x 8-in (nominal) or smaller wood posts and timber poles (classes 1-6) that have drilled holes near the bases as breakaway supports for dual-support roadside signs. Due to the recent rapid increase in the lightweight-car population, crash tests were conducted with 2205-lb cars on these designs to determine whether they met performance criteria recommended in Transportation Research Circular 191 [now superseded by National Cooperative Highway Research Program Report 230, which recommends tests with even lighter-weight cars (1800 lb)]. When impacted by 2205-lb vehicles at 19.8 and 57.7 mph, the 6 x 8-in wood posts met all the criteria. A 9.25-in-diameter timber pole impacted by a 2205-lb vehicle at 19.2 mph did not break away. A modified timber-pole design was similarly tested; it broke away but was still too stiff. Consequently, timber-pole supports are no longer used on new construction in California. A 7.875 x 14.875-in laminated wood veneer box-section post that had saw cuts in the webs was impacted with a 2205-lb vehicle at 19.2 and 58.4 mph and met all test criteria. The design was adopted as a standard in California. A number of full-scale pendulum and static-bend tests on various breakaway support designs was conducted during this project.

For a number of years, roadside signs on California state highways have used breakaway wood-post or timber-pole supports. They have holes drilled near the base to make them break away when impacted by a vehicle. This design was based on three vehicle impact tests conducted by the California Department of Transportation (Caltrans) in 1966 and 1967 (1). This design has proved quite successful in California.

In July 1976, the Federal Highway Administration (FHWA) distributed FHWA Notice N5040.20 (2), which stated that all new federal-aid projects should comply with the FHWA suggested guidelines for application of breakaway requirements of the American Association of State Highway and Transportation Officials (AASHTO) Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals (3), which were attached to the notice. These guidelines stated that in an 8-ft path, single wood posts should be no larger than 4x6 in and double posts no larger than 3x6 in or 4x5 in (full dimension). Hence, the timber poles and the 6x6-in and 6x8-in wood posts used by Caltrans would no longer be acceptable unless they were successfully tested by vehicle impacts in accordance with the FHWA guidelines.

Between 1972 and 1975, there were 11 fatal accidents on California state highways that involved wood sign supports. However, most of these accidents included vehicle rollovers, occupant ejections, motorcycle impacts, or multiple fixed-object impacts. Hence, the record looked good, but there was concern for the future, where many more lightweight cars would be on the highways. The FHWA guidelines recognized this trend.

The objective of this research was to conduct crash tests by using a lightweight (2250-lb) vehicle on the largest wood-post size used by Caltrans (6x8 in) and the largest size timber pole expected to meet the new FHWA guidelines. If these sizes met the criteria, all smaller sizes would qualify automatically.

If these tests were unsuccessful, the support designs would be modified or new types of wood supports would be developed and tested. Midway through the project it was decided to include full-scale static-bend tests to check wind load designs

and full-scale pendulum tests to screen out new breakaway designs.

The crash tests were conducted in accordance with Transportation Research Circular (TRC) 191 (4). These procedures encompassed the requirements in the FHWA guidelines (2) and AASHTO specifications (3) and included detailed test procedures.

Table 1 summarizes all the known crash tests on dual-legged breakaway wood supports other than a lightly documented series in Pennsylvania in 1968 (7).

TEST CONDITIONS

Test Facility

All crash tests and some static-bend tests took place at Caltrans' Dynamic Test Facility. All pendulum tests and some static-bend tests were performed under contract with Southwest Research Institute (SwRI). For all crash tests and pendulum tests, the breakaway supports were embedded in standard soil pits in accordance with TRC 191 (4).

Test Vehicles

The test vehicles used for the six crash tests were 1976 Toyota Corolla 2-door sedans. The test inertial mass of these vehicles (excluding the part 572 dummy weight) was 2205 lb.

Test Sign Construction

The dimensions of the test signs are given in Table 1 and Figure 1. All posts and poles were made of Douglas fir; the posts were No. 1 grade. The sign panels were aluminum with a paper honeycomb core, either 1.125 or 2.625 in thick. A truck-mounted auger or bucket auger was used to drill holes in the ground for the supports. The sign panels were attached to the supports on the ground and then the entire sign was set in the holes. The holes were backfilled and tamped. Finally, breakaway holes and sawcuts were cut in the supports. Asphalt concrete pavement was removed around the supports.

Wood Post Properties

Caltrans uses wood posts in sizes from 4x4 to 6x8 in as single and dual supports for roadside signs. The largest wood-post size of 6x8-in Douglas fir could support a sign panel area up to 90 ft². The 6x8-in posts that have 2.5-in-diameter holes near the base were used in tests 351 and 352.

Timber Pole Properties

Test 353

Caltrans formerly used timber poles to support sign panels with areas from 85 to 265 ft². The poles were classes 1 to 6 and had average diameters from approximately 6.5 to 12.5 in near the ground line (8). There could be considerable variation in the average pole diameter for any given class because the diameter varied with the length of the pole and,

in addition, the Caltrans specification (9) allowed the minimum circumference to be exceeded by as much as 5 in.

After examining the results of previous crash and pendulum tests on wood supports, it was concluded that some of the larger-sized poles might not break away. It was decided to crash test 9.25-in-diameter poles that had 3-in-diameter breakaway holes and a net shear area of 40 in².

SwRI Pendulum Tests

After the pole design used in crash test 353 stopped the 2205-lb test vehicle impacting at 19.2 mph without breaking, it was decided to evaluate some poles that had other hole patterns with pendulum tests.

One hole pattern that was pendulum tested at SwRI looked promising and was used for crash test 354. The timber-pole supports in test 353 had been virtually undamaged; therefore, they were reused for test 354, except that the opposite pole was impacted. The 4-in-diameter holes and connecting sawcut shown in Figure 1 were added to the existing 3-in-diameter holes.

Caltrans Static-Bend Tests

Following test 354, which was unsuccessful, Caltrans conducted static-bend tests on three pole specimens that had hole and sawcut patterns similar to those in test 354. These tests were to check the wind load design and to determine if larger holes could be cut in the poles.

Laminated Wood Veneer Box and I-Section Properties

SwRI Pendulum and Static-Bend Tests

After the timber-pole designs in tests 353 and 354 proved inadequate by crash testing, it was decided to try built-up wood-post sections by using high-strength laminated wood veneer lumber. Pendulum and static-bend tests were conducted at SwRI on box- and H-section posts. The 1-in-diameter holes and connecting sawcuts were used when rectangular web cutouts reduced the static-bend strength too much.

Studies of parallel-laminated wood veneer lumber have been conducted by the Forest Products Laboratory of the U.S. Forest Service (10,11). Some of the benefits of this lumber, when compared with solid sawn lumber, include the following:

1. Higher yield of material from logs,
2. Improvement in grade quality due to dispersal of knots and minimization of knot volumes,
3. Consequent higher average strength with less variation in strength, and
4. Longer lengths of material that are more dimensionally stable.

The laminated wood veneer lumber was built up from 0.125- or 0.1-in-thick C and D grade plywood-type Douglas fir veneers that had been ultrasonically graded and combined to obtain a specific bending strength. The veneers were all oriented with the grain of the wood parallel to the length of the member in order to maximize the bending strength in that direction. The lumber was manufactured in "billets" 2 ft wide and up to 80 ft long.

An exterior type glue (phenol-formaldehyde) was used to join the veneers. The flange and web elements of the built-up posts were joined with a phenol-resorcinol adhesive.

The lumber was available in allowable bending stress grades of 2500 to 3150 psi; a 2650-psi grade

was used and applied both to billet material and the whole box section. The ultimate bending strength was 7400 psi; the modulus of elasticity was 2.0×10^6 psi. Allowable shear stress was the same for all bending stress grades. For shear perpendicular to the glue lines (neutral axis of box section), the allowable stress used was 285 psi and the average ultimate stress was 855 psi. For shear parallel to the glue lines (joint between flange and web), the allowable stress was 190 psi and the ultimate stress was 570 psi. Allowable stress adjustment factors were used for wind loading, wet condition of use, and shape factor. It was assumed the holes and sawcuts would reduce the ultimate bending strength of the box section by 20 percent, which was accurate.

The penetration and retention of preservatives in parallel-laminated wood veneer lumber is good. This is due to the lathe checks formed when the veneers are peeled from the logs and flattened (10,11). Waterborne preservatives require a strength reduction, but oil-borne preservatives do not. Built-up sections should be treated after gluing the joints. The glues and preservatives used are durable and not deleterious to each other (12-15).

Caltrans Static-Bend Test

The static-bend strengths for the SwRI post tests were low, probably due to a short clamping length with resultant high shear stresses. Hence, Caltrans performed one test on a box section fully embedded in the ground. The final hole and sawcut pattern was used. The ultimate moment of the post at ground level was an acceptable 79.8 kip-ft.

Two box-section posts can support 200-ft² sign panels that have midpanel heights of 21 ft. The design wind loading was 18.7 lb/ft² from a 60-mph wind at 15-30 ft heights, which is the maximum wind speed in California over a 10-year mean recurrence interval (except in local high wind areas).

The box section, which weighs 12 lb/ft, was selected over the H-section. It should be less susceptible to handling damage, more resistant to wind loads without increased impact resistance, and higher in torsional and lateral load resistance.

The box-section posts used for the tests cost approximately \$6.00/linear ft. A verbal quote in August 1981 for small quantities, free on board (FOB) in Oregon, was \$6.90/linear ft for type M and \$8.80/linear ft for type L (see Figure 2).

Bolts that extended completely through the sign panel and box section were used for test 355. Because both posts were sheared off in this test, lag screws were used in test 356 to connect the sign panel to the adjacent box-section flange only.

A 12-ft-long wire rope choker that had swagged looped ends was buried 2-3 ft below ground around the post for east in extracting the post stub after a crash test.

TEST RESULTS

The results of the crash tests are summarized in Table 1.

Test 351

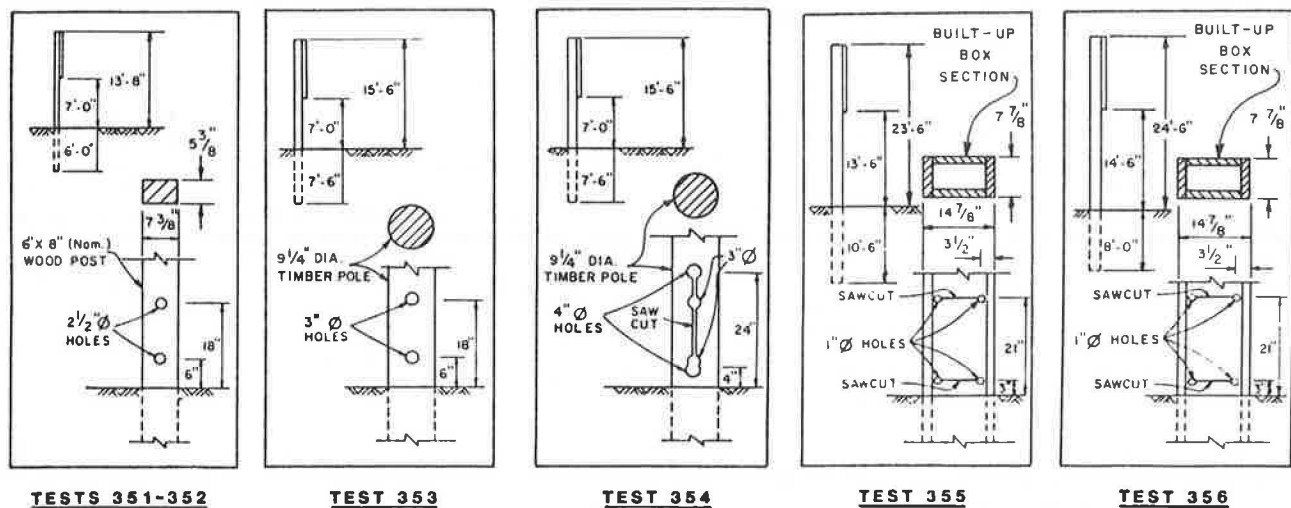
During impact, the post first split between the 2.5-in-diameter breakaway holes, and the split continued down below ground (see Figures 3 and 4). The post was torn off at the upper hole and the split stub below it was loaded because of two independent cantilevers that failed 10 in below ground. These two cantilevered post segments, which were 29.5 in long, stayed together and lodged beneath the

Table 1. Summary of crash tests.

Test Identification			Breakaway Support					Sign Panel		Ground Clearance (ft)
Ref- erence No.	Test No.	Test Date	Type	Modification	Net Shear Area (in ²)	Spacing (ft)	Embed- ment (ft)	Connection to Support	Size ^a	
1	151	11/66	6 x 6-in Douglas fir posts	None	43	9.0	6.0	3/8-in bolts	5 ft by 14 ft by 1 in	7.0
1	152	5/67	11-in Douglas fir poles	None	95	12.0	9.5	3/8-in lag screws	10 ft by 20 ft by 2.5 in	7.0
1	153	5/67	11-in Douglas fir poles	3- and 4-in holes at 4, 10, and 16 in aboveground	52	12.0	9.5	3/8-in lag screws	10 ft by 20 ft by 2.5 in	7.0
5	351	4/78	6 x 8-in Douglas fir posts	2- and 2.5-in holes at 6 and 8 in aboveground	25	8.0	6.0	Eight 3/8-in threaded rods	6 ft 8 in by 13 ft by 1.125 in	7.0
5	352	8/78	6 x 8-in Douglas fir posts	2- and 2.5-in holes at 6 and 8 in aboveground	25	8.0	6.0	Eight 3/8-in threaded rods	6 ft 8 in by 13 ft by 1.125 in	7.0
5	353	1/79	9.25-in Douglas fir poles	2- and 3-in holes at 6 and 8 in aboveground	40	8.0	7.5	Eight 3/8-in lag screws	8 ft 6 in by 13 ft by 1.125 in	7.0
5	354	5/80	9.25-in Douglas fir poles	Same as test 353 plus two 4-in holes at 4 and 24 in with sawcut between	31	8.0	7.5	Eight 3/8-in lag screws	8 ft 6 in by 13 ft by 1.125 in	7.0
5	355	1/81	7.875 x 14.875-in box section	1-in holes 3.5 in from each edge and sawcut between at 3 and 21 in aboveground	30	12.0	10.5	Eight 3/8-in threaded rods	10 ft by 21 ft by 2.625 in	13.5
5	356	3/81	7.875 x 14.875-in box section	Same as test 355	30	13.0	8.0	Sixteen 1/2- by 5-1/2-in lag screws	10 ft by 21 ft by 2.625 in	14.5
6	902	1/79	6 x 8-in Douglas fir posts	Two 2.5-in holes at 6 and 18 in aboveground	28	8.0	6.0	3/8-in threaded rods	6 ft 8 in by 13 ft by 1.125 in	7.0

^aMaterial used = aluminum.

Figure 1. Hole patterns for breakaway supports: crash tests 351-356.



vehicle. The upper section of the post and sign panel were pushed back by the vehicle as it yawed 35°.

Test 352

The impacted post failed the same way as the one in test 351 (see Figures 5 and 6). Again, a 28-in post segment separated from the post, lodged under the vehicle, and was dragged by the vehicle until it stopped. The upper part of the post, which was connected to the sign panel, was thrust up in the air while the vehicle passed underneath it and continued straight downstream.

Test 353

The timber-pole support was virtually undamaged by

the vehicle except for scuff marks. The ground-line movement of the pole was 0.75 in (see Figures 7 and 8).

Timber-Pole Pendulum Tests: SwRI

One of four hole patterns met the change-of-momentum requirements. This pattern was used in the timber poles for test 354. In test 354, the vehicle sheared off the pole and pushed it ahead 5.5 ft before stopping and rebounding to a point 1.75 ft beyond the original pole location (see Figures 9 and 10). The segment of the pole between the bored holes separated from the main pole and split into several pieces.

Vehicle				Test Results								
				Occupant-Compartment Impact Velocity (ft/s)		Initial Momentum, MV (lb·s)	Change of Momentum, ΔMV (lb·s)		High 50-ms Avg Longitudinal Vehical Acceleration (g)	Initial Vehicle Kinetic Energy, KE (kips·ft)	Change in Kinetic Energy, ΔKE (kips·ft)	Maxi- mum Front Vehicle Crush (in)
							Film	Acceleration				
Test Inertia Mass (lb)	Impact Velocity (ft/s)	Impact Velocity (mph)	Impact Angle (°)									
4540	55.7	38.0	0	2.93		7858	414			219	22	
4540	58.7	40.0	0	5.87		8272	827			243	46	
2000	57.2	39.0	0	17.6		3553	1093			102	53	
2205	29.0	19.8	0	14.0	10.0	1989	958	685	-3.7	29	16	7
2205	84.7	57.7	0	10.0	3.82	5797	685	262	-1.9	245	22	8
2205	28.2	19.2	0	33.2	29.4	1930	1930	1930	-11.2	27	27	16
2205	29.2	19.9	0	17.0	18.0	1999	1160	1230	-7.5	29	25	13
2205	28.2	19.2	0	10.3	10.5	1928	706	721	-4.3	27	16	10
2205	85.7	58.4	0	3.2	3.74	5865	219	256	-4.0	251	21	10
2250	28.9	19.7	0	28.9	9.17	2021	2021	1380		29	16	

Timber-Pole Static-Bend Tests: Caltrans

The failure mode was different in each of the three static-bend tests. The ultimate bending moments varied from 1.5 to 2.4 times the design wind load bending moment.

Box- and H-Section Posts

Both pendulum and static-bend tests were conducted by SwRI and Caltrans. The final tests in this set showed the box-section posts had good static-bend strength and good impact performance (see Figure 11).

Test 355

After impact in test 355, the post split between the upper and lower 1-in holes on the upstream side and split to the ground from the lower downstream 1-in hole (see Figures 12-15). Then most of the post sheared off through the lower holes and sawcut. The vehicle moved in a circular path, pushing the box-section post in front of it. When this post was 15° off vertical, cracks appeared in the nonimpacted post. Eventually this post was twisted off at its base through the lower sawcuts. The sign panel remained attached to the posts but buckled in the middle. The vehicle went under the impacted post and stopped beyond the fallen sign.

Test 356

In test 356, the post was torn off through the lower sawcuts (see Figures 16-19). The upstream flange split away from the box section starting at its midpoint; however, the flange stayed attached to the sign panel with lag screws. The separated flange and the rest of the box section were thrust into the air by the vehicle, which passed underneath with no contact. When the partial box section struck the ground, it split into three pieces--two webs and the downstream flange. Meanwhile, the upstream flange

of the nonimpacted post split off the box section from the top of the post to the bottom of the sign panel, which rotated and tore off the post. The upper upstream flange piece remained attached to the sign panel by the eight lag screws. The sign panel dropped flat on the ground.

DISCUSSION OF TEST RESULTS

The crash test results were compared with the three appraisal factors recommended in TRC 191 (4).

Structural Adequacy

In tests 353 and 354, the timber poles stopped the test vehicles too abruptly; thus, they did not meet the structural adequacy requirements. In test 355, the fallen sign projected 11 ft laterally beyond the original post location, thereby posing a possible traffic hazard. The switch from through bolts to lag screws for the sign-panel-to-post connection in test 356 prevented pull down of the nonimpacted post. The post pieces in test 356 projected out laterally 15 ft. The 1.5-in-thick pieces were flat on the ground. They would pose a psychological hazard more than a physical hazard.

In tests 351 and 355, which had impact speeds of 19-20 mph, the vehicles stayed in contact with the posts while stopping. Despite this, there was no apparent danger of passenger-compartment penetration.

Occupant Risk (Impact Severity)

The test results were compared against maximum recommended change-of-momentum values in TRC 191 (4) of 1100 lb-s (absolute) and 750 lb-s (preferred). Tests 351 and 352 on 6x8-in posts and tests 355 and 356 on box-section posts had values less than 750 lb-s and satisfied the criterion. Tests 353 and 354 on timber poles had values more than 1100 lb-s and failed the criterion.

Figure 2. Caltrans standard plan for laminated wood box post for roadside signs.

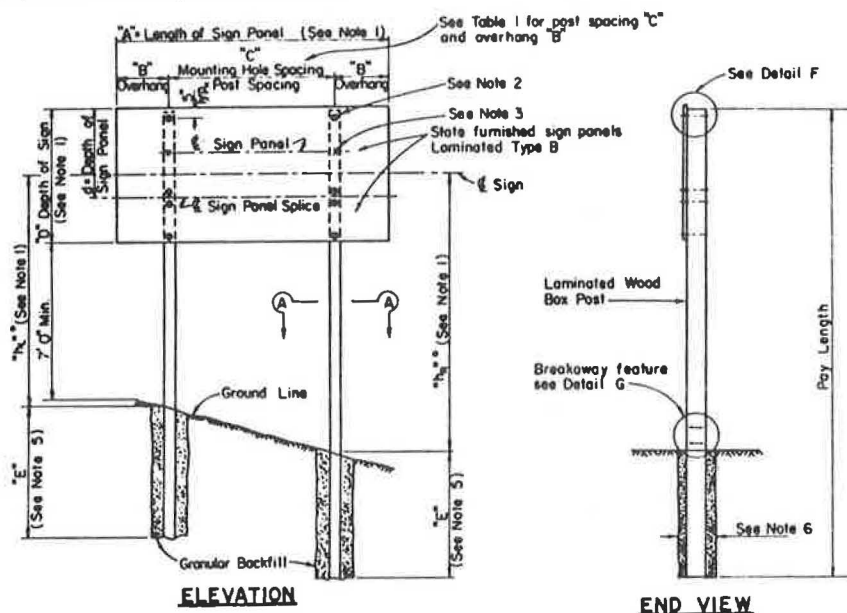


TABLE 1

SIGN PANEL LENGTH (See Note 1)	SIGN PANEL OVERHANG	MOUNTING HOLE SPACING
"A"	"B"	"C"
8'-0"	18"	5'-0"
9'-0"	22"	5'-4"
10'-0"	24"	6'-0"
11'-0"	24"	7'-0"
12'-0"	30"	7'-0"
13'-0"	30"	8'-0"
14'-0"	30"	9'-0"
15'-0"	36"	9'-0"
16'-0"	39"	9'-6"
17'-0"	39"	10'-6"
18'-0"	42"	11'-0"
19'-0"	45"	11'-6"
20'-0"	48"	12'-0"
21'-0"	51"	12'-6"
22'-0"	51"	13'-6"
23'-0"	54"	14'-0"
24'-0"	57"	14'-6"

* Dimensions shown on project plans are for fabrication. At time of installation adjust these dimensions to provide a level sign approximately 7' above roadway shoulder.

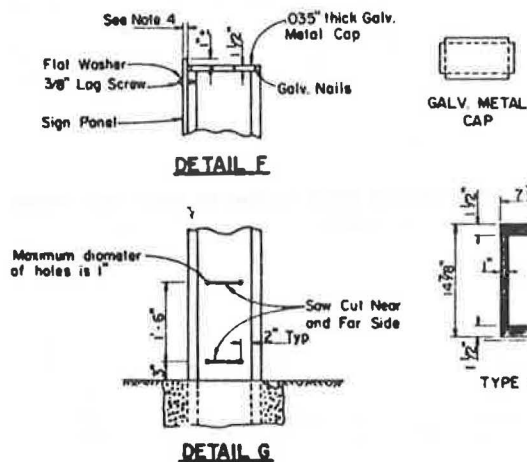
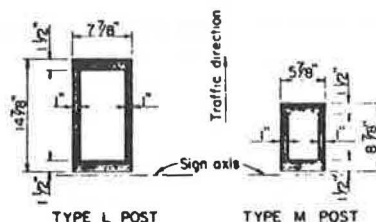


TABLE 2
MINIMUM POST EMBEDMENT "E"
FOR TYPE L POST

"h _L " or "h _M " to (in feet)	TOTAL SIGN AREA (sq. ft.)
40 to 90	90 to 140
90 to 140	140 to 190
140 to 190	190 to 240
190 to 240	240 to 290
240 to 290	290 to 340
340 to 390	390 to 440
440 to 490	490 to 540
540 to 590	590 to 640
640 to 690	690 to 740
740 to 790	790 to 840
840 to 890	890 to 940
940 to 990	990 to 1040
1040 to 1090	1090 to 1140
1140 to 1190	1190 to 1240
1240 to 1290	1290 to 1340
1340 to 1390	1390 to 1440
1440 to 1490	1490 to 1540
1540 to 1590	1590 to 1640
1640 to 1690	1690 to 1740
1740 to 1790	1790 to 1840
1840 to 1890	1890 to 1940
1940 to 1990	1990 to 2040
2040 to 2090	2090 to 2140
2140 to 2190	2190 to 2240
2240 to 2290	2290 to 2340
2340 to 2390	2390 to 2440
2440 to 2490	2490 to 2540
2540 to 2590	2590 to 2640
2640 to 2690	2690 to 2740
2740 to 2790	2790 to 2840
2840 to 2890	2890 to 2940
2940 to 2990	2990 to 3040
3040 to 3090	3090 to 3140
3140 to 3190	3190 to 3240
3240 to 3290	3290 to 3340
3340 to 3390	3390 to 3440
3440 to 3490	3490 to 3540
3540 to 3590	3590 to 3640
3640 to 3690	3690 to 3740
3740 to 3790	3790 to 3840
3840 to 3890	3890 to 3940
3940 to 3990	3990 to 4040
4040 to 4090	4090 to 4140
4140 to 4190	4190 to 4240
4240 to 4290	4290 to 4340
4340 to 4390	4390 to 4440
4440 to 4490	4490 to 4540
4540 to 4590	4590 to 4640
4640 to 4690	4690 to 4740
4740 to 4790	4790 to 4840
4840 to 4890	4890 to 4940
4940 to 4990	4990 to 5040
5040 to 5090	5090 to 5140
5140 to 5190	5190 to 5240
5240 to 5290	5290 to 5340
5340 to 5390	5390 to 5440
5440 to 5490	5490 to 5540
5540 to 5590	5590 to 5640
5640 to 5690	5690 to 5740
5740 to 5790	5790 to 5840
5840 to 5890	5890 to 5940
5940 to 5990	5990 to 6040
6040 to 6090	6090 to 6140
6140 to 6190	6190 to 6240
6240 to 6290	6290 to 6340
6340 to 6390	6390 to 6440
6440 to 6490	6490 to 6540
6540 to 6590	6590 to 6640
6640 to 6690	6690 to 6740
6740 to 6790	6790 to 6840
6840 to 6890	6890 to 6940
6940 to 6990	6990 to 7040
7040 to 7090	7090 to 7140
7140 to 7190	7190 to 7240
7240 to 7290	7290 to 7340
7340 to 7390	7390 to 7440
7440 to 7490	7490 to 7540
7540 to 7590	7590 to 7640
7640 to 7690	7690 to 7740
7740 to 7790	7790 to 7840
7840 to 7890	7890 to 7940
7940 to 7990	7990 to 8040
8040 to 8090	8090 to 8140
8140 to 8190	8190 to 8240
8240 to 8290	8290 to 8340
8340 to 8390	8390 to 8440
8440 to 8490	8490 to 8540
8540 to 8590	8590 to 8640
8640 to 8690	8690 to 8740
8740 to 8790	8790 to 8840
8840 to 8890	8890 to 8940
8940 to 8990	8990 to 9040
9040 to 9090	9090 to 9140
9140 to 9190	9190 to 9240
9240 to 9290	9290 to 9340
9340 to 9390	9390 to 9440
9440 to 9490	9490 to 9540
9540 to 9590	9590 to 9640
9640 to 9690	9690 to 9740
9740 to 9790	9790 to 9840
9840 to 9890	9890 to 9940
9940 to 9990	9990 to 10040



NOTES:

- See Project Plans for:
Location of each sign.
Length of sign panel "A".
Depth of sign "D".
Height "h_L" and "h_M" of centerline of sign above ground line at each post.
Type of post, L or M.
See Standard Plan S41-3 for other details.
- "e" indicates location of 3/8" log screws and existing holes in panels. Log screws are to be embedded at least 1 1/2" into post.
- "x" indicates location of additional 3/8" log screws required when the depth of sign panel (d) and the length of sign panel (A) are as follows:

d	A
60"	17'-0" to 24'-0"
54"	19'-0" to 24'-0"
48"	21'-0" to 24'-0"
42"	24'-0"

- State-furnished Type B laminated sign panels are 1 1/8" thick for sign lengths of 15 feet and less. Panels over 15 feet in length are 2 3/8" thick.
- Embedment "E" for Type L posts shall conform to the requirements in Table 2. Embedment for Type M posts shall be 6 feet minimum.
- Diameter of post holes for Type L posts shall be at least 30 inches. Diameter of post holes for Type M posts shall be at least 24 inches.

Figure 3. Test 351: impact sequence.

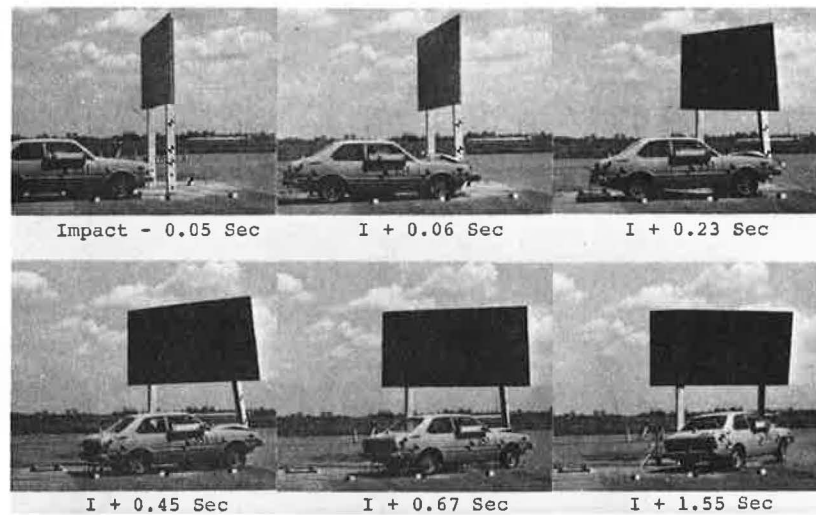


Figure 4. Test 351: final locations of test sign and vehicle after impact.

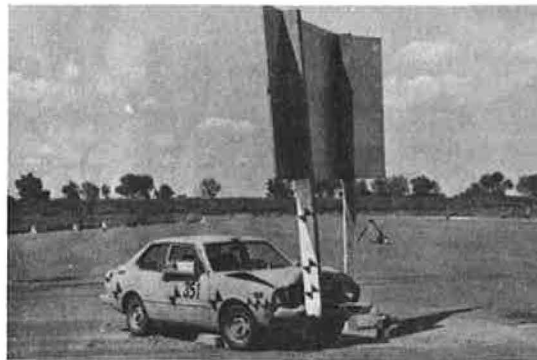


Figure 5. Test 352: impact sequence.

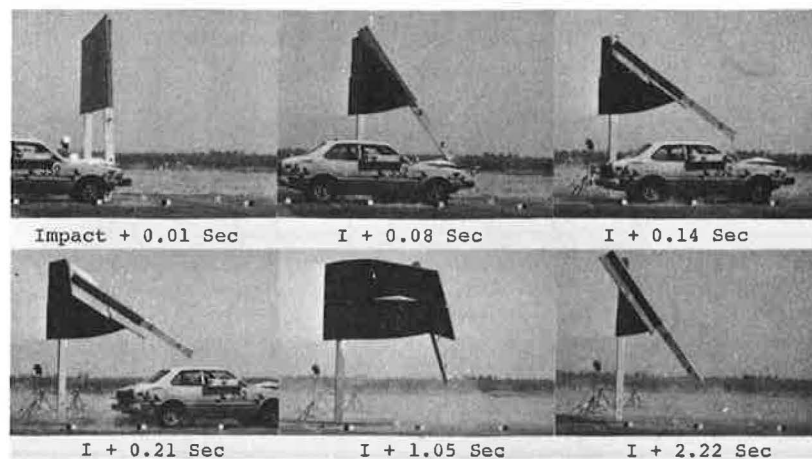


Figure 6. Test 352: crush at front of vehicle.



The test results were also compared against the new criterion in National Cooperative Highway Research Program (NCHRP) Report 230 (16) for maximum occupant and compartment impact velocities in the longitudinal direction that have a 2-ft flail space

of 15 ft/s and a maximum ridedown acceleration of -15 g over any 10-ms period thereafter. Again, tests 351, 352, 355, and 356 met the criterion and tests 353 and 354 did not.

Figure 7. Test 353: impact sequence.

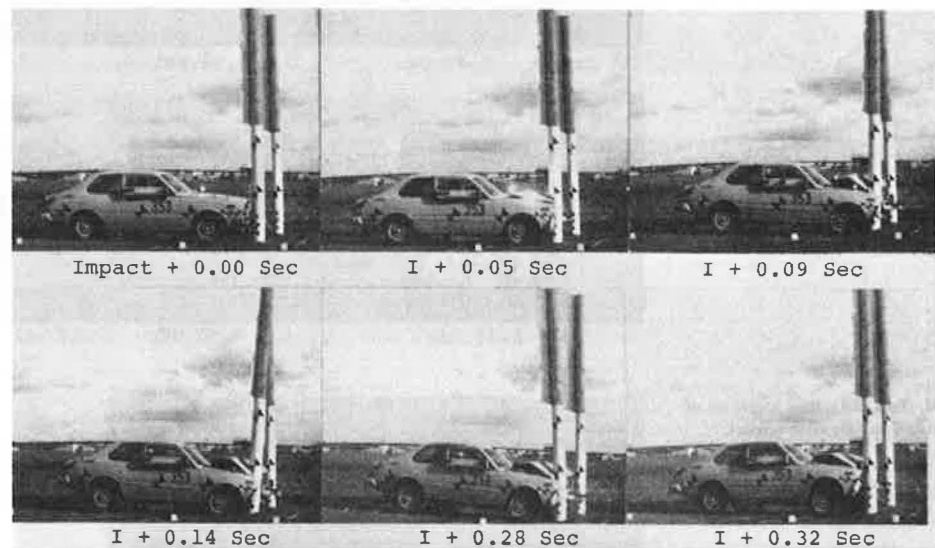


Figure 8. Test 353: final locations of test sign and vehicle after impact.

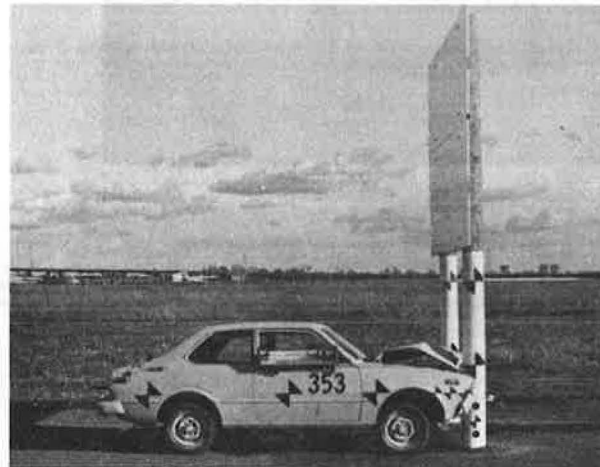


Figure 9. Test 354: impact sequence.

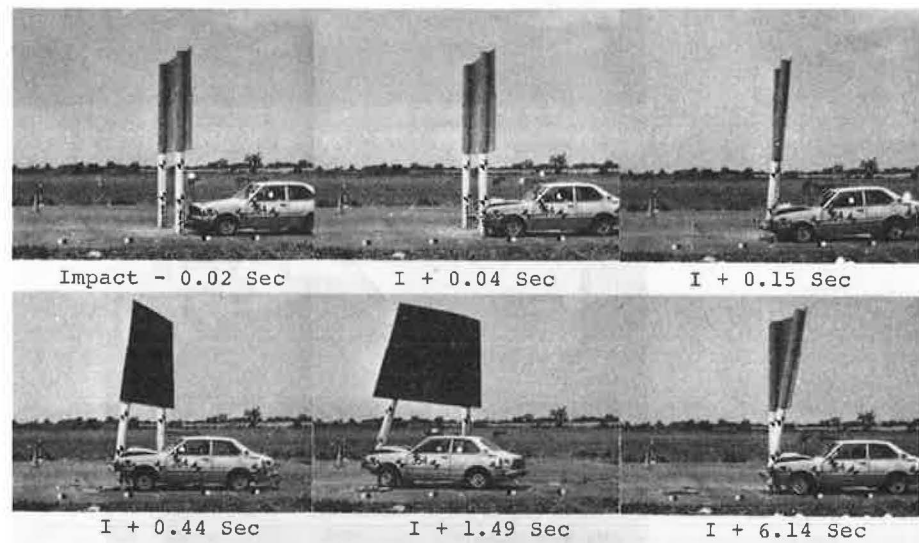


Figure 10. Test 354: crush at front of vehicle.

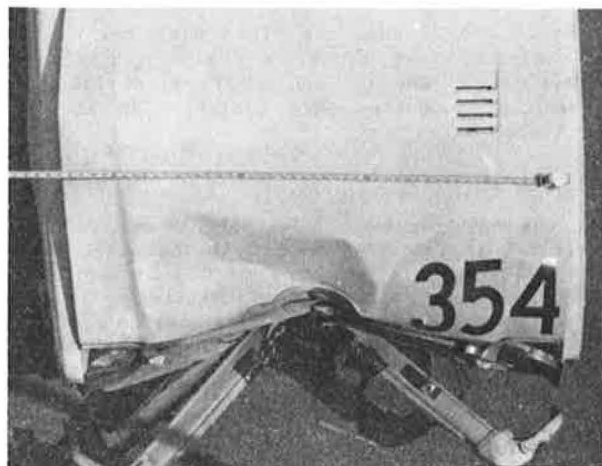


Figure 11. Static-bend test of laminated wood box-section post—broken stub.

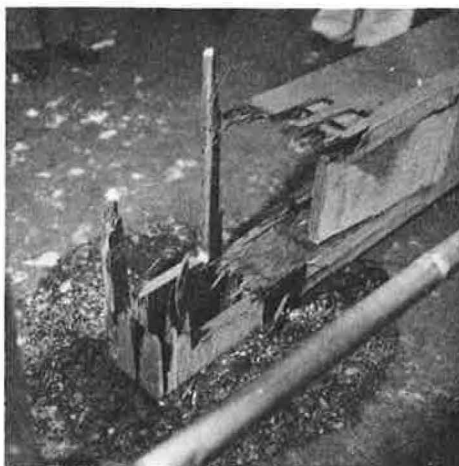


Figure 12. Test 355: impact sequence.

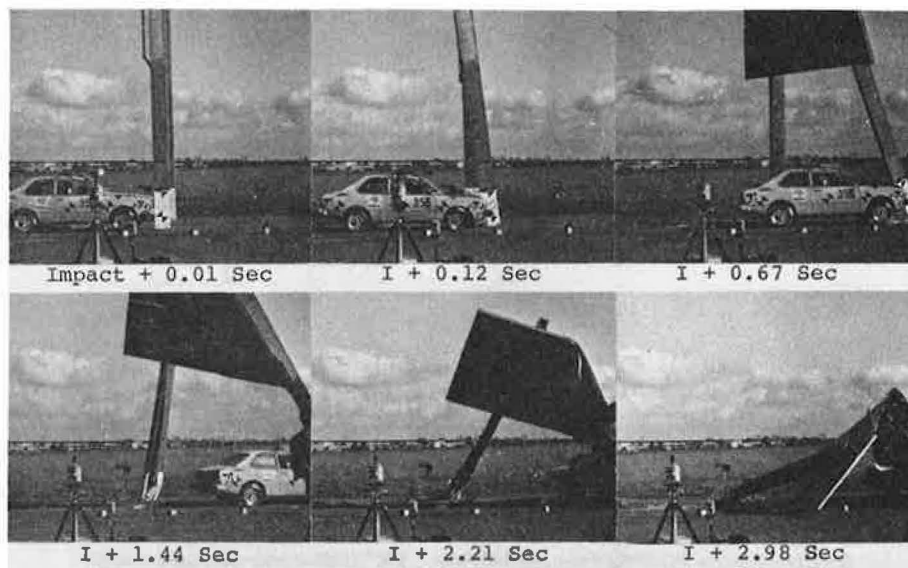


Figure 13. Test 355: test vehicle and box-section post before impact.

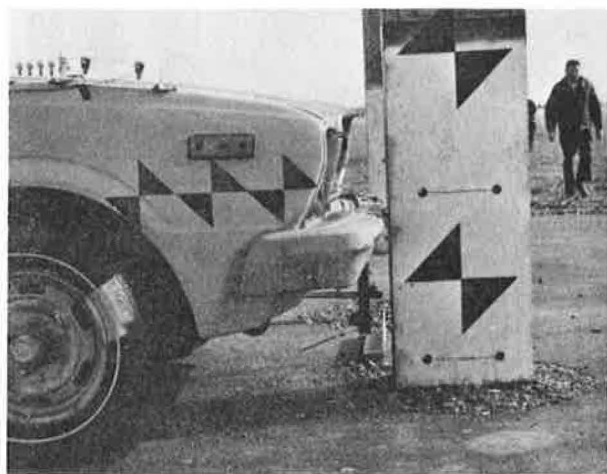


Figure 14. Test 355: final location of test sign and vehicle, looking downstream.



Figure 15. Test 355: stub of impacted box-section post.



Vehicle Trajectory

Figures 20 and 21 show the final positions of the test vehicles, test signs, and sign debris. The criteria in TRC 191 (4) and NCHRP Report 230 (16) for vehicle trajectory were satisfied in all six crash tests.

Implementation

After the unsuccessful timber-pole tests, Caltrans substituted a standard design by using steel posts and a slip base in February 1980. In mid-1981, box-section posts were added as an alternative (see Figure 2). The standard plan for roadside signs by using 6x8-in or smaller wood posts was unchanged. Although the steel post and slip base designs have functioned well, Caltrans has preferred wood support designs for the following reasons: (a) The wood supports have generally been less expensive in California, (b) their service life has proved to be sufficient, (c) they are easier for maintenance

Figure 16. Test 356: impact sequence.

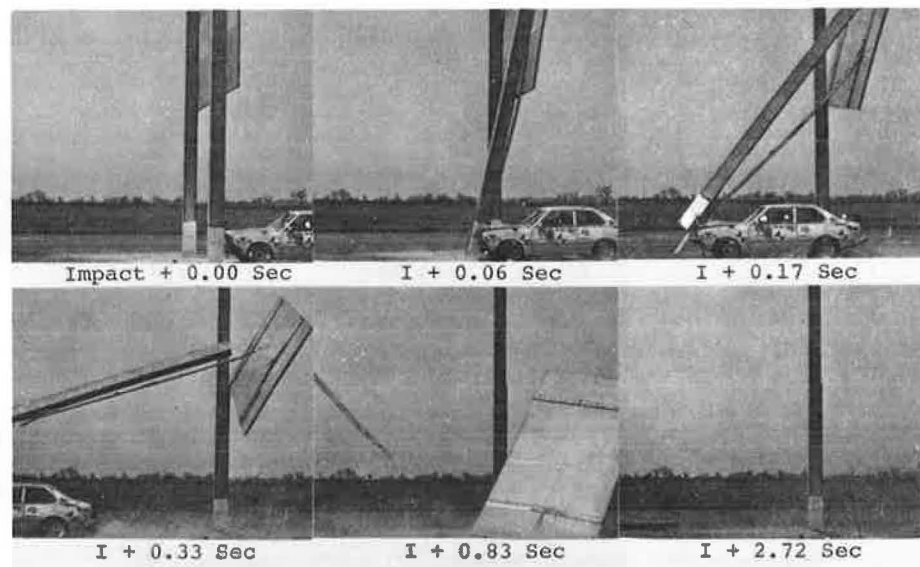


Figure 17. Test 356: crush at front of vehicle.

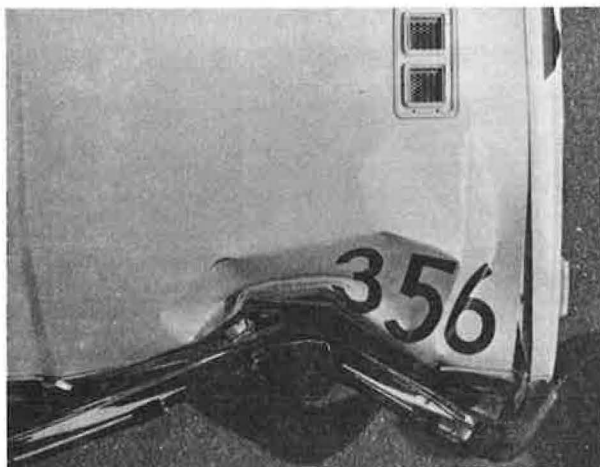


Figure 18. Test 356: final location of sign panel and pieces of impacted box-section post, looking upstream.



Figure 19. Test 356: nonimpacted post that had upper 10 ft of flange torn off.

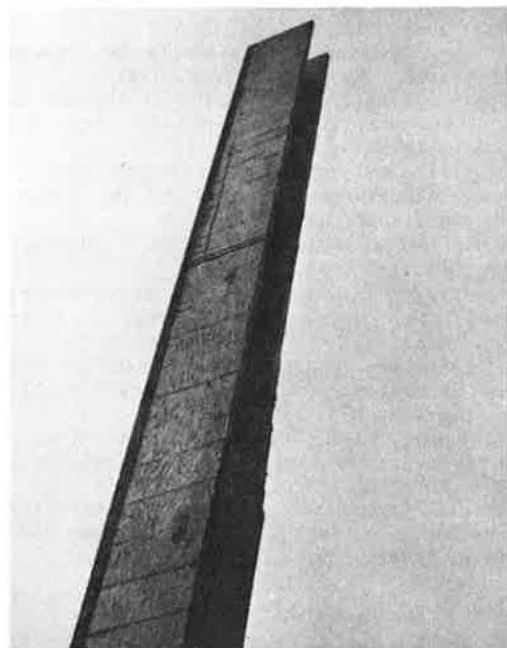
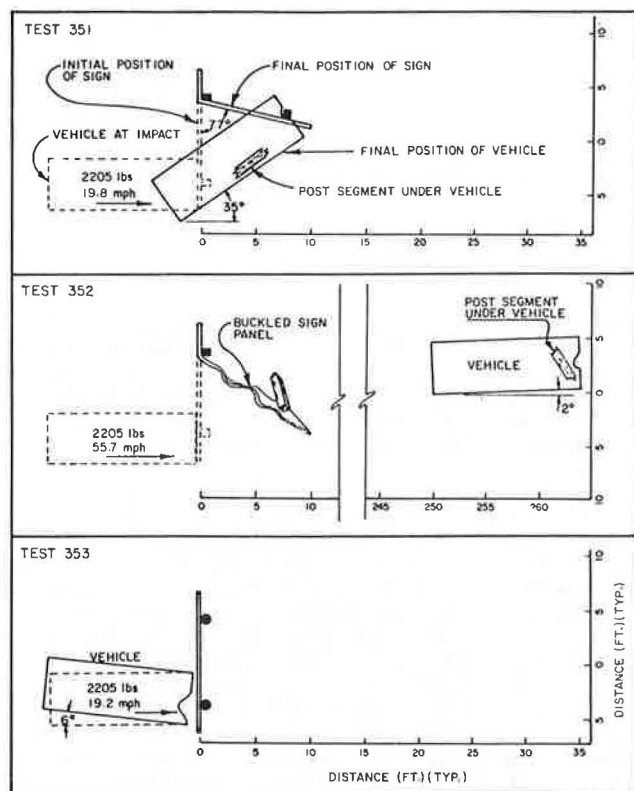


Figure 20. Final position of test vehicle and sign: tests 351-353.

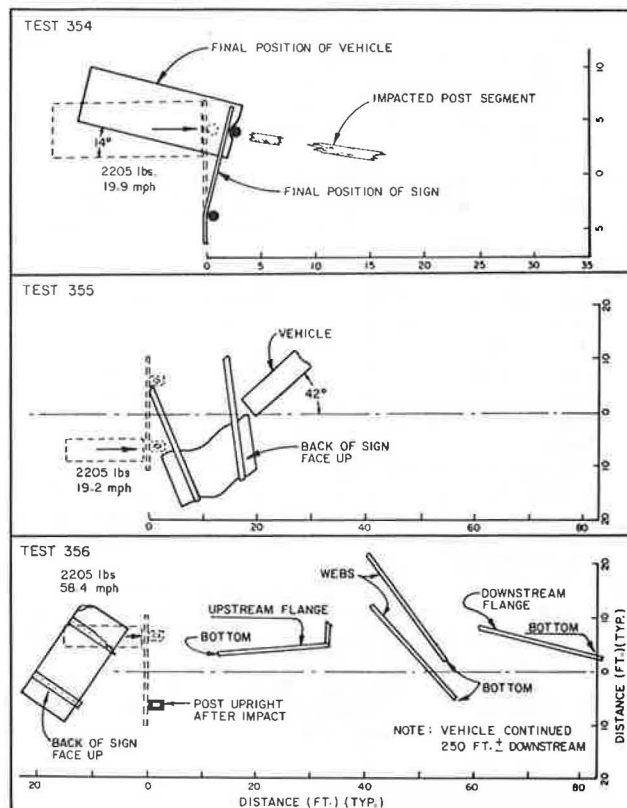


personnel to erect, and (d) they can be stocked in a small number of standard sizes and easily sawed to the correct length.

Future Work

Additional crash tests should be conducted by using

Figure 21. Final position of test vehicle and sign: tests 354-356.



1800-lb vehicles on 6x8-in and box-section breakaway wood sign supports as recommended in NCHRP Report 230 (16), the new crash-test guidelines.

CONCLUSIONS

Crash tests, pendulum tests, and static-bend tests were conducted on three general types of breakaway wood supports for dual-legged roadside signs. The tests were judged against criteria in the AASHTO guidelines (3), in TRC 191 (4), and, to some extent, in NCHRP Report 230 (16). Wood posts 6x8 in and smaller that have holes drilled through the webs reasonably met the above criteria. Timber poles 9.25 in in diameter with 3-in-diameter holes or 4-in-diameter holes with a connecting sawcut did not meet the above criteria and are not recommended for new construction. It is recommended that new sign installations that use the box-section posts be subjected to an in-service evaluation equal or similar to the one recommended in NCHRP Report 230 (16). Complete details of this research project are contained in a report by Stoughton and others (5).

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Thrie-Beam Guardrails for School and Intercity Buses

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The results of full-scale tests that were conducted to establish the upper performance limits of conventional W-beam guardrail and Thrie-beam guardrail systems are described. The tests showed that these conventional guardrail systems cannot safely redirect a 9070-kg (20 000-lb) school bus in a 15° angle impact at 96.5 km/h (60 mph). The development and evaluation of a modified Thrie-beam guardrail are also described. A series of full-scale tests has demonstrated that the unique feature of this guardrail system, a special 0.36-m (14-in) deep blockout, not only prevents the wheels of mini-compact cars from snagging on the posts but also raises the rail during impact to stably redirect heavier vehicles such as school and intercity buses.

In order to provide safer highway appurtenances for the public, there is an increasing emphasis on designing traffic barriers such as guardrails and bridge rails for a wider spectrum of highway vehicles. Witness the growing emphasis on designing guardrail terminals for mini-compact cars as they become a more significant part of the vehicle fleet and also recent efforts to design bridge rails for both school and intercity buses (1,2).

This report describes work that was aimed at investigating the feasibility of enlarging the spectrum of vehicles considered in the guardrail design process. Until recently, guardrails have been designed to accommodate a 2041-kg (4500-lb) automobile at 96.5 km/h (60 mph) and 25° as the most critical test. The goal of this study was to determine if a relatively conventional guardrail design is suitable to safely redirect a 9072-kg (20 000-lb) school bus moving at 96.5 km/h and at an impact

angle of 15°. If this proved not to be the case, the objective was to see if reasonably economical guardrails can be designed to accomplish this task.

To reach these objectives, the tests described in Table 1 were conducted. The cross sections of the guardrail for each test are shown in Figures 1, 2, and 3.

The tests were conducted in the order given in Table 1. The Thrie-beam guardrail shown in Figure 1 was selected for the first test. Because it was a choice between the conventional W-beam guardrail and the conventional Thrie-beam guardrail, the following reasoning dictated the choice of the Thrie-beam. If the Thrie-beam (G9) guardrail failed to redirect a school bus, there was no reason to test the W-beam, since it would certainly be of lower capacity. This might save one test that could be used to evaluate a modified Thrie-beam rail. If the Thrie-beam functioned reasonably well, there was a chance that the W-beam (G4-1S) guardrail would also perform adequately. The W-beam guardrail then would be selected for the second test. The testing program would prove the latter situation to be the one encountered. Although detailed accounts of these individual tests are given in subsequent parts of this report, a brief description of each test is presented here.

DISCUSSION OF TEST RESULTS

In the first test, which was conducted on the Thrie-