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TRANSPORTATION
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VEHICULAR IMPACT TESTS OF BREAKAWAY WOOD SUPPORTS FOR DUAL-SUPPORT ROADSIDE SIGNS

Caltrans

STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF CONSTRUCTION
OFFICE OF TRANSPORTATION LABORATORY

VEHICULAR IMPACT TESTS OF BREAKAWAY WOOD SUPPORTS FOR DUAL-SUPPORT ROADSIDE SIGNS

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NOTICE

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Neither the State of California nor the United States Government endorse products or manufacturers. Trade or manufacturers' names appear herein only because they are considered essential to the object of this document.

CONVERSION FACTORS

English to Metric System (SI) of Measurement

Quantity	English unit	Multiply by	To get metric equivalent
Length	inches (in)or(")	25.40 .02540	millimetres (mmm) metres (m)
	feet (ft)or(')	.3048	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in^2)	6.432×10^{-4}	square metres (m^2)
	square feet (ft^2) acres	.09290 .4047	square metres (m^2) hectares (ha)
Volume	gallons (gal)	3.785	litres (l)
	cubic feet (ft^3)	.02832	cubic metres (m^3)
	cubic yards (yd^3)	.7646	cubic metres (m^3)
Volume/Time (Flow)	cubic feet per second (ft^3/s)	28.317	litres per second (l/s)
	gallons per minute (gal/min)	.06309	litres per second (l/s)
Mass	pounds (lb)	.4536	kilograms (kg)
Velocity	miles per hour (mph) feet per second (fps)	.4470 .3048	metres per second (m/s) metres per second (m/s)
Acceleration	feet per second squared (ft/s^2)	.3048	metres per second squared (m/s^2)
	acceleration due to force of gravity (G)	9.807	metres per second squared (m/s^2)
Weight Density	pounds per cubic (lb/ft^3)	16.02	kilograms per cubic metre (kg/m^3)
Force	pounds (lbs) kips (1000 lbs)	4.448 4448	newtons (N) newtons (N)
Thermal Energy	British thermal unit (BTU)	1055	joules (J)
Mechanical Energy	foot-pounds (ft-lb) foot-kips (ft-k)	1.356 1356	joules (J) joules (J)
Bending Moment or Torque	inch-pounds (ft-lbs) foot-pounds (ft-lbs)	.1130 1.356	newton-metres (Nm) newton-metres (Nm)
Pressure	pounds per square inch (psi)	6895	pascals (Pa)
	pounds per square foot (psf)	47.88	pascals (Pa)
Stress Intensity	kips per square inch square root inch (ksi $\sqrt{in}$)	1.0988	mega pascals $\sqrt{metre}$ (MPa $\sqrt{m}$)
	pounds per square inch square root inch (psi $\sqrt{in}$)	1.0988	kilo pascals $\sqrt{metre}$ (KPa $\sqrt{m}$)
Plane Angle	degrees (°)	0.0175	radians (rad)
Temperature	degrees fahrenheit (F)	$\frac{tF - 32}{1.8} = tC$	degrees celsius (°C)

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1. INTRODUCTION

1.1 Problem

For a number of years almost all roadside signs on California state highways have used breakaway wood post or timber pole supports. The larger size posts and poles have holes drilled near the base to make them break away when impacted by a vehicle. This design was based on a series of three vehicular impact tests conducted by Caltrans in 1966-67 (1). This Design has proven quite successful in California.

In July 1976, 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 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 eight-foot path, single wood posts should be no larger than 4 in. x 6 in. and double posts no larger than 3 in. x 6 in. or 4 in. x 5 in. (full dimension). Hence, the timber poles and the 6 in. x 6 in. and 6 in. x 8 in. wood posts used by Caltrans would no longer be acceptable unless they were successfully tested by vehicular impacts in accordance with the FHWA guidelines. The only alternative would be to use breakaway steel sign supports which would be more difficult and costly, both to install and to repair or replace.

1.2 Objectives - Scope

Initially the objective of this research was to conduct crash tests on the standard Caltrans wood post and timber pole breakaway sign supports for two-support signs in order to determine whether they met the most recent criteria established by FHWA. It was decided to test the largest wood post size allowed, 6-inch x 8-inch supports. It was assumed that if this size was satisfactory, all smaller sizes of wood post would be automatically qualified for use. Likewise, it was decided to test the largest diameter timber pole expected to meet the test criteria in order to qualify all smaller sizes of poles.

If these designs did not pass the tests, then the additional objective was to modify the designs or develop new types of supports, conduct crash tests on them, and add them to the California Standard Plans if successful.

Midway through the project it was also decided to perform some static bend tests on some of the sign support designs to determine their resistance to wind loads acting on the sign panel.

The crash tests were conducted in accordance with Transportation Research Circular (TRC) No. 191, "Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances" (4).

TRC No. 191 recommends that the first test on a breakaway support design be conducted with a vehicle impact speed of 20 mph. If the vehicle change of momentum is over 1100 lb-sec, the design fails; if under 750 lb-sec, the design passes, and if between 750 and 1100 lb-sec, a second 20 mph test must be conducted. The change of momentum must be under 1100 lb-sec in the second test. Following the 20 mph test requirement, the design must be tested with a vehicle impact speed of 60 mph. In this test, the change of momentum must be under 1100 lb-sec. The testing in this project followed the above procedures.

1.3 Literature Search - Background

There have been only a handful of tests by other agencies on breakaway supports for two-legged signs, and most of them were not recent. In Section 5.3, Discussion of Test Results, Table 5 summarizes the results of tests on wood supports. Tables F3-F7 in Appendix F summarize all other crash tests on two-legged signs using metal breakaway supports.

Caltrans previously had performed one short test series on breakaway wood sign supports. In a Caltrans research report entitled "Dynamic Tests of Wood Post and Timber Pole Sign Supports, Series XV", dated December, 1967 (1), the impact severity of wood sign supports was measured in three crash tests using Dodge sedans weighing about 4500 lbs and a Volkswagen sedan weighing about 2000 lbs. Using time and velocity changes determined by high speed cameras, the maximum change in momentum was calculated for each of these impact tests.

In a 38 mph impact into a 6-inch x 8-inch D.F. wood post without holes by the 4500 lb vehicle, the calculated momentum change was 414 lb-sec. In a 40 mph impact with the 4500 lb vehicle into an 11-inch diameter Class 2 D.F. timber pole, also without holes, the momentum change was calculated to be 827 lb-sec. In the third test, the 2000 lb. vehicle impacted an 11-inch diameter Class 2 D.F. timber pole with three 4-inch diameter holes located 4, 10, and 16 inches above ground at a speed of 39 mph. The calculated momentum change was 1093 lb-sec.

In the latter test, the Volkswagen readily fractured the pole and passed safely underneath it as it flew up and over the roof of the vehicle. Damage to the vehicle was minimal with the left front fender crushed into the wheel well. The vehicle was driveable after the impact.

The Caltrans standard post and pole sizes and bored breakaway hole sizes for roadside sign supports were determined on the basis of the above three tests and were unchanged until the time of the current test series.

There was no adverse accident experience with these designs known to the researchers at the time of the current test series. This test series would not have been conducted except for the recent concern about the effect of the designs on lightweight cars impacting at low and high speeds. This concern extends to all types of highway safety barriers and appurtenances and was just developing nationwide at the beginning of this test series. More discussion on this topic is contained in Section 5.3.5, Accident Data.

2. CONCLUSIONS

2.1 Dual-Legged Roadside Signs With Breakaway 6 in. x 8 in. D. F. Wood Post Supports

The design for roadside signs with 6 in. x 8 in. breakaway wood posts contained in the 1981 California Standard Plans (5) was crash tested with a 2205 lb vehicle at 19.8 and 57.7 mph. The posts successfully met the three performance appraisal criteria of structural adequacy, occupant risk and vehicle trajectory as described in Transportation Research Circular (TRC) No. 191 (4). It was concluded that all smaller wood post sizes would also meet these criteria. The largest wood post size allowed is 6 in. x 8 in. which can support sign panels up to 90 square feet in area.

2.2 Dual-Legged Roadside Signs With Breakaway 9 1/4 In. Diameter Timber Pole Supports

The design for roadside signs with 9 1/4 in. diameter breakaway timber poles contained in the 1981 California Standard Plans (5) when crash tested with a 2205 lb vehicle at 19.2 mph was far from meeting the structural adequacy and occupant risk requirements described in TRC No. 191 (4). It is concluded that larger pole sizes as allowed in the current Standard Plans would not comply with the test criteria, and some smaller pole sizes would not comply either. A second crash test with a 2205 lb vehicle traveling 19.9 mph and impacting a modified 9 1/4 in. diameter pole with larger holes and connecting vertical sawcut was also unsuccessful in meeting the test criteria even though pendulum tests had indicated the modified design would work. It was concluded that timber poles could not be easily modified to meet the test criteria. However, since impact resistance in this second test was significantly reduced from the first test and only slightly above the acceptable level, it appears that the modified breakaway hole and sawcut pattern would be an acceptable interim retrofit process for existing timber poles if operational experience indicates that a problem exists in the future.

2.3 Dual-Legged Roadside Signs With Breakaway Laminated Wood Veneer Box Section Supports

A new breakaway wood post design using laminated wood veneer lumber to form a 7 7/8 in. x 14 7/8 in. box section with 1 1/2 in. flanges and 1 in. webs was crash tested with a 2205 lb vehicle at speeds of 19.2 and 58.4 mph. This design successfully met the performance appraisal criteria in TRC No. 191 as well as performing satisfactorily in preliminary pendulum tests. This post design also provided twice the bending resistance needed to resist wind loads on a sign panel as measured in a full scale static bend test. This post design was sized to support a 240 square foot sign panel, the largest size normally used on roadside signs in California, and thus could be used in the future in place of timber poles.

3. RECOMMENDATIONS

° Breakaway supports for roadside signs using 6 in. x 8 in. and smaller D.F. wood posts as shown in the 1981 California Standard Plans (5) are acceptable for use and need not be modified.

° Breakaway supports of current design for roadside signs using timber poles should not be permitted on new construction.

° Work should continue on methods of retrofitting existing timber pole sign supports so that they will provide less resistance when impacted by lightwight cars weighing 2250 lbs or less.

° Breakaway supports for roadside signs using the laminated wood veneer box section developed and tested in this project should be used as a replacement for timber poles on new construction.

° The box section supports should be subjected to an in-service evaluation as outlined in NCHRP Report No. 230 (6) or by a similar procedure to verify the adequacy of performance.

° If the in-service evaluation proves the box section supports are effective, they should be crash tested again with 1800 lb passenger cars as recommended in the newly published NCHRP Report No. 230. This NCHRP report calls for testing with both 1800 and 2250 lb cars, and specifies that the impact point for 60 mph tests shall be at the quarter point of the bumper. Crash tests with 1800 lb cars would provide extra assurance that the posts function properly, even with extremely lightweight cars. In the test series with 2205 lb vehicles reported herein, the impact point was at the center point of the bumper.

4. IMPLEMENTATION

The Division of Traffic Engineering and the Office of Structures Design withdrew the standard plan for roadside signs with timber pole supports for use on new construction in February 1980, Figure E3. It was replaced with a steel post/slip base design, Figure E4. In mid-1981 they added a design using the laminated wood veneer box section posts developed in this project, Figure E5. The Division of Traffic Engineering will be responsible for the in-service evaluation of this new design.

5. TECHNICAL DISCUSSION

5.1 Test Conditions

5.1.1 Test Facilities

All six vehicular impact tests on roadside signs in this project were conducted at the Caltrans Dynamic Test Facility in Bryte, California, near Sacramento. The tests took place on a flat paved asphalt concrete surface.

Eleven full scale pendulum tests were conducted at the Southwest Research Institute (SWRI) in San Antonio, Texas.

Four full scale static bend tests were conducted at SWRI, and four were conducted at Caltrans facilities.

Standardized soil was placed in six-foot deep pits as recommended in Reference 4. The sign supports subjected to crash tests were all embedded in standardized soil. The soil below the pits was an expansive clay. Oversized holes were drilled in the soil. The sign supports were set in the holes which were then carefully backfilled and compacted. The hole drilling and sign erection were performed by Caltrans drill crews and sign maintenance crews.

The sign supports subjected to pendulum tests at SWRI were also embedded in the standard soil.

All sign supports subjected to static bend tests were clamped at their lower ends to simulate soil embedment except that the box section tested by Caltrans was embedded in one of the standard soil pits.

5.1.2 Breakaway Wood Support Designs and Test Procedures

5.1.2.1 Two-Legged Roadside Sign With 6-inch x 8-inch Douglas Fir Supports

The first two crash tests, 351 and 352, were conducted on signs with two 6-inch x 8-inch supports that were No. 1 grade Douglas fir (posts and timbers). Although West Coast hemlock and redwood are also permitted in the California Standard Specificions (7), Douglas fir is more commonly used. (Wood post and timber pole supports designs are referenced to the 1981 California Standard Plans and Specifications; however, they are virtually identical to the plans and specifications in effect during the course of this research project.) These posts were selected by an inspector from one of the Caltrans district offices. He was directed to choose posts with a minimum number of knots and defects so that the posts would not breakaway at an abnormally low force level.

The sign panels were composed of a paper honeycomb core sandwiched between two sheets of aluminum, a standard design used in California. Two panel sections each 13 ft-0 in. wide x 3 ft-4 in. high were used to make up the full sign panel which had overall dimensions of 13 ft-0 in. x 6 ft-8 in. x 1 1/8 in. thick.

This roadside sign design used the largest size solid rectangular wood posts allowed, 6-inch x 8-inch, and close to the largest size sign panel allowed, given the post size and the height of the sign panel above ground. The sign panel clearance from the ground was 7 ft-0 in., the minimum allowed. It was assumed that a low sign panel clearance would increase the bending and torsional resistance of the sign as a whole when one support was impacted. Post spacing was 8 ft-0 in.

Installation of the test signs was done by a Caltrans district sign crew in order to duplicate typical installation procedures. The crew included two maintenance workers and a foreman. The post holes were drilled with an auger on a truck-mounted boom to the 6-ft embedment depth. With the posts laid on the ground near the holes, the two sign half-panels were connected to them with eight 3/8-inch-diameter through bolts. The truck boom then was used to lift the assembled sign and set the posts in the holes. The posts were plumbed and the holes backfilled. Breakaway holes were then drilled in the posts through the 8-inch faces. The holes were 2 1/2 inches in diameter and were centered 6 and 18 inches above the finish grade. The holes reduce the shear area of the post, thus decreasing the breakaway resistance of the post. Since the holes are drilled on the neutral axis of the post, however, they minimize the reduction in bending resistance of the post for wind loads. Enough asphalt concrete paving was removed around the posts so that it would not restrict post movement during impact.

It was decided that the plane of the sign panel would be oriented perpendicular to the approach path of the vehicle for Tests No. 351-356. The breakaway resistance of wood supports seems to be related in part to the net shear area in the impact zone. Since the strength of wood is quite variable, and the breakaway wood post designs had no calculable change in impact resistance with respect to angle of impact, only "head-on" tests were used.

Copies of the California Standard Plans (5) showing details for wood post sign supports are reproduced in Appendix E as Figures E1-E5. Figure 1 shows the post size selection chart for rectangular wood post supports (7). Figure 2 contains simplified drawings of the breakaway hole patterns for all the sign supports tested. Table 2 in Section 5.1.2.4 gives a summary of all test articles used in this project.

5.1.2.2 Two-Legged Roadside Signs With 9 1/4-Inch Diameter Timber Pole Supports

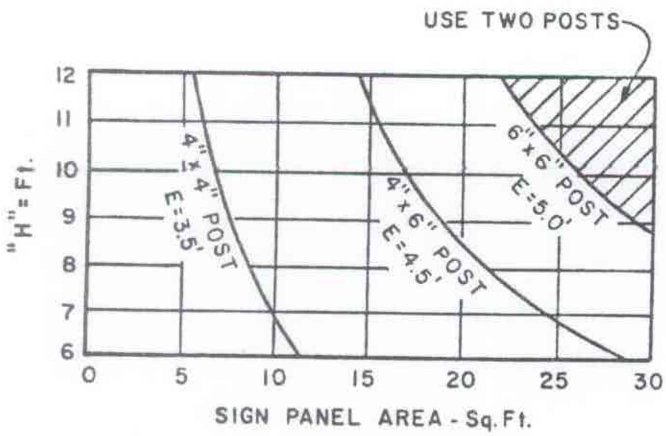
Timber Poles for Crash Test 353

When larger sign panels were required than could be supported by 6-inch x 8-inch wood posts, timber poles were used. Figure E3 in Appendix E is the standard plan design for timber poles (5). Figure 1 contains the selection chart for sizing the poles (8).

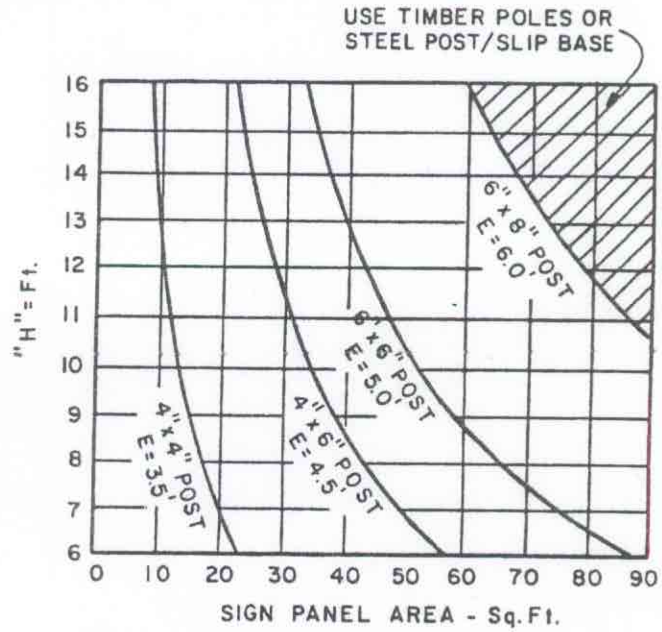
A series of pole sizes was permitted ranging from Class 1 to Class 6. The poles conformed to "Specifications and Dimensions for Wood Poles" (9). Although the California Standard Specifications (7) allowed the poles to be either ponderosa pine or Douglas fir; Douglas fir was generally used, and was chosen for these tests. For any given pole class, the Douglas fir pole diameters would be different than those for ponderosa pine. Table 1 gives the range in pole diameters for each class. The California Standard Specifications (7) allowed the pole circumferences to be up to 5 inches more than the stated minimums. Also pole diameters vary in any given class depending on pole length. Hence, pole selection by class for given sign panel areas was not a very precise design procedure.

WOOD POST AND TIMBER POLE SELECTION CHARTS

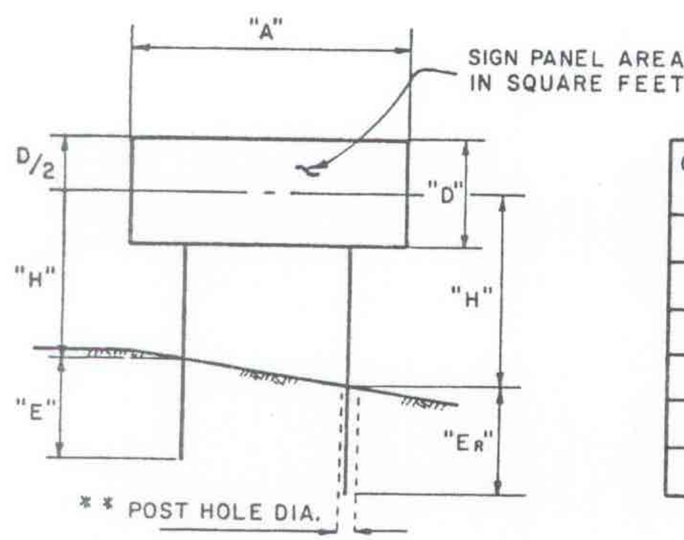
FIGURE 1



SINGLE POST CHART



TWO POST CHART



ELEVATION

CLASS OF POLE	MAX. SIGN PANEL AREA= Ft²	EMBEDMENT "E" = Ft.	SUGGESTED MAX. POLE LENGTH *
1.	265	10.0	25'
2.	215	9.5	30'
3	170	9.0	35'
4.	130	8.5	NO LIMIT
5.	110	7.5	NO LIMIT
6	85	7.0	NO LIMIT

TIMBER POLE SELECTION CHART

*This limit is suggested to keep the maximum diameter at the ground line about 1'-0". Breakaway steel posts provide a safer installation for large signs.

**Diameter of post hole should equal the butt diameter plus 6" to 12" for timber poles.

HOLE PATTERNS FOR BREAKAWAY SUPPORTS CRASH TESTS 351-356

FIGURE 2

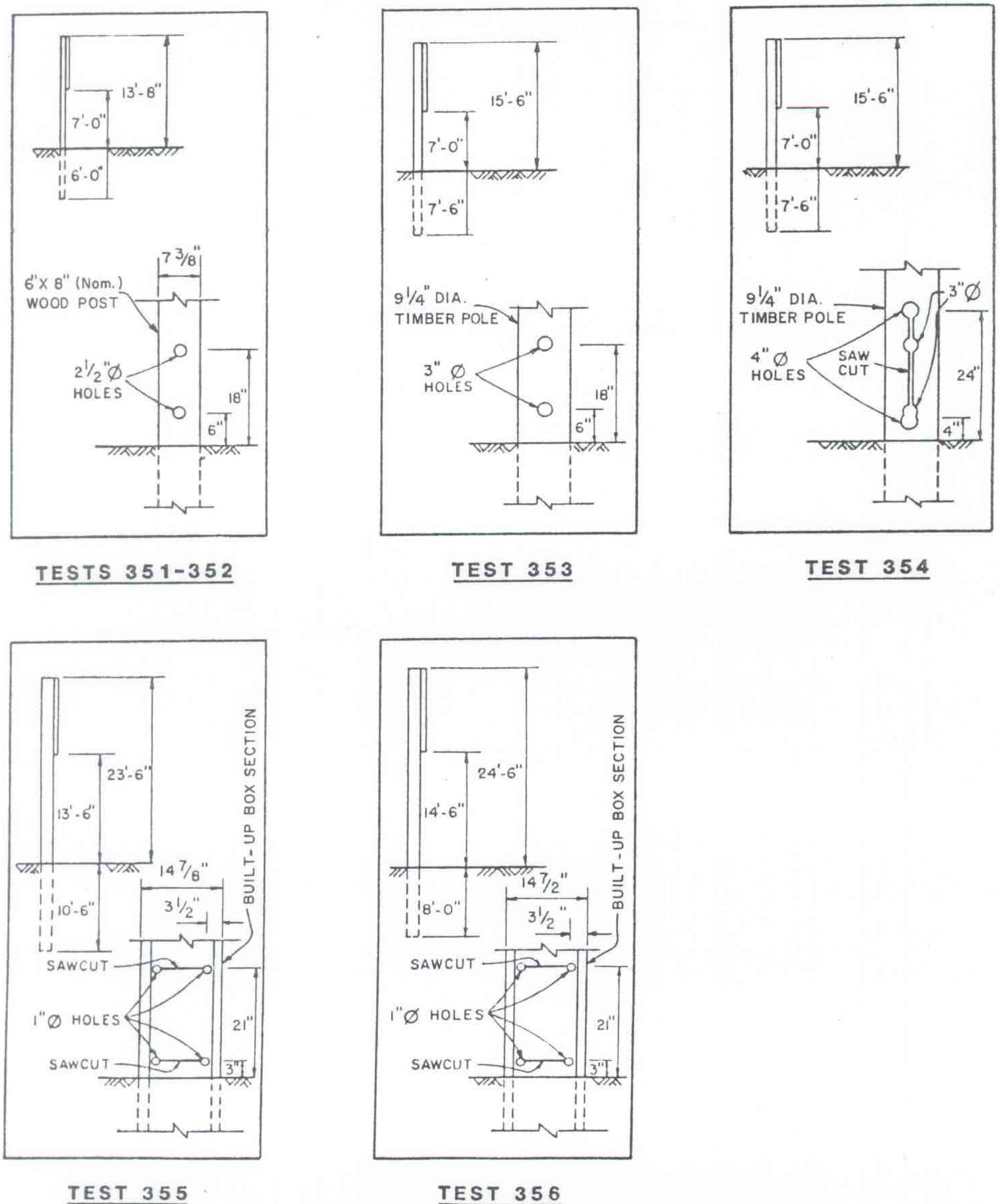


TABLE 1. SUMMARY OF DOUGLAS FIR TIMBER POLE DIMENSIONS*

Class	Maximum Length (ft)	Maximum Embedment (ft.)	Maximum Sign Area (ft^2)	Circumference 6 ft. from Butt End (in.)	Circumference at Top (in.)	Avg. Diameter 6 ft. from Butt End (in.)	Avg. Diameter at Top (in.)
1	25	10.0	265	33.5 - 38.5	27 - 32	10.66 - 12.25	8.59 - 10.19
2	30	9.5	215	34.0 - 39.0	25 - 30	10.82 - 12.41	7.96 - 9.55
3	20	9.0	170	27.0 - 32.0	23 - 28	8.59 - 10.19	7.32 - 8.91
	25			29.5 - 34.5		9.39 - 10.98	
	30			32.0 - 37.0		10.19 - 11.78	
	35			34.0 - 39.0		10.82 - 12.41	
4	20	8.5	130	25.0 - 30.0	21 - 26	7.96 - 9.55	6.68 - 8.28
	25			27.5 - 32.5		8.75 - 10.35	
	30			29.5 - 34.5		9.39 - 10.98	
	35			31.5 - 36.5		10.03 - 11.62	
5	20	7.5	110	23.0 - 28.0	19 - 24	7.32 - 8.91	6.05 - 7.64
	25			25.5 - 30.5		8.12 - 9.71	
	30			27.5 - 32.5		8.75 - 10.35	
	35			29.0 - 34.0		9.23 - 10.82	
6	20	7.0	85	21.0 - 26.0	17 - 22	6.68 - 8.28	5.41 - 7.00
	25			23.0 - 28.0		7.32 - 8.91	
	30			25.0 - 30.0		7.96 - 9.55	
	35			27.0 - 32.0		8.59 - 10.19	

*References:
1) American National Standard (ANSI) "Specifications and Dimensions for Wood Poles", 1972, Tables 5 and 8
2) Caltrans Standard Specifications, January 1981, Section 56-2.02C, "Timber Poles", page 56-8. (Allows circumferences to be 5 inches maximum more than value given in ANSI Specifications.)
3) Caltrans Sign Reference Sheet 26, July 5, 1973.
4) Caltrans' specifications permit use of ponderosa pine which has different circumferences than Douglas fir for each class.

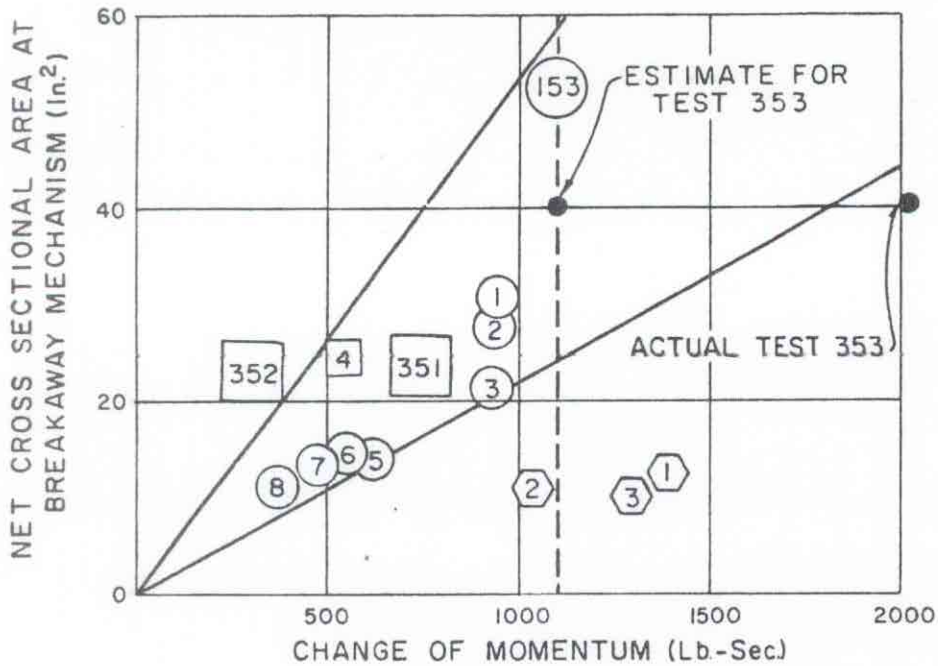
Based upon the results of the previous wood sign support tests, the researchers were quite certain the larger sized poles would not breakaway in crash tests with small cars. A small sampling of Caltrans districts and pole suppliers indicated there were only a handful of signs in place using Class 1 or 2 poles. Most poles were Classes 3-6. An attempt was made to estimate the largest size pole that would breakaway satisfactorily in a crash test. Figure 3 shows a plot of various crash tests and pendulum tests previously performed (1,10,11). It was decided to test poles having a net shear area of 40 square inches for Test 353. This was achieved by drilling 3-inch diameter holes in Class 5 D.F. poles having a 9 1/4-inch diameter at a point 18 inches above ground.

The test sign design and construction procedures in Test 353 were similar to those for the signs using 6-inch x 8-inch posts. Poles were selected from the supply yard of a neighboring utility company on the basis of straightness, lack of defects, and proper diameter. It should be noted that the poles were not perfectly round, hence, the pole diameters discussed in this report were actually average diameters based on a circumferential measurement. The sign panel again came in two sections, each 13 ft-0 in. x 4 ft-3 in. high. Overall sign panel size was 13 ft-0 in. x 8 ft-6 in. x 1 1/8 in. thick; sign panel composition was the same as for Tests 351-352, a sandwich construction. The sign panel size was close to the largest area allowed for Class 5 poles. Ground clearance was 7 ft-0 in. and pole spacing was 8 ft-0 in.

The installation procedure was similar to that for Tests 351-352. Pole embedment was 7 ft-6 in. instead of 6 ft-0 in. Eight 3/8-inch diameter lag screws were used to attach the sign panel to the poles in accordance with the Standard Plans (Figure E3). The 3-inch diameter breakaway holes were bored 6 and 18 inches above ground.

SUMMARY OF IMPACT TESTS ON WOOD POSTS AND TIMBER POLES

FIGURE 3



CALTRANS VEHICULAR TESTS

(153) Cl. 2 Timber Pole, DF, 11" dia, 4" dia bored holes, 2000 lb veh/ 40 mph/0°

[351] 6"x8" DF Wood Post; 2 1/2" dia bored holes; 2370 lb veh/19.8 mph/0°

[352] 6"x8" DF Wood Post; 2 1/2" dia bored holes; 2370 lb veh/57.7 mph/0°

SWRI PENDULUM TESTS, 20 mph, 2250 lb mass

(1) Cl. 4 Util. Pole, SP, 10.87" dia, 5" dia bored holes and 1/2" V notch

(2) Cl. 4 Util. Pole, SP, 10.66" dia, 5" dia bored holes and 1/2" V notch

(3) Cl. 4 Util. Pole, SP, 10.91" dia, 6" dia bored holes and 1/2" V notch

[4] 6"x8" SP Wood Post; 2 1/4" and 5/8" bored holes

(5) Cl. 4 Util. Pole, SP, 11.19" dia, staggered slot/shim; 1.25" uncut section remaining

(6) Cl. 4 Util. Pole, SP, 11.19" dia, staggered slot/shim; 1.25" uncut section remaining

(7) Cl. 4 Util. Pole, SP, 10.63" dia, staggered slot/shim; 1.25" uncut section remaining

(8) Cl. 4 Util. Pole, SP, 10.96" dia, staggered slot/shim; 1" uncut section remaining

SWRI VEHICULAR TESTS, Southern Pine

⬡1 Cl. 5 Util. Pole, 45 ft, 11.38" dia, staggered slot/shim; 1.25" uncut section; 2275 lb veh/20 mph/6°

⬡2 Cl. 5 Util. Pole, 45 ft, 10.83" dia, staggered slot/shim; 1" uncut section; 2275 lb veh/20.6 mph/4.1°

⬡3 Cl. 5 Util. Pole, 45 ft, 10.82" dia, staggered slot/shim; 1" uncut section; 2230 lb veh/61.8 mph/5.7°

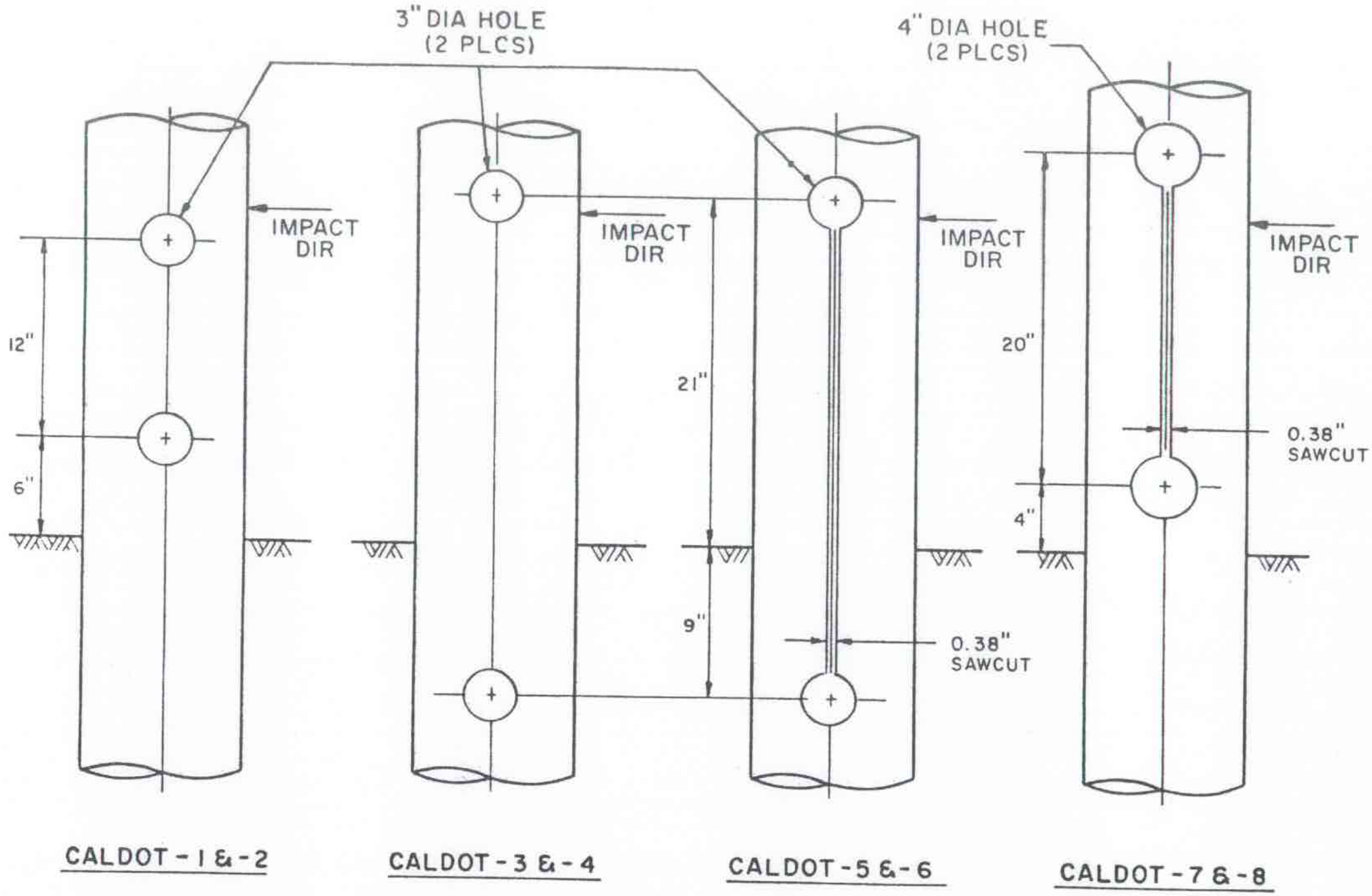
Timber Poles for SWRI Pendulum Tests

When the pole failed to breakaway when impacted by a 2205 lb car at 19.2 mph in Test 353, various other designs were considered and discarded. The slot-shim method as developed at Southwest Research Institute for utility poles was eliminated because it did not retain sufficient bending resistance to counteract wind loads on the sign panel. A braced post design was proposed but dropped because of aesthetic and maintenance objections.

Finally it was decided to conduct pendulum test on the standard design as a control and three other designs with different breakaway hole locations and diameters, and with a sawcut between holes. The hole patterns tested are shown in Figure 4. Southwest Research Institute (SWRI) performed the tests because they were one of only three agencies known to have a pendulum facility capable of performing the tests in the United States. The poles were selected in California from the yard of a pressure treatment company and shipped to SWRI. The results of the SWRI pendulum tests are reported in Reference 12 and were used to select the breakaway hole and sawcut pattern used in Crash Test 354.

Timber Poles for Crash Test 354

Since the test sign used in Test 353 was virtually undamaged, it was used again for Test 354 except that the other pole was impacted. Both poles were modified by drilling new 4-inch-diameter holes at 4 and 24 inches above ground and connecting them with a saw cut. The bottom hole overlapped the existing 3-inch-diameter hole. A special hole boring rig was designed to center the holes in the pole and permit easier drilling



HOLE PATTERNS FOR BREAKAWAY TIMBER POLES SwRI PENDULUM TESTS

FIGURE 4

than with a hand held drill. Even so, the drill bit tended to drift where it overlapped the existing hole. A small chain saw was used to connect the holes. Figure 5 shows the hole boring equipment and the sawcut being made.

Timber Poles for Caltrans Static Bend Tests

The vehicle impact results with the 4-inch hole/sawcut pattern used in Test 354 were a significant improvement over Test 353, but still resulted in an overly high change of momentum in the test vehicle. Therefore, it was decided to conduct static bend tests on some 9 1/4 inch diameter poles with the 4-inch hole/sawcut pattern used in Test 354 to determine whether or not the poles were overdesigned for wind loading or could be weakened further.

The three test samples for the static bend tests by Caltrans were 30-foot long Class 5 D.F. timber poles. They were selected by the researchers from the neighboring utility district supply yard. Final test length of the pole specimens was 16 ft-0 in., cut so that the average pole diameter at the upper 4-inch diameter hole was 9 1/4 inches. Table F2 in Appendix F is a summary of knots counted in the pole specimens.

The drill and jig used to drill 4-inch holes in the poles for Test 354 were used again to drill holes in the three poles. A chain saw was used to cut the slot between holes. It was discovered after two poles had been drilled that the holes were off center. This appeared to be due in part to a slight misalignment of the drill shaft with the clamping jig, and to the irregular shape of the pole. It can be shown, for example, that if a hole is drilled midway between the smallest and largest diameter segments of an oblong shaped pole section,

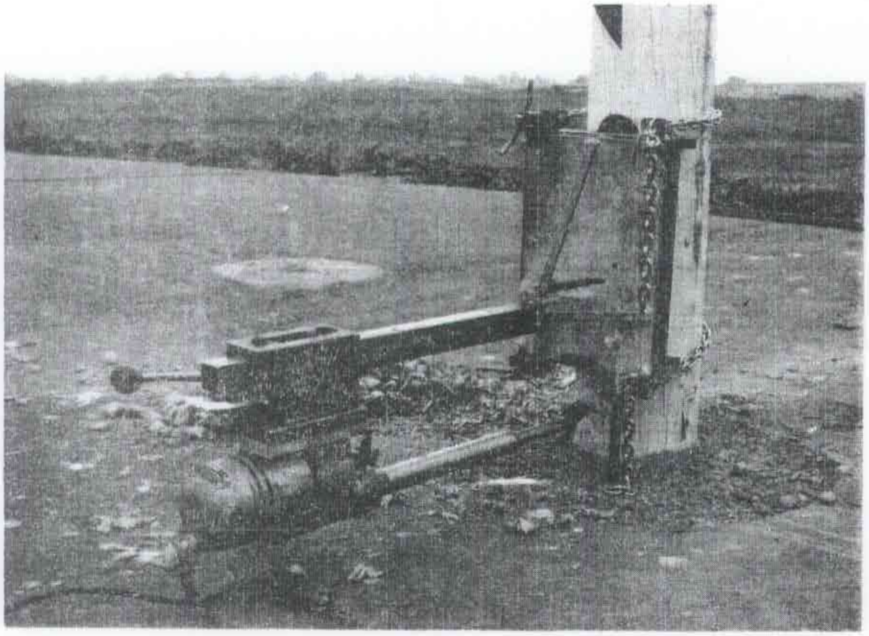
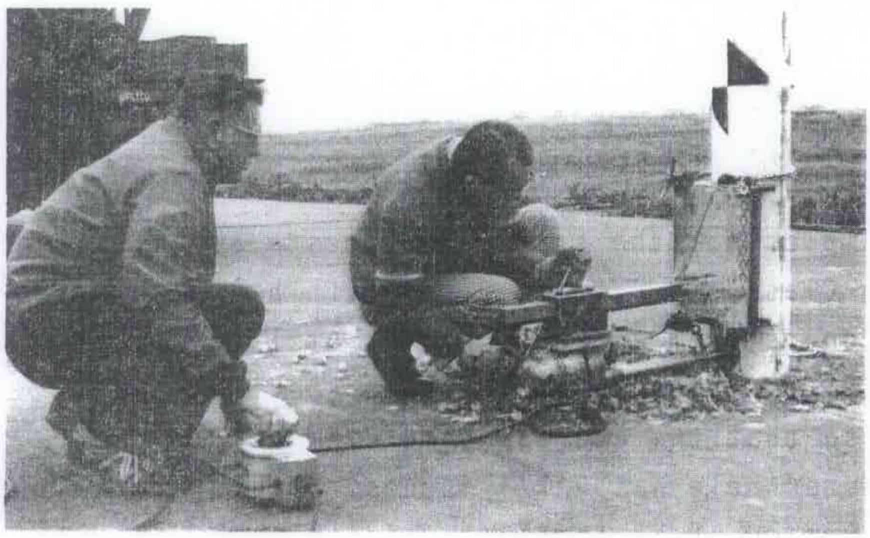


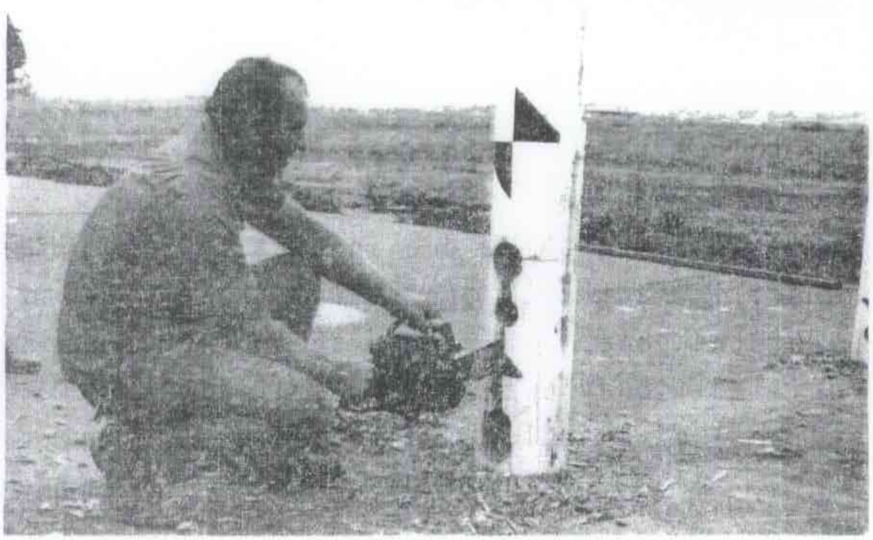
Figure 5

Test 354

Drill Jig Clamped
On Pole



Drilling 4-Inch
Diameter Holes



Using Chain Saw
To Make Sawcut
Between Holes

the hole will automatically be off center using that clamping jig. Figure 6 gives the dimensions of the holes in the three specimens.

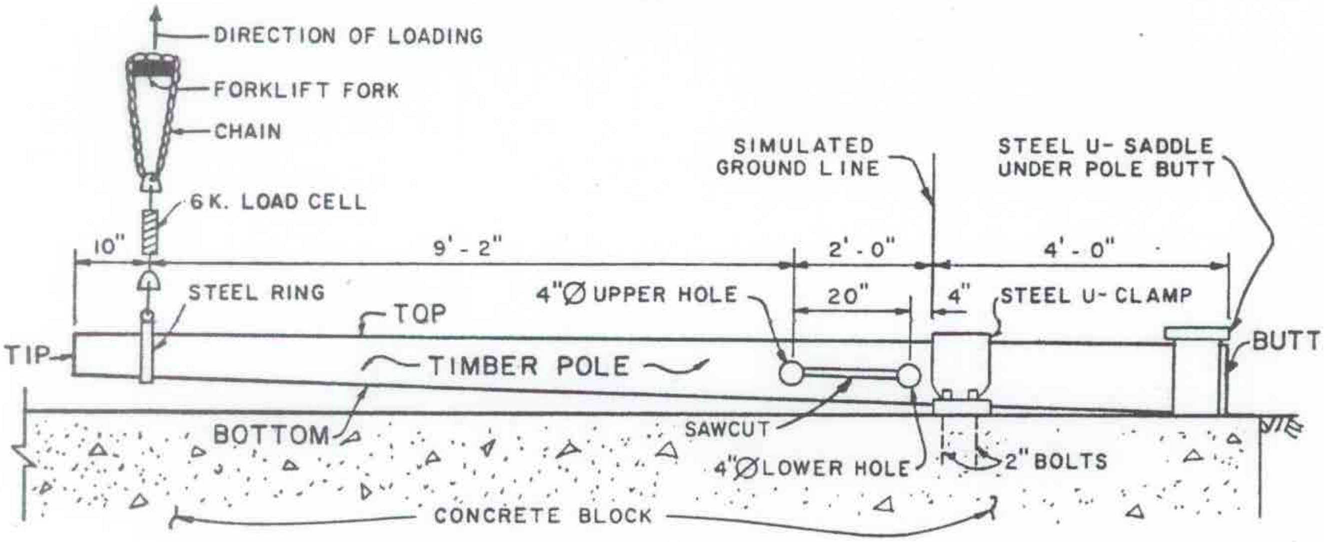
The poles were anchored to a thick existing concrete slab using embedded 2-inch-diameter bolts that projected above the concrete. A U-shaped steel plate was put over the pole at the simulated ground line and attached to the projecting bolts. A 1/4-inch-thick rubber pad placed between the pole and clamp helped spread the load slightly, and allowed a small deflection to simulate slight yielding in the soil. The butt end of the pole was cradled by a U-shaped steel plate that rested on the concrete slab. A narrow ring cut from a round steel pipe fit over the tip of the pole, and was used to load the pole at a point 11 ft-2 in. from the "groundline" clamp. The 11 ft-2 in. dimension was the same height as that of the resultant load on the sign panel used in Tests No. 353 and 354. The test setup is shown in Figures 6 and 7.

A large forklift was used to load the poles. A chain was put over one fork, and was connected to the steel loading ring with U-shaped shackles. A 6-kip load cell was inserted between the shackles to measure the load. A Houston pot was placed near the loading point to measure deflection of that point. The loading rate was relatively slow, but not uniform throughout the test or from one test to another. It was controlled manually by the lift lever on the fork-lift. Loading to failure took under 30 seconds.

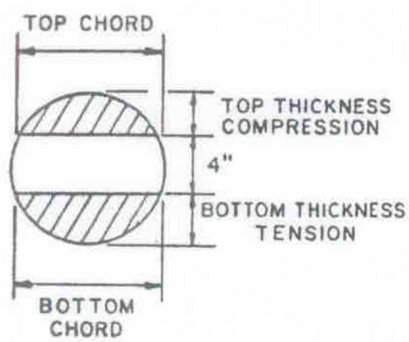
The axes of the drilled holes were on a level horizontal plane during the tests. The holes in the poles used for Tests 1 and 2 were off center, so the thinnest section on

STATIC BEND TESTS OF TIMBER POLES
SPECIMEN DIMENSIONS

FIGURE 6



TEST SETUP - ELEVATION VIEW



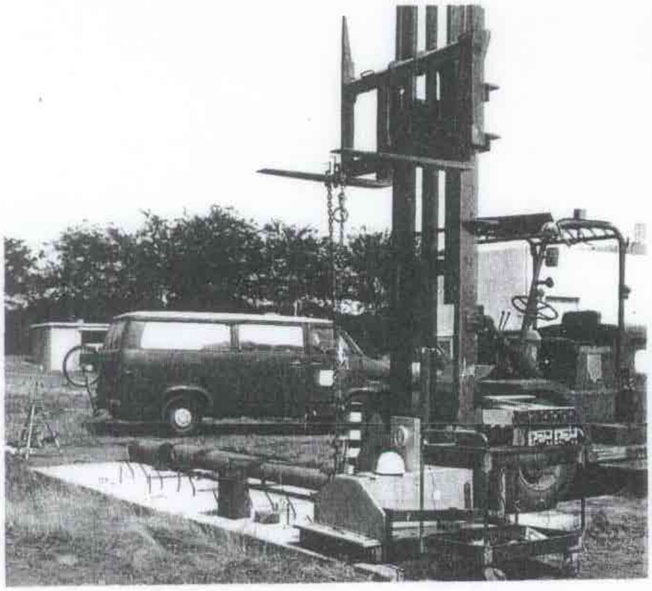
SECTION THROUGH POLE AT HOLES

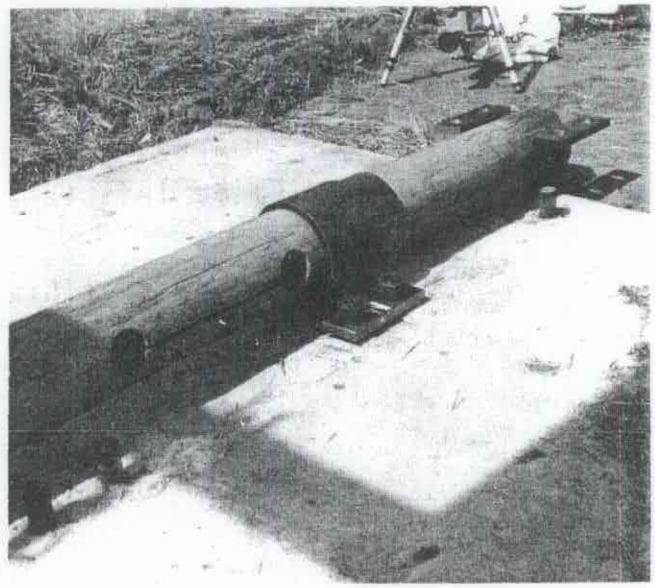
AVERAGE DIAMETERS OF POLES (In.)

Location	Test 1	Test 2	Test 3
Tip	8.56	7.48	7.92
Upper Hole	9.17	9.25	9.19
Lower Hole	9.23	9.39	9.51
Ground	9.23	9.47	9.58
Butt	9.71	10.07	10.11

DIMENSIONS AT DRILLED HOLES (In.)

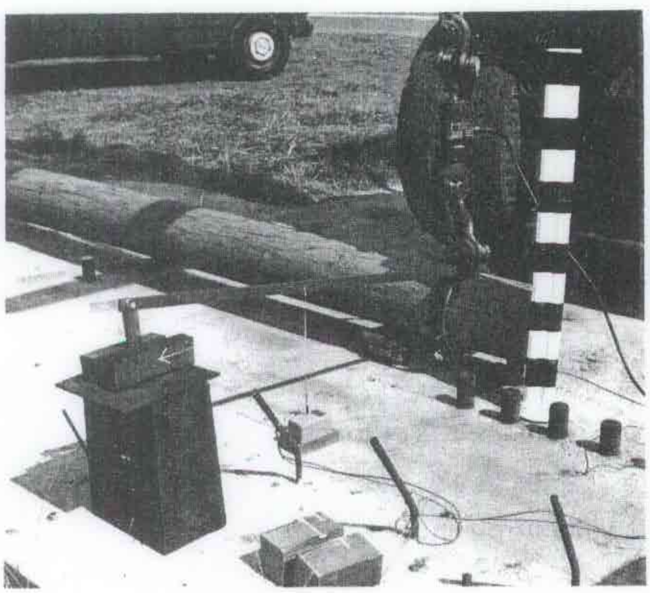
Location	Test 1	Test 2	Test 3
Upper Hole			
Top Thickness	2 1/4	2 1/4	2 1/2
Top Chord	7 3/4	7 5/8	8
Bottom Thk.	3	3 1/8	2 3/4
Bottom Chord	8 1/2	8 1/2	8 3/8
Lower Hole			
Top Thickness	2 1/4	2 3/8	2 3/4
Top Chord	7 3/4	8	8 1/2
Bottom Thk.	3 1/8	3 1/8	2 3/4
Bottom Chord	8 5/8	8 1/2	8 5/8
Sawcut Width	1/4-1/2"	1/4-1/2"	1/4-1/2'

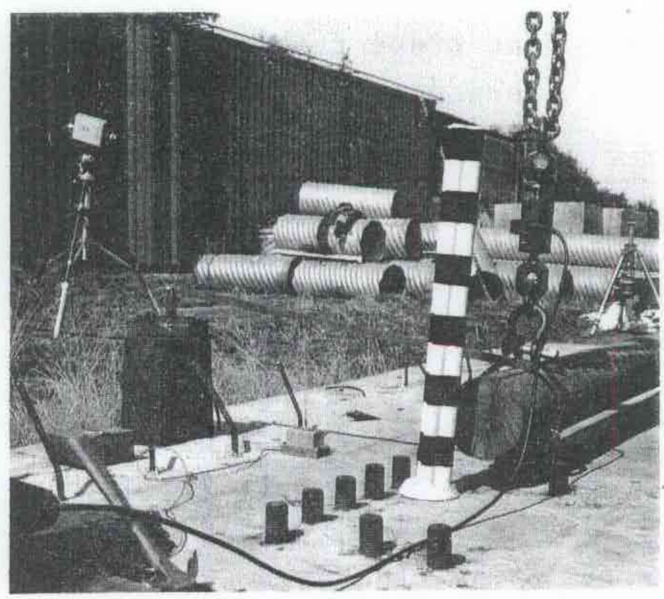




Forklift Used To
Load Poles

Clamps For Poles





Deflection Pot Attached To Lever Arm, Loading Ring, Load Cell Between Shackles

Figure 7 Caltrans Static Bend Tests On Timber Poles one side of the holes was placed in an up position where compression would occur during bending. It was assumed the ultimate compressive strength of the wood parallel to the grain would be less than the ultimate tensile strength.

In July 1980 the cost of Class 5 D.F. timber poles was quoted at $3.12 to $3.28 per lineal foot.

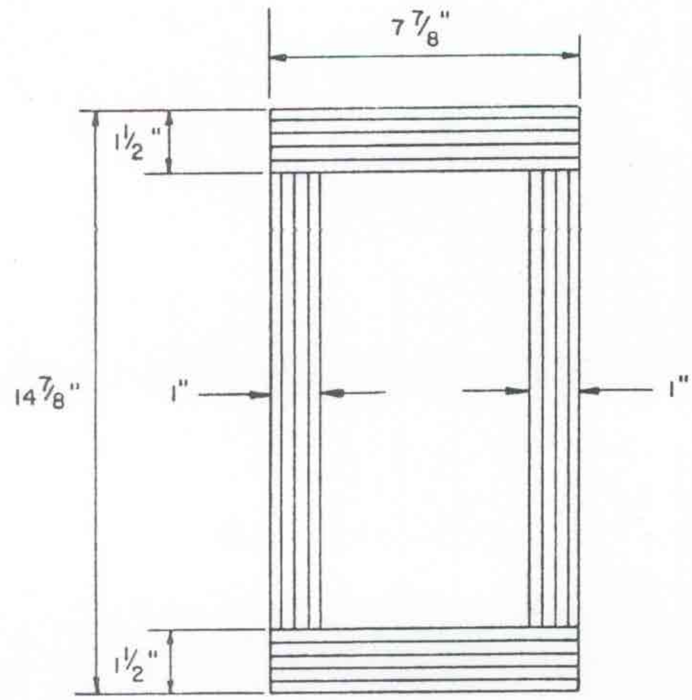
5.1.2.3 Two-Legged Roadside Signs With Laminated Wood Veneer Box Section Supports

After the timber pole designs in Tests 353 and 354 proved inadequate, it was decided to try built-up wood post sections using high strength parallel-laminated wood veneer lumber. The contract with SWRI was extended to include pendulum and static bend tests on these designs. Figures 8 and 9 show the structural sections and breakaway cutout patterns that were tested. Appendix D provides a detailed description of the properties of laminated wood veneer lumber. All veneers were Douglas fir.

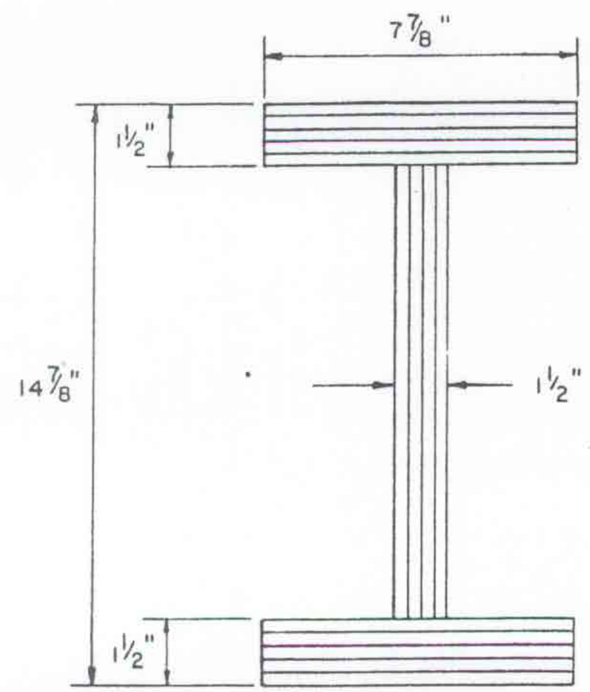
Both box and H-section posts were subjected to pendulum and static bend tests at SWRI. The built-up section dimensions suggested by the manufacturer allowed full use of a 2 ft-0 in. standard width billet of the laminated lumber without any waste material. The flanges were cut 7 7/8 inches wide (3 pieces from a billet, allowing for two sawcuts) and the webs were cut 11 7/8 inches wide (2 pieces from a billet). The flange and web of the H-section were both 1 1/2 inches thick; the box section had 1 1/2-inch thick flanges and 1-inch thick webs. Overall dimension of both sections were 7 7/8 x 14 7/8 inches. The laminated veneer lumber was fabricated in Oregon, shipped to Boise, Idaho where it was

DIMENSIONS FOR LAMINATED WOOD VENEER BOX AND H - SECTION POSTS

FIGURE 8



(a) CROSS-SECTION OF BOX SECTION SHOWING LAMINATIONS

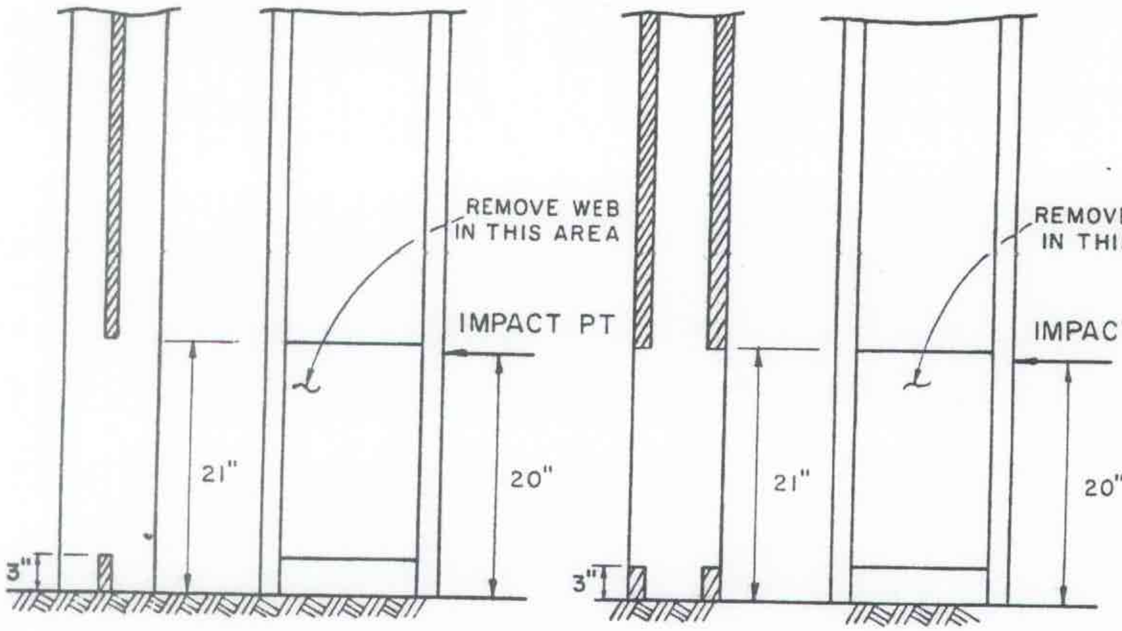


(b) CROSS-SECTION OF H-SECTION SHOWING LAMINATIONS

HOLE PATTERNS FOR BREAKAWAY LAMINATED WOOD VENEER BOX AND H - SECTION POSTS

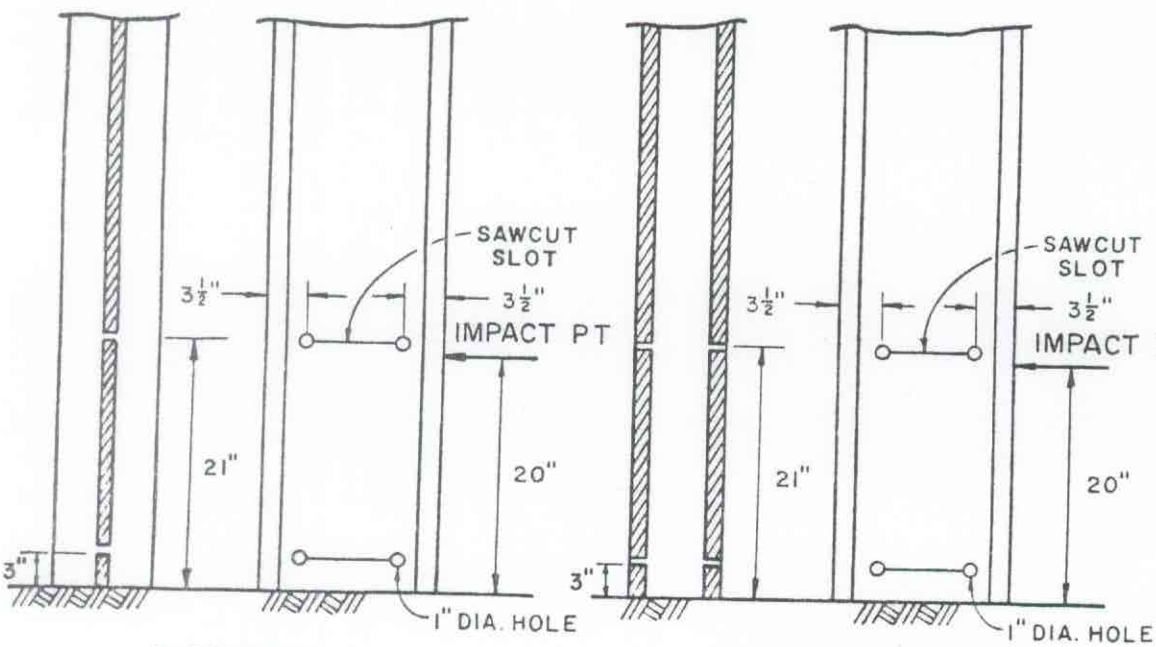
SwRI PENDULUM AND STATIC BEND TESTS

FIGURE 9



H-SECTION   BOX SECTION

WINDOW CUTOUT METHOD



H-SECTION   BOX SECTION

HOLE / SLOT METHOD

assembled into box and H-section and posts treated with pentachlorophenol in oil, then shipped to SWRI.

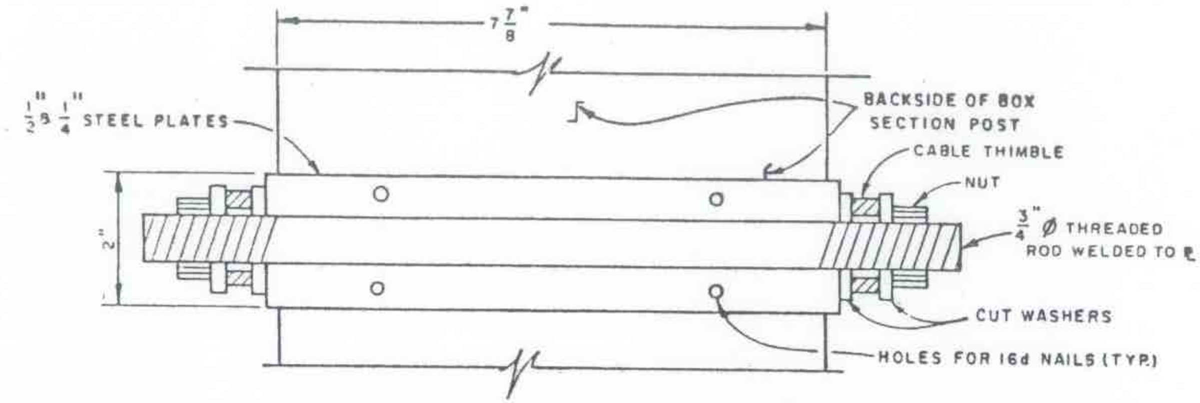
Breakaway modifications were made to the posts after they reached SWRI. Table 2 gives the cutout patterns for each of the test specimens. The 1-inch-diameter holes with connecting sawcuts were used when it was determined the full web cutouts reduced the static bend strength too much.

Even with this change, the resultant static strength was not high enough. It was determined that the method of clamping a short length of the beam four feet long, which was much shorter than the moment arm from load to clamp, caused an unusually high shear stress in the tests. It was concluded that if a box beam were embedded in the ground to a depth of 7 to 10 feet and loaded to simulate wind forces, the shear on the post would be less and would occur farther from the end of the box beam. The resisting forces from the soil would be more distributed than the clamp reactions, less inclined to cause flange crushing at load concentration points, and be representative of the anticipated field conditions. Hence, it was more likely that the true full strength of the box beam could be developed when subjected to windloads without premature shear or crush failure.

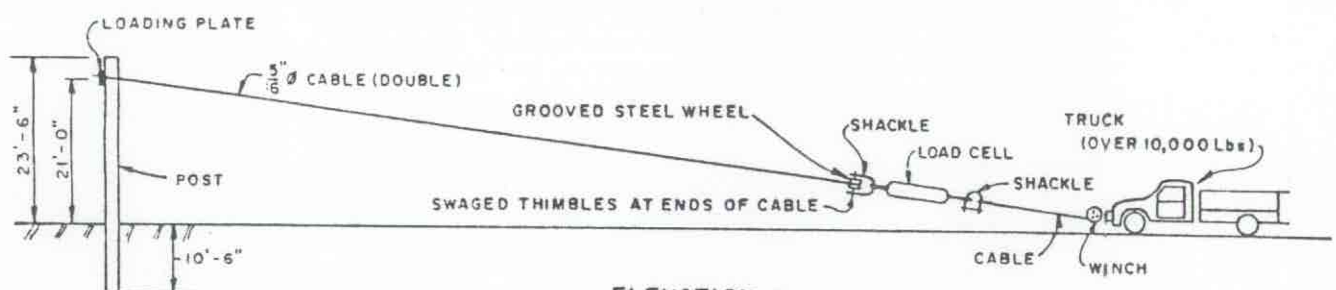
Based on the above assumptions, a static bend test of a box section post was conducted by Caltrans. Figure 10 shows the test setup. The post was sized to support one half of a 200-square-foot sign panel with a clearance of 16 feet from the ground to the bottom of the sign. The post was embedded 10 ft-6 in. in the ground. It was set in a 24-inch-diameter hole that was drilled with a bucket auger. The post was set in the hole and plumbed, and the hole was backfilled and

STATIC BEND TEST OF A LAMINATED WOOD VENEER BOX SECTION POST

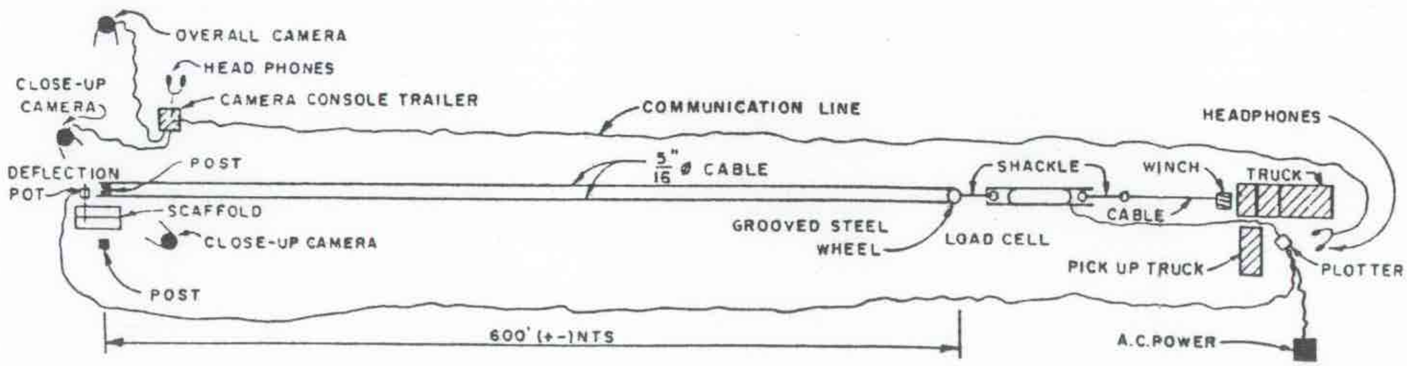
FIGURE 10



LOAD APPLICATION, PLATE AND BOLT



ELEVATION



PLAN

hand tamped in layers. An electric drill and saber saw powered by a small portable generator were used to cut the hole and slot patterns in the post after it was set in the ground.

A steel bracket was attached to the post 21 ft-0 in. above ground which represented the resultant wind loading point of a 10-foot-high sign panel. A double 5/16-inch-diameter steel cable was connected between the steel bracket and a winch on a heavy drill rig truck about 600 feet away. This long length of cable minimized the downward load component on the post. It was expected that most roadside sign panels having a ground clearance of 16 feet would be less than 200 square feet in area. Therefore, the post size tested should be adequate to withstand wind loads for most sign panels that would be used on roadside signs by Caltrans.

During the time the box and H-section posts were being sized, the Caltrans design units decided to use the 10-year mean recurrence interval wind speed map from the AASHTO specifications (3) as a standard. The maximum wind speed for California on that map is 60 mph, with the exception of a small area in the northeast corner of the state which is slightly higher. There are, of course, a few local areas known to have higher wind speeds which would be treated individually. The 10 year/60 mph wind criterion was chosen based on the philosophy that this would result in the "softest" possible design for impacts by lightweight vehicles, and that if a few signs were blown down by unusually high winds, this could be tolerated.

After the pendulum and static bend tests had been completed, it was decided to use a box section in preference to an

H-section for several reasons: (1) the box section would resist a greater wind load without increasing the impact resistance too much, (2) the manufacturer felt the box section might be less susceptible to damage during handling, considering, for example, an H-section dropped on the edge of a flange, and (3) the box section would have greater torsional and transverse load capacity.

Since the box section has slightly more material - two 1-inch webs vs. one 1 1/2-inch web in the H-section - it was slightly more expensive. The cost of the posts purchased in March 1980 for the SWRI test were:

$4.51/lin. ft. - H-section
$6.04/lin. ft. - Box section
$0.75/lin. ft. - Treatment with PCP in oil

By fall 1980 the cost of the box section had decreased slightly. These costs were estimated by the manufacturer to be typical market prices. These costs should not be compared directly with the timber pole costs quoted in the last section because those poles were for a sign panel almost half the area of the ones supported by the box section posts. The manufacturer stated that most of the cost was for the material and would vary 15-20% over the bending strength range of 2500 to 3150 psi.

Actually, the cost of the box section post should be compared to the cost for a steel post with slip base and concrete footing which is the only current acceptable alternate.

The box section posts used for Tests 355 and 356 were designed and installed in the same way as the post used for the Caltrans static bend test. Again, a Caltrans drill crew augered the holes and a Caltrans district sign crew erected the test sign. Post embedment was 10 ft.-6 in. and 8 ft-0 in. respectively for Tests 355 and 356. The embedment depth was decreased in Test 356 because 10 ft-6 in. was considered excessive. The box section posts weighed approximately 12 lbs per foot. High posts were used in this test to maximize the mass of the test sign, assuming this would be the worst test condition.

Two sign panel sections each 21 ft-0 in. x 5 ft-0 in. high were used to make up a full sign panel with overall dimensions of 21 ft-0 in. x 10 ft-0 in. x 2 5/8 in. thick. Sign panel ground clearance was 13 ft-6 in. and 14 ft-6 in. The greater sign panel thickness in Tests 355 and 356 was required because of the greater post spacing of 12 ft-0 in. and 13 ft-0 in. respectively. Basic panel construction was the same as the thinner panels and consisted of a treated paper honeycomb core sandwiched between two aluminum sheets. Two vertical extruded aluminum rectangular tubes inside the panel were located at the same spacing as the posts, and attachment hardware went through these tubes. For Test 355 eight 1/2-inch-diameter bolts were used to connect the sign panel to the posts. The bolts went entirely through the box section. For Test 356 the connectors were sixteen 1/2-inch diameter x 5 1/2-inch long lag screws which only penetrated the box section flange adjacent to the sign panel. Table F1 in Appendix F summarizes the results of some lag screw pull-out tests.

After the static bend test it was impossible to pull out the post stub embedded in the ground. The bucket auger was used to grind out the post while redrilling the hole for the next test sign. This splintered wood clogged the auger teeth and slowed the operation.

When the posts were set for Test 355, wire rope chokers 12 feet long with swaged loops on each end were put around the posts about 2-3 feet below the ground surface. One end was put through the loop on the other end, drawn tight and the upper loose end was buried a few inches below the ground surface. After the test a rectangular solid wood mandrel two feet long was lowered inside the box section to the level of the choker where it went around the post. The mandrel prevented the choker from crushing the post completely. The upper loop end of the choker cable was attached to the hoist on a drill rig, and the post stub was extracted quite easily.

5.1.2.4 Table of Wood Supports Tested

The following Table 2 lists all the test specimens and their breakaway modifications that were subjected to static bend tests, pendulum tests, and crash tests during this project.

TABLE 2. TEST ARTICLE DESCRIPTION

Full Scale Static Bend Tests (SwRI and Caltrans)

Test No.	Test Organization	Support Type	Breakaway Modification
SwRI-1	SwRI	H-Section	Web removed between 3" and 21" above "ground"
SwRI-2	SwRI	H-Section	Ditto
SwRI-3	SwRI	Box Section	Ditto - Both webs
SwRI-4	SwRI	Box Section	1"-dia. holes in webs 3 1/2" from flanges @ 3" and 21" aboveground; horizontal sawcuts between holes
1	Caltrans	Class 5 D.F. Pole	4"-dia. holes @ 4" and 24" aboveground connected with sawcut
2	Caltrans	Class 5 D.F. Pole	Ditto
3	Caltrans	Class 5 D.F. Pole	Ditto
4	Caltrans	Box Section	1"-dia. holes in webs 3 1/2" from flanges @ 3" and 21" aboveground; horiz. sawcuts between holes

Notes: 1. H- and box section supports were built up from laminated wood veneer lumber; overall dimensions were 7 7/8" x 14 7/8". Poles were 9 1/4" dia. at 24" aboveground.

Full Scale Pendulum Tests (SwRI)

Test No.	Support Type	Breakaway Modification
CALDOT-1	D.F. Pole	3"-dia. holes @ 6" and 18" aboveground
CALDOT-2	D.F. Pole	Ditto

Full Scale Pendulum Tests (SwRI) (Cont'd)

Test No.	Support Type	Breakaway Modification
CALDOT-3	D.F. Pole	3"-dia. holes @ 21" above-ground & 9" below ground
CALDOT-4	D.F. Pole	Ditto
CALDOT-5	D.F. Pole	Ditto plus holes connected with a sawcut
CALDOT-6	D.F. Pole	Ditto
CALDOT-7	D.F. Pole	4"-dia. holes @ 4" and 24" aboveground and connected with a sawcut
CALDOT-8	D.F. Pole	Ditto
CALDOT-9	H-Section	Web removed between 3" and 21" aboveground
CALDOT-10	Box Section	Ditto - both webs
CALDOT-11	H-Section	1"-dia. holes in web 3 1/2" from outer face of flanges @ 3" and 21" aboveground; horiz. sawcuts between holes

Notes:
1. Poles varied from 9.13" to 9.53" dia. at grade.
2. H- and box sections were built up from laminated wood veneer lumber; overall dimensions 7 7/8" x 14 7/8".
3. Pendulum mass 2250 lbs, impact speed 20 mph, honey-comb nose - five stage "Vega".

Vehicular Impact Tests (Caltrans)

Test No.	Veh. Impact Speed (mph)	Support Type	Breakaway Modification
351	19.8	6" x 8" post	2 1/2"-dia. holes @ 6" and 18" aboveground
352	57.7	6" x 8" post	Ditto

Vehicular Impact Tests (Caltrans) (Cont'd)

Test No.	Veh. Impact Speed (mph)	Support Type	Breakaway Modification
353	19.2	9 1/4" dia. pole	3"-dia. holes @ 6" and 18" aboveground
354	19.9	9 1/4" dia. pole	4"-dia. holes @ 4" and 24" aboveground connected with a sawcut.
355	19.2	7 7/8" x 14 7/8" box section	1"-dia. holes in webs 3 1/2" from flanges @ 3" and 21" aboveground; horiz. sawcuts between holes
356	58.4	7 7/8" x 14 7/8" box sections	Ditto

5.1.3 Test Vehicles and Pendulum Mass

Two 1976 Toyota Corolla 2-door sedans were used for all six crash tests. After each test all damaged vehicle parts were replaced. Hence, for all tests the vehicles were in good condition and free of major body damage and missing structural parts. All equipment on the vehicles was standard. Their engines were front mounted. Vehicle dimensions are shown in Figure A1 in Appendix A.

The gross static mass of the vehicle was 2370 lbs, including instrumentation and the 165 lb dummy. The test inertial mass of the vehicle, which excludes the dummy mass, was 2205 lbs. No ballast was used.

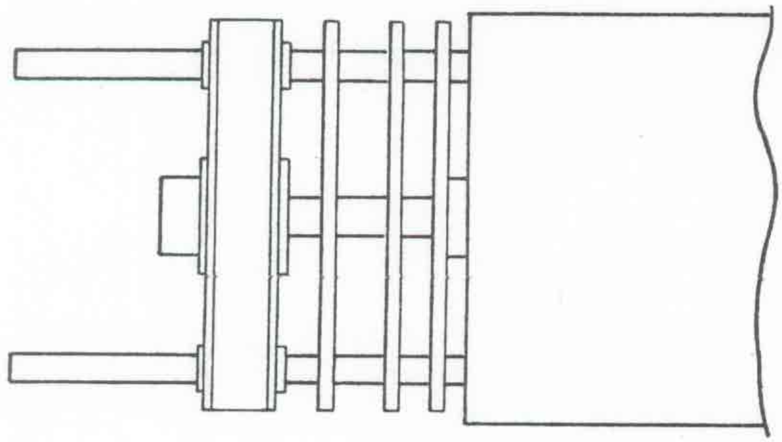
The vehicles were self-powered; a speed control device maintained the desired impact speed once it was reached; and the ignition was cut off just before impact. Remote braking was possible after impact. Guidance of the vehicle was achieved with an anchored cable which passed through a knockoff bracket on one of the front wheels of the vehicle. No constraints were put on the steering wheel.

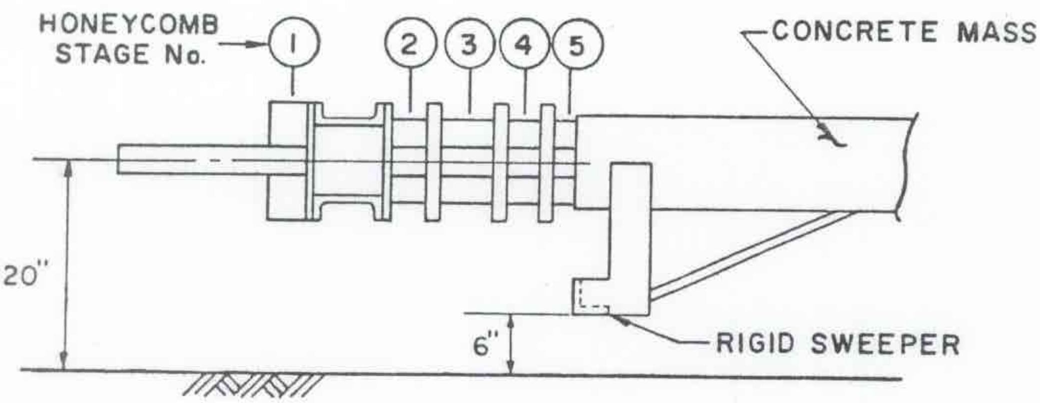
A detailed description of the test vehicle equipment and guidance system is contained in Appendix A.

The pendulum mass used at SWRI was reinforced concrete and weighed 2250 lbs. The crushable nose attached to the front end of the pendulum mass was designed to simulate the crush characteristics of a pre-1974 Chevrolet Vega. A diagram of the pendulum nose is shown in Figure 11. The pendulum mass has a swing radius of 26 feet and could be positioned to obtain impact speeds of 20 mph.

CRUSHABLE PENDULUM NOSE DESIGN

FIGURE 11





HONEYCOMB CONFIGURATION

Stage No.	Height (in.)	Width (in.)	Thickness* (in.)	Static Strength (psi)
1	12	8	4	75
2	8	4	4	75
3	8	4	6	130
4	8	4	4	230
5	8	8	2	230

*Thickness before 1/4-in. precrush

5.1.4 Data Acquisition Systems

The impact phase of each crash test was recorded with several high speed movie cameras, one normal speed movie camera, one black and white sequence camera and one color slide sequence camera. All of these cameras were mounted on tripods except that one high speed camera was mounted in the car to record the dummy's motions. The test vehicle and test sign were photographed before and after impact with a normal speed movie camera, a black and white still camera and a color slide camera. A film report of this project has been assembled using edited portions of the movie coverage.

High speed movies and still photographs were also used to record the pendulum tests and static bend tests. Four accelerometers were mounted on the floor board of the vehicle in the passenger compartment at the longitudinal/lateral center of gravity. Two accelerometers were mounted in the longitudinal direction and one each in the lateral and vertical directions. Accelerometer data were collected to judge the occupant risk during impact. Two accelerometers were also used in the SWRI pendulum tests. They were mounted in the longitudinal direction at the rear of the pendulum mass.

An anthropomorphic dummy with tri-axial accelerometers mounted in its head cavity was placed in the driver's seat of the test vehicle to obtain motion and acceleration data. The dummy, Willie Makit, a Part 572 dummy built to conform to Federal Motor Vehicle Safety Standards by the Sierra Engineering Co., is a 50th percentile American male weighing 165 lbs. The dummy was restrained with a standard lap and shoulder belt for all tests.

A sliding weight device was attached to the right side of the vehicle. Upon impact the weight, fitted with ball bearings, slides two feet forward on a smooth rod. This was used as a rough check on the rattlespace time which was used to calculate the occupant/compartment impact velocity (O/C IV). The rattlespace time is the time required for the weight to slide two feet forward after impact. The O/C IV is a new measure of occupant risk outlined in Reference 6 which was just published. It was calculated more accurately using film and accelerometer data.

A strain-gaged load link was connected between the crane hook and test specimen in the SWRI static bend tests on box and H-section posts. A chart of load vs. time was obtained which showed the load at failure.

Load cells and deflection pots were used to obtain a plot of load vs. deflection for the Caltrans static bend tests on three timber poles and one box section post. These plots also showed the failure loads.

Appendices B and C contain a detailed description of the photographic and electronic equipment, camera layout, data collection and reduction techniques, accelerometer records, and film data plots.

5.1.5 New Crash Test Procedures

After the planned tests had been performed and when this report was being written, NCHRP Report No. 230 was published as an update of TRC No. 191. Report No. 230 called for crash tests with 1800 lb cars in addition to 2250 lb cars. It also recommended in the 60 mph tests the impact point should be at the quarter point of the vehicle bumper, rather than at the center of the bumper. Additional tests could not be included in this project, but the results of 2205 lb vehicle tests were compared with the new performance criteria in Report No. 230. This comparison is contained in Section 5.3 of this report, "Discussion of Test Results".

5.2 Test Results

Detailed test results from film and accelerometer data are contained in Appendices B and C. A film report has been assembled which shows the static bend test on a box section post and the six crash tests conducted by Caltrans. The pendulum and static bend tests conducted by SWRI are described in detail in References 12 and 13. Tables comparing test results and diagrams showing the final location of the test vehicles and test signs are contained in Section 5.3, Discussion of Test Results. The vehicle damage indices, TAD and VDI, assigned in the data summary sheets for the crash tests, are explained in References 14 and 15.

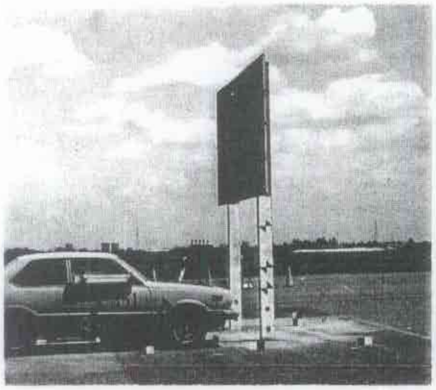
5.2.1 Test 351 - 6x8 Wood Post (2205 lbs/19.8 mph)

The summary of test data and photos taken before and after impact are shown in Figures 12 through 15.

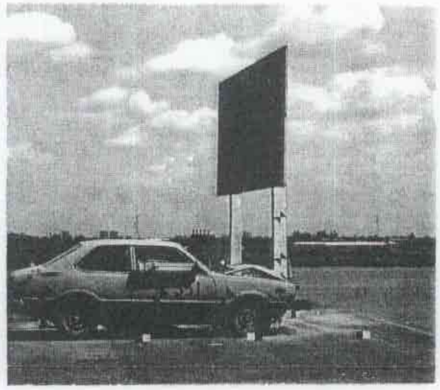
5.2.1.1 Impact Description - 351

The test vehicle impacted the right hand 6-inch x 8-inch post head-on, 2 inches off the longitudinal centerline of the vehicle, at 19.8 mph. The vehicle broke off a section of post 19 1/2 inches above ground next to the upper post hole, and 10 inches below ground.

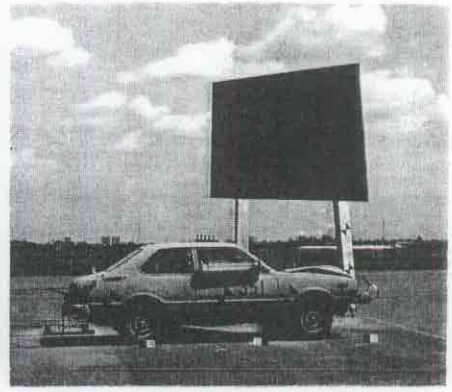
FIGURE 12. DATA SUMMARY SHEET - TEST 351



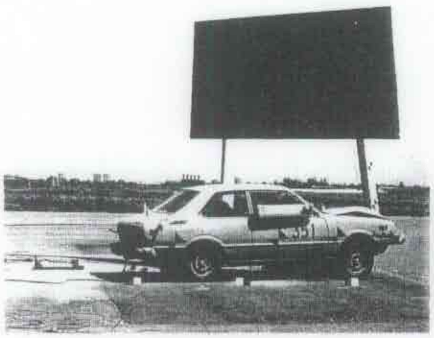
Impact + 0.00 Sec



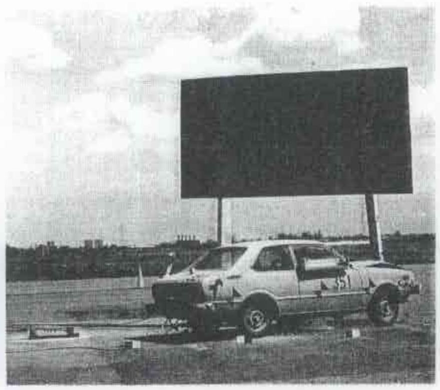
I + 0.06 Sec



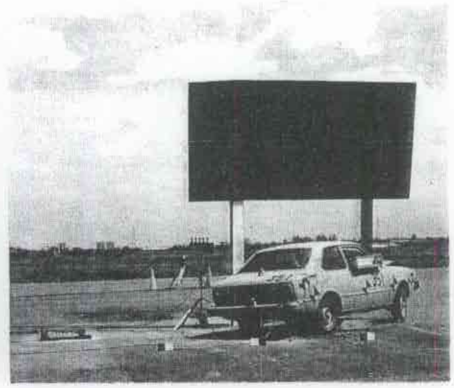
I + 0.23 Sec



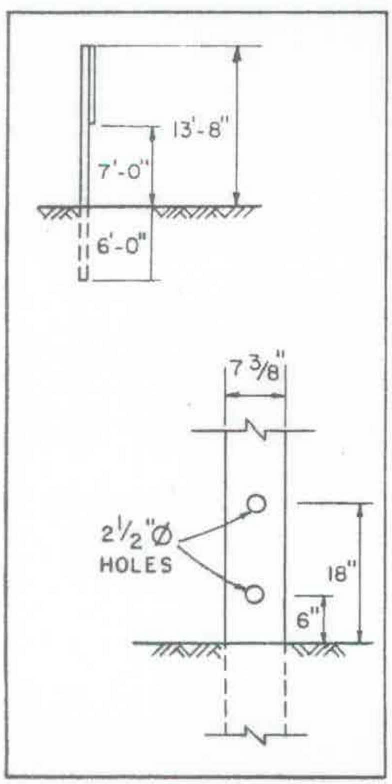
I + 0.45 Sec



I + 0.67 Sec



I + 1.55 Sec



TEST DATE	April 27, 1978
SIGN SUPPORTS	Douglas Fir Posts
Support Size	5 3/8" x 7 3/8" (6" x 8" Nom.)
Breakaway Holes	2 1/2"Ø @ 6" and 18" Aboveground
Support Spacing/Embedment	8'-0"/6'-0"
Soil Type	Std. - TRC #191
SIGN PANEL	Alum. 1 1/8" x 6'-8" x 13'-0" Wide
Ground Clearance	7'-0"
Support Connection	8 - 3/8"Ø Threaded Rods
TEST VEHICLE	1976 Toyota Corolla
Test Inertial Mass	2205 lbs
Gross Static Mass	2370 lbs
Impact Speed/Angle	19.8 mph/0°
DRIVER DUMMY	Part 572, 50th Percentile, 165 lb.
Restraints	Lap, shoulder belts
TEST RESULTS	
Occup/Compart. Impact Veloc.- Film	14.0 ft/sec
- Accel.	10.0 ft/sec
Change of Momentum - Film	959 lb-sec
- Accel.	685 lb-sec
Highest 50 ms Avg. Long. Accel.	-3.7 G's
Max. Crush - Front of Vehicle	7 in
Max. Rise/Pitch/Yaw	3"/3°/35°
Vehicle Damage TAD/VDI	FC-3/12FCMN3
Head Injury Criterion	--

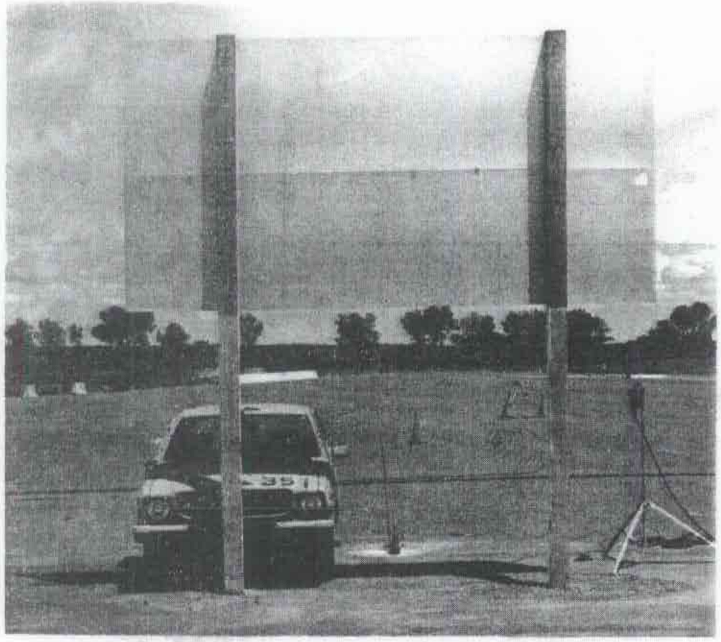
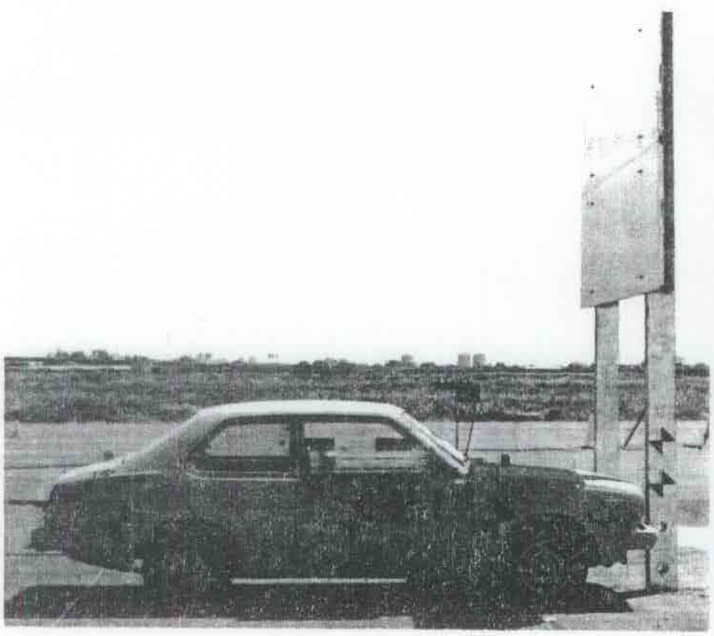
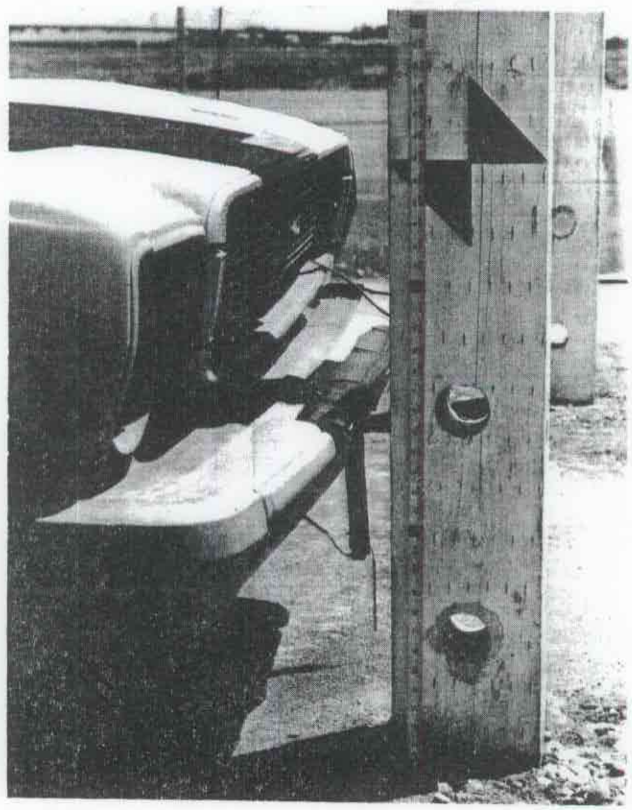


Figure 13

Test 351

Test Vehicle and Test
Sign Before Impact





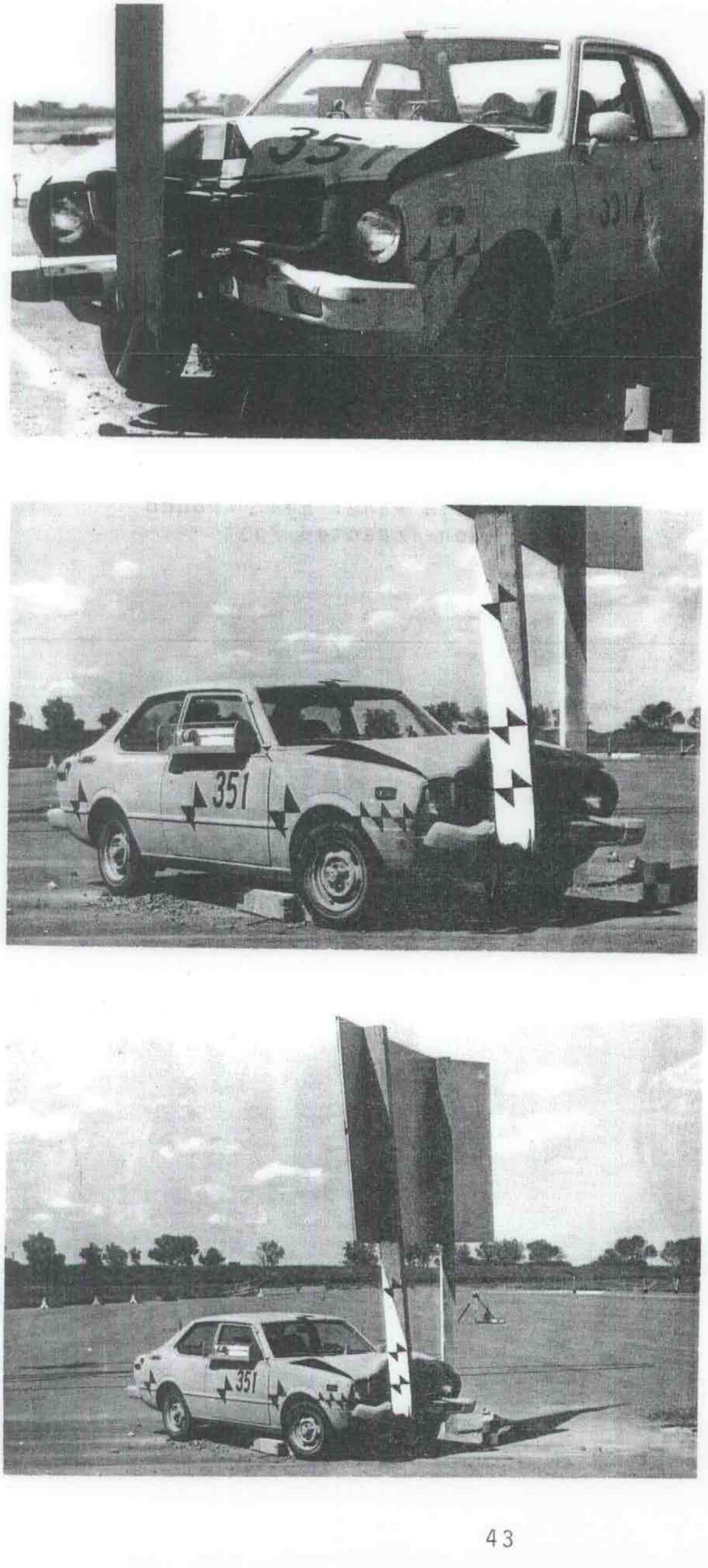


Figure 14

Test 351

Test Vehicle and Test Sign After Impact

Note Post Segment Under Car

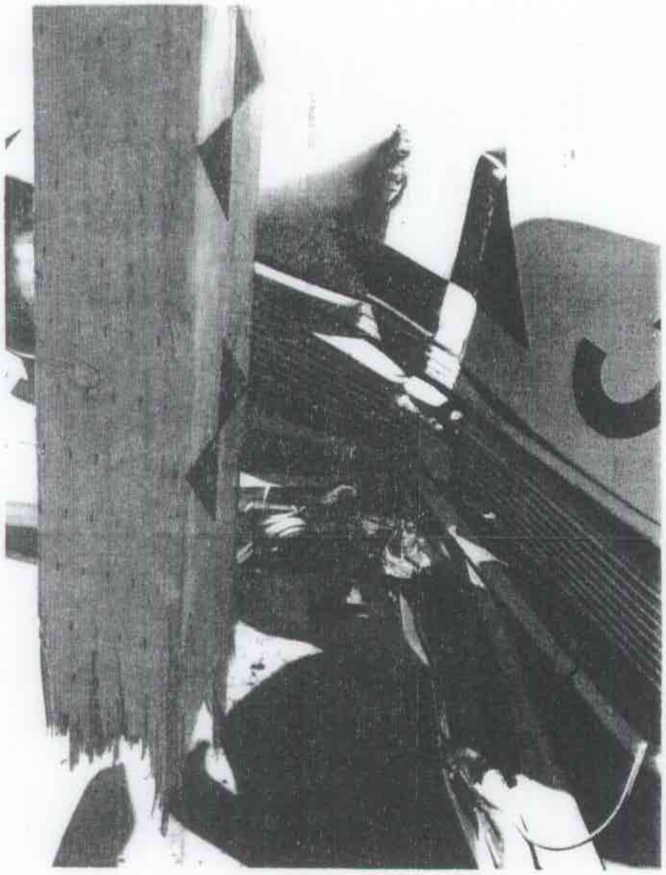


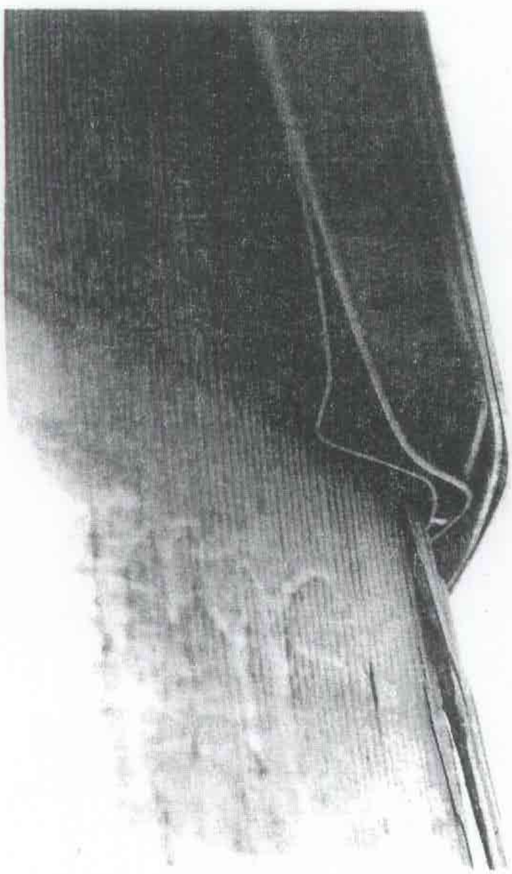
Figure 15

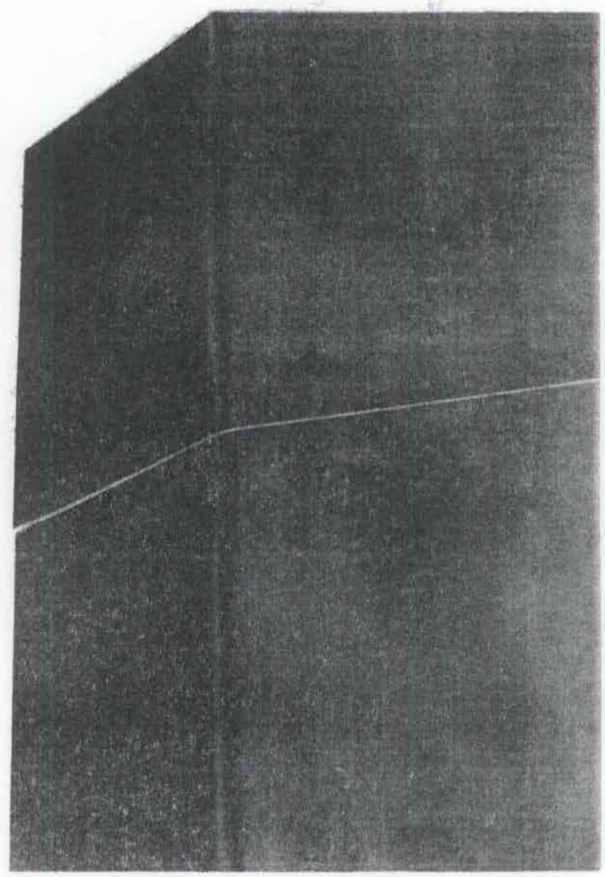
Test 351

Crush At Front Of Vehicle

Buckling At Bottom Of Sign Panel

Sign Panel Bent Around
Non-Impacted Post





This post segment lodged horizontally under the vehicle. The upper section of the post and the sign panel were pushed back by the vehicle as it yawed 35° in a counter-clockwise direction. After the vehicle came to its first stop, it rebounded approximately 2 feet. It came to a final stop with the center of the front bumper 7.3 ft beyond the original plane of the sign panel. The final position of the vehicle and test sign are shown in Figure 49 in Section 5.3.4, Vehicle Trajectory. Accelerometer data plots are shown in Figures C1-C6 in Appendix C.

5.2.1.2 Vehicle Damage - 351

The front of the test vehicle deformed around the 6 in. x 8 in. post and was crushed back about 7-8 inches from its original plane. The radiator was pushed back to the block and was leaking. The supporting member for the radiator was pushed back about 3-4 inches. Scrapes on the oil pan were due to the post segment which lodged under the car during impact. The right door was jammed, and the vehicle could not be driven away due to fan/radiator contact. There was no intrusion of vehicle or sign components into the passenger compartment during impact.

5.2.1.3 Sign Damage - 351

The sign panel bent around the nonimpacted 6 in. x 8 in. post for the full panel height, and delaminated slightly at the bend. An angle of 77° was measured between the bent sign panel and its original plane. Other than the bend, there was no damage to the sign panel. The bolts which attached the sign panel to the posts did not pull through, and only caused a minor depression in the panel at one bolt location.

During impact the 30-inch post segment that separated from the main post first split lengthwise into halves with the split passing through the 2 1/2-inch diameter holes. As the upper post section moved forward, the post segment halves below it were loaded independently as cantilevers and failed in bending below ground.

Movement of the nonimpacted 6 in. x 8 in. post in the soil was 1/2 inch. The post was not damaged.

5.2.1.4 Dummy Behavior - 351

The test dummy was positioned in the driver's seat and restrained with lap and shoulder belts which prevented impact with the car interior. After impact the dummy was found slumped over toward the passenger seat. There were no scraped or damaged areas found on the dummy.

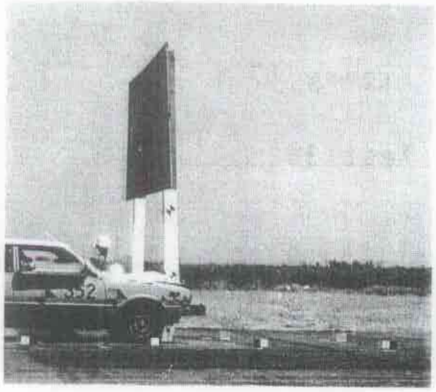
5.2.2 Test 352 - 6x8 Wood Post (2205 lbs/57.7 mph)

The summary of test data and photos taken before and after impact are shown in Figures 16 through 19.

5.2.2.1 Impact Description - 352

The test vehicle impacted one of the 6 in. x 8 in. posts head-on, 3 inches off the longitudinal centerline of the vehicle at 57.7 mph. The vehicle sheared off the post kicked up the upper portion of the post, passed beneath it, without further touching it, and continued to travel fairly straight with only a slight reduction in speed. It veered four feet off line after the brakes were applied remotely, and stopped 250 feet downstream from the sign. The vehicle

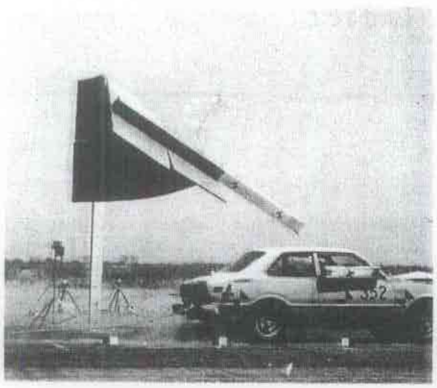
FIGURE 16. DATA SUMMARY SHEET - TEST 352



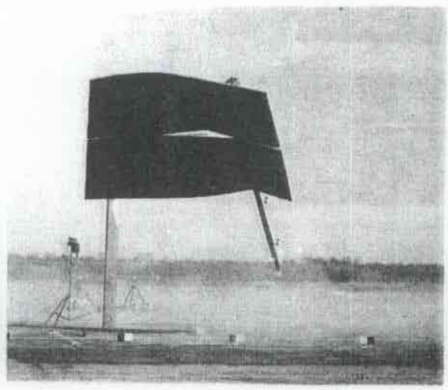
Impact + 0.01 Sec

I + 0.08 Sec

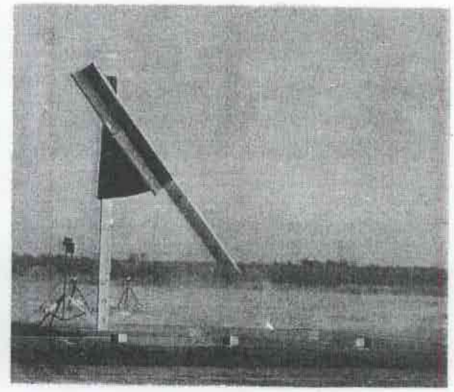
I + 0.14 Sec



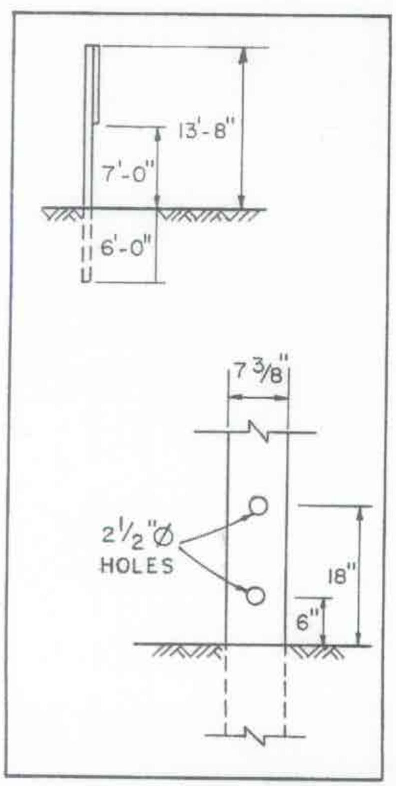
I + 0.21 Sec



I + 1.05 Sec



I + 2.22 Sec

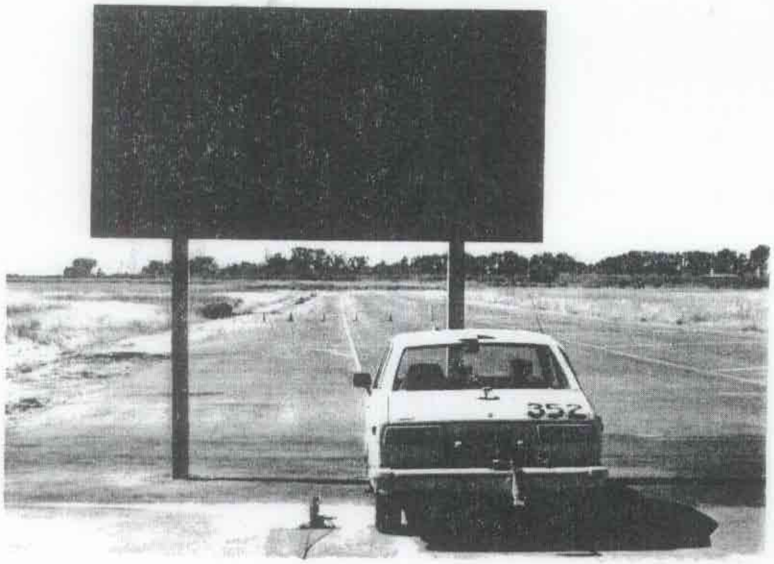


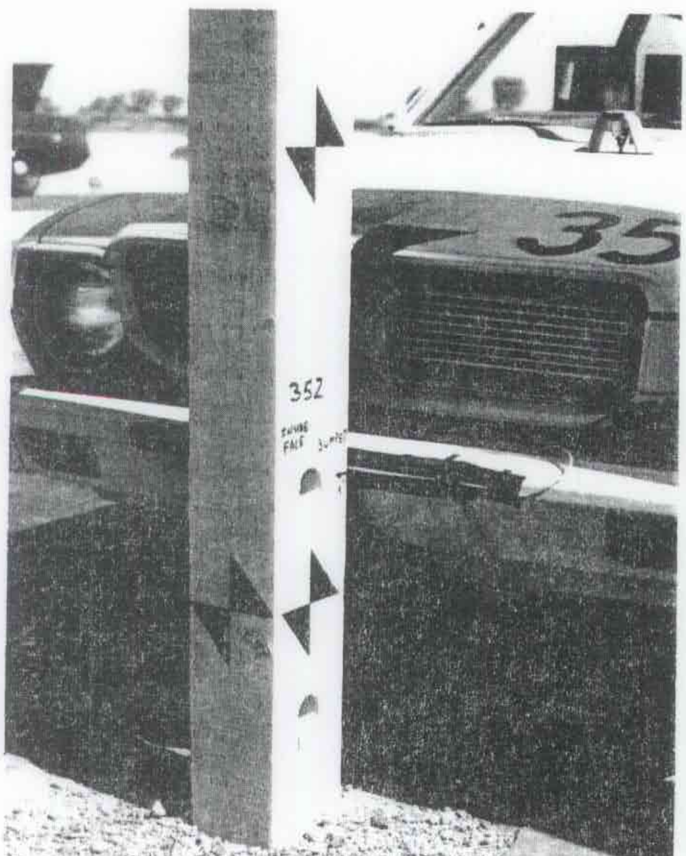
TEST DATE	August 3, 1978
SIGN SUPPORTS	Douglas Fir Posts
Support Size	5 3/8" x 7 3/8" (6" x 8" Nom.)
Breakaway Holes	2 1/2"Ø @ 6" and 18" Aboveground
Support Spacing/Embedment	8'-0"/6'-0"
Soil Type	Std. - TRC #191
SIGN PANEL	Alum. 1 1/8" x 6'-8" x 13'-0" Wide
Ground Clearance	7'-0"
Support Connection	8 - 3/8"Ø Threaded Rods
TEST VEHICLE	1976 Toyota Corolla
Test Inertial Mass	2205 lbs
Gross Static Mass	2370 lbs
Impact Speed/Angle	57.7 mph/0°
DRIVER DUMMY	Part 572, 50th Percentile, 165 lbs
Restraints	Lap, shoulder belts
TEST RESULTS	
Occup/Compart. Impact Veloc. - Film	10.0 ft/sec
- Accel.	3.82 ft/sec
Change of Momentum - Film	685 lb-sec
- Accel.	262 lb-sec
Highest 50 ms Avg. Long. Accel.	-1.9 G's
Max. Crush - Front of Vehicle	8 in
Max. Rise/Pitch/Yaw	5"/2°/2°
Vehicle Damage TAD/VDI	FC-3/12FCMN3
Head Injury Criterion	--

Figure 17

Test 352

Test Vehicle and Test Sign Before Impact





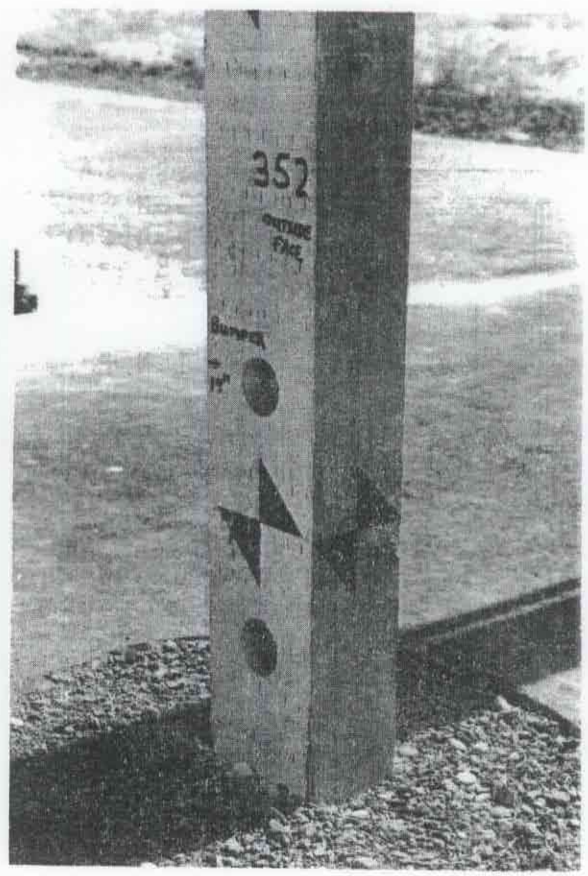
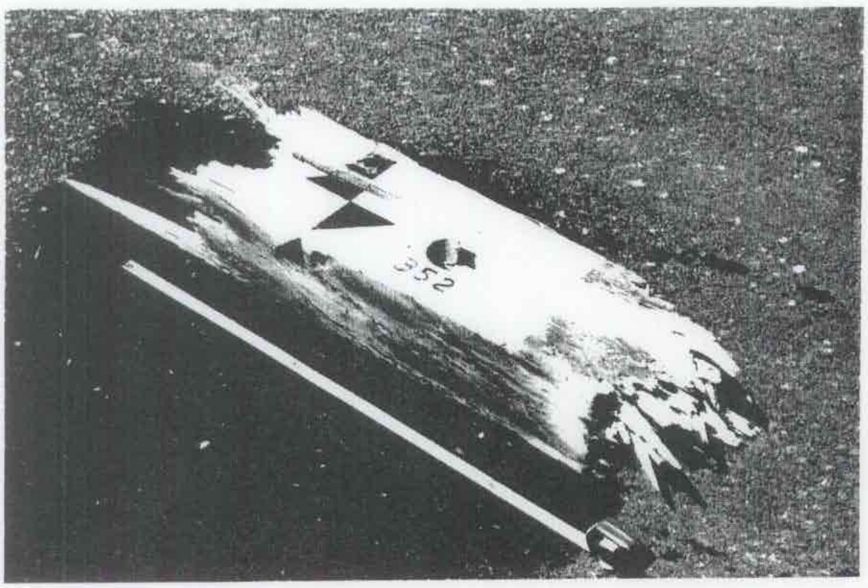


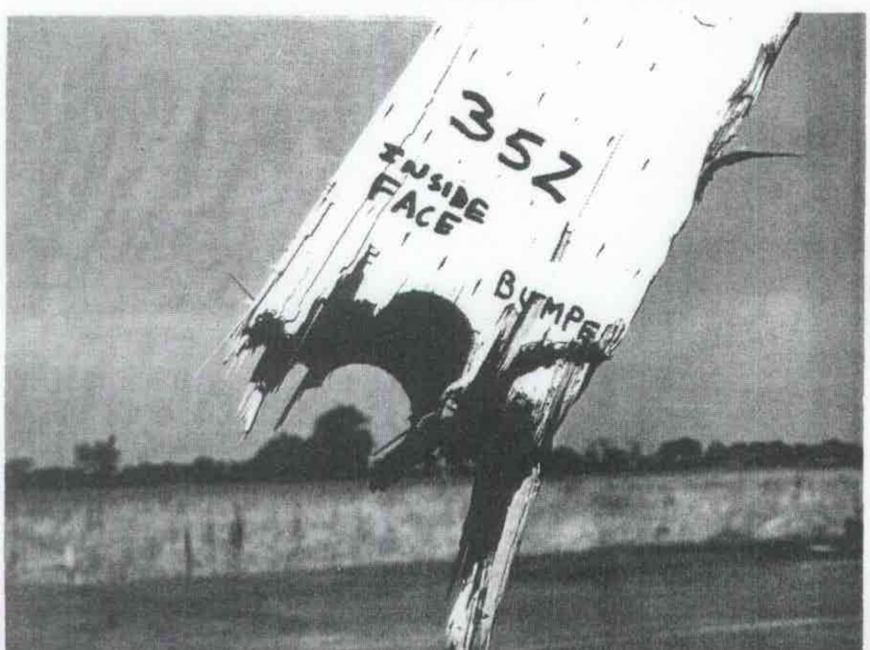
Figure 18

Test 352

Vehicle After Impact



Post Segment



Failure Through Upper Hole of Post

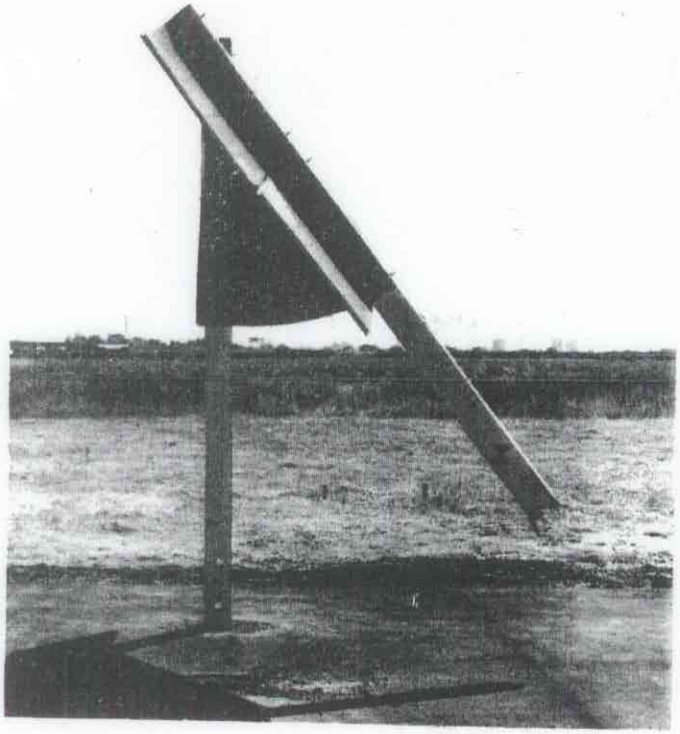
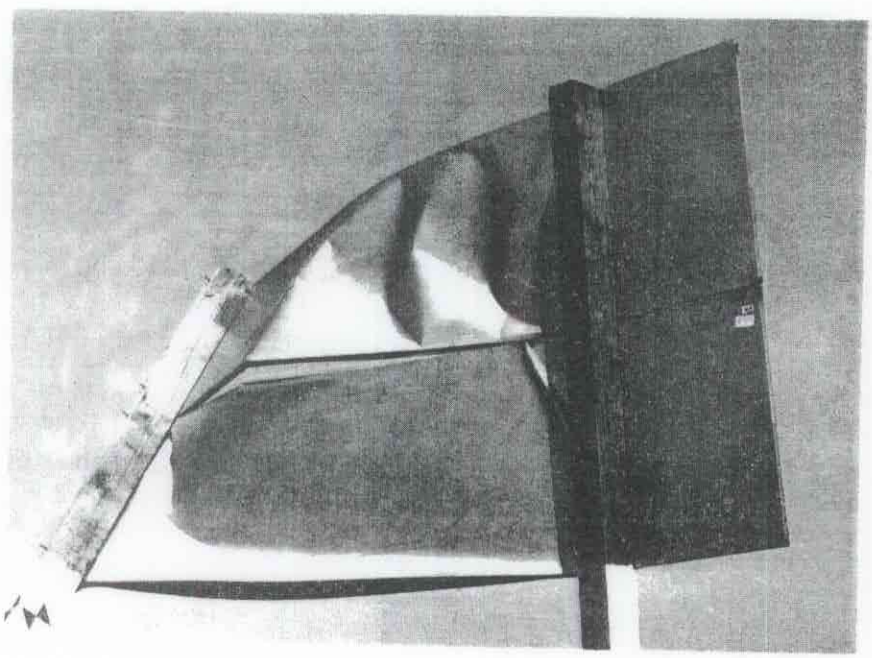


Figure 19

Test 352

Test Sign After Impact



broke off a section of post 20 inches above ground next to the upper post hole and 8 inches below ground. This post segment lodged underneath the front cross member of the vehicle during impact and remained there until the vehicle stopped. The final position of the sign and car are shown in Figure 49 in Section 5.3.4. Accelerometer data plots are shown in Figures C1-C6 in Appendix C.

5.2.2.2 Vehicle Damage - 352

The front of the test vehicle was bent around the 6 in. x 8 in. post during impact. Maximum vehicle crush, measured at the centerline of the vehicle at the top edge of the bumper, was about 9 inches, slightly more than in Test 351. Fluid was leaking from the radiator which was pushed back to the engine block during impact. The cross member supporting the radiator was pushed back about 4 inches by the dislodged post segment. The vehicle could not be driven away after impact. There was no intrusion of vehicle or sign components into the passenger compartment after impact.

5.2.2.3 Sign Damage - 352

The sign panel buckled near its midpoint between the two supporting posts about an axis parallel to the top of the sign. There was no local buckling around the sign panel bolts. Some separation occurred between the aluminum sheets on the panel and the honeycomb core. The nonimpacted post was not damaged.

The broken post segment which was lodged underneath the vehicle was 28 inches in length. This segment split lengthwise in halves initially during impact similar to the post in Test 351. These two halves failed in bending below ground as the car bumper loaded the top of the post segment.

5.2.2.4 Dummy Behavior - 352

The anthropomorphic dummy driver was wearing a lap and shoulder harness. The passenger compartment camera revealed the shoulder harness kept the dummy from striking the steering wheel or dash. The impact caused the dummy's head to snap forward quickly with its upper torso moving ahead shortly after. The dummy was found slumped over toward the driver's side, and had no scrapes or damaged areas.

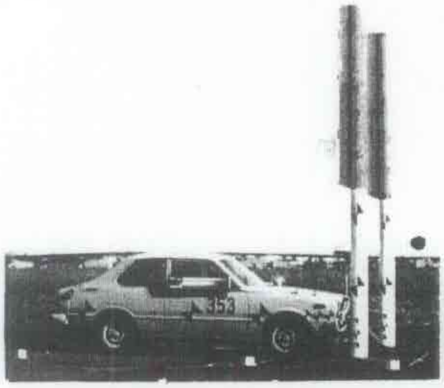
5.2.3 Test 353 - Timber Pole (2205 lbs/19.2 mph)

The summary of test data and photos taken before and after impact are shown in Figures 20 through 23.

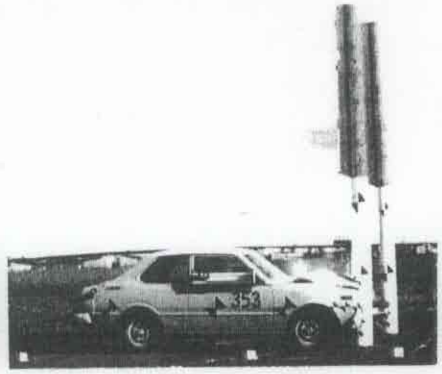
5.2.3.1 Impact Description - 353

The test vehicle impacted one of the timber poles head-on, 7 inches offset from the longitudinal centerline of the vehicle, at 19.2 mph. The test vehicle did not break through the 9 1/4-inch timber pole. Instead, it stopped when it impacted the pole and then rebounded 8 inches back from the face of the sign before coming to rest. The test vehicle also yawed clockwise about 6 degrees during the impact. This motion was probably due to the slight eccentric impact attitude of the vehicle. The final position of the vehicle and test sign are shown in Figure 49 in Section 5.3.4. Accelerometer data plots are shown in Figures C1-C6 in Appendix C.

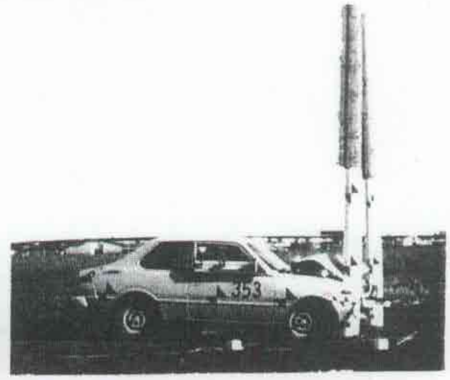
FIGURE 20. DATA SUMMARY SHEET - TEST 353



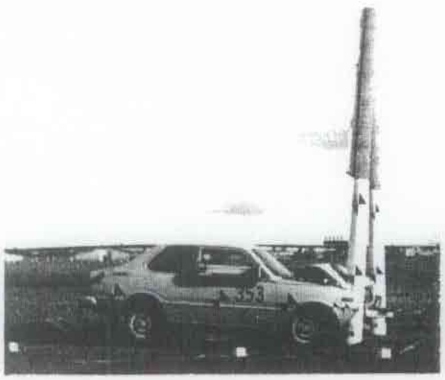
Impact + 0.00 Sec



I + 0.05 Sec



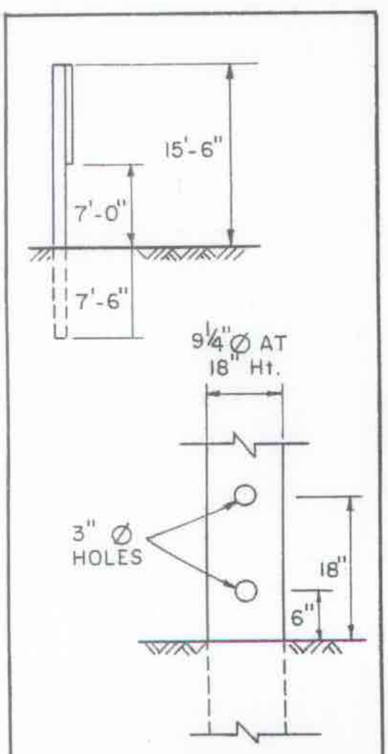
I + 0.09 Sec



I + 0.14 Sec

I + 0.28 Sec

I + 0.32 Sec



TEST DATE		January 12, 1979
SIGN SUPPORTS		Class 5 Douglas Fir Poles
Support Size		9 1/4"Ø @ 18" Aboveground
Breakaway Holes		3"Ø @ 6" and 18" Aboveground
Support Spacing/Embedment		8'-0"/7'-6"
Soil Type		Std. - TRC #191
SIGN PANEL		Alum. 1 1/8" x 8'-6" x 13'-0" Wide
Ground Clearance		7'-0"
Support Connection		8 - 3/8"Ø x 6" Lag Screws
TEST VEHICLE		1976 Toyota Corolla
Test Inertial Mass		2205 lbs
Gross Static Mass		2370 lbs
Impact Speed/Angle		19.2 mph/0°
DRIVER DUMMY		Part 572, 50th Percentile, 165 lbs
Restraints		Lap, shoulder belts
TEST RESULTS		
Occup/Compart. Impact Veloc.	- Film	33.2 ft/sec
	- Accel.	29.4 ft/sec
Change of Momentum	- Film	1930 lb-sec
	- Accel.	1930 lb-sec
Highest 50 ms Avg. Long. Accel.		-11.2 G's
Max. Crush - Front of Vehicle		16 in
Max. Rise/Pitch/Yaw		8"/3°/-6°
Vehicle Damage TAD/VDI		FC-5/12FCMN5
Head Injury Criterion		--

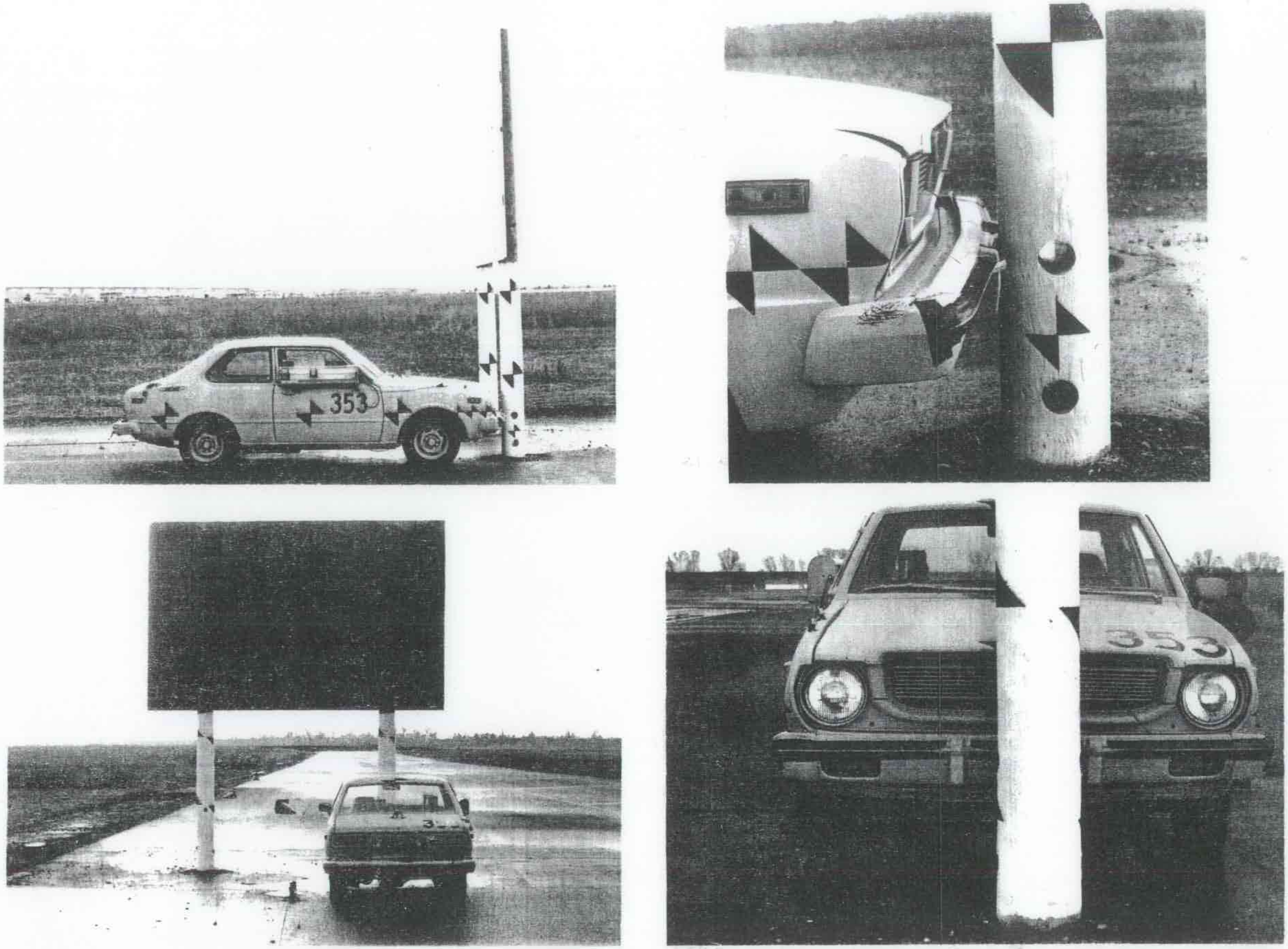


Figure 21 Test 353 Test Vehicle and Test Sign Before Impact

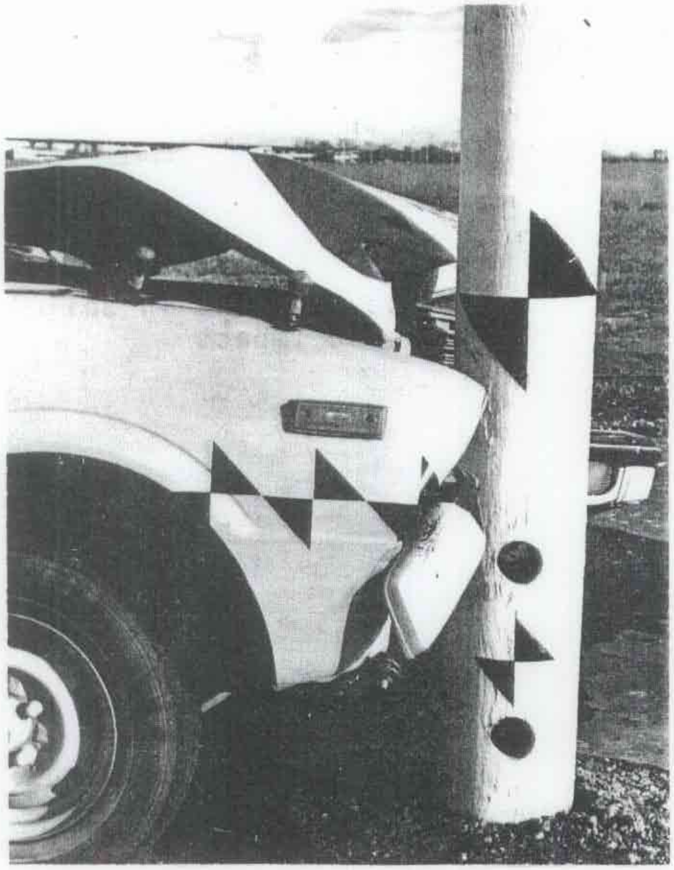
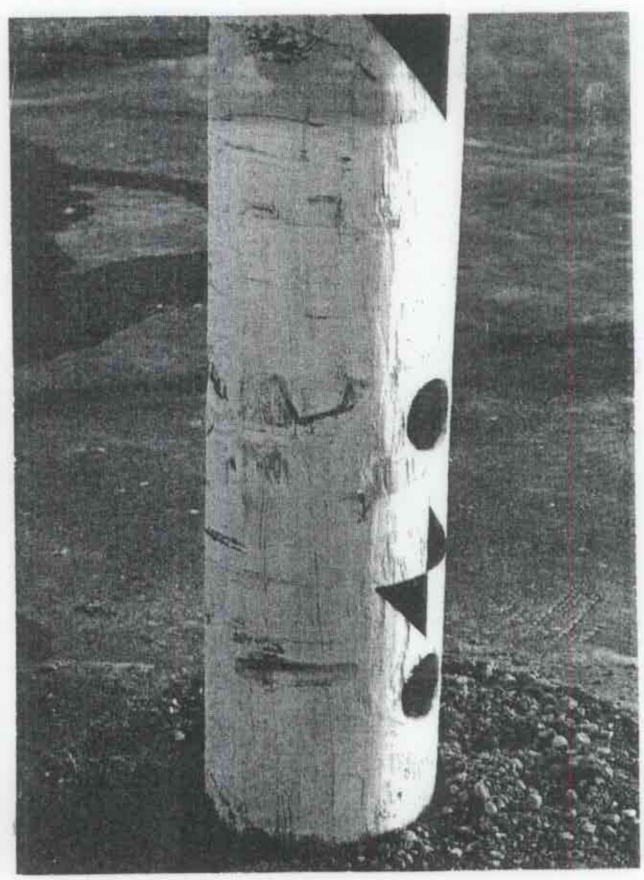


Figure 22

Test 353

Test Vehicle and Test Sign After Impact

Scuff Marks Due to Impact



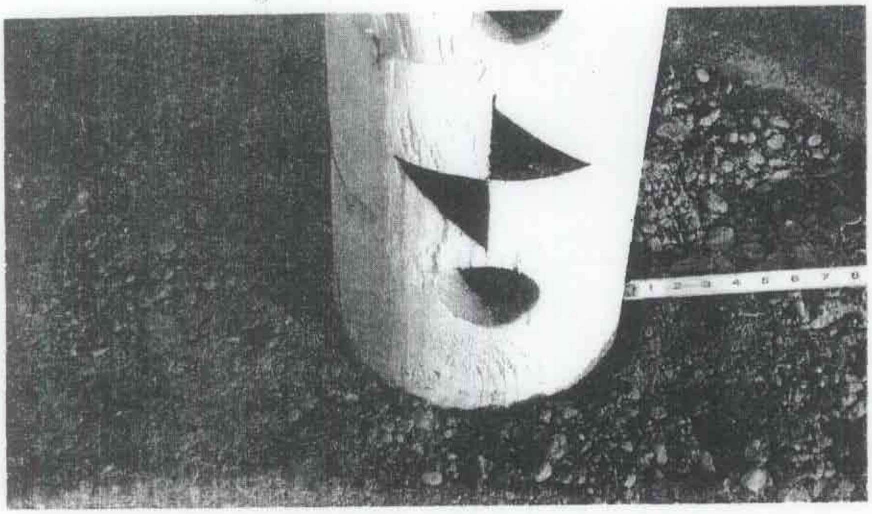
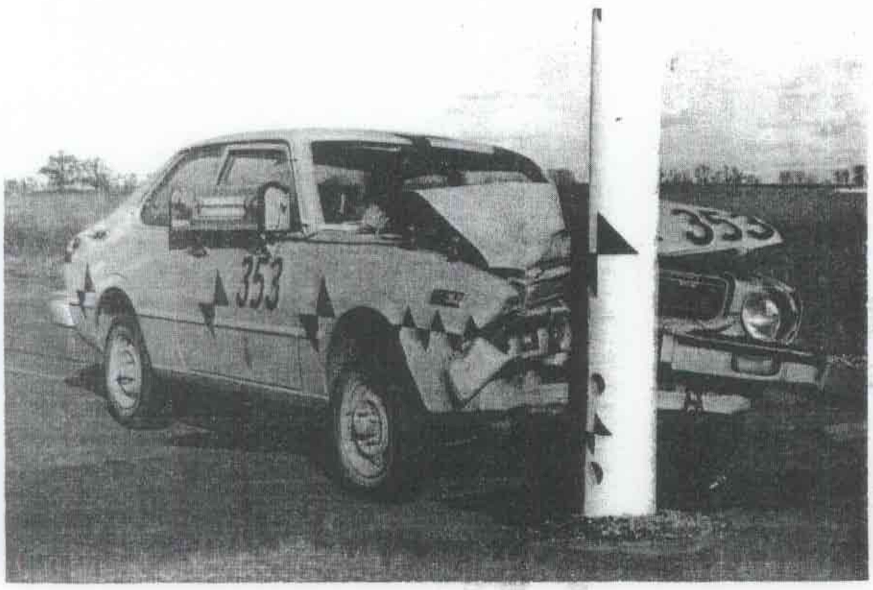


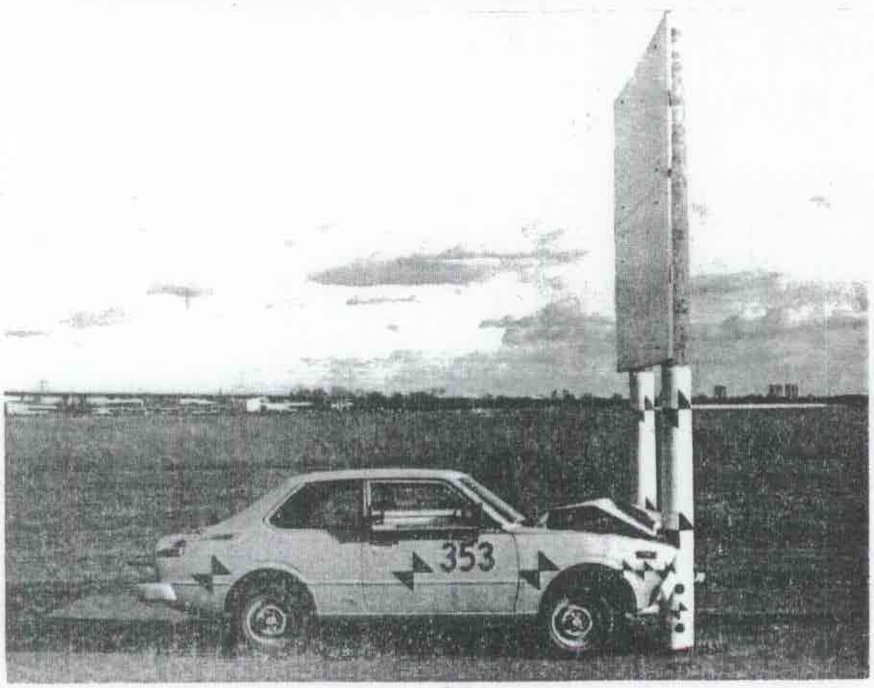
Figure 23

Test 353

Post Movement in Soil
Due to Impact



Test Vehicle and
Test Sign After Impact



5.2.3.2 Vehicle Damage - 353

The test vehicle suffered major front-end damage during the test. Frontal crush of the vehicle was 16 inches, maximum. The right front wheel of the test vehicle was pinnned back against the wheel well. The tie rods on this side of the vehicle were also bent. The front bumper, the hood, and the radiator of the test vehicle were all pushed back into the engine block. The radiator was also punctured during the test and fluid started to drain after the impact.

The test vehicle could not be rolled away from the impact area after the test. There was no intrusion of vehicle or sign components into the passenger compartment of the vehicle during the test.

5.2.3.3 Sign Damage - 353

The roadside sign suffered virtually no damage during the impact. The impacted pole was dented and scuffed slightly in the vicinity of the impact zone. There was also a hairline fracture extending between the breakaway holes in the pole. The high speed movie film showed a crack opening up between the ground and the lower sole in the impacted pole for a few milliseconds after impact and then closing. Both timber poles were pushed forward slightly during the impact. Groundline movements of the impacted pole and the adjacent pole were 3/4 inch and 3/16 inch respectively.

The sign panel, its attachment hardware and the timber pole adjacent to the impacted pole were not damaged during the test.

5.2.3.4 Dummy Behavior - 353

The test dummy, restrained by lap and shoulder belts, lunged forward during the test. In the movie film the dummy's head appeared to impact the steering wheel. After the test the dummy was found slumped toward the front passenger's side of the vehicle. The legs and knees were pointed toward the driver's side of the test vehicle. There were no scraped or damaged areas found on the dummy.

5.2.4 Pendulum Tests - Timber Poles - SWRI (CALDOT-1 Through CALDOT-8)

Pendulum tests were conducted on timber poles with four different breakaway hole patterns. Two tests were conducted on each design. The hole patterns are shown in Section 5.1.2, Figure 4. Test results are shown in Table 3. Detailed results and test photos are contained in Reference 12.

5.2.5 Test 354 - Timber Pole (2205 lbs/19.9 mph)

The summary of test data and photos taken before and after impact are shown in Figures 24 through 27.

5.2.5.1 Impact Description - 354

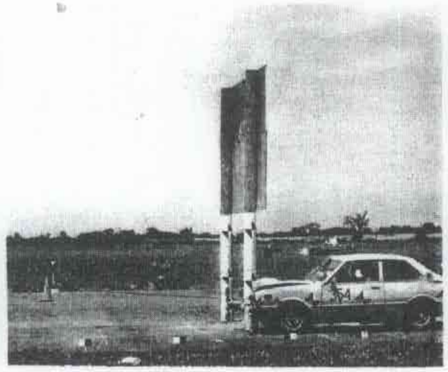
The test vehicle impacted one of the timber poles head-on, one inch offset from the longitudinal centerline of the vehicle, at 19.9 mph. The vehicle sheared off the pole and pushed it ahead a maximum distance of 5 ft-6 in. without losing contact with the pole. Maximum yaw of the car was 27°. Energy was stored in the sign panel and pole which then pushed the car backwards. It came to rest 1 ft-9 in.

TABLE 3. SUMMARY OF PENDULUM TEST RESULTS
(All tests performed by SwRI)

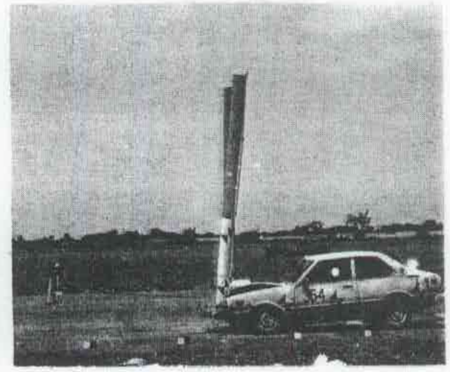
Test No.	Specimen Size at Grade (in.)	Breakaway Modification*	Impact Velocity (ft/sec)	Velocity Change (ft/sec)	Momentum Change (lb-sec)	Peak Accel. (g's)	Pulse Duration (msec)	Honeycomb Crush (in.)
CALDOT-1	9.31 Ø pole	3 in. dia hole @ +6 in. and +18 in.	29.33	29.33	2052	-17.6	245	16.9
CALDOT-2	9.27	3 in. dia hole @ +6 in. and +18 in.	29.33	19.39	1355	-20.4	220	17.1
CALDOT-3	9.53	3 in. dia hole @ -9 in. and +21 in.	29.33	14.15	989	-20.6	150	16.9
CALDOT-4	9.39	3 in. dia hole @ -9 in. and +21 in.	29.33	29.33	2051	-21.4	174	17.1
CALDOT-5	9.50	3 in. dia hole @ -9 in. and +21 in.; holes connected with sawcut	29.33	18.33	1281	- 8.4	175	15.9
CALDOT-6	9.31	3 in. dia hole @ -9 in. and +21 in.; holes connected with sawcut	29.33	12.54	876	- 8.2	200	15.3
CALDOT-7	9.13	4 in. dia hole @ +4 in. and +24 in.; holes connected with sawcut	29.33	11.29	789	- 9.0	96	14.8
CALDOT-8	9.25	4 in. dia hole @ +4 in. and +24 in.; holes connected with sawcut	29.33	12.32	861	- 9.3	100	14.8
CALDOT-9	H-section 7 7/8 x 14 7/8	Web removed from 3 in. to 21 in. above grade	29.33	4.28	299	- 3.0	82	8.36
CALDOT-10	Box section 7 7/8 x 14 7/8	Webs removed from 3 in. to 21 in. above grade	29.33	4.55	318	- 3.9	80	9.44
CALDOT-11	H-section 7 7/8 x 14 7/8	Two 1-in. dia holes in web at 3 in. and 21 in. above grade; holes connected by horizontal sawcut	29.33	8.20	573	- 7.0	92	14.11

*Positive value indicates hole is above grade; negative value means hole is below grade.

Impact + 0.00 Sec



I + 0.04 Sec



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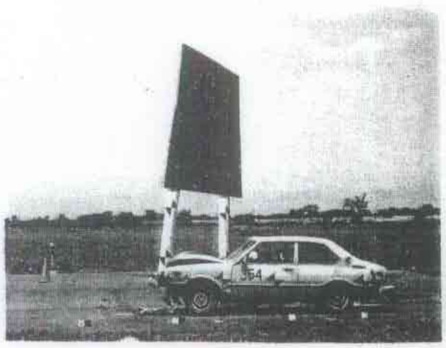
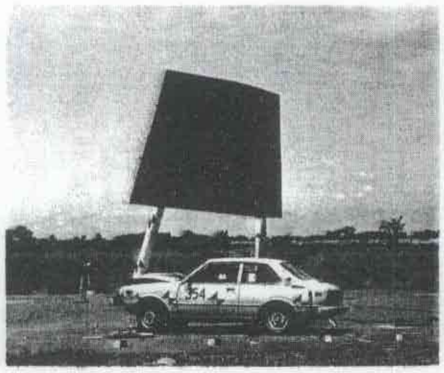
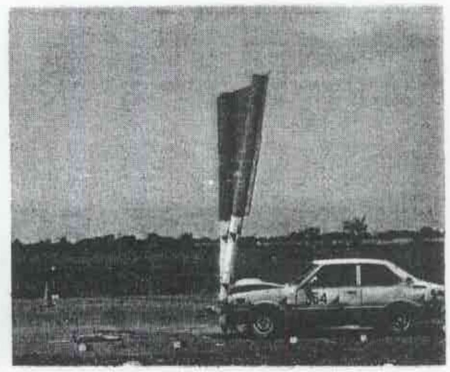


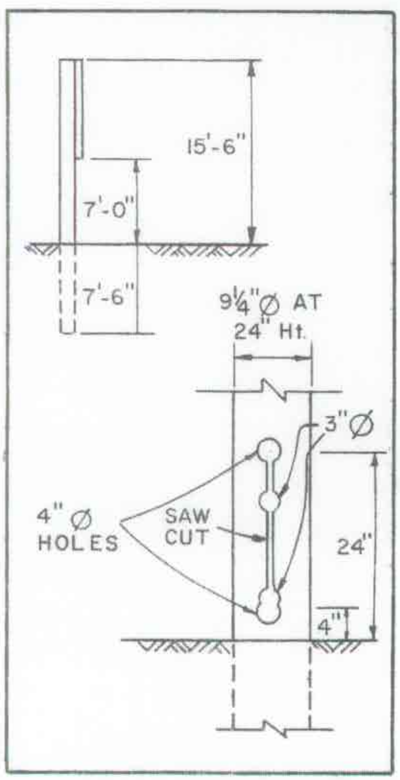
I + 0.44 Sec



I + 1.49 Sec



I + 6.14 Sec



TEST DATE	May 21, 1980
SIGN SUPPORTS	Class 5 Douglas Fir Poles
Support Size	9 1/4"Ø @ 18" Aboveground
Breakaway Holes	4"Ø @ 4" and 24" Aboveground with Sawcut Between
Support Spacing/Embedment	8'-0"/7'-6"
Soil Type	Std. - TRC #191
SIGN PANEL	Alum. 1 1/8" x 8'-6" x 13'-0" Wide
Ground Clearance	7'-0"
Support Connection	8 - 3/8"Ø x 6" Lag Screws
TEST VEHICLE	1976 Toyota Corolla
Test Inertial Mass	2205 lbs
Gross Static Mass	2370 lbs
Impact Speed/Angle	19.9 mph/0°
DRIVER DUMMY	Part 572, 50th Percentile, 165 lbs
Restraints	Lap, shoulder belts
TEST RESULTS	
Occup/Compart. Impact Veloc. - Film	17.0 ft/sec
- Accel.	18.0 ft/sec
Change of Momentum - Film	1160 lb-sec
- Accel.	1230 lb-sec
Highest 50 ms Avg. Long. Accel.	-7.5 G's
Max. Crush - Front of Vehicle	13 in
Max. Rise/Pitch/Yaw	4"/3°/-14°
Vehicle Damage TAD/VDI	FC-4/12FCMN3
Head Injury Criterion	--

Figure 25

Test 354

Test Vehicle and
Test Sign Before Impact

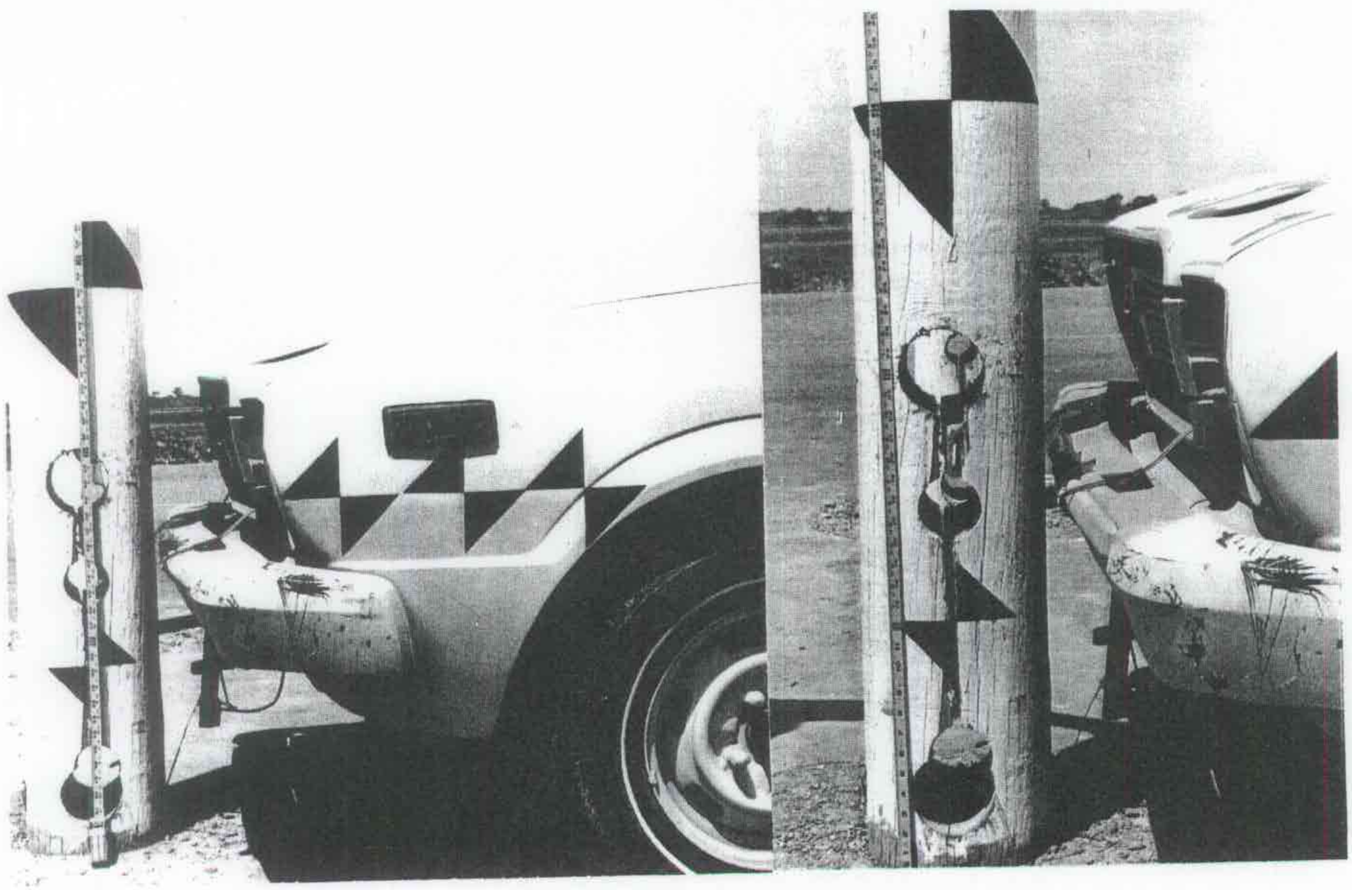


Figure 26

Test 354

Test Vehicle and
Test Sign After Impact

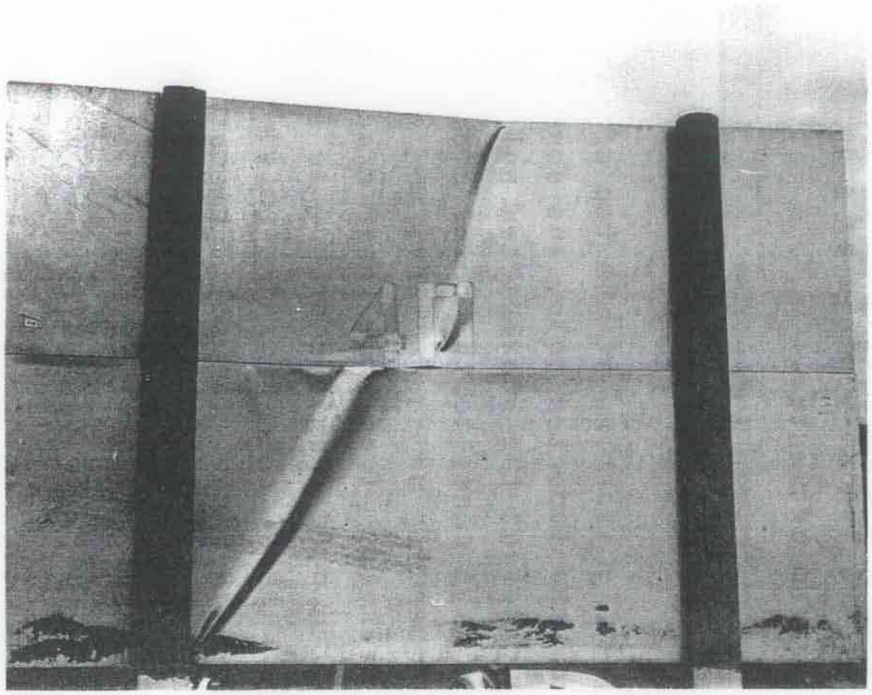
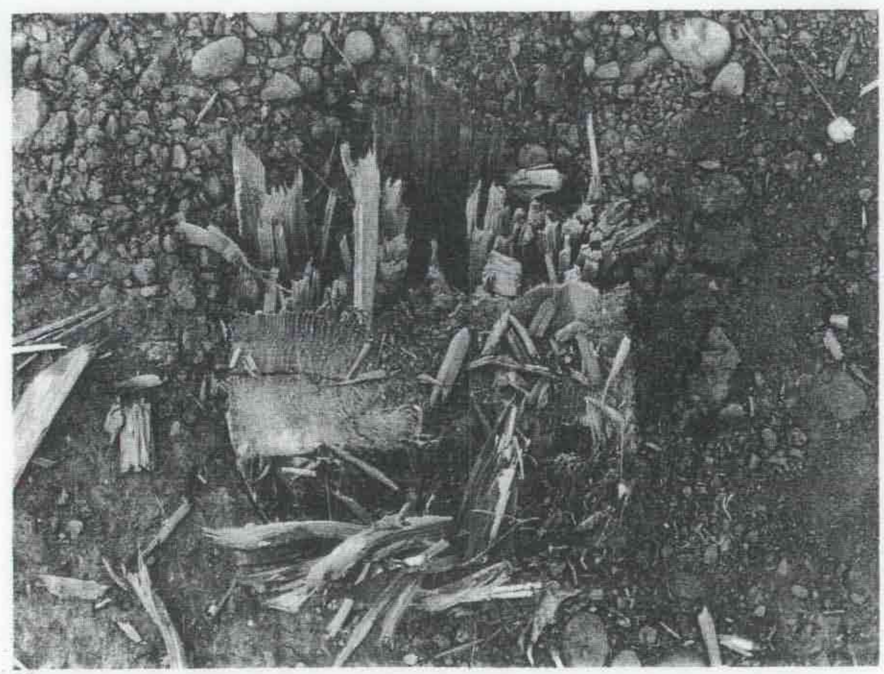


Figure 27

Test 354

Test Sign After Impact



beyond the original pole location with a yaw of 14°. The vehicle traveled in a circular path to the right as it pushed the pole ahead. The segment of the pole between the bored holes separated from the main pole and split into several pieces approximately 20-30 inches long. The final position of the vehicle and test sign are shown in Figure 50 in Section 5.3.4. Accelerometer data plots are shown in Figures C1-C6 in Appendix C.

5.2.5.2 Vehicle Damage - 354

The front of the test vehicle crushed around the pole to a maximum depth of 13 inches measured 21 1/2 inches above the ground at the bumper midpoint. Fluid was leaking from the radiator which was crushed back to the engine block. The front of the vehicle was not crushed back at all on the left and right sides. It was not possible to drive the car away. There was no intrusion of vehicle or sign components into the passenger compartment.

5.2.5.3 Sign Damage - 354

The sign panel buckled diagonally starting at the top of the panel, three feet in from the impacted pole, and continued to the bottom of the panel at the nonimpacted pole. The lag screws fastening the sign panel to the poles did not pull out; however, minor bending of the washers and dimples in the panel were observed. Torsional shear cracking occurred in the nonimpacted pole from the ground to the upper breakaway hole. There were also some cracks noted at the holes which opened up to 1/16 inch. The split pieces of the broken out pole segment landed 3 to 12 feet downstream of the original sign location, but did not lodge under the car in this test. There was no displacement of either pole in the soil.

5.2.5.4 Dummy Behavior - 354

The test dummy was positioned in the driver's seat and restrained with lap and shoulder belts which prevented impact with the car interior. After impact the dummy was found slumped to the right. There was no evidence of damage to the dummy.

5.2.6 Static Bend Tests - Timber Poles - Caltrans (Tests 1, 2 & 3)

Photos and diagrams of the poles after they were loaded to failure are shown in Figures 28 through 31. A summary of the test results is contained in Table 4. Load vs. deflection plots are included as Figure C19 in Appendix C.

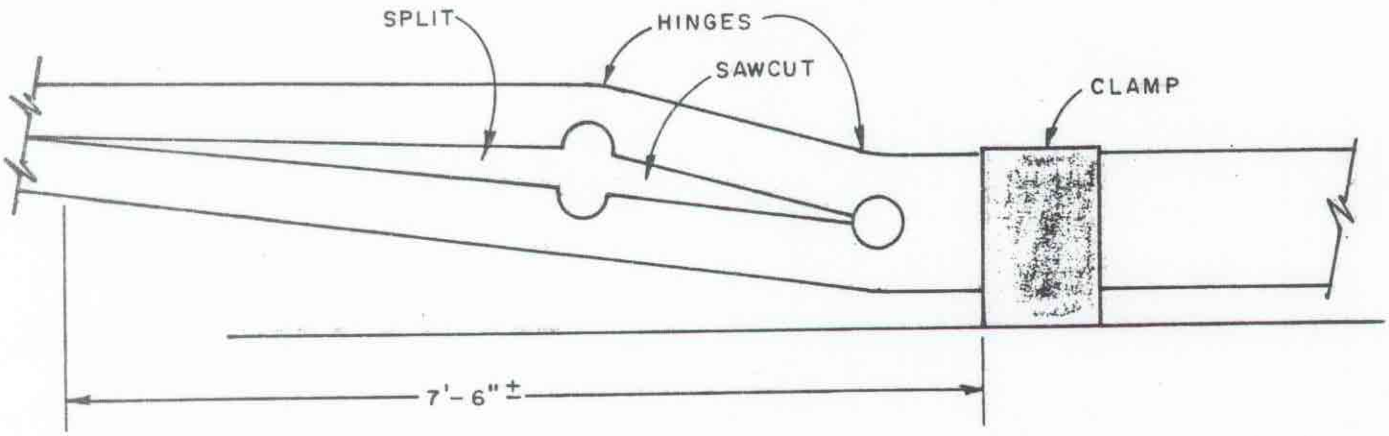
The failure mode was different for each of the three poles tested. In Test 1 the pole split beyond the upper hole in the same plane as the sawcut between the two holes, a distance of over seven feet beyond the hold down clamp. The upper segment of the pole between the 4-inch holes buckled up, forming a hinge at each hole, thus failing in bending.

In Test 2 the pole failed in compression close to the upper hole. Long strips of wood on the top side of the pole buckled up, failing along deep pre-existing longitudinal cracks in the wood.

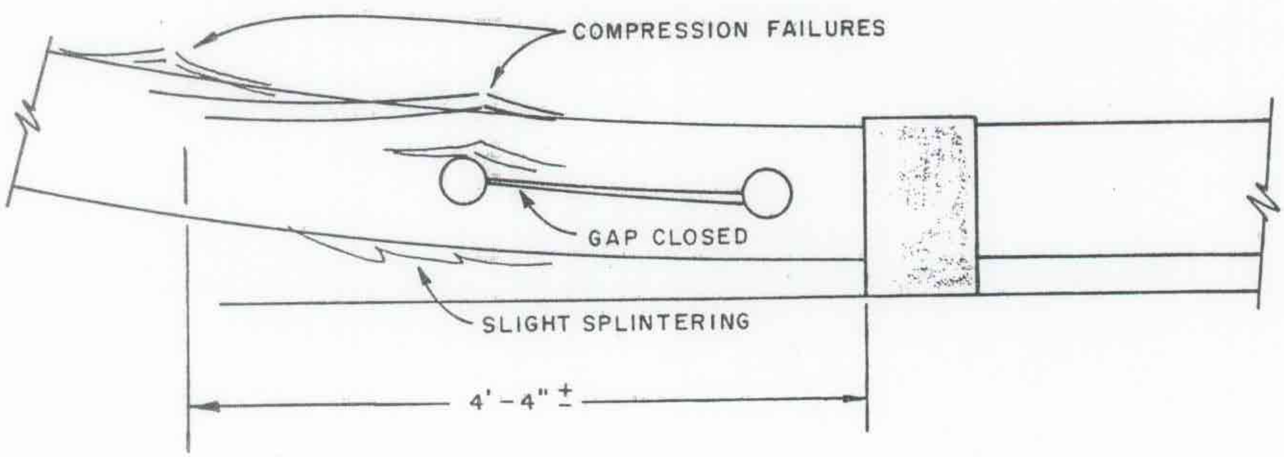
In Test 3 the pole failed in tension at the lower hole. There were two tight knots in that area which probably weakened the section somewhat.

STATIC BEND TESTS-TIMBER POLES
FAILURE MODES

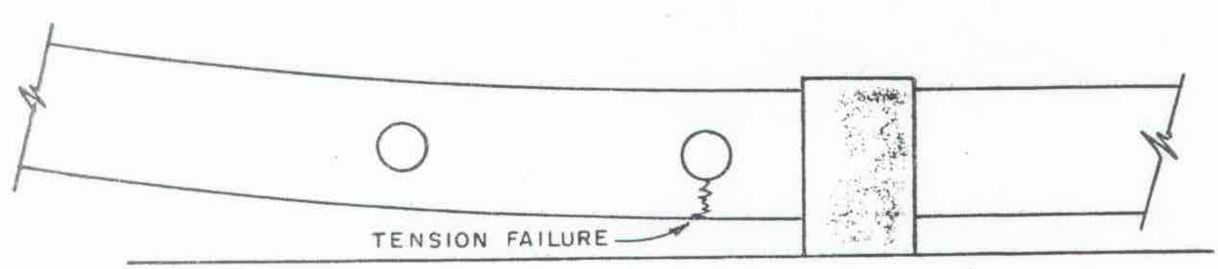
FIGURE 28



TEST 1



TEST 2



TEST 3

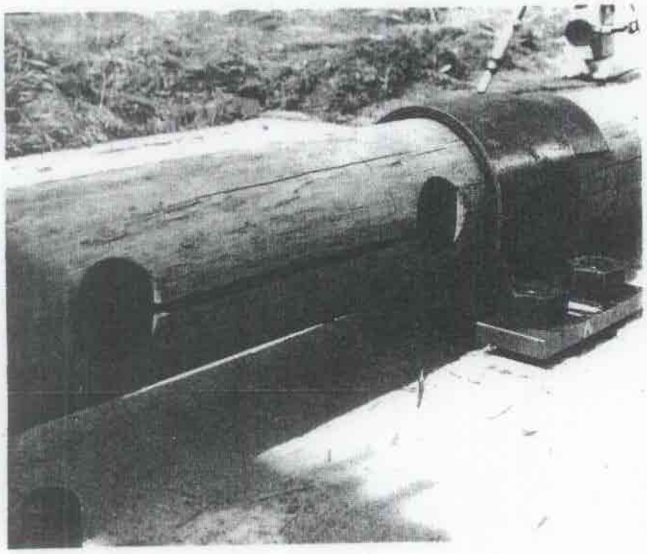
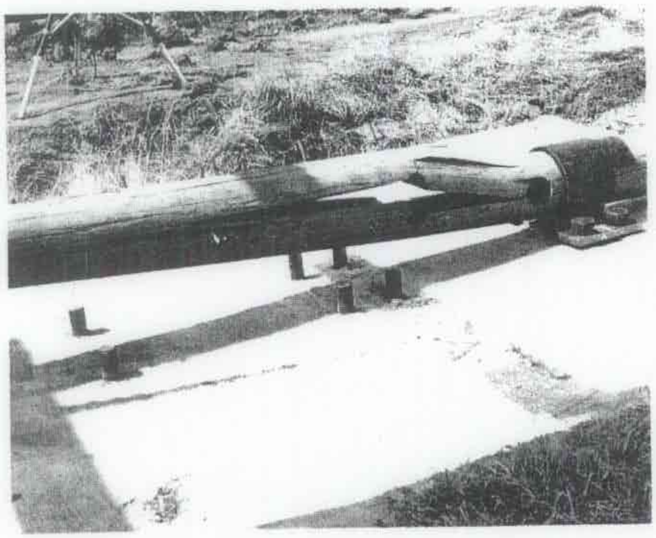


Figure 29

Caltrans Static Bend Test - 1

Pole Before Test



Pole After Test

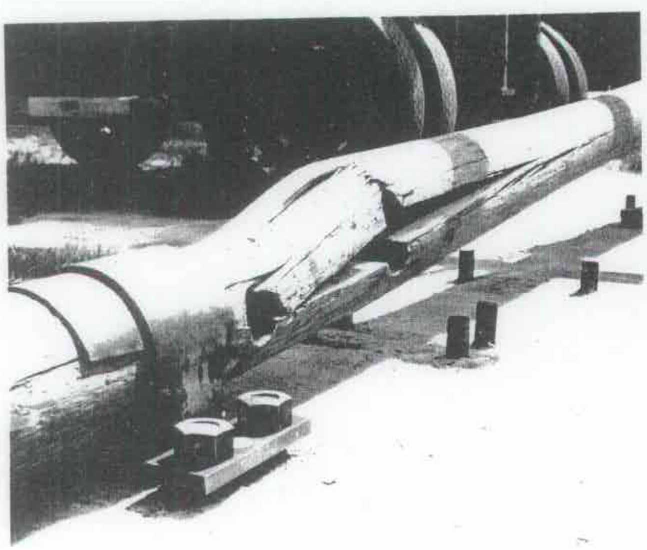
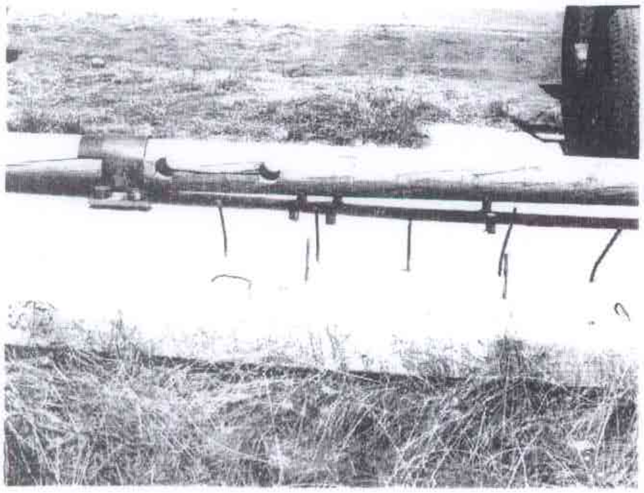
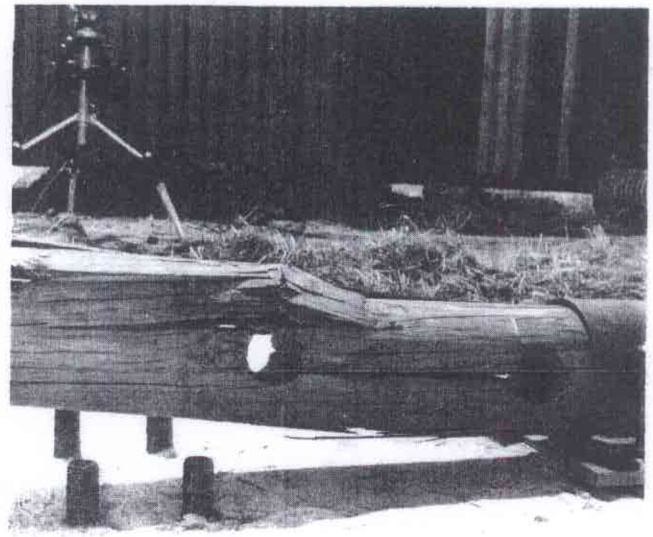


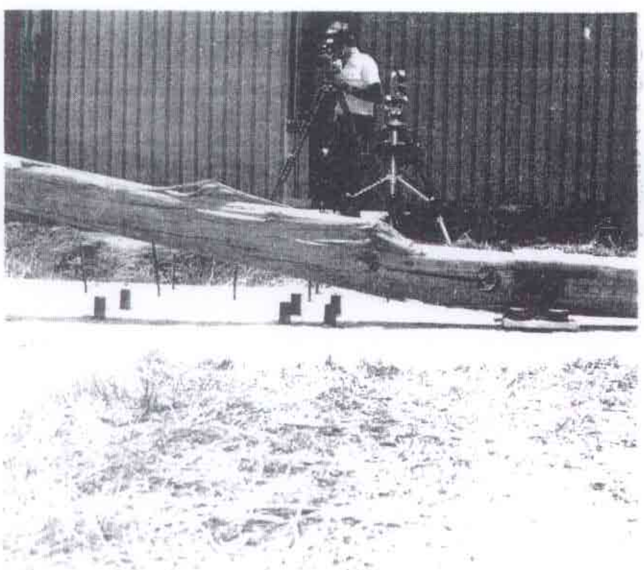
Figure 30 Caltrans Static Bend Test - 2

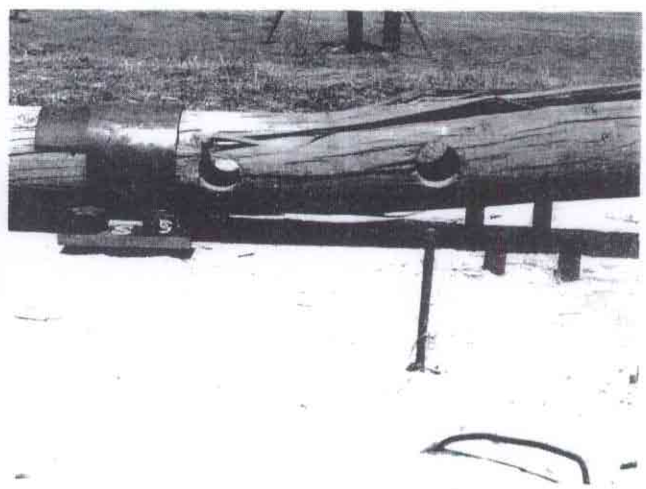


Pole Before Test



Pole After Test





Pole After Test

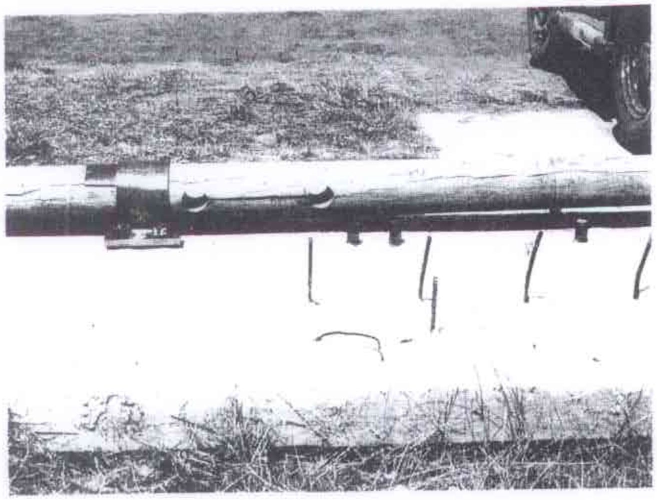
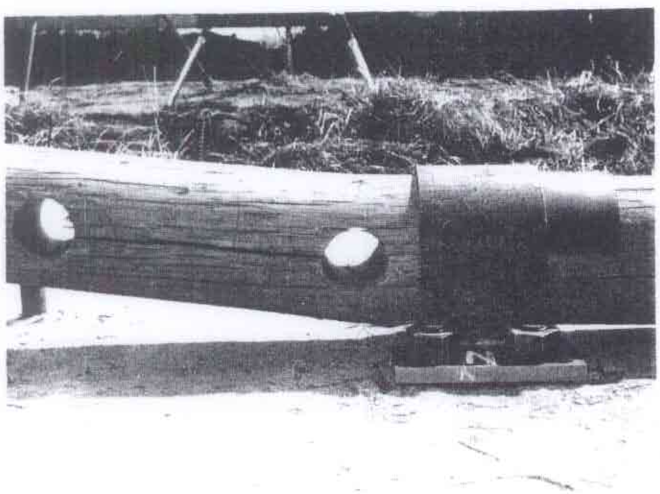


Figure 31

Caltrans Static Bend Test - 3

Pole Before Test



Pole After Test

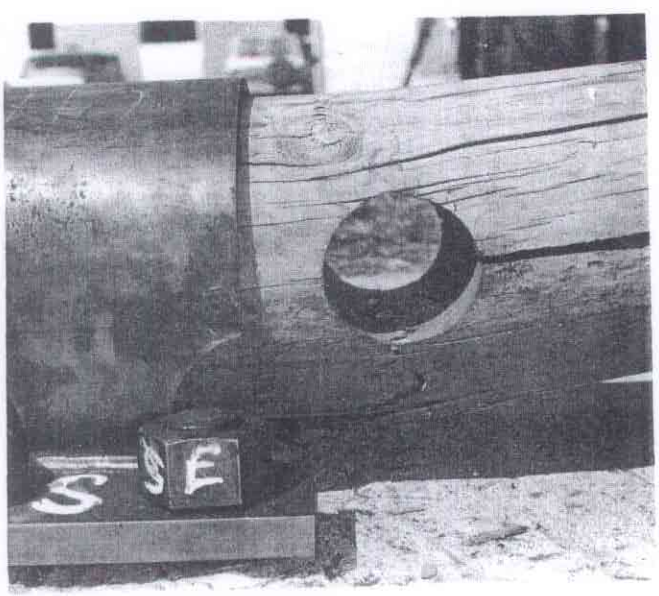


TABLE 4. SUMMARY OF STATIC BEND TESTS

Test No.	Specimen Type	Breakaway Modification	Support Lgth(ft)	Load Lgth(ft)	Failure Load(lbs)	Ult. Base Moment(ft-k)	Failure Description
SwRI-1	Lam. Wood H-section 7 7/8 x 14 7/8	Web removed in area between 3 in. to 21 in. from clamp	7.2	23.4	1600	37.4	Shear and peeling at glue joints from window cutout outward toward load point. Top flange/web joint failed for entire length; bottom flange/web joint failed for 8.6 ft length. Secondary flexure failure of top flange at clamp and bottom flange at outer edge of window.
SwRI-2	Lam. Wood H-section 7 7/8 x 14 7/8	Ditto	5.0	15.5	1600	24.8	Shear and peeling at upper glue joint from window cutout inward (in support area). Secondary flexure failure of top and bottom flange at clamp.
SwRI-3	Lam. Wood Box section 7 7/8 x 14 7/8	Ditto - both webs	7.2	23.0	1890	43.5	Shear and peeling at glue joints from window cutout outward toward load point. Top/side joints failed for entire length; bottom/side joints failed for 3.1 ft length.
SwRI-4	Lam. Wood Box section 7 7/8 x 14 7/8	1"-dia holes in webs 3 1/2" from each edge at 3" and 21" above ground; horiz. sawcuts between holes	6.0	16.0	3360	53.8	Flexure failure beginning at top side at clamp, progressing to top holes closest to clamp, down through slot to bottom holes, and ending in bottom flange adjacent to those holes. Secondary shear and peeling failure in upper glue joint for entire length in support area.
CT-1	D.F. Pole 9.17" dia	4" dia holes at 4" and 24" above ground	4.0	11.2	5000+	56.0	Pole split beyond upper hole; upper segment of pole between 4" dia holes hinged at each end and buckled up.
CT-2	D.F. Pole 9.25" dia	Ditto	4.0	11.2	3150	35.3	Pole failed in compression close to upper 4" dia hole.
CT-3	D.F. Pole 9.19" dia	Ditto	4.0	11.2	3640	40.8	Pole failed in tension at lower hole.
CT-4	Lam. Wood Box section 7 7/8 x 14 7/8	1"-dia holes in webs 3 1/2" from each edge at 3" and 21" above ground; horiz. sawcuts between holes	10.5	21.0	3800	79.8	Post failed through bottom sawcuts at 3" above ground.

Notes: 1. Pole diameters measured at upper hole, 24" above ground.
2. First four tests by SwRI, second four by Caltrans.

The knot count in Table F2, Appendix F indicates that Test 1 with the highest ultimate load had many less large size knots than the other two polhs with lower strength. This may or may not have been a coincidence.

5.2.7 Pendulum and Static Bend Tests - Box and H-Section Posts - SWRI (CALDOT 9, 10 & 11 and Tests 1-4) and Caltrans (Test 4)

Results of the CALDOT 9, 10 and 11 pendulum tests are summarized in Table 3. Results of SWRI Tests 1-4, static bend tests, are shown in Table 4. Failure diagrams for each static bend test taken from the SWRI report are shown in Figures 32 and 33. Complete details of these tests are contained in Reference 13.

Caltrans Test 4, a static bend test on a box section post with drilled 1-inch diameter holes and connecting horizontal sawcuts, is also summarized in Table 4. Movies of this test are included in the project film report. Photos of Caltrans Test 4 are shown in Figures 34 and 35. A plot of load versus deflection is shown in Figure C20 in Appendix C.

5.2.8 Test 355 - Box Section (2205 lbs/19.2 mph)

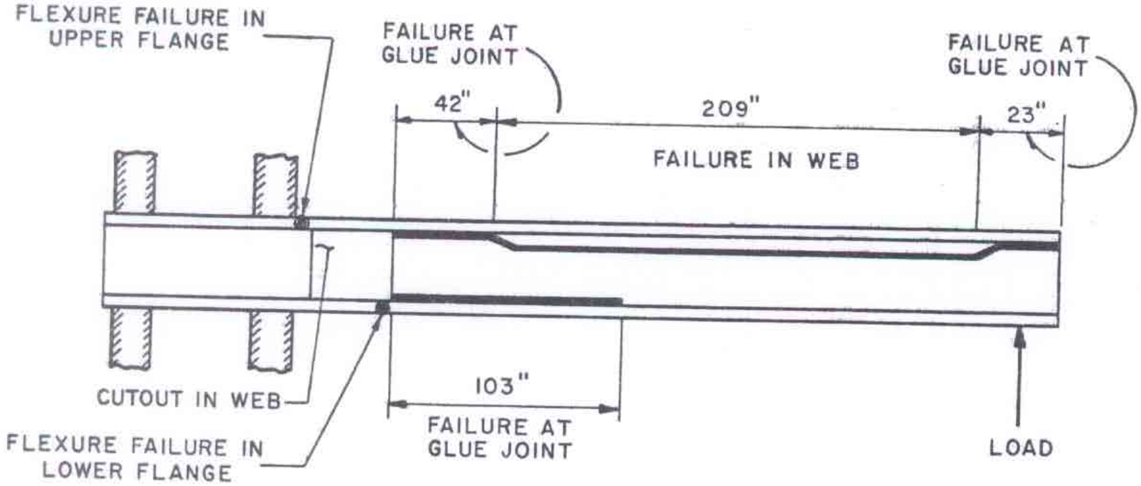
The summary of test data and photos taken before and after impact are shown in Figures 36 through 39.

5.2.8.1 Impact Description - 355

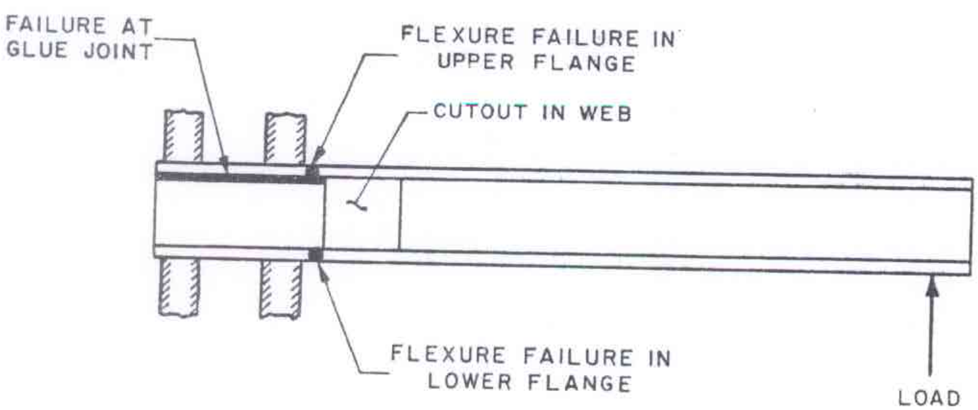
The test vehicle impacted the right hand post head-on, within one inch of the longitudinal axis of the vehicle, at 19.2 mph. After impact, crush at the center front of the vehicle occurred

STATIC BEND TESTS ON LAMINATED WOOD VENEER POSTS
FAILURE DESCRIPTIONS TESTS No. 1 & 2

FIGURE 32



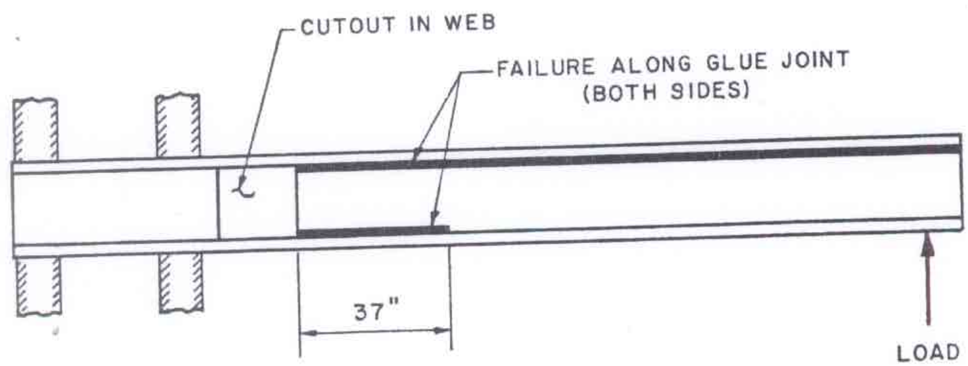
FAILURE MODE - STATIC TEST No. 1



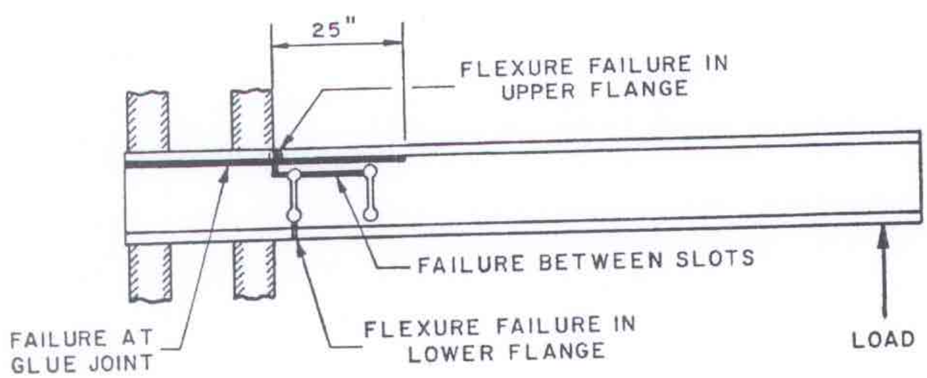
FAILURE MODE - STATIC TEST No. 2

STATIC BEND TESTS ON LAMINATED WOOD VENEER POSTS
FAILURE DESCRIPTIONS TESTS No. 3 & 4

FIGURE 33

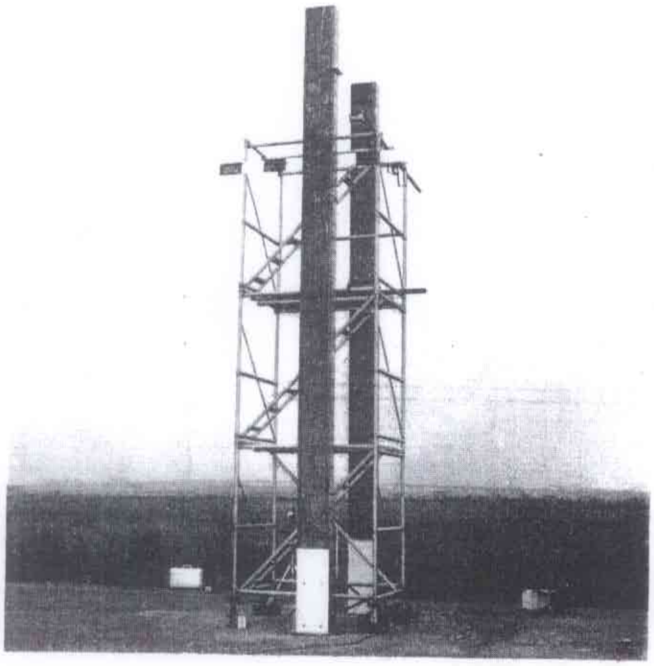


FAILURE MODE - STATIC TEST No. 3

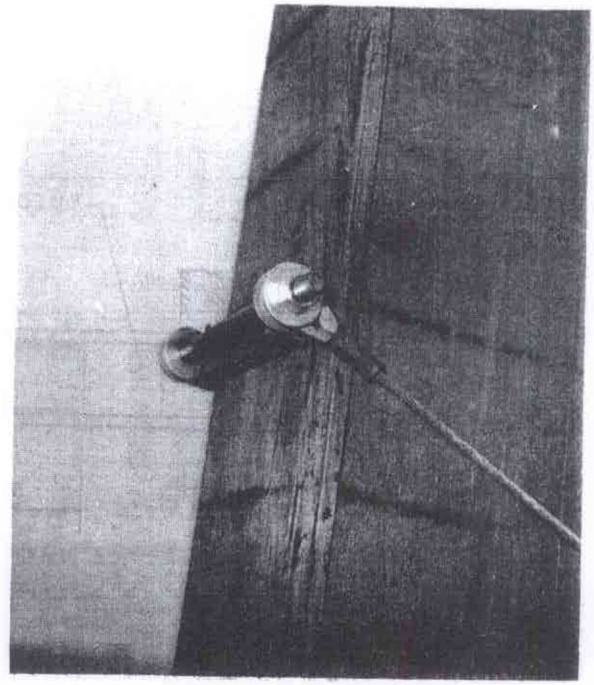


FAILURE MODE - STATIC TEST No. 4

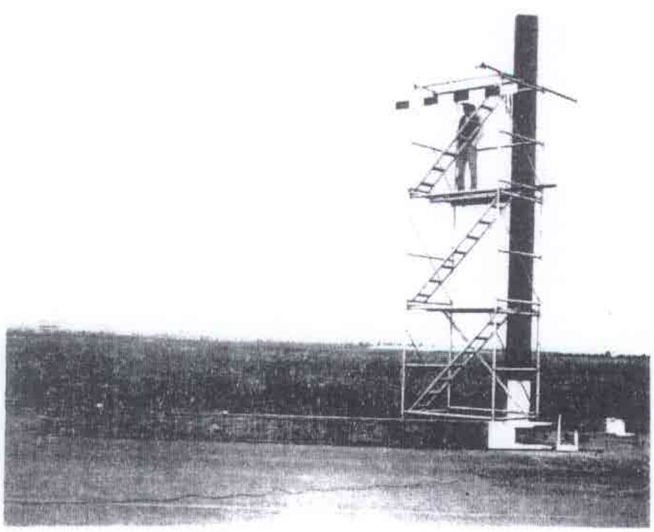
Figure 34 Caltrans Static Bend Test on Box Section Post



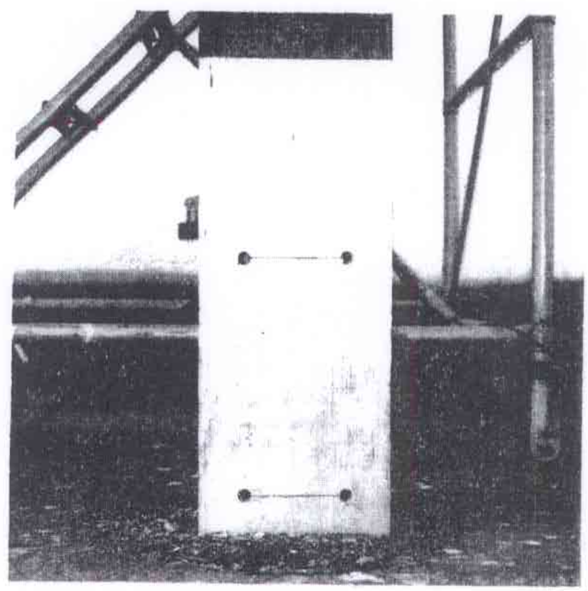
Post Before Test With Cable Attached



Loading Plate and Cable



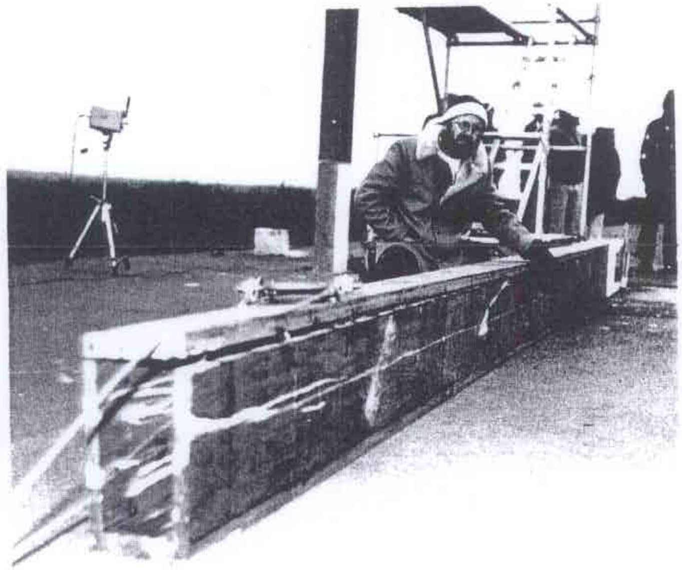
Post on Ground After Test



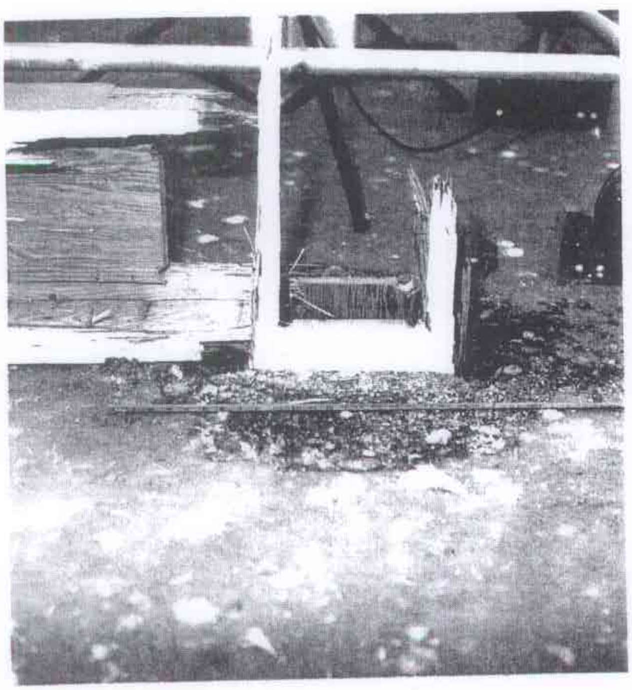
1-inch Diameter Holes Sawcuts in Box Section

Figure 35 Caltrans Static Bend Test on Box Section Post - Views After Test

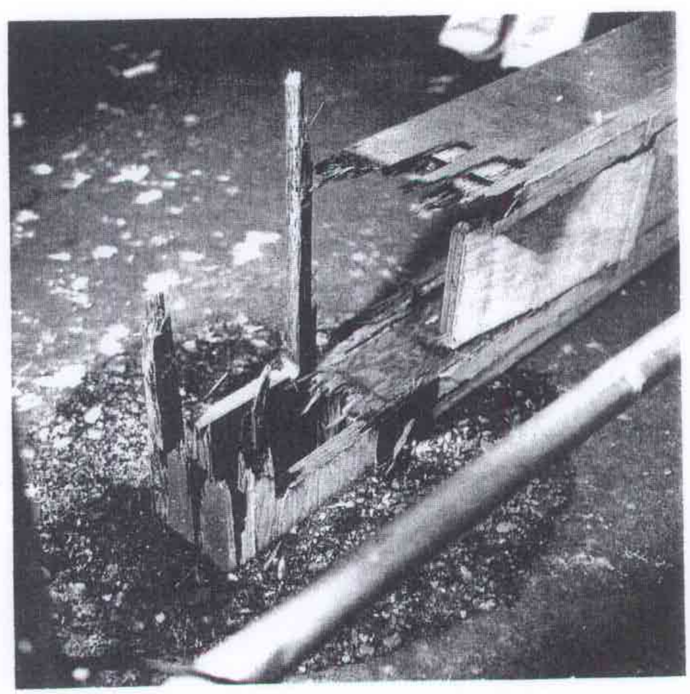
Bottom of Post



Top of Post



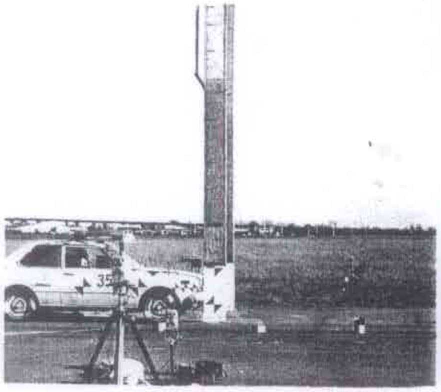
Post Stub - Left Side



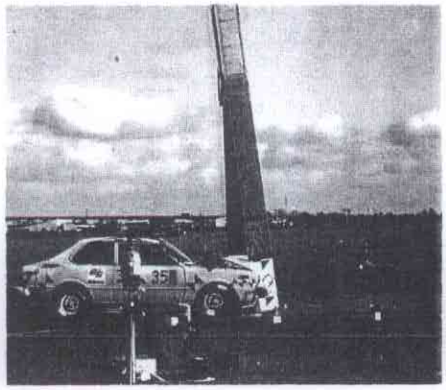
Post Stub - Right Side

first as usual. The first signs of distress in the post were splits between the upper and lower 1-inch holes on the upstream side, and a split going down to the ground from the lower downstream 1-inch hole. Then most of the post sheared off through the lower holes and sawcut. The upstream flange up to the upper hole was pushed over by the car. Only this flange and some splinters were passed over by the car which was not snagged or delayed in any way. There was virtually no pitch of the vehicle during impact. It continued to stay in contact with the post and pushed it around in a circular path to the left. About the time the post was 15° off a vertical line and the car was three quarters of its length over the post stub, cracks appeared in the left hand post. These cracks progressed up the post and became wider and wider as the post was subjected to bending and torsion. Eventually this post was twisted off near its base at the lower sawcut. As the impacted post was pushed ahead by the vehicle, it rotated down and finally pivoted about the right front corner of the roof. At this point it landed on the sliding weight device which was mounted on the roof and projected over the windshield. This device was pushed down into the windshield and cracked it. The post alone probably would not have cracked the windshield. The vehicle passed under the post as the post was rotating, and stopped just beyond the fallen sign. As the left hand post came down following the impacted post, the sign panel buckled severely in the middle and delaminated. The test vehicle came to rest approximately 28 feet beyond the original sign location, in line with the left hand post, and with final yaw angle of 42°. Final positions of the test sign and vehicle are shown in Figure 50 in Section 5.3.4. Accelerometer data plots are shown in Figures C7-C9 in Appendix C.

FIGURE 36. DATA SUMMARY SHEET - TEST 355

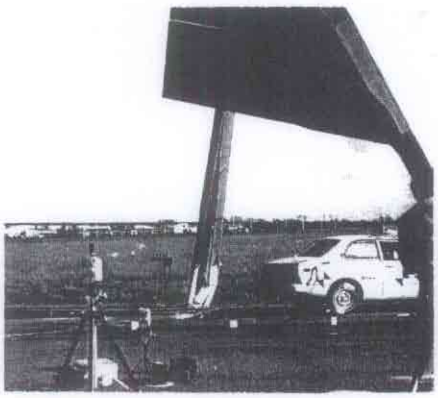


Impact + 0.01 Sec

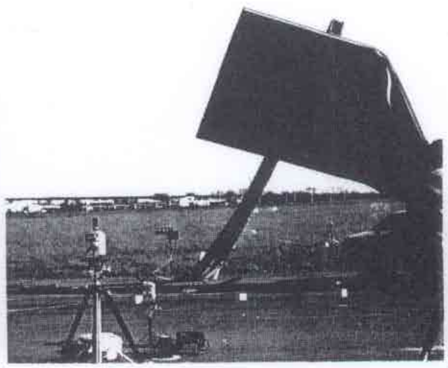


I + 0.12 Sec

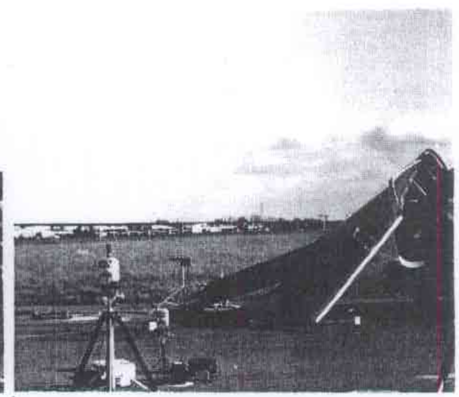
I + 0.67 Sec



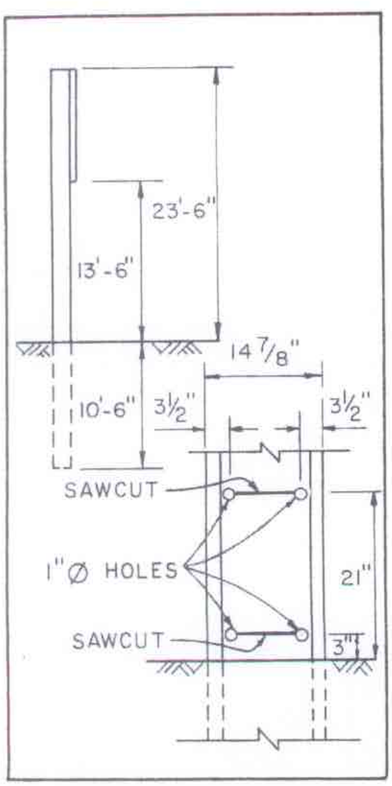
I + 1.44 Sec



I + 2.21 Sec



I + 2.98 Sec



TEST DATE		January 30, 1981
SIGN SUPPORTS		Laminated Wood Veneer Box Section
Support Size-7 7/8"x 14 7/8"(1 1/2" Flange, 1" Web)		
Breakaway Holes		1"Ø-3 1/2" from Ea. Edge - Sawcut Betw. @ 3" & 21" Aboveground - Both Webs
Support Spacing/Embedment		12'-0"/10'-6"
Soil Type		Std. - TRC #191
SIGN PANEL		Alum. 2 5/8" x 10'-0" x 21'-0" Wide
Ground Clearance		13'-6"
Support Connection		8 - 1/2"Ø Threaded Rods
TEST VEHICLE		1976 Toyota Corolla
Test Inertial Mass		2205 lbs
Gross Static Mass		2370 lbs
Impact Speed/Angle		19.2 mph/0°
DRIVER DUMMY		Part 572, 50th Percentile, 165 lbs
Restraints		Lap, shoulder belts
TEST RESULTS		
Occup/Compart. Impact Veloc.	- Film	10.3 ft/sec
	- Accel.	10.5 ft/sec
Change of Momentum	- Film	706 lb-sec
	- Accel.	721 lb-sec
Highest 50 ms Avg. Long. Accel.		-4.3 G's
Max. Crush - Front of Vehicle		10 in
Max. Rise/Pitch/Yaw		1"/1°/42°
Vehicle Damage TAD/VDI		FC-3/12FCMN3
Head Injury Criterion		6.9

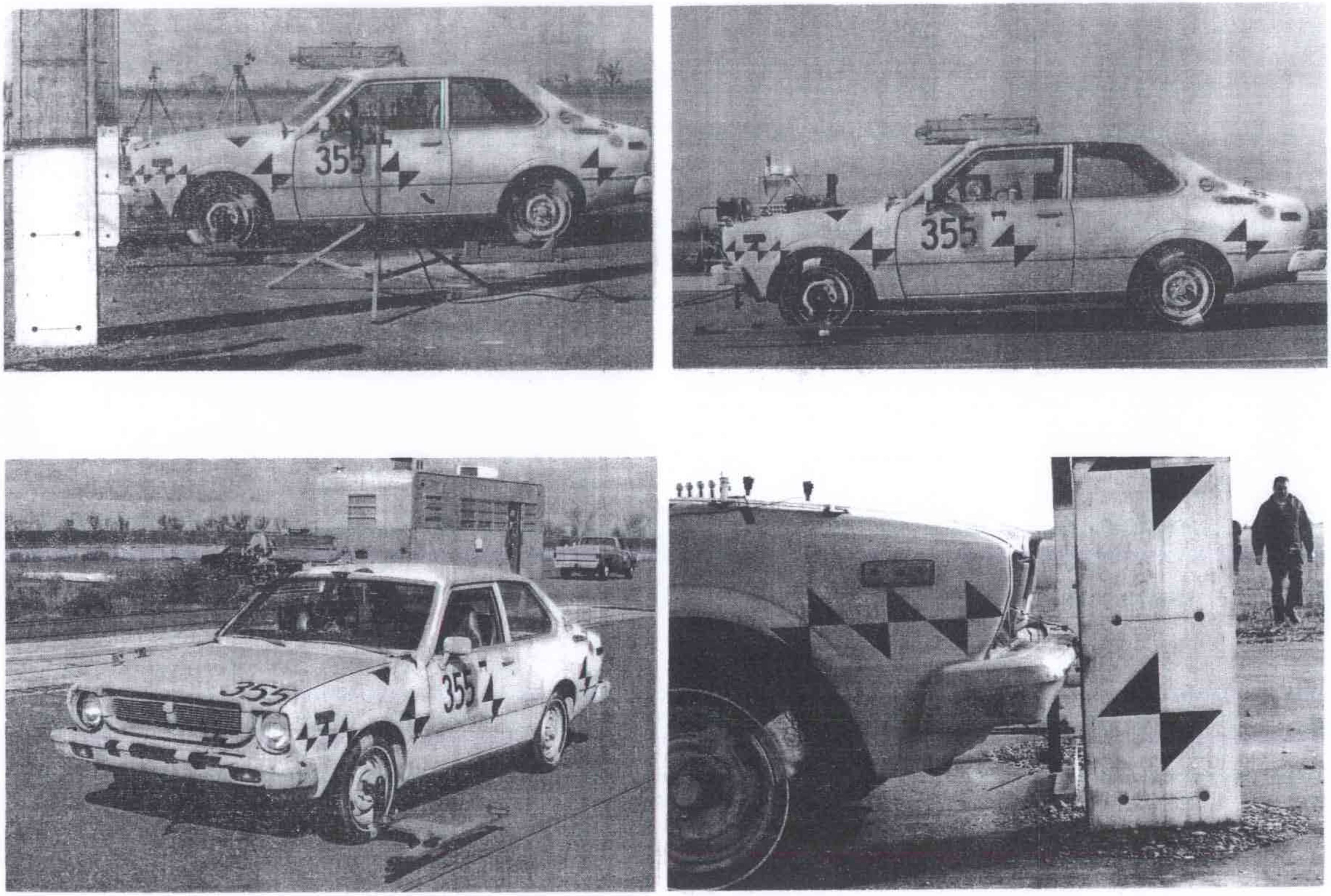
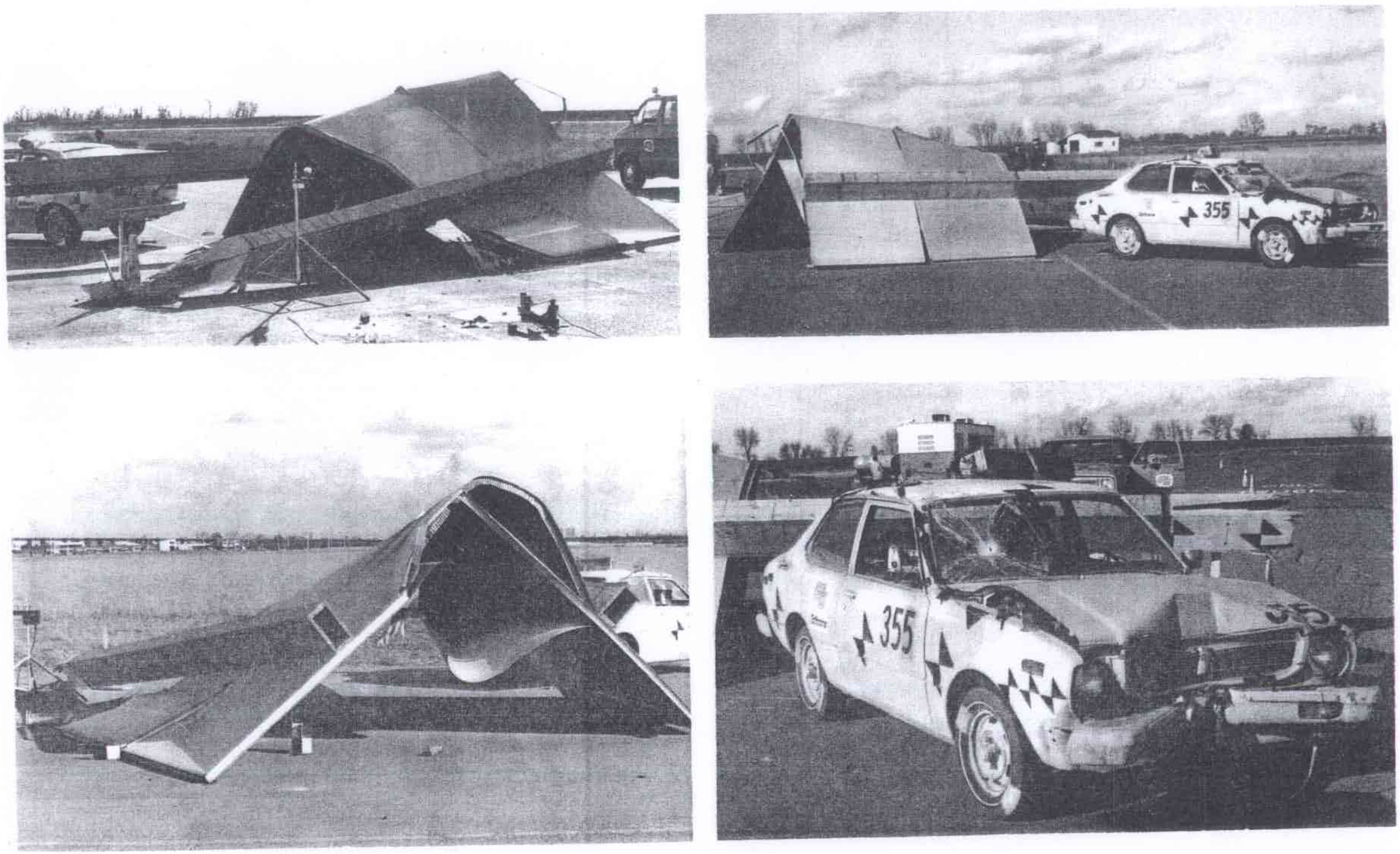


Figure 37 Test 355 Test Vehicle and Test Sign Before Impact



Top: View From Upstream

Bottom: View From Right Side

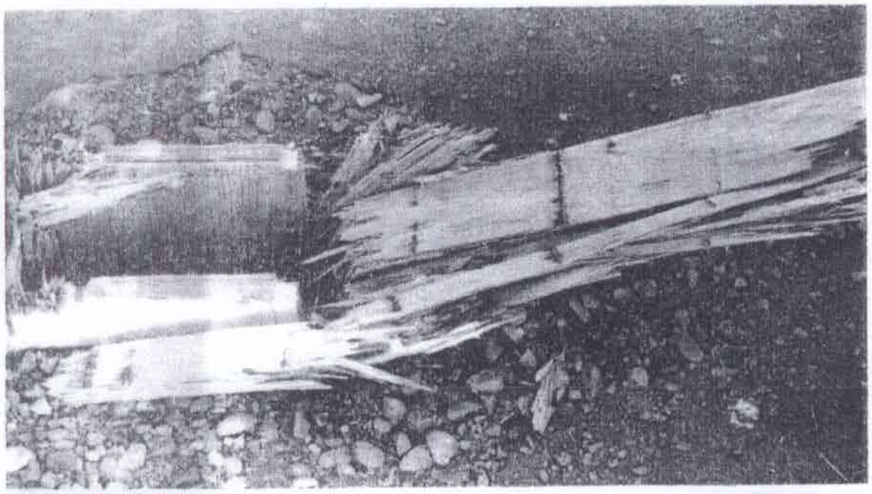
Top: View From Downstream

Bottom: Close up View From Downstream

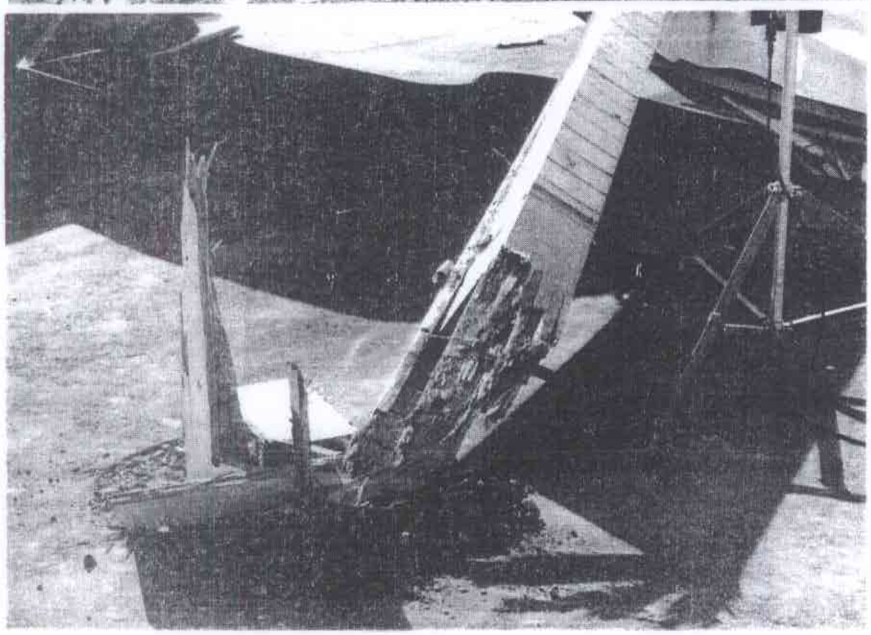
Figure 38 Test 355 Test Vehicle and Test Sign After Impact

Figure 39

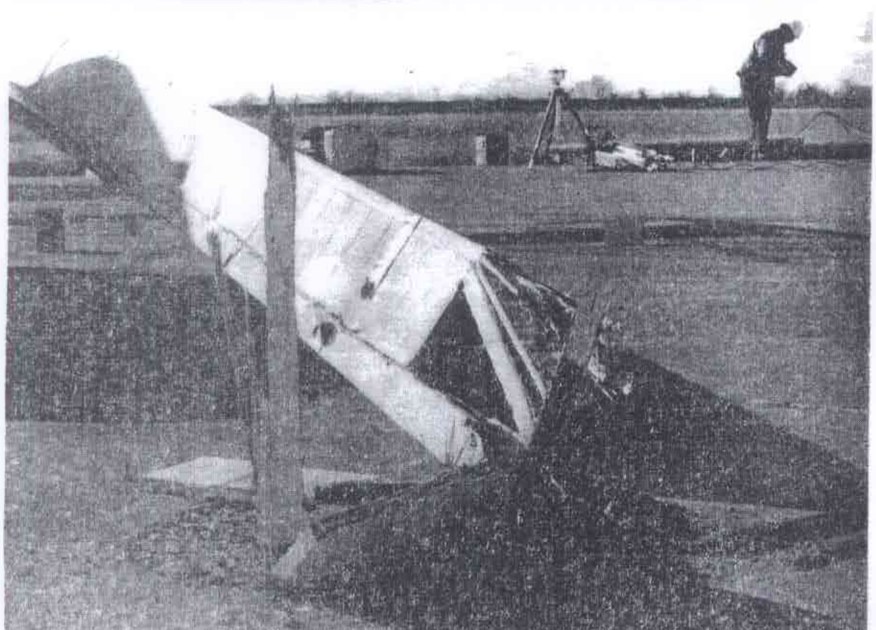
Test 355



Impacted Post



Other Post (Not Impacted)



Other Post (Not Impacted)

5.2.8.2 Vehicle Damage - 355

Maximum front vehicle crush was 4 inches. The radiator was pushed back to the fan; the engine block did not move. The doors were not jammed and the tires were intact, but the vehicle could not be driven away due to the front crush. There was no intrusion of vehicle or sign components into the passenger compartment during impact. Overall the damage was relatively light.

5.2.8.3 Sign Damage - 355

The test sign was a total loss since both posts failed near the ground, and the sign panel was badly buckled. The through bolts kept the posts attached to the sign panel throughout the impact and did not pull out. There was very little soil movement behind the embedded post stubs. The posts and sign panel fell directly beyond the original test sign location.

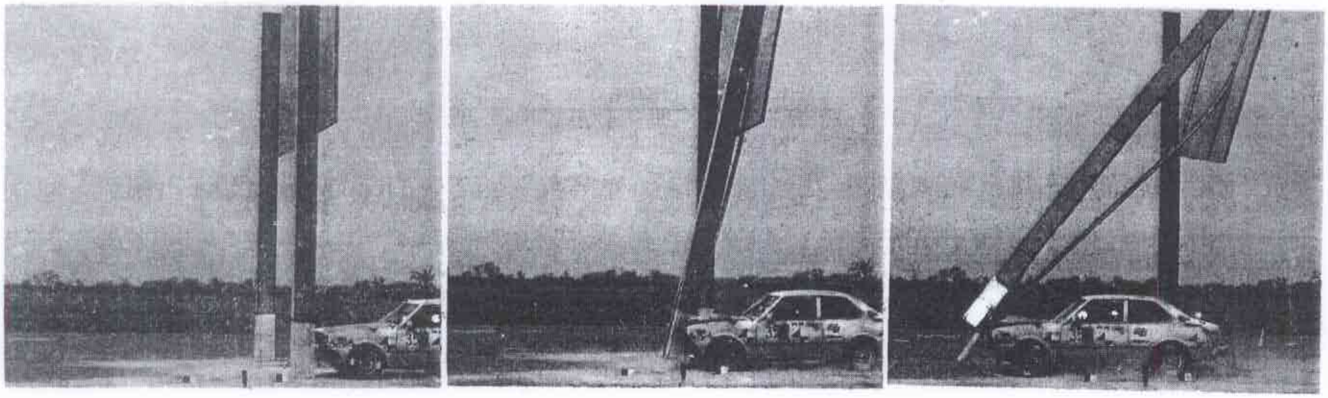
5.2.8.4 Dummy Behavior - 355

The test dummy was positioned in the driver's seat and restrained with lap and shoulder belts which prevented impact with the car interior. The dummy did not appear to be damaged during the test.

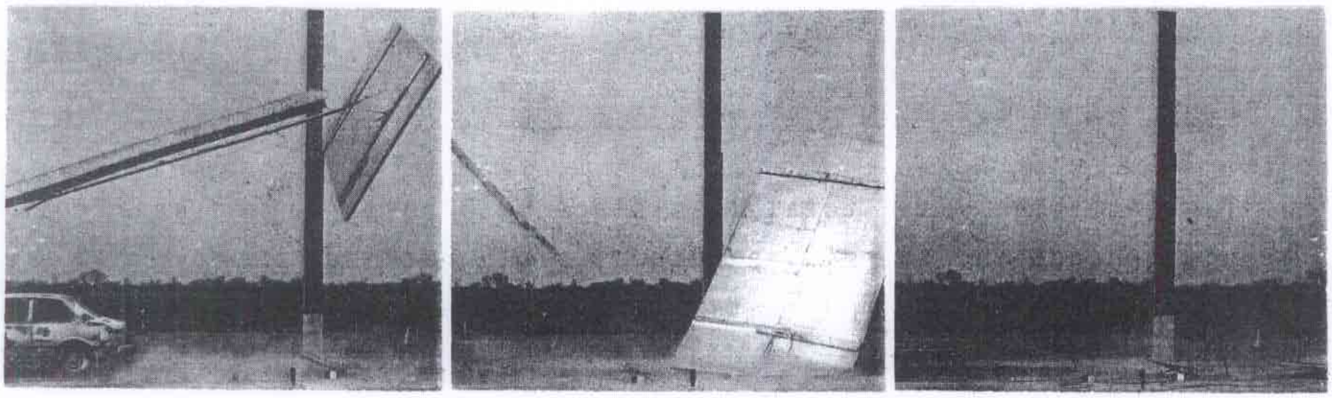
5.2.9 Test 356 - Box Section (2205 lbs/58.4 mph)

The summary of test data and photos taken before and after impact are shown in Figures 40 through 43.

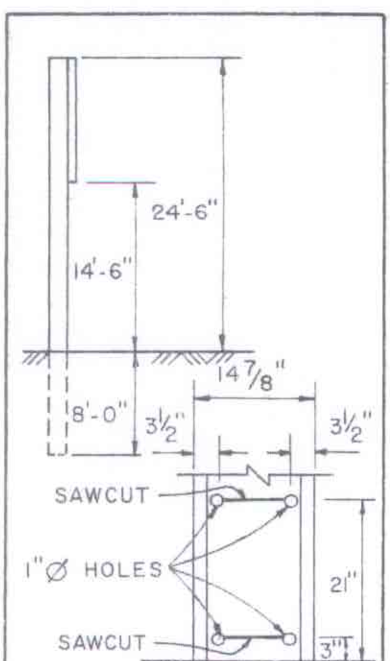
FIGURE 40. DATA SUMMARY SHEET - TEST 356



Impact + 0.00 Sec | I + 0.06 Sec | I + 0.17 Sec



I + 0.33 Sec | I + 0.83 Sec | I + 2.72 Sec



TEST DATE	March 12, 1981
SIGN SUPPORTS	Laminated Wood Veneer Box Section
Support Size	7 7/8"x 14 7/8"(1 1/2" Flange,1" Web)
Breakaway Holes	1"Ø - 3 1/2" from Ea. Edge - Sawcut Betw. @ 3" & 21" Aboveground - Both Webs
Support Spacing/Embedment	13'-0"/8'-0"
Soil Type	Std. - TRC #191
SIGN PANEL	Alum. 2 5/8" x 10'-0" x 21'-0" Wide
Ground Clearance	14'-6"
Support Connection	16 - 1/2"Ø x 5 1/2" Lag Screws
TEST VEHICLE	1976 Toyota Corolla
Test Inertial Mass	2205 lbs
Gross Static Mass	2370 lbs
Impact Speed/Angle	58.4 mph/0°
DRIVER DUMMY	Part 572, 50th Percentile, 165 lbs
Restraints	Lap, Shoulder Belts
TEST RESULTS	
Occup/Compart. Impact Veloc.- Film	3.20 ft/sec
- Accel.	3.74 ft/sec
Change of Momentum - Film	219 lb-sec
- Accel.	256 lb-sec
Highest 50 ms Avg. Long. Accel.	-4.0 G's
Max. Crush - Front of Vehicle	10 in
Max. Rise/Pitch/Yaw	0/1°/—
Vehicle Damage TAD/VDI	FC-3/12FCMN2
Head Injury Criterion	2.6

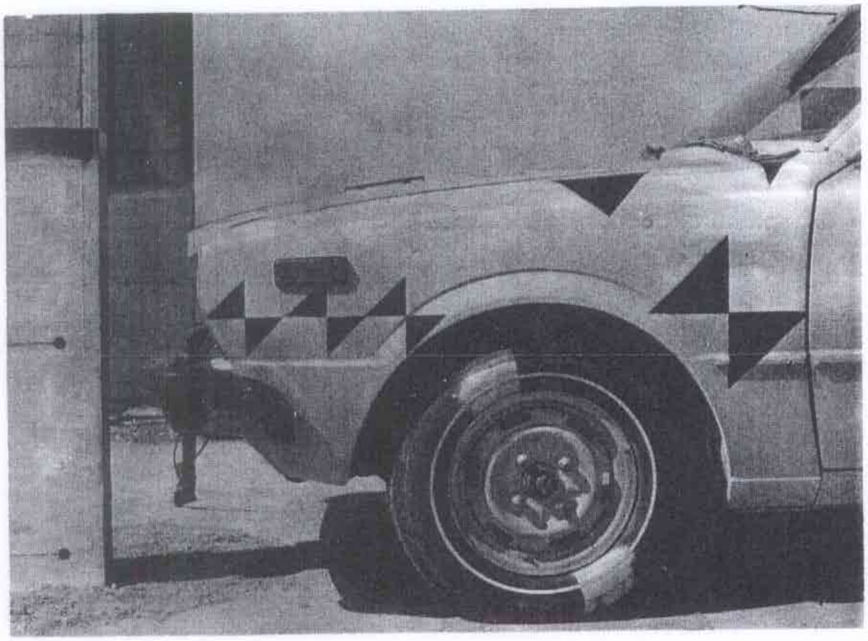
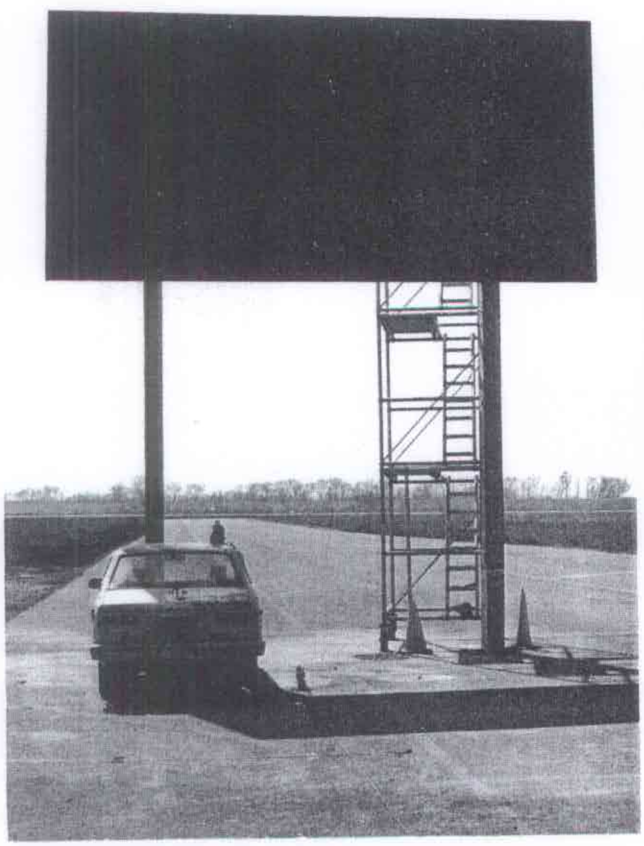


Figure 41

Test 356

Test Vehicle and
Test Sign Before Impact



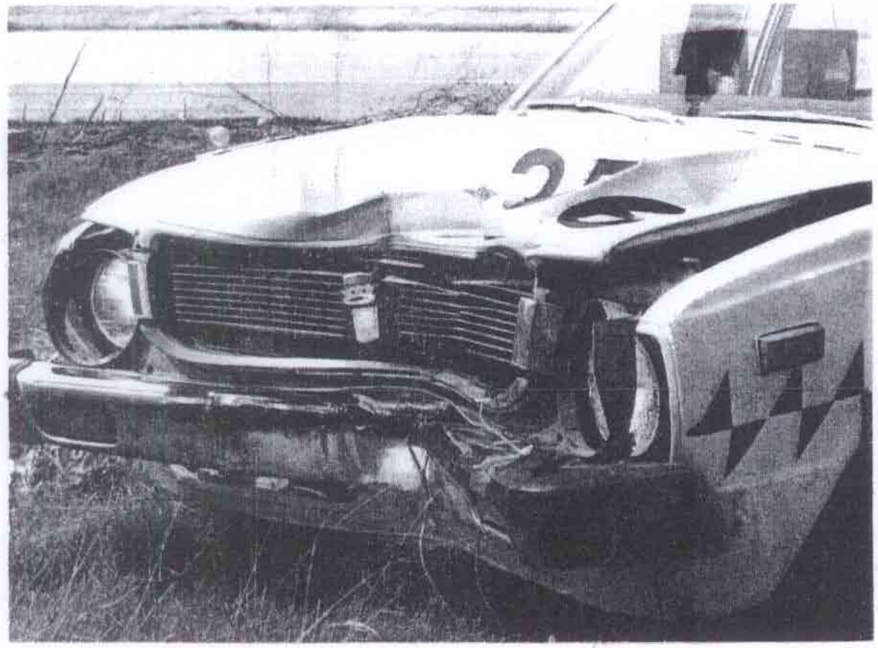
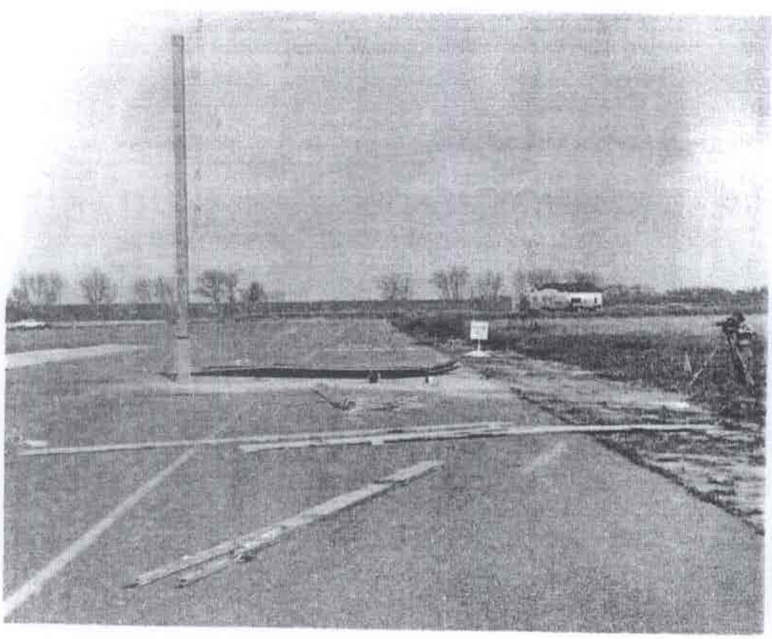


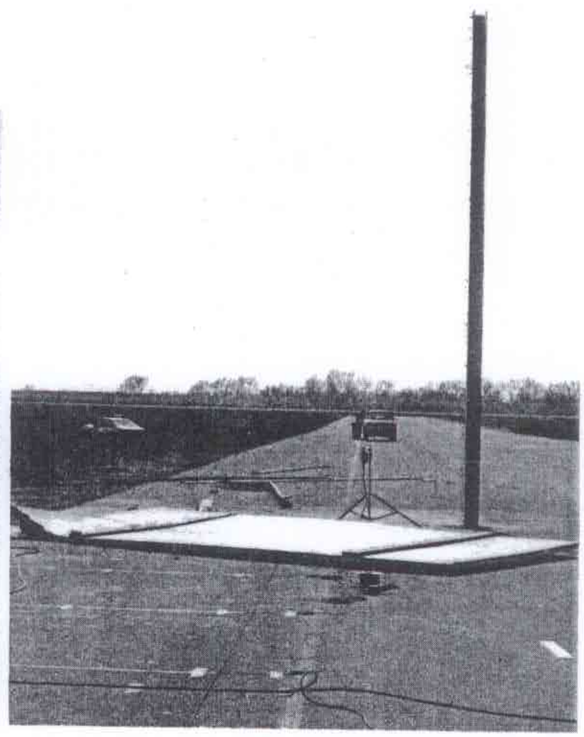
Figure 42

Test 356

Test Vehicle and
Test Sign After Impact



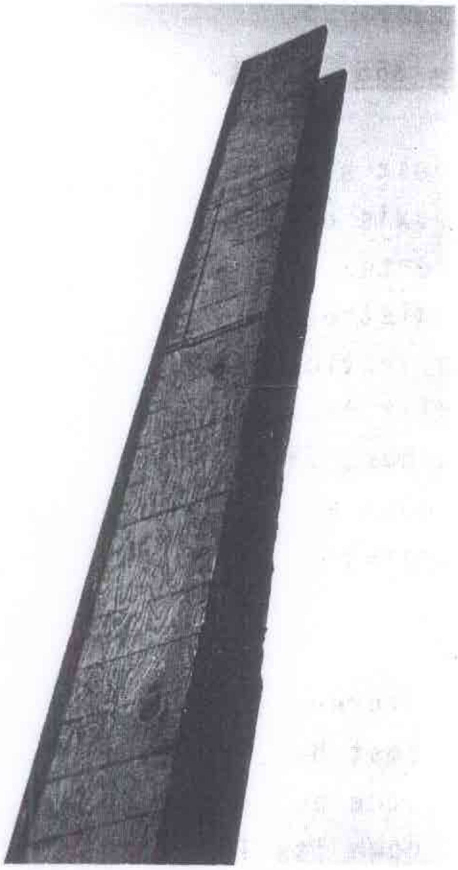
View Looking Upstream Shows
Final Location of Flange and
Web Pieces From Box Section Post

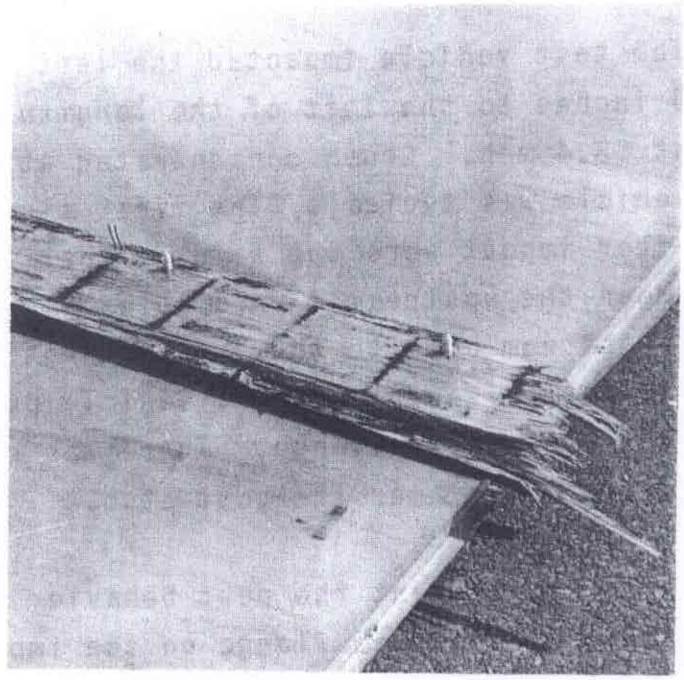


View Looking Downstream
Shows Final Location of
Sign Panel and Test Vehicle

Figure 43

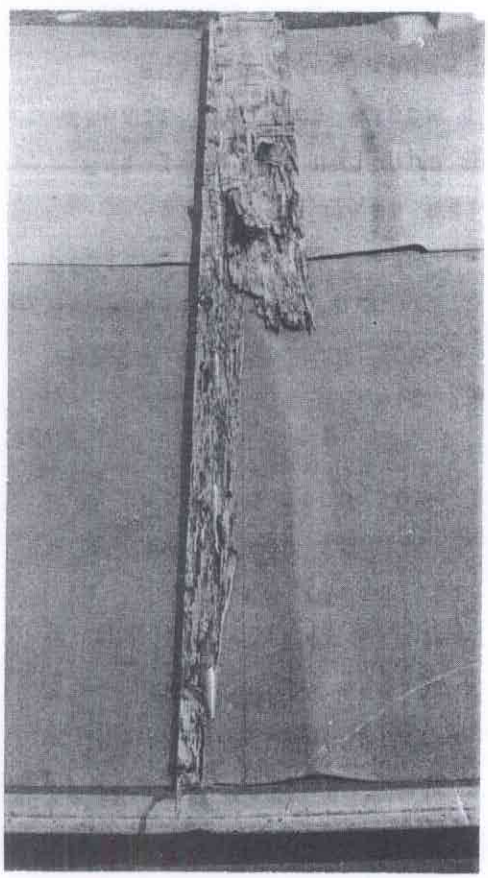
Test 356

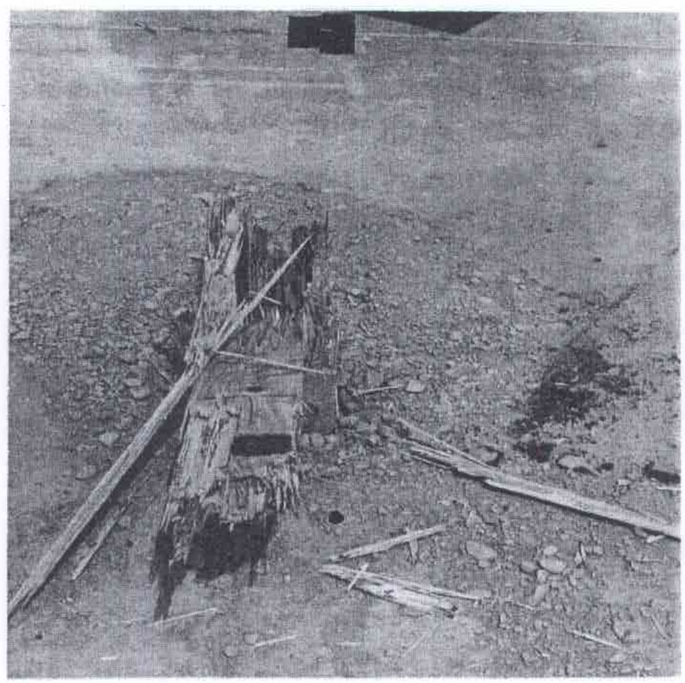




Left: Non-Impacted Post With Upper Flange Stripped Off

Above: Upper Flange Attached To Sign Panel





Left: Upper Flange From Impacted Post Attached to Sign Panel

Above: Impacted Post Stub

5.2.9.1 Impact Description - 356

The test vehicle impacted the left hand post head-on, about 5 inches to the left of the longitudinal axis of the vehicle, at 58.4 mph. Crush concentrated at the center front of the vehicle was typical. The first signs of distress in the post after impact were the same as Test 355, a vertical split between the upstream 1-inch holes, and a split from the bottom downstream hole to the ground. Again the post sheared off at the bottom sawcut and the vehicle pushed down a short height of the upstream flange. There was no snagging of the vehicle as it passed over the post stub.

Beyond this point the post behavior was different than Test 355. The upstream flange on the impacted post began to split away from the rest of the box section near the bottom of the sign panel. As it split away both up and down its length, it was flexed like a bow until it separated from the rest of the box section completely. A portion of the upper half of the flange remained attached to the sign panel where the lag screws held them together. The free flange piece and the rest of the box section were kicked up in the air by the vehicle which passed underneath them without further contact. The three-sided box section rotated about 180°, struck the ground, and shattered into three long pieces. It failed in the wood lamination at the glue joints between the webs and downstream flange.

Meanwhile the upstream flange of the right hand post split away from the box section from the top of the post downward. The split continued to the bottom of the sign panel which rotated about this point and eventually tore off the post. The upper flange piece was firmly attached to the sign panel by eight lag screws. The right hand post opened up cracks 1/4-1/2 inch wide at the upstream and downstream web to flange joints for heights of 2 to 3 feet above ground. These splits closed up after the sign panel was torn off this post. The right hand post remained standing and appeared to be undamaged except for the cracks at the bottom and the upper 10 feet of the upstream flange which was torn off with the sign panel.

The sign panel ended face down on the ground, directly upstream of the original test sign location. The vehicle continued straight downstream, then steered to the left when the brakes were applied remotely. Final positions of the test sign and test vehicle are shown in Figure 50 in Section 5.3.4. Accelerometer data plots are shown in Figures C10-C12 in Appendix C.

5.2.9.2 Vehicle Damage - 356

Maximum front vehicle crush was 6 inches. The radiator was pushed back to the fan; the engine block was unmoved. The doors were not jammed and the tires were intact. Due to the front crush, the vehicle could not have been driven away. There was no intrusion of vehicle or test sign components into the passenger compartment.

5.2.9.3 Sign Damage - 356

The impacted post was separated into four flange and web pieces. The other post probably would need replacement since the upper upstream flange was torn off. There was no pullout of the lag screws connecting the sign panel to the box section flanges. The sign panel was damaged mainly at the corner where it first struck the ground. It was bent and had delaminated in this area. There was very little soil movement or displacement behind the posts.

5.2.9.4 Dummy Behavior - 356

The test dummy was positioned in the driver's seat and restrained with lap and shoulder belts which prevented impact with the vehicle interior. The dummy did not appear to be damaged during the test.

5.3 Discussion of Test Results

5.3.1 General - Criteria

In Transportation Research Circular (TRC) No. 191, "Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances" (4), three appraisal factors are recommended for use in judging performance of highway safety appurtenances. The three factors which will be discussed in the following sections are (1) structural adequacy, (2) impact severity (occupant risk), and (3) vehicle trajectory. The crash test and pendulum test results will be judged against these criteria.

In addition the results will be compared on a relative basis with reference to all the tests in this project plus similar tests by other agencies. Data from all these tests is summarized in Table 5.

National Cooperative Highway Research Program (NCHRP) Report No. 230, "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances" (6) is an update of TRC No. 191 and was published at the time this report was being written. Where the appraisal factors have been revised, these changes will be noted in the following sections with comment on the crash tests.

DATA SUMMARY OF CRASH TESTS ON BREAKAWAY WOOD SUPPORTS FOR DUAL LEGGED ROADSIDE SIGNS

TEST I.D. REF. NO.	TEST I.D. TEST NO.	TEST I.D. TEST DATE	BREAKAWAY SUPPORT TYPE	BREAKAWAY SUPPORT BREAKAWAY MODIFICATION	BREAKAWAY SUPPORT NET SHEAR AREA (In^2)	BREAKAWAY SUPPORT SPACING (ft.)	BREAKAWAY SUPPORT EMBEDMENT (ft.)	SIGN PANEL CONNECTION TO SUPPORT	SIGN PANEL SIZE	SIGN PANEL GRND. CLR. (ft.)	VEHICLE TEST INER. MASS (lbs.)	VEHICLE IMPACT VELOC. FPS (MPH)	VEHICLE IMPACT ANGLE (Deg)	TEST RESULTS OCCUPANT/COMPARTMENT IMPACT VELOCITY (FPS) FILM	TEST RESULTS OCCUPANT/COMPARTMENT IMPACT VELOCITY (FPS) ACCEL.	TEST RESULTS INITIAL MOMENTUM MV (lb-sec)	TEST RESULTS CHANGE OF MOMENTUM ΔMV (lb-sec) FILM	TEST RESULTS CHANGE OF MOMENTUM ΔMV (lb-sec) ACCEL.	TEST RESULTS HIGH 50 MS. AVG. LONG. VEH. ACCEL. (G's)	TEST RESULTS INIT. VEH. KINET. ENER. KE (ft-K)	TEST RESULTS CHANGE IN KIN. ENER. ΔKE (ft-K)	TEST RESULTS MAX FRONT VEH. CRUSH (In)
1 Calif	151	11-66	6" x 8" D.F. Posts	None	43	9.0	6.0	3/8"Ø Bolts	5' x 14' x 1" Aluminum	7.0	4540	55.7 (38.0)	0	2.93		7858	414			219	22	
"	152	5-67	11"Ø D.F. Poles	None	95	12.0	9.5	3/8"Ø Lag Screws	10'x 20' x 2 1/2" Alum.	"	"	58.7 (40.0)	0	5.87		8272	827			243	46	
"	153	5-67	"	3 - 4"Ø Holes @ 4", 10" & 16" Above-ground	52	"	"	"	"	"	2000	57.2 (39.0)	0	17.6		3553	1093			102	53	
Calif	351	4-78	6" x 8" D.F. Posts	2 - 2 1/2"Ø Holes @ 6" & 18" Above-ground	25	8.0	6.0	8 - 3/8"Ø Threaded Rods	6'-8" x 13'-0" x 1 1/8" Alum.	"	2205	29.0 (19.8)	0	14.0	10.0	1989	958	685	- 3.7	29	16	7
"	352	8-78	"	"	25	"	"	"	"	"	"	84.7 (57.7)	0	10.0	3.82	5797	685	262	- 1.9	245	22	8
"	353	1-79	9 1/4"Ø D.F. Poles	2 - 3"Ø Holes @ 6" & 18" Aboveground	40	"	7.5	8 - 3/8"Ø Lag Screws	8'-6" x 13'-0" x 1 1/8" Alum.	" "	" "	28.2 (19.2)	0	33.2	29.4	1930	1930	1930	-11.2	27	27	16
"	354	5-80	"	Ditto plus 2 4"Ø Holes @ 4" & 24" w/Sawcut Between	31	"	"	8 - 3/8"Ø Lag Screws	"	"	"	29.2 (19.9)	0	17.0	18.0	1999	1160	1230	- 7.5	29	25	13
"	355	1-81	7 7/8" x 14 7/8" Box Sect.	1"Ø Holes 3 1/2" from Each Edge and Sawcut Between @ 3" & 21" Aboveground	30	12.0	10.5	8 - 1/2"Ø Threaded Rods	10'-0" x 21'-0" x 2 5/8" Alum.	13.5	"	28.2 (19.2)	0	10.3	10.5*	1928	706	721	- 4.3	27	16	10
"	356	3-81	"	"	30	13.0	8.0	16-1/2"Ø x 5 1/2" Lag Screws	"	14.5	"	85.7 (58.4)	0	3.2	3.74*	5865	219	256	- 4.0	251	21	10
33 ENSCO	902	1-79	6" x 8" D.F. Posts	2 - 2 1/2"Ø Holes @ 6" & 18" Above-ground	28	8.0	6.0	3/8"Ø Threaded Rods	6'-8" x 13'-0" x 1 1/8" Alum.	7.0	2250	28.9 (19.7)	0	28.9	9.17	2021	2021	1380	--	29	16	

*From Waveform Analyzer Calculation, Figures C8 & C11; not Figures C17 and C18 which are based on rattlespace times from film data.

TABLE 5

The result of the static bend tests will be compared with the wind load designs contained in the AASHTO "Standardized Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals" (3).

The film report on this project can be used to compare the results of the six crash tests by Caltrans.

5.3.2 Structural Adequacy

In Table 4 of TRC No. 191 (4) this appraisal factor is described as follows for breakaway supports:

> "B. The test article shall not pocket or snag the vehicle causing abrupt deceleration or spinout or shall not cause the vehicle to roll over. The vehicle shall remain upright during and after impact although moderate roll and pitching is acceptable. The integrity of the passenger compartment must be maintained. There shall be no loose elements, fragments or other debris that could penetrate the passenger compartment or present undue hazard to other traffic."

These criteria are essentially the same in NCHRP No. 230 (6).

The above criteria were satisfied for all crash tests with four exceptions:

(1) In Test 353 the pole did not breakaway and the vehicle decelerated to an abrupt stop. Except for the abrupt stop, all other criteria for structural adequacy were satisfied in Test 353.

(2) In Test 354 the structural adequacy criteria were met except that the revised timber pole breakaway design was still stiffer than desired.

(3) In Test 355 the fallen sign projected approximately 11 feet to the right of the right hand post. If the vehicle had struck the left hand post, the position of the fallen sign would have been reversed, presumably, and would have projected out toward the traveled way 11 feet. If the sign were located close to the edge of the traveled way, this might pose a hazard.

(4) In Test 356 the shattered pieces of the box section post projected a maximum of approximately 15 feet to the left of the left hand post. These pieces might have projected into the traveled way if it was located close to the sign. Since these "planks", which were 1 inch and 1 1/2 inch thick, were laying flat on the ground, they would pose more a psychological hazard than a real hazard to oncoming traffic. This condition would be more likely than the hump backed sign in Test 355 because in that test the through bolts held the posts and sign panel together. The lag screws used in Test 356 allowed the flange to peel away from the rest of the box section and the sign panel which dropped flat on the ground.

Although it would be preferable for the sign panel to remain attached to the box section post not impacted similar to the smaller signs used with 6 in. x 8 in. posts in Tests 351 and 352, this is probably not possible with a wood post design supporting large, quite rigid sign panels.

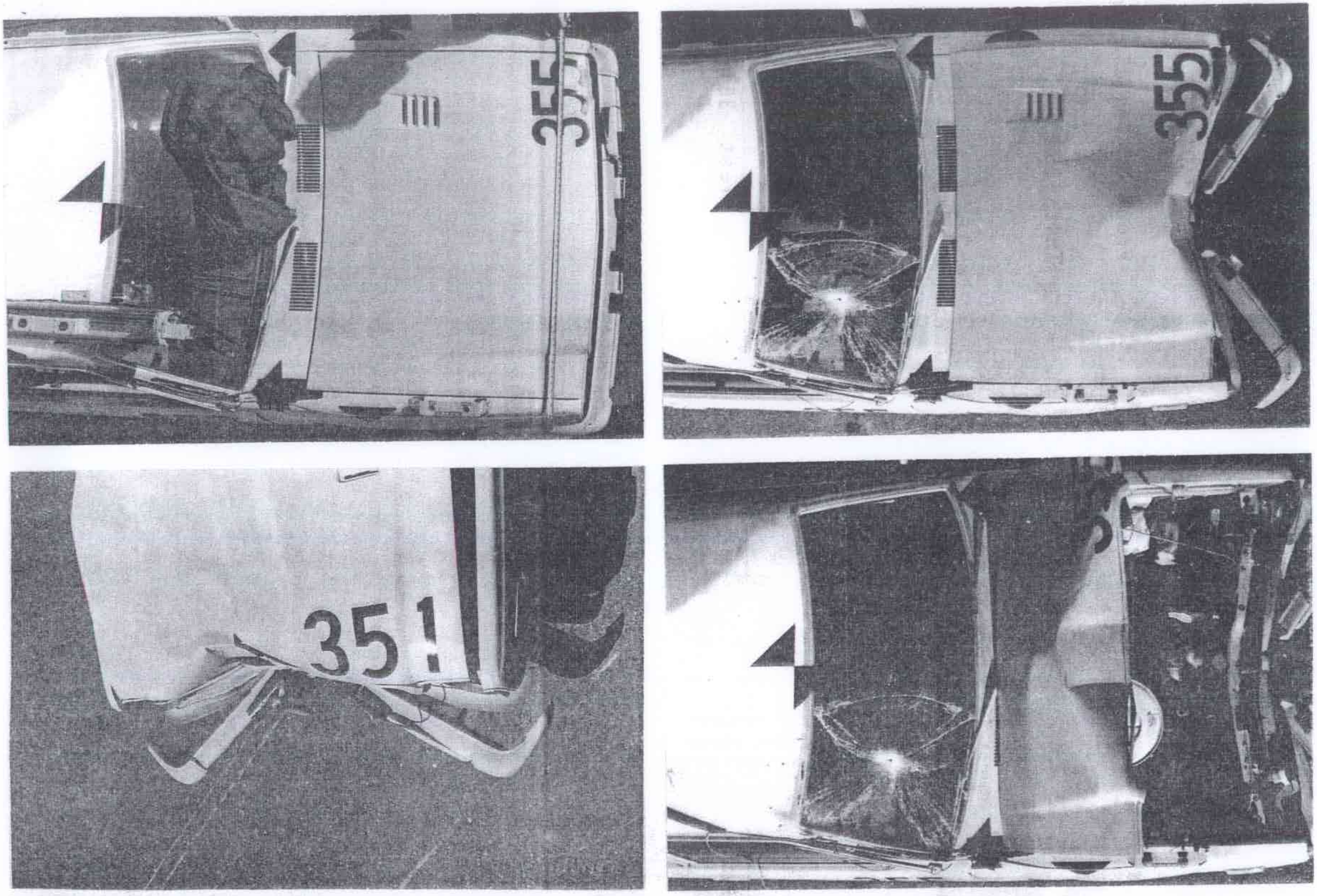
In Caltrans Test 153 conducted in the mid-60's with a VW impacting a large Class 2 timber pole at 40 mph, the sign panels fell to the ground. They were attached to the poles with lag screws. That design was the basis for the timber pole designs used since that time by Caltrans.

In Tests 351, 354, and 355 conducted at impact speeds of 19-20 mph the vehicles tended to stay in contact with the posts while they came to a stop. Despite this prolonged contact, it did not appear that the passenger compartments were ever in danger of being penetrated through the windshield or elsewhere by the posts.

Front vehicle crush is one measure of the adequacy of a breakaway device. Figures 44-46 shows the crush profiles of the test vehicles. Much more crush was encountered in Tests 353 and 354 using timber poles than in the other tests. The TAD (14) and VDI (15) vehicle damage scales are given on the data summary sheets for each test.

The pendulum tests conducted at SWRI showed that the breakaway performance of timber poles could be improved by increasing the breakaway hole diameter, increasing the distance between holes, and connecting the holes with a sawcut. Crash Test 354 showed that although the most promising design tested at SWRI improved the breakaway performance of the timber pole over that in Test 353, the pole was still overly stiff when used in a dual-support sign.

The pendulum tests at SWRI on box and H-section posts showed the breakaway cutouts worked well in all tests.



Top - Undamaged Vehicle
Bottom: Test 351-6"x8" Post/19.8mph

Top and Bottom - Test 355
Box Section/19.2mph

Figure 44 Front of Vehicle Crush

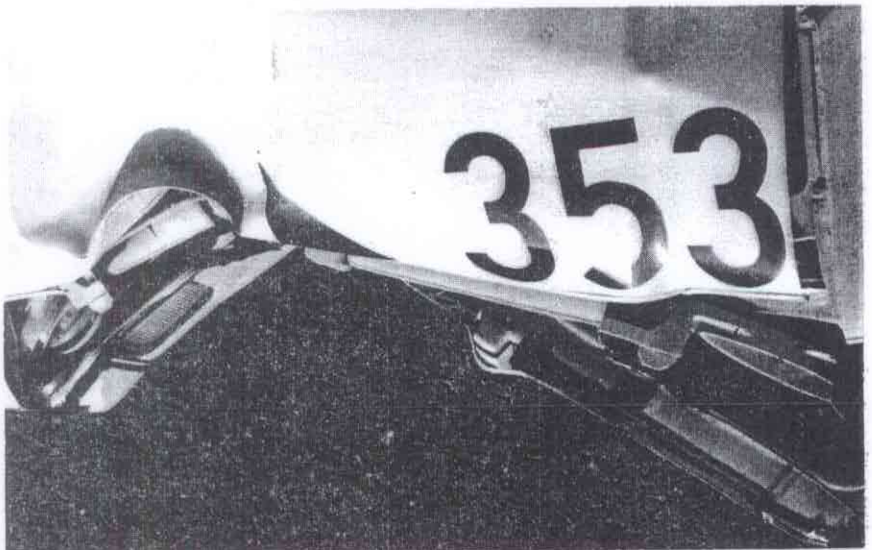
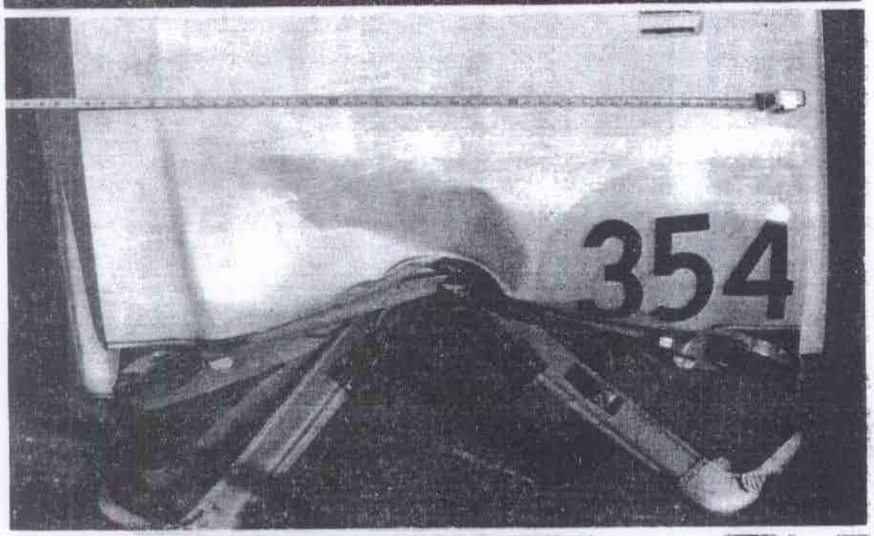


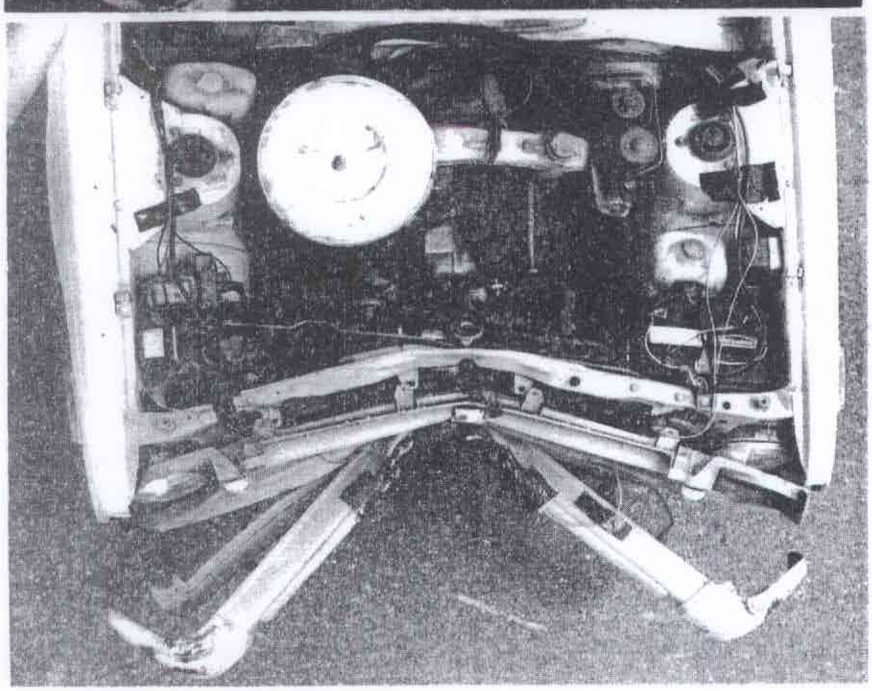
Figure 45

Front of Vehicle Crush

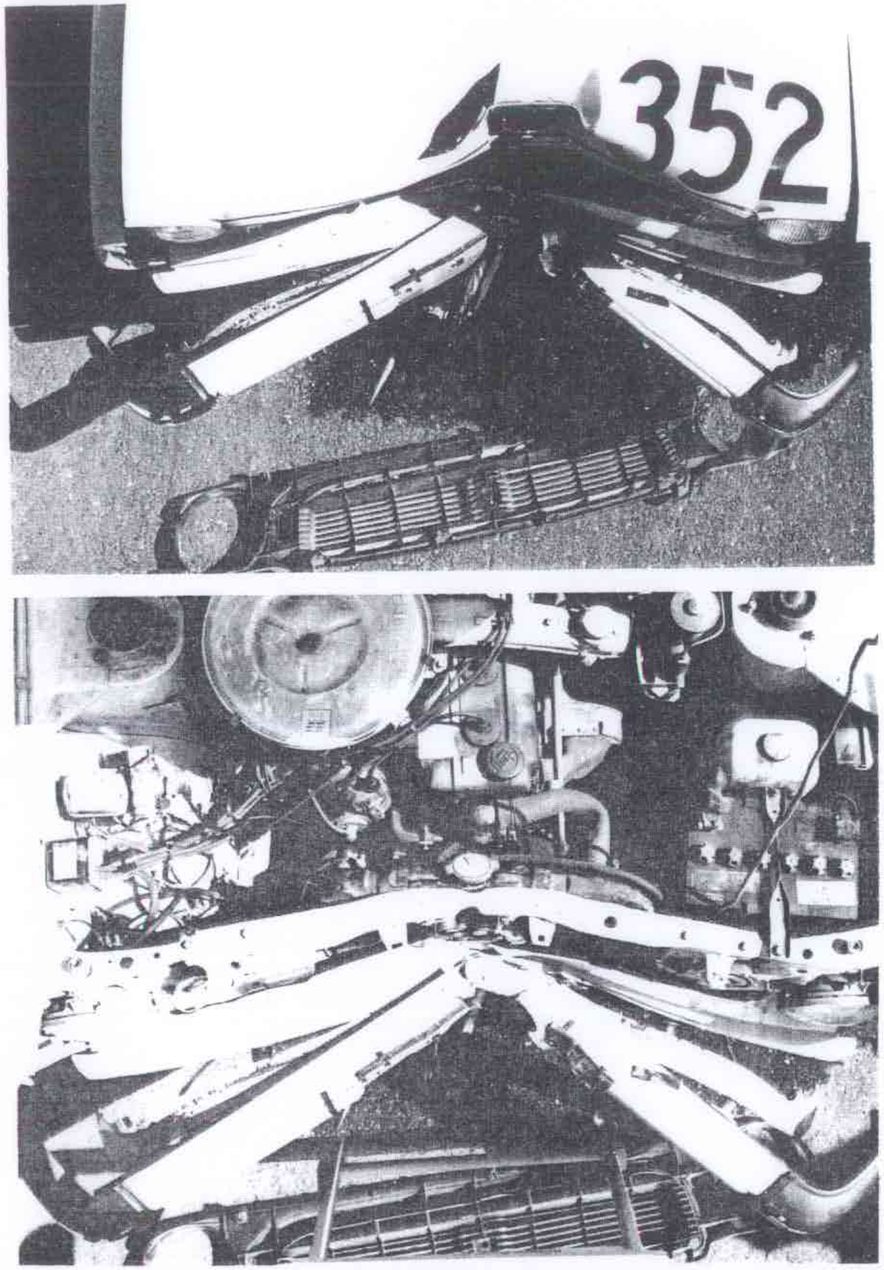
Test 353



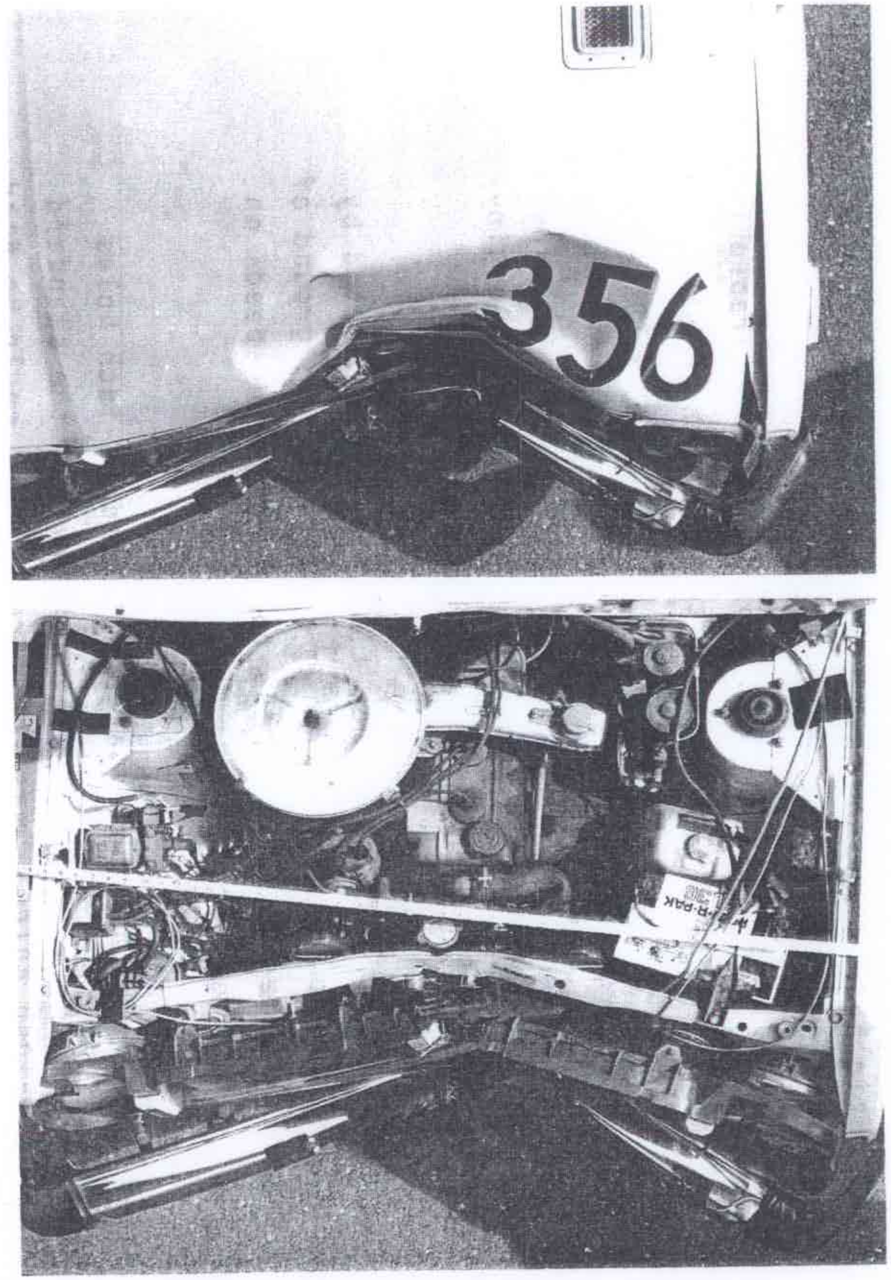
Test 354



Test 354



Test 352 - 6"x8" Post/57.1mph



Test 356 - Box Section/58.4mph

Figure 46 Front of Vehicle Crush

The static bend tests on box and H-section posts at SWRI resulted in failure loads that were less than twice the design wind loads specified by AASHTO, an undesirable condition for wood which has a high coefficient of variation. When the box section was embedded in the ground for a static bend test by Caltrans, the failure load was almost exactly twice the design wind load assuming 60 mph wind speeds. This was judged acceptable by the design engineers in the Caltrans Office of Structures Design.

The static bend tests on three timber poles conducted by Caltrans showed ultimate bending moments at the ground of 1.5 to 2.4 times the moment due to 60 mph wind speeds on a 110 sq ft sign panel.

This showed that the hole pattern tested (4-inch holes with sawcut between), which was larger than the standard design (3-inch holes), was the largest that could be used while maintaining the bending resistance needed for wind loads. Since the poles tested were 9 1/4 inches in diameter whereas some poles in use range up to 12-13 inches in diameter, and since the larger 4-inch diameter hole pattern did not pass the crash test requirements, it is evident that retrofitting the existing operational poles to make them more breakaway may be quite difficult. That problem was not explored further in this project.

The static bend tests and the pendulum tests showed the variable strength that can be expected with timber poles (Tables 3-4). This unpredictable strength makes timber poles a poor material choice when designing a breakaway system that must operate over a narrow range of strength. This strength variability was heightened by the wide range in pole diameters possible with the selection procedures and specifications previously used to choose a timber pole size for any given sign. The variability in strength was not as critical when crash tests with heavy passenger vehicles traveling 40 mph were the standard. However, when light weight low-speed vehicles were used, this property became much more critical.

In summary, the 6 in. x 8 in. D.F. breakaway posts and the laminated wood veneer box section posts were judged structurally adequate in Tests 351, 352, 355 and 356. The timber poles used in Test 353 were inadequate and those used in test 354 were borderline. It should be noted, however, that as with all highway safety appurtenances, the final judgement on the approved designs should be made only after they have been installed and their field performance studied critically.

5.3.3 Impact Severity (Occupant Risk)

In Table 4 of TRC No. 191 (4) the impact severity appraisal factor is described as follows:

> "D. Maximum momentum change of the vehicle during impact shall be 1100 lb-sec and preferably less than 750 lb-sec."

This criterion gives a measure of occupant risk; however, it was not intended "for use in predicting occupant injury in real or hypothetical accidents." The commentary states, "Impact severity is evaluated according to vehicle responses of accelerations and change in momentum. This presumes that there is a relationship between vehicle dynamics and occupant safety. This relationship is tenuous, as it involves such important but widely varying factors as occupant physiology, size, seating position, attitude, and restraint, and vehicle interior geometry and padding."

In NCHRP Report No. 230 the appraisal factor is labled "occupant risk" instead of "impact severity" and is presented in a different form. Table 6 in NCHRP Report No. 230 (6) states:

> "E. The vehicle shall remain upright during and after collision although moderate roll, pitching and yawing are acceptable. Integrity of the passenger compartment must be maintained with essentially no deformation or intrusion.
>
> F. Impact velocity of hypothetical front seat passenger against vehicle interior, calculated from vehicle accelerations and 24 in. forward and 12 in. lateral displacements, shall be less than:
>
> | Occupant Impact Velocity-fps | |
> |---|---|
> | Longitudinal | Lateral |
> | $40/F_1$ | $30/F_2$ |
>
> and vehicle highest 10 ms average accelerations subsequent to instant of hypothetical passenger impact should be less than:
>
> | Occupant Ridedown Accelerations-g's | |
> |---|---|
> | Longitudinal | Lateral |
> | $20/F_3$ | $20/F_4$ |
>
> where F_1, F_2, F_3, and F_4 are appropriate acceptance factors."

Since all tests were head-on, only the longitudinal velocities and accelerations were critical and calculated. The values suggested for F_1 and F_3 in the commentary are 2.67 and 1.33 respectively yielding maximum values of 15 ft/sec and 15 g's. Generally, low values for these velocities and accelerations "indicate less hazardous appurtenances." A detailed discussion of these new criteria is contained in the commentary of NCHRP Report No. 230 (6). The acceptance levels of safety performance are about the same using the old and new methods. NCHRP Report No. 230 calls for tests with 1800 lb cars, but that was beyond the scope of this project.

Change of momentum, occupant/compartment impact velocity (O/CIV), and highest 50 millesecond values of deceleration (a criterion used in TRC No. 191 (4) for other highway safety appurtenances) values were all computed for comparison. These values are all tabulated in Table 5. Both film and accelerometer data were used to calculate these values. They agreed quite well except in Tests 351 and 352 where the film values were significantly larger than the accelerometer values. The researchers could not determine the reason for this difference.

On the basis of change of momentum, the 6 in. x 8 in. D.F. wood posts and the laminated wood veneer box sections were successful with values less than the preferred maximum value of 750 lb-sec and the absolute maximum value of 1100 lb-sec. The only exception was the film data value for Test 351 which was over 750 lb-sec but was under 1100 lb-sec. The timber poles in Tests 353 and 354 were not successful with all values of change of momentum over 1100 lb-sec.

Values of occupant/compartment impact velocity (O/CIV) gave identical results. The values were obtained graphically in Appendix C in Figures C13-C18. Only the timber poles in Tests 353 and 354 did not meet the criterion - a maximum value of 15 fps. It is interesting to note, however, that in Test 353 where the timber pole did not break away, the O/CIV was close to 30 fps. Although this is twice the value recommended inNCHRP No. 230 (6) for breakaway sign and luminaire supports, it is right at the maximum value suggested for crash cushions, longitudinal barriers and terminals, and breakaway utility poles. Therefore, the breakaway timber poles would not be acceptable for new construction, but existing poles should not be considered extremely hazardous for 2205 lb/20 mph impacts. A more critical impact condition would exist at higher impact speeds which are not quite high enough to shear off the pole. Under these conditions the O/CIV would exceed 30 fps.

The second part of the NCHRP Report No. 230 (6) criterion calls for a highest 10 ms average value of longitudinal vehicle accelerage of -15 g's after the theoretical occupant/compartment impact occurs. This value was not computed but was much less than -15 g's, by inspection, for all tests, comparing Figures C1, C7 and C10 with Figures C13-C18.

The 50 ms average acceleration values yielded similar judgements. Only in Test 353 was the -11.2 g acceleration excessive, but not over the maximum value of 12 g's permitted for crash cushions in TRC No. 191 (4). The value was excessive relative to the state of the art for breakaway supports.

The requirement in NCHRP Report No. 230 (6) calling for an upright vehicle; minimal pitch, roll, and yaw; and no intrusion of the passenger compartment was satisfied in all tests.

The SWRI pendulum tests were judged on the basis of change of momentum. The summary of results in Table 3 show that out of all the timber pole specimens only the 4-inch-diameter hole with sawcut pattern in timber poles achieved a change of momentum less than 1100 lb-sec for both specimens (CALDOT 7 and 8). This was the pattern used in Crash Test 354 where the change of momentum went over 1100 lb-sec. This difference could be attributed to the variability in strength of timber poles and/or the possibility that the pole used in a dual-support sign and crash tested was stiffer than the single pole subjected to a pendulum impact.

The change of momentum for all three of the pendulum tests on box and H-secton posts was well below both the 1100 lb-sec and the preferred 750 lb-sec maximum allowable values. The cutout pattern used in CALDOT 11 was the pattern used for Tests 355 and 356. The change of momentum obtained in CALDOT 11 of 573 lb-sec was between the 20 mph and 60 mph crash test values of 721 and 256 lb-sec respectively.

There are number of sources of small error that enter into film and accelerometer data reduction. Therefore, results should not be intepreted too finely. For example, even though accelerations are reported to 0.1 g, the real values of acceleration may vary by 1 to 2 g's. There is this much variation in accelerometers mounted back to back at times.

Use of dummies is optional. TRC No. 191 (4) suggests a maximum Head Injury Criterion (HIC) of 1000 based on accelerometer data from the head of a dummy that is restrained with lap and shoulder belts. NCHRP Report No. 230 (6) also calls for a maximum HIC value of 1000, but from an unrestrained dummy. The HIC was calculated only for Tests 355 and 356 with a fully restrained dummy and was 6.9 and 2.6 respectively, extremely low values. If the dummy had been unrestrained, the values most probably still would have been well under 1000.

5.3.4 Vehicle Trajectory

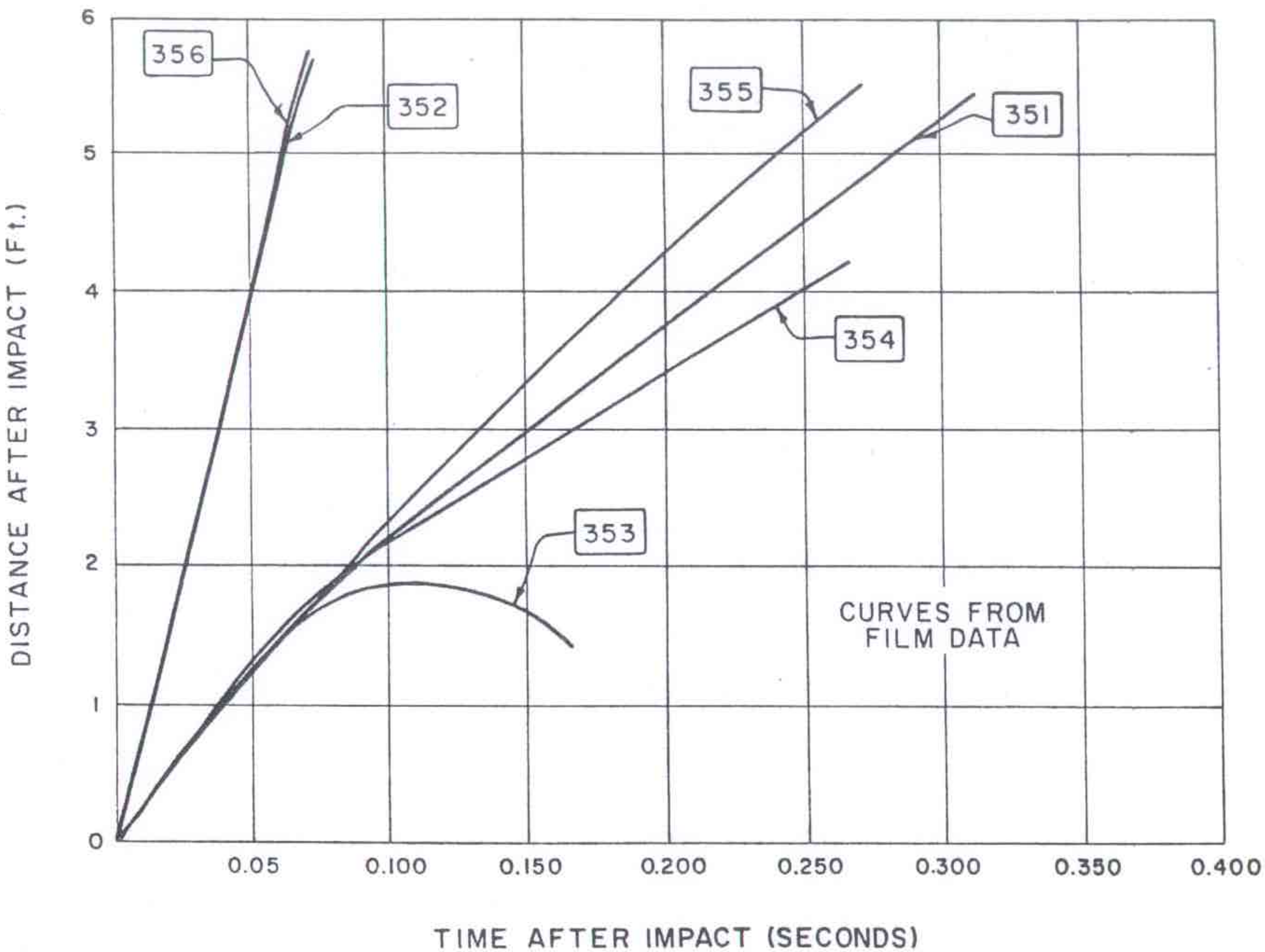
In Table 4 of TRC No. 191 (4) the vehicle trajectory appraisal factor is described as follows:

> "A. After impact, the vehicle trajectory and final stopping position shall intrude a minimum distance into adjacent traffic lanes."

The requirement in NCHRP Report No. 230 (6) is virtually identical.

In all 20 mph crash tests the vehicle stayed close to the original location of the test sign and did not intrude into "adjacent traffic lanes." In the 60 mph tests the vehicle continued straight ahead until it was braked remotely. Thereafter it steered to the left before it stopped.

Figures 47 and 48 compare the post impact displacements and velocities of the vehicle for Tests 351-356. Figures 49 and 50 show the final position of the test vehicles, test signs, and sign debris.

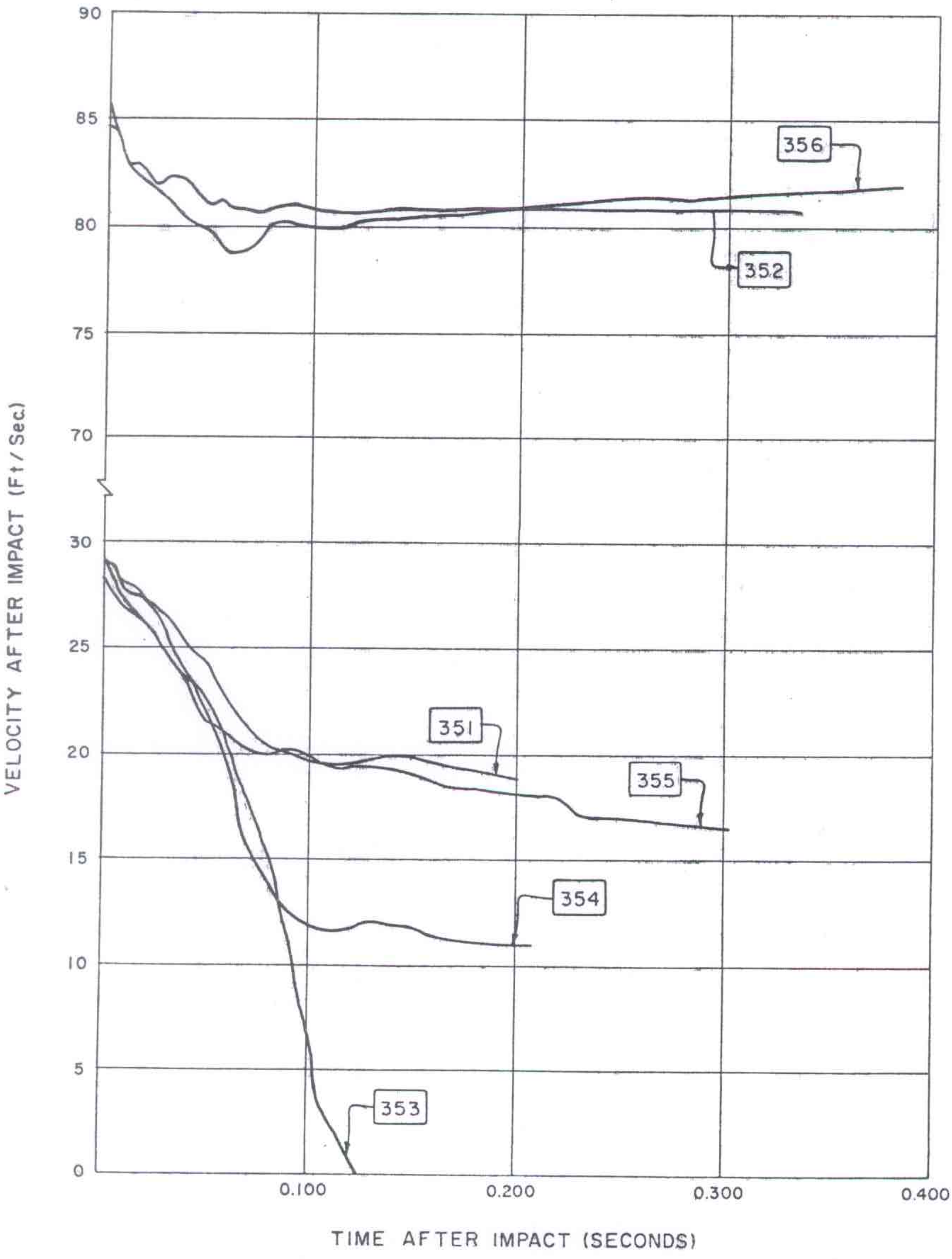


CAR DISTANCE VS TIME - TESTS 351 - 356

FIGURE 47

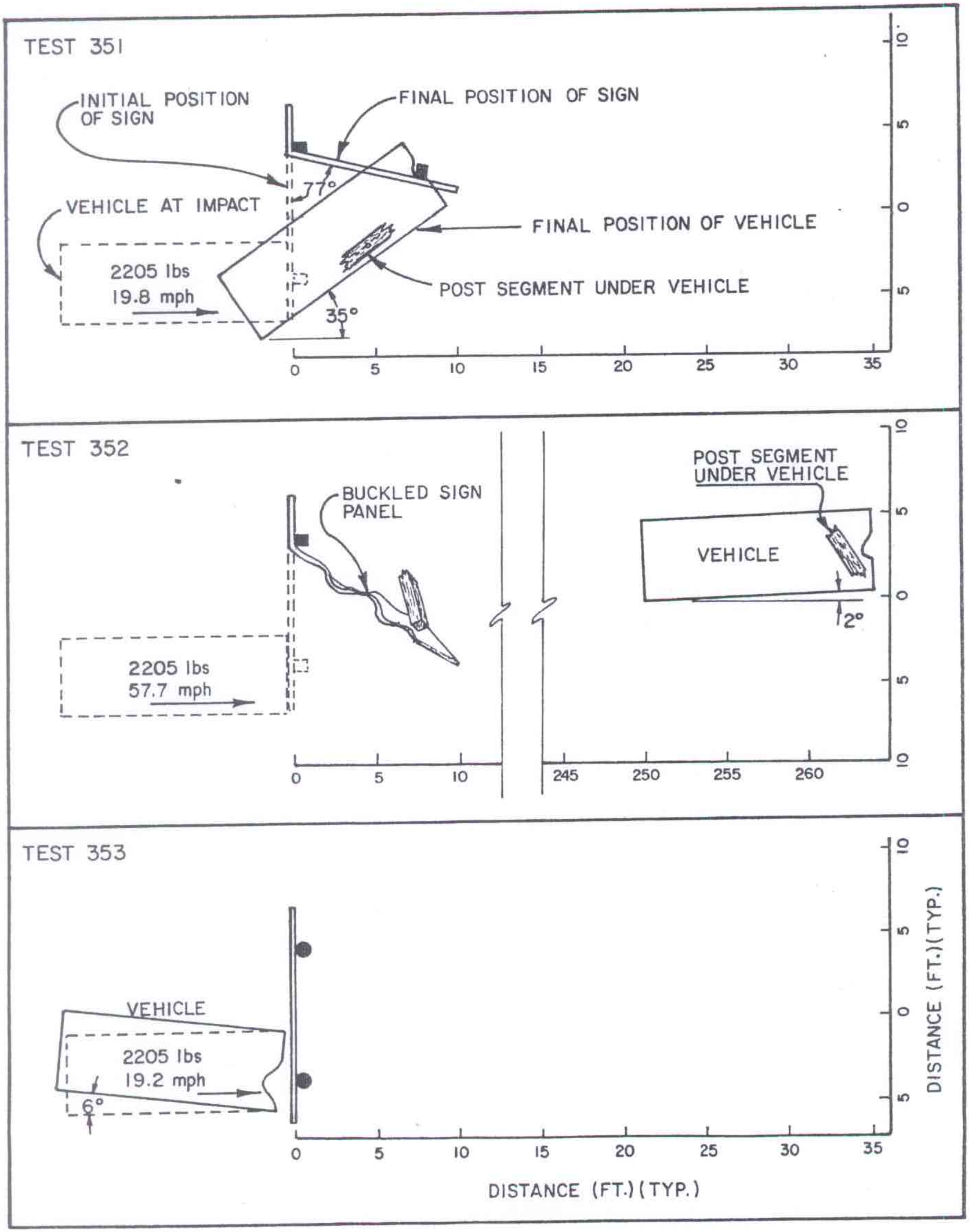
CAR VELOCITY VS TIME - TEST 351-356

FIGURE 48



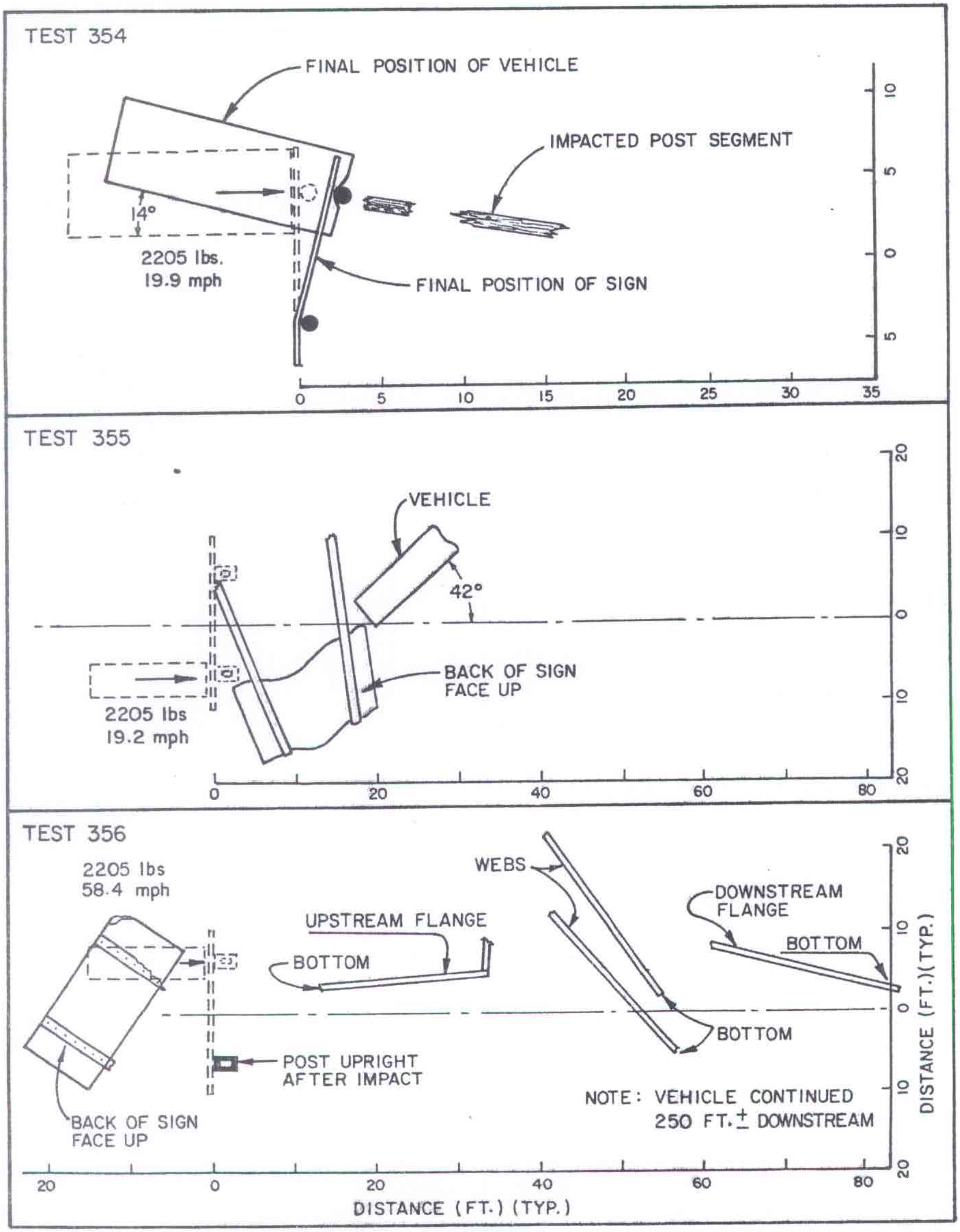
FINAL POSITION OF TEST VEHICLE AND SIGN
TESTS 351-353

FIGURE 49



FINAL POSITION OF TEST VEHICLE AND SIGN
TESTS 354-356

FIGURE 50



5.3.5 Accident Data

A brief look at sign support accident data may help put this project in perspective. Unfortunately the Caltrans accident data system does not segregate accidents with breakaway supports for roadside signs. Accident reports for all post and pole type accidents must be hand sorted to find relevant data.

In 1976, accident reports were sorted for the four year period 1972 through 1975. All fatal accidents involving wood post or timber pole sign supports were collected. Eleven reports were found. Following are brief descriptions of several of those accidents:

1. The vehicle rolled over and the driver was ejected into the sign pole. His head struck the pole but his vehicle did not.

2. The impacting vehicle rolled over several times after knocking down the sign. The size of the supports was unknown; the occupants may have been killed by the impact or the rollover.

3. The wood posts broke away; the driver was ejected and killed. The size of the posts was unknown.

4. The vehicle struck the sign, then some trees and a right-of-way fence. It is unknown what part of this sequence caused the fatality.

5. The impacting vehicle was a motorcycle.

6. The impacting vehicle was a dune buggy which rolled over before striking the sign support. The driver was ejected.

7. The sign support was struck by the side of a 1964 passenger car. The side strength of 1960's model cars was less than later model cars. Depending on the impact velocity, this might have made a difference.

8. A Cadillac struck two light standards, then two 8-inch sign supports, and then rolled over. The driver was ejected. Sign supports of that size with drilled holes would not offer much resistance to a Cadillac. The rollover and/or ejection probably caused the fatality.

9. Another accident involving a motorcycle.

Given the exposure of breakaway sign supports to large volumes of traffic in California over a four year period, the above group of accidents indicates no problem with breakaway supports. In most of the accidents above there is strong reason to believe the breakaway supports were not the ultimate cause of the fatalities. This research study, as stated previously, was begun on the premise that the rapid increase in the population of lightweight cars might require redesign of breakaway sign supports, but not because of unsatisfactory performance in the past.

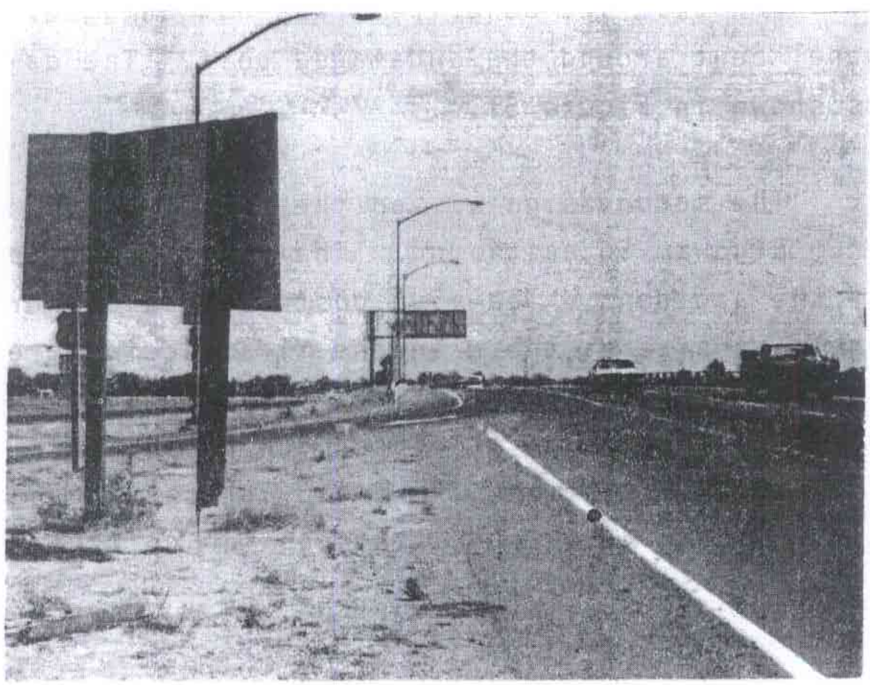
During the course of this research project, the results of two accidents involving breakaway sign supports were observed in Sacramento. Brief descriptions follow:

1. A two-post sign was on the Watt Ave. on-ramp to west bound Highway 50 going to Sacramento. The vehicle had left the scene of the accident. The sign construction was similar to that for Test 351. The supports were two 6-inch x 8-inch D.F. posts spaced 8 ft-0 in. apart. The sign panel was 1 1/8 in. x 5 ft-0 in. x 13 ft-0 in. It was connected to the posts with four 3/8-inch diameter bolts and had a ground clearance of 7 ft-0 in. The breakaway holes were 2 1/4-inch in diameter (should have been 2 1/2 inches) and were 6 and 18 inches above ground. Both post holes were not completely backfilled by about 1 ft-0 in. The left side post was impacted about 6 inches to the right of the left front wheel. Wheel tracks were about 48 to 55 inches wide indicating a small car (a Pinto is 55 inches). There were 80 feet of skid marks on the pavement upstream from the gore area, tire tracks on the grassy gore surface, and 30 feet of tire tracks beyond the sign. The impacted post broke off at the upper hole 18 inches above ground and 24 inches below ground. The 42-inch long broken post segment was split through the holes like the ones in Test 351 and 352. The other post was not damaged. The sign panel bent around the undamaged post. The damaged sign is shown in Figure 51.

2. The second sign was on the Sunrise Blvd. off-ramp from Highway 50 eastbound. The vehicle had left the scene of the accident. The sign posts and panel were exactly the same size as those in the first accident except that the drilled holes were 2 1/2 inches in diameter. The sign was mounted on a 6-inch high raised gore surface and was 53.5 feet back from the nose of this gore surface. The impacted post failed through the upstream face at the

Figure 51

Accident at Watt Ave.
and Highway 50



upper hole diagonally down to the downstream face of the lower hole with considerable splintering. This mode of failure was probably influenced by the asphalt concrete surface that surrounded the base of the post. The adjacent post was not damaged. The impacting vehicle struck the post about 8 inches off-center. The vehicle was skidding before it mounted the 6-inch high gore surface, and left 23- and 47-foot skids on top of the gore surface. These marks stopped 10 feet beyond the sign. Wheel track width was 62.5 inches indicating a large car. The bumper height was estimated at 20.5 inches based on markings on the post. The sign panel bent along the edge of the undamaged post. The damaged sign is shown in Figure 52. No accident reports were ever filed on either of the two above accidents.

Reference 16 was a comprehensive study of accidents with breakaway and non-breakaway poles. Unfortunately it only included seven accidents with multi-support large break-away signs. It was concluded that steel support/slip base designs were significantly safer than non-breakaway signs.

5.3.6 Tests by Others

A few crash tests have been conducted on small, single, wood-support signs using 4 in. x 4 in. and 4 in. x 6 in. lumber. There have been practically no other tests on larger sized wood posts and poles used with dual-support signs by other agencies. Table 5 shows only one test other than those conducted by Caltrans and it was conducted with a bogie test vehicle.

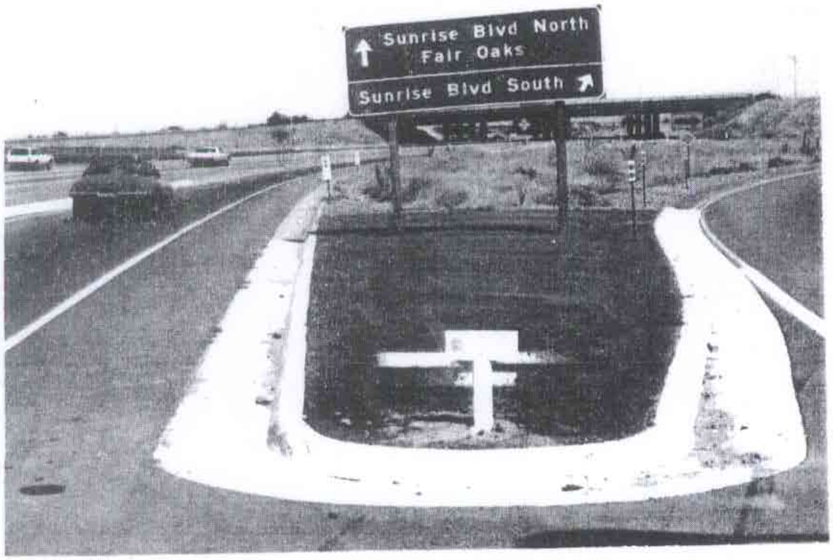
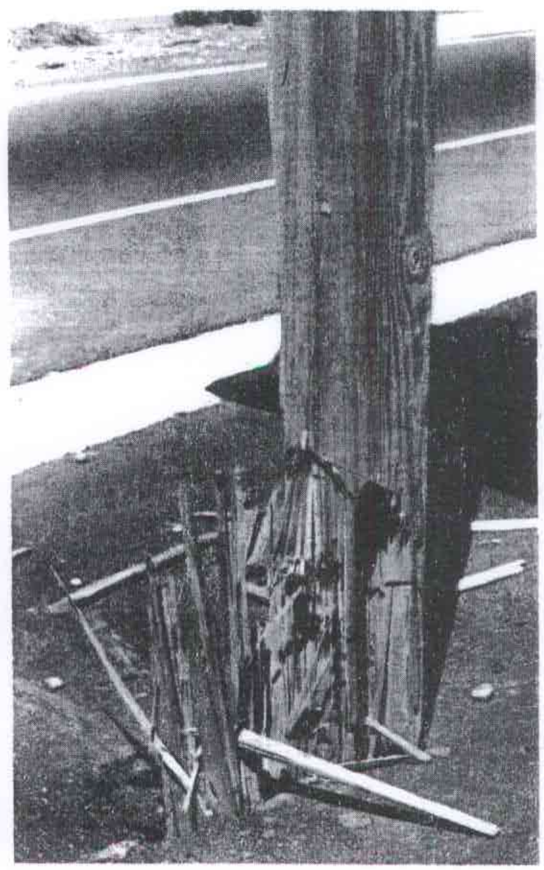


Figure 52

Accident at Sunrise Blvd. and Highway 50



In 1968 the Pennsylvania Department of Highways conducted 10 tests on signs using 4 in. x 4 in., 6 in. x 6 in. and 6 in. x 8 in. wood supports having different breakaway hole and notch patterns. These tests were generally successful but there were few crash test data in the reference (17).

Test 902 shown in Table 5 resulted in a higher change of momentum value of 1380 lb-sec than that for Test 351 of 685 lb-sec. In test 902 there was considerable soil displacement behind the post. This lack of soil resistance and/or the use of the bogie may have accounted for the higher change of momentum.

Tables F3-F7 in Appendix F show the results of crash tests on dual-support signs using metal supports of various types. A number of these designs have been successful. Although they could be used as alternate breakaway support designs, they do not have some of the advantages of wood supports:

1) Metal supports are generally more expensive.

2) It is more difficult to stock extra supports since there is a wide variation in support heights along the highway. A new metal post must be fabricated after one has been hit. Wood posts can be stocked in a small number of sizes and lengths and easily sawed to the correct length when one is needed.

3. Metal supports perhaps provide a longer service life than is needed. The service life of wood posts is expected to be sufficient, but not excessive.

4. Wood supports are easier to erect than metal supports, an important maintenance consideration.

The above points are all generalizations, unsupported in this report with data, but they represent the general thinking of the Caltrans Division of Maintenance, Traffic, and Structures.

Given the minimal amount of crash testing on breakaway wood supports, this may be an area deserving more work in the future.

5.3.7 Changes in the Standard Plans

Following Test 353 the Caltrans Division of Traffic Engineering decided that timber poles would not be used as breakaway supports in any new construction (Figure E3). In their place a steel post/slip base design was approved for use (Figure E4). Caltrans had approved a similar design several years earlier but it had been used so seldom that it was not included in the Standard Plans in recent years. After Tests 355 and 356 proved successful, standard plans and specifications were drawn up for a laminated wood box sign support (Figure E5). All of the above plans and specifications are contained in Appendix E.

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APPENDIX A: Test Vehicle Equipment and Cable Guidance System

The test vehicles were modified as follows for the six crash tests:

°The gas tanks on the test vehicles were disconnected from the fuel supply line and drained. Shortly before the test, dry ice was placed in the tank as a safety precaution to drive out the gas fumes. A one-gallon safety gas tank was installed in the trunk compartment and connected to the fuel supply line.

°Four 12-volt wet cell motorcycle storage batteries were mounted in the trunk. Two were used to supply power to a high speed camera located inside the vehicle. The other pair of batteries were used to operate the solenoid-valve braking system and other test equipment in the vehicle.

°The accelerator pedal was linked to a small cylinder with a piston which opened the throttle. The piston was activated by a manually thrown switch mounted on the top of the rear fender of the test vehicle. The piston was connected to the same CO_2 tube used for the brake system, but a separate regulator was used to control the pressure.

°A speed control device connected between the negative side of the coil and the battery of the vehicle regulated the speed of the test vehicle based on speedometer cable output. This device was calibrated prior to the test by conducting a series of trial runs through a speed trap composed of two tapeswitches set a known distance apart connected to a digital timer.

°A cable guidance system was used to direct the vehicle into the barrier. The guidance cable, anchored at each end of the vehicle path to a threaded coupler embedded in a concrete footing, passed through a guide bracket bolted to the spindle of the front wheel of the vehicle. A steel knockoff bracket anchoring the end of the cable closest to the barrier to a concrete footing, projected high enough to knock off the guide braket, thereby releasing the vehicle from the guidance cable prior to impact.

°A micro switch was mounted below the front bumper and connected to the ignition system. A trip plate placed on the ground near impact triggered the switch when the car passed over it, thus opening the ignition circuit and cutting the vehicle engine prior to impact.

This switch also released the sliding weight (mounted on top of the car) from an electro-magnet so the weight was free to travel slightly before the instant of impact.

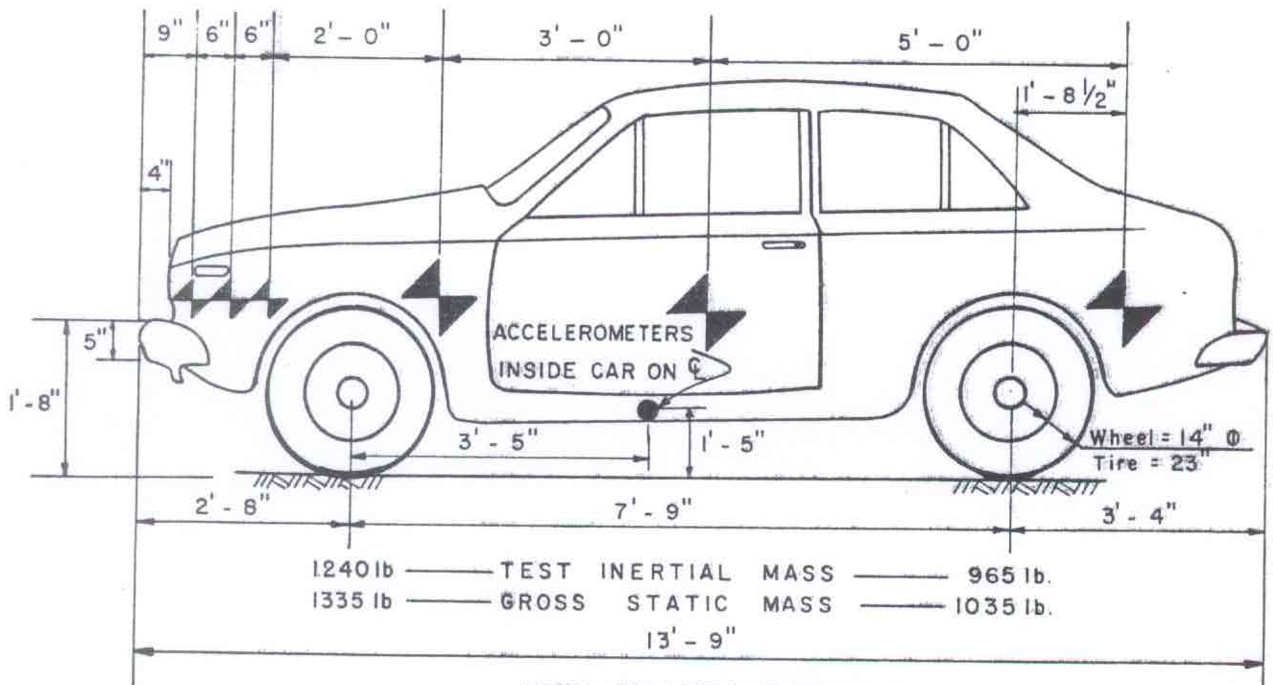
°A solenoid-valve actuated CO_2 system was used for remote control braking after impact or for emergency braking any other time. Part of this system was a cylinder with a piston, which was attached to the brake pedal. The pressure used to operate the piston was regulated according to the test vehicle's weight, to stop the test vehicle without locking up the wheels. When activated, the brakes were applied in less then 100 milliseconds.

°The remote brakes were controlled at the console trailer. A cable ran from the console trailer to the electronic instrumentation trailer. From there the remote brake signal was carried on one channel of the tether line which was connected to the test vehicle. Any loss of continuity in these cables activated the brakes and cut off the ignition automatically. Also, when the brakes were applied by remote control from the console trailer, the ignition was automatically cut off.

°Figure A1 shows the vehicle dimensions.

CAR DIMENSIONS

FIGURE A1



1976 TOYOTA COROLLA

APPENDIX B: Photo-Instrumentation

Several high speed movie cameras were used to record the impact during crash tests. The types of cameras used and their locations are shown in Figure B1. These cameras were electrically activated from a central control panel mounted on a small trailer near the impact area, or were turned on by operators at the cameras in a few instances. The camera mounted in the test vehicle was triggered from a switch mounted on the rear bumper that was activated by a short tether line.

Following are the pre-test procedures that were used in order to perform the film data reduction on a Vanguard Motion Analyzer:

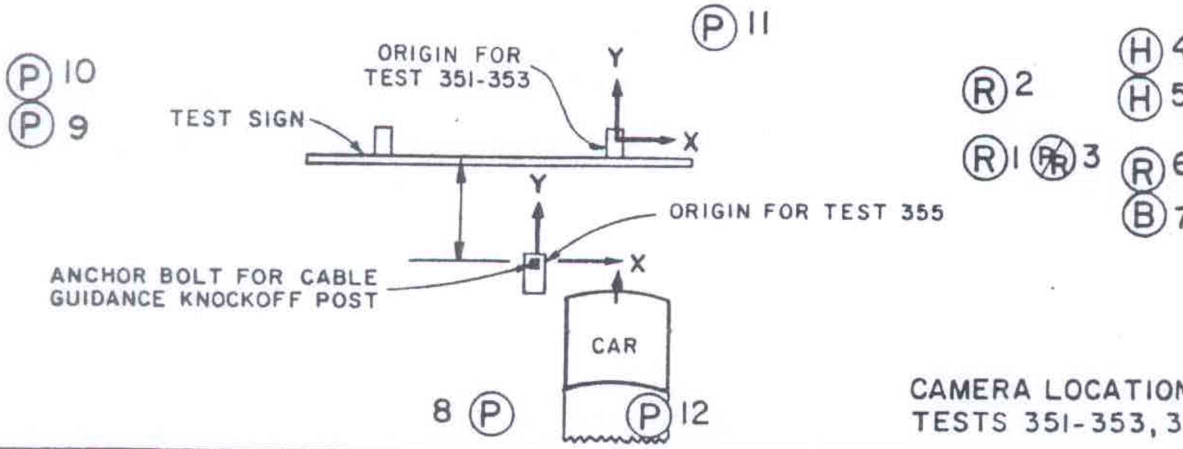
°Butterfly targets were attached to the top and sides of the test vehicle and to the sign support posts. The target locations are shown in Figure A1. They were needed to establish scale factors.

°Flashbulbs, mounted on the test vehicle, were electronically flashed to establish (a) initial vehicle/post contact, (b) the application of the vehicle's brakes, and (c) beginning and end of sliding weight travel. The impact flashbulbs have a delay of several milliseconds before lighting up.

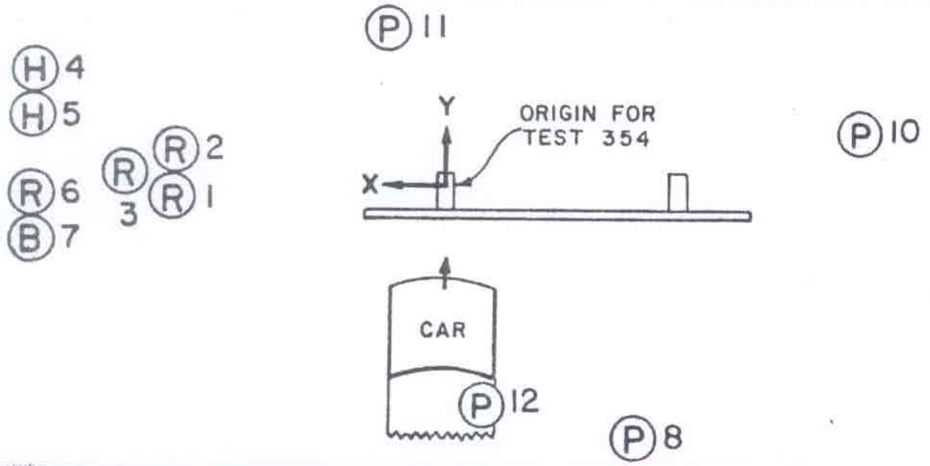
°Five tape switches, placed at ten foot intervals, were attached to the ground perpendicular to the path of the impacting vehicle near the sign support. Flashbulbs were activated sequentially when the tires of the test vehicle rolled over the tape switches. The flashbulb

CAMERA DATA AND LAYOUT

FIGURE B-1



CAMERA LOCATIONS FOR TESTS 351-353, 355



CAMERA LOCATIONS FOR TESTS 354, 356

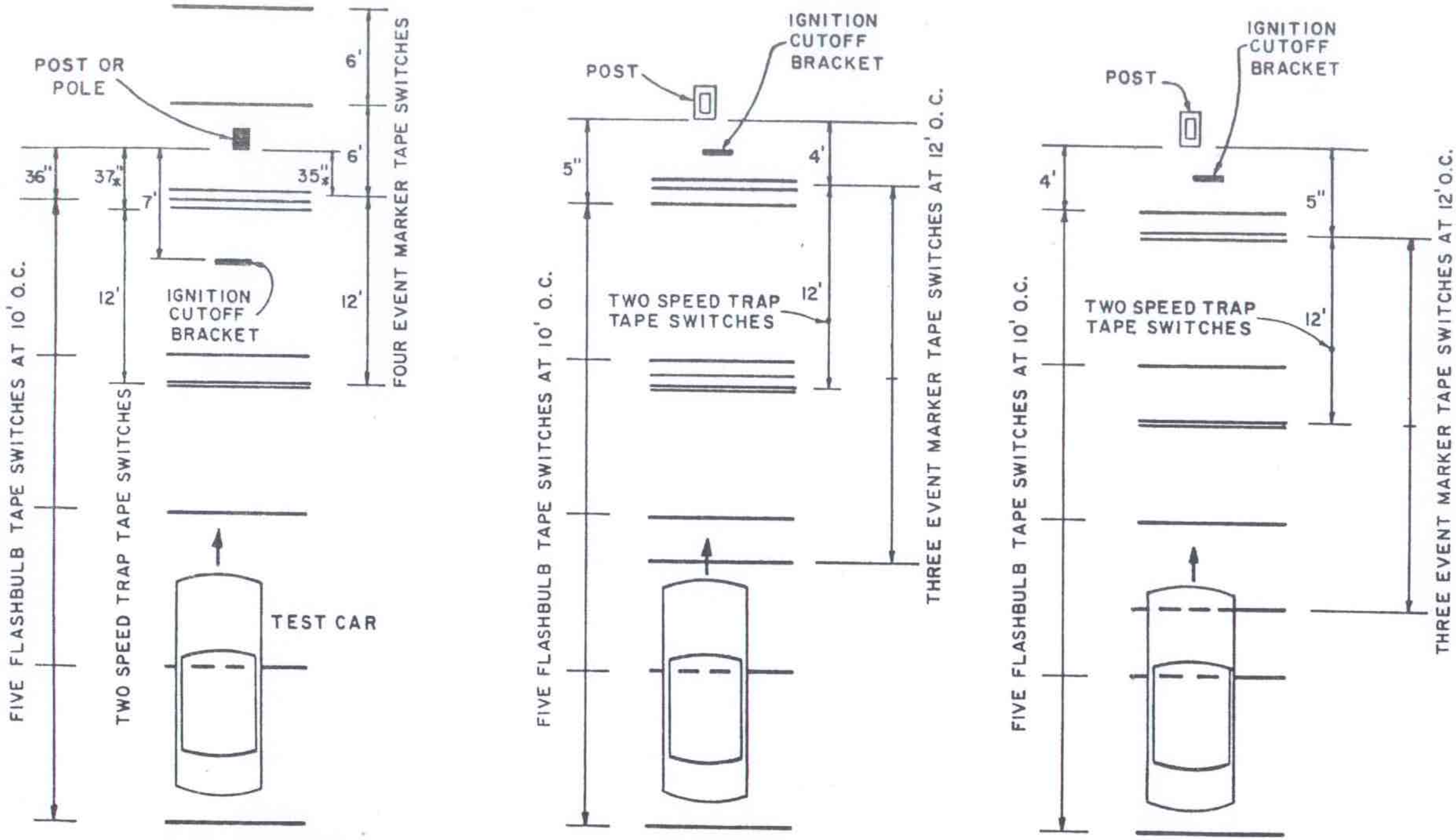
Cam. No.	Camera and Lens	Coordinates (ft.) 351-352 x	y	353 x	y	354 x	y	355 x	y
1	16mm Redlake Locam - 50mm	42	0	43	0	44	0	30	9
2	16mm Redlake Locam - 25mm	57	3	27	13	42	11	43	19
3	16mm Photo-Sonics - 13mm	51	6	50	6	-	-	-	-
	16mm Redlake Locam - 13mm	-	-	-	-	44	6	42	9
4	35mm Hulcher - 105mm	51	-12	51	8	69	9	71	18
5	70mm Hulcher - 150mm	54	-9	51	3	69	13	70	15
6	16mm Redlake Locam - Zoom	57	0	47	0	48	3	52	9
7	16mm Bolex - Zoom	57	0	47	0	48	3	52	9
8	16mm Photo-Sonics - 50mm	-8	-105	-8	-105	-	-	-6	-68
9	16mm Photo-Sonics - 13mm	-63	6	-	-	-	-	-	-
10	16mm Photo-Sonics - 100mm	-60	12	-73	65	-60	9	-83	18
11	16mm Photo-Sonics - 100mm	0	159	0	157	0	263	0	269
12	16mm Photo-Sonics - 5mm	-	-	-	-	-	-	-	-

Notes: Some coordinates were paced. Coordinates were not measured for Test 356, but were similar to other tests. Nominal camera speeds in frames per second were 20 for #4 and #5, 24 for #7, 200 for #12, and 400 for all others. All cameras were on tripods except #12. Cameras #6 and #7 were pan cameras. In Test 354, #4 lens was 85mm, #10 was 55mm; in Test 355, #2 was 55mm, #4 was 80mm, #8 was 13mm.

stand was placed in view of all the data cameras. It was used to correlate the cameras with the impact events; and to calculate the impact speed independent of the electronic speed trap. The tape switch layouts for each test are shown in Figure B2.

°All high speed cameras were equipped with timing light generators which exposed red timing pips on the film at a rate of 1000 per second. The pips were used to determine camera frame rates and to establish time-sequence relationships.

Plots of test vehicle distance and velocity vs. time after impact that were derived from film data are contained in Appendix C in combination with plots from accelerometer data.



TESTS 351-354 | TEST 355 | TEST 356

* TEST 354≈30"

TAPE SWITCH DIMENSIONS

FIGURE B-2

APPENDIX C: Electronic Instrumentation and Data

C.1 Crash Tests No. 351-356

A total of seven accelerometers were used for deceleration measurements. Two Statham accelerometers (unbonded strain gage) and two Endevco accelerometers (Model 2262-200 piezoresistive) were mounted on the floorboard of the test vehicle at the center of gravity in the longitudinal and lateral directions. These accelerometers actually were mounted on a small rectangular steel plate which was bolted to another steel braket that was welded to the floorboard. Three Statham accelerometers were mounted in the head cavity of the dummy. Table C1 provides data on the above accelerometers.

Data from the accelerometers in the test vehicle were transmitted through a 1000 foot Belden #8776 umbilical cable connecting the vehicle to a 14-channel Hewlett Packard 3924C magnetic tape recording system. This recording system was mounted in an instrumentation trailer located in the test control area.

Pressure-activated tape switches were placed on the ground on both sides of the sign support that was to be impacted. They were spaced at measured intervals of 6 feet or 12 feet. When the test vehicle tires passed over them, the switches produced sequential impulses or "event blips" which were recorded concurrently with the accelerometer signals on the tape recorder, and served as "event markers". A tape switch on the front bumper of the car closed at the instant

TABLE C1. ACCELEROMETER INFORMATION

Channel No.	Test No.	Accel. No.	Range (G's)	Calib. Mag. (G's)	Location	Orientation
1	351-352	589	50	50	Dummy head	Long.
	353	586	50	20	Veh. c.g.	Long.
	354-356	589	50	20	Veh. c.g.	Lat.
2	351-352	591	100	50	Dummy head	Lat.
	353	589	50	20	Veh. c.g.	Lat.
	354-356	590	100	50	Veh. c.g.	Vert.
3	351-352	1029	100	50	Dummy head	Vert.
	353	591	100	50	Veh. C.g.	Vert.
	354-356	591	100	50	Veh. c.g.	Long. #1
4	354-356	1029	100	50	Veh. c.g.	Long. #2
5	351-352	586	50	20	Veh. c.g.	Lat.
7	351-352	AN92	200	20	Veh. c.g.	Long.
	353,355,356	EW21	200	50	Dummy head	Long.
	354	EW69	200	50	Dummy head	Lat.
8	351-352	DG66	200	20	Veh. c.g.	Vert.
	353,355,356	EW46	200	50	Dummy head	Vert.
	354	EW21	200	50	Dummy head	Long.
9	353,355,356	EW69	200	50	Dummy head	Lat.
	354	EW46	200	50	Dummy head	Vert.

of impact and activated flash bulbs mounted on the car. The closure of the bumper switch also put a "blip" or "event marker" on the event. A time cycle was also recorded continuously on the tape with a frequency of 500 cycles per second. The impact velocity of the vehicle could be determined from these tape switch impulses and timing cycles. Two other tape switches connected to digital readout equipment were placed 12 feet apart just upstream from the sign support specifically to determine the impact speed of the test vehicle immediately after the test. The tape switch layouts are shown in Appendix B in Figure B2.

After the test, the tape recorder data was played back through a Visicorder which produced an oscillographic trace (line) on paper for each channel of the tape recorder. Each paper record contained a curve of data representing one accelerometer, signals from the event marker tape switches and bumper impact switch, and the time cycle markings. This procedure was used for Tests 351-354.

Some of the data from the accelerometers mounted on the test vehicle contained high frequency spikes. All the test vehicle data were filtered at 100 Hertz and 12 db with a Krohn-Hite filter to facilitate data reduction by hand. The smoother resultant curves gave a good representation of the overall acceleration of the vehicle without significantly altering the amplitude and time values of the acceleration pulses. The data from the accelerometers in the dummy's head were smoother and were not filtered. The test vehicle and dummy head accelerometer records for Tests 351-354 are shown in Figures C1-C6. The cross hatched areas on the accelerometer records from the test vehicles show the interval when the highest 50 ms, average values of acceleration occurred.

Accelerometer data from Tests 355 and 356 were processed on a Norland Model 3001 waveform analyzer. The raw data were digitized and manipulated, test results were printed, and various curves were plotted by the waveform analyzer. These data curves are shown in Figures C7-C12.

The plots needed to determine the occupant/compartment impact velocity (O/CIV) as recommended in Reference 6 are shown in Figures C8 and C11. The O/CIV is theoretical; however, on the plot of distance vs. time the curves can be visualized, for example as representing the car windshield and the driver's head. It is assumed that the head starts out two feet behind the windshield. The point where the curves cross represents the impact between the head and the windshield because the windshield has slowed down from the impact velocity, but the head has not. The time when the windshield/head impact occurs (rattlespace time) is carried to the plot of velocity vs. time. The O/CIV is the difference between the vehicle impact velocity and the vehicle velocity at the end of the rattlespace time.

Plots of velocity vs. time and distance vs. time obtained from film and accelerometer data are shown in Figures C13-C18. These plots also show the O/CIV. The rattlespace times for Tests 355 and 356 are different on Figures C8 and C11 than on C17 and C18 for the accelerometer data because the rattlespace time from film data was used in Figures C17 and C18 for both film and accelerometer data.

C.2 Pendulum Tests - SWRI

The accelerometers used on the pendulum mass were Bell & Howell 4-202-000 strain gage type, ±100g, 2.43g/MV sensitivity, 0-1250 hz frequency response, 0.75% nonlinearity. The tape recorder used was a Sangamo Electric Co. Sabe VII, Model 8246 FM Recorder, D.C. to 20 khz bandwidth. Before each test the accelerometers were subjected to a known voltage excitation and the response recorded on tape, thus providing a calibration standard.

The data were processed using:

(1) SWRI design electronic filters conforming to SAE J211, Class 60;

(2) Honeywell Model 1858 Oscillograph;

(3) Analog to Digital Converter including:
- °Sangamo Sabre III 3600 Magnetic Tape Recorder
- °Hewlett-Packard HP-2310C A/D Converter
- °Hewlett-Packard HP-2781A Pacer
- °Hewlett-Packard HP-7970E Magnetic Tape Unit
- °Hewlett-Packard HP-2100S Computer
- °Hewlett-Packard HP-91701A Data Communication Package

(4) Hewlett-Packard HP-2100A Computer

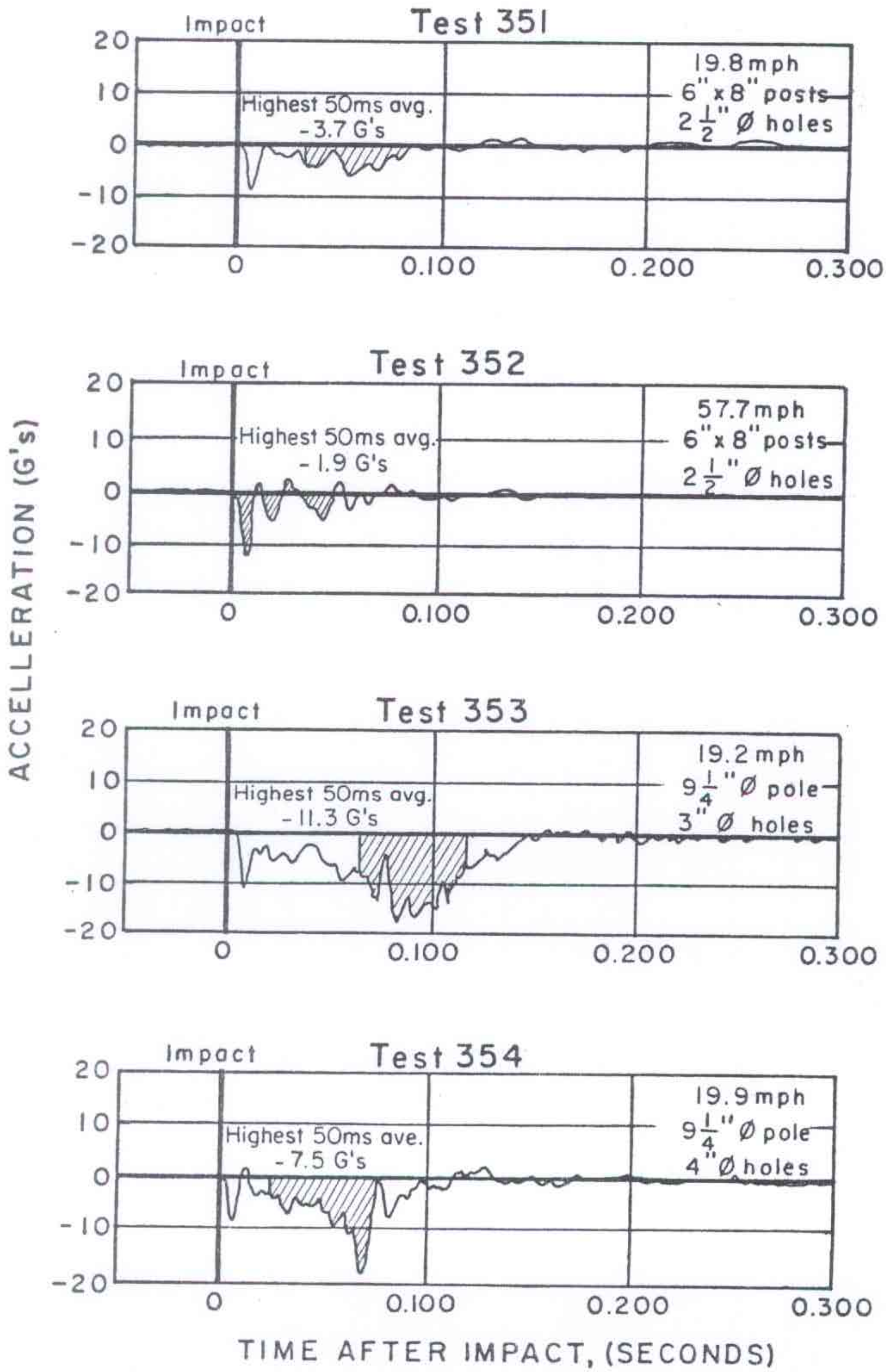
(5) Calcomp 565 Plotter

The accelerometer data were processed through the oscillograph for a quick visual output after the test. Later the data were digitized and put through a computer program.

C.3 Static Bend Tests - SWRI and Caltrans

The instrumentation used for these tests is described in the main body of the report. Curves of load vs. deflection also are shown in Figures C19 and C20 for the Caltrans tests.

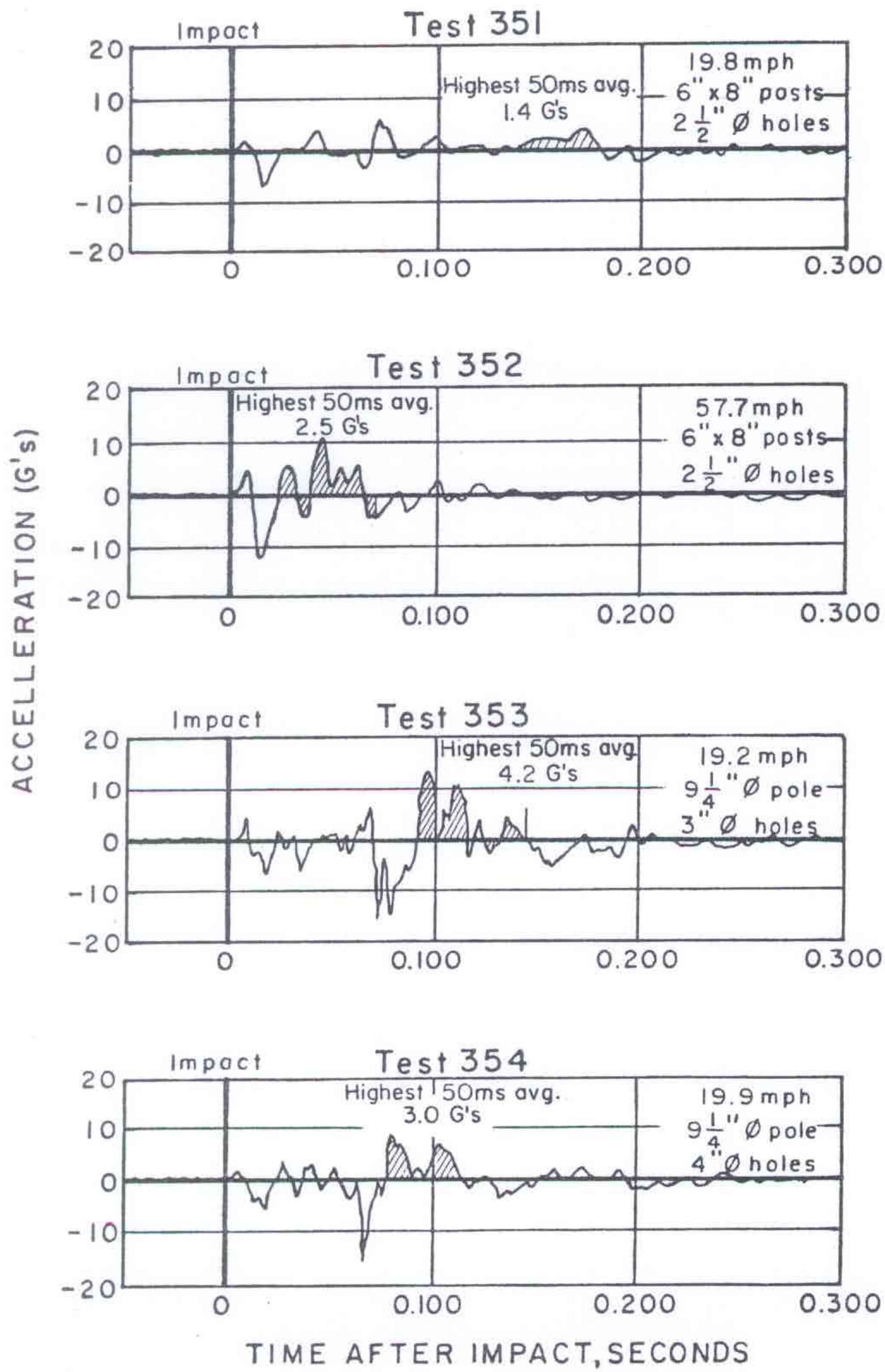
Figure C1. VEHICLE C.G. ACCELERATION VS TIME
LONGITUDINAL



All charts filtered at 100 Hz

Figure C2. VEHICLE C.G. ACCELERATION VS TIME

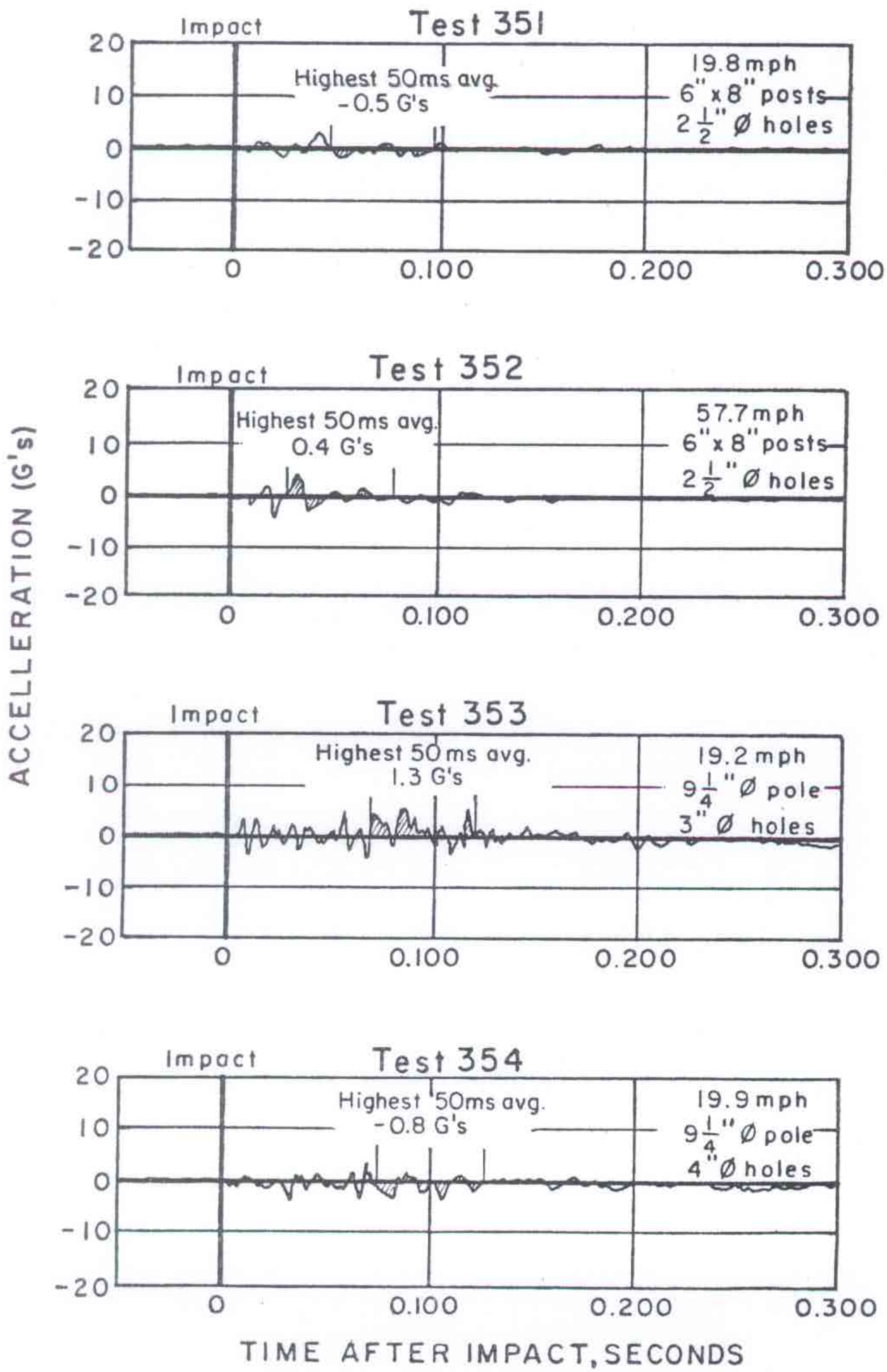
VERTICAL



All charts filtered at 100 Hz

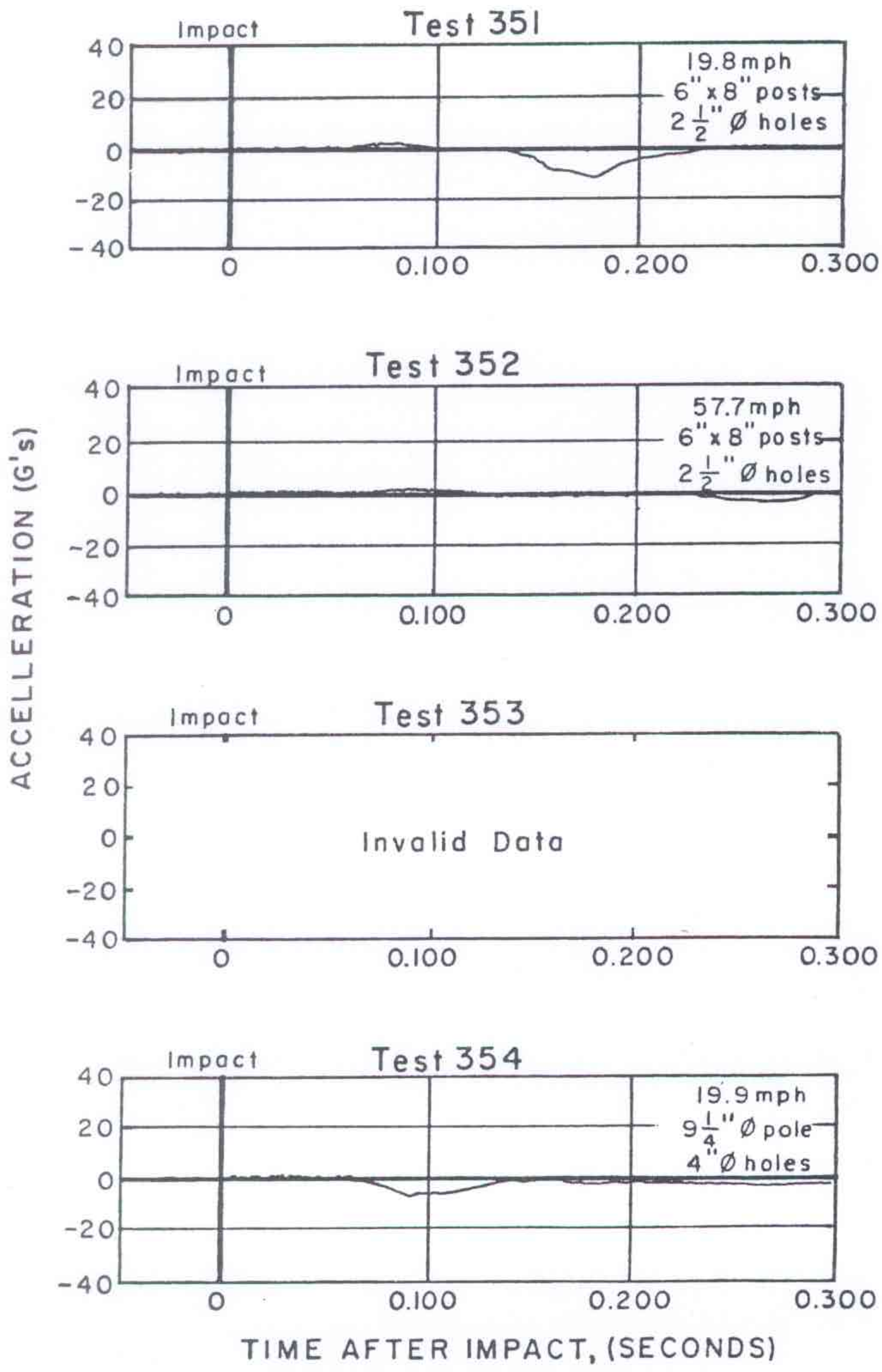
Figure C3. VEHICLE C.G. ACCELERATION VS TIME

LATERAL



All charts filtered at 100 Hz

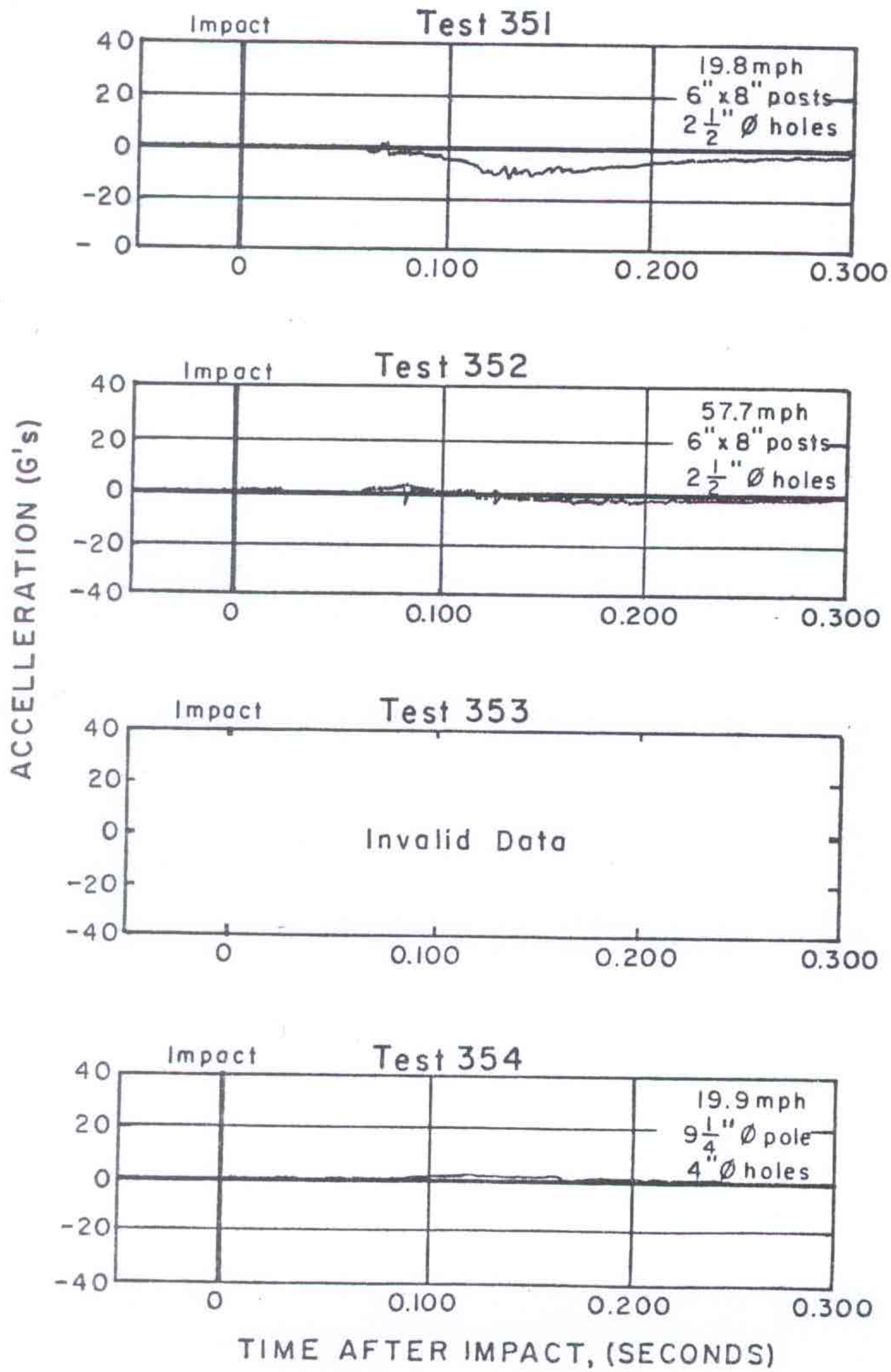
Figure C4. DUMMY HEAD ACCELERATION VS TIME
LONGITUDINAL



All charts are unfiltered

Figure C5. DUMMY HEAD ACCELERATION VS TIME

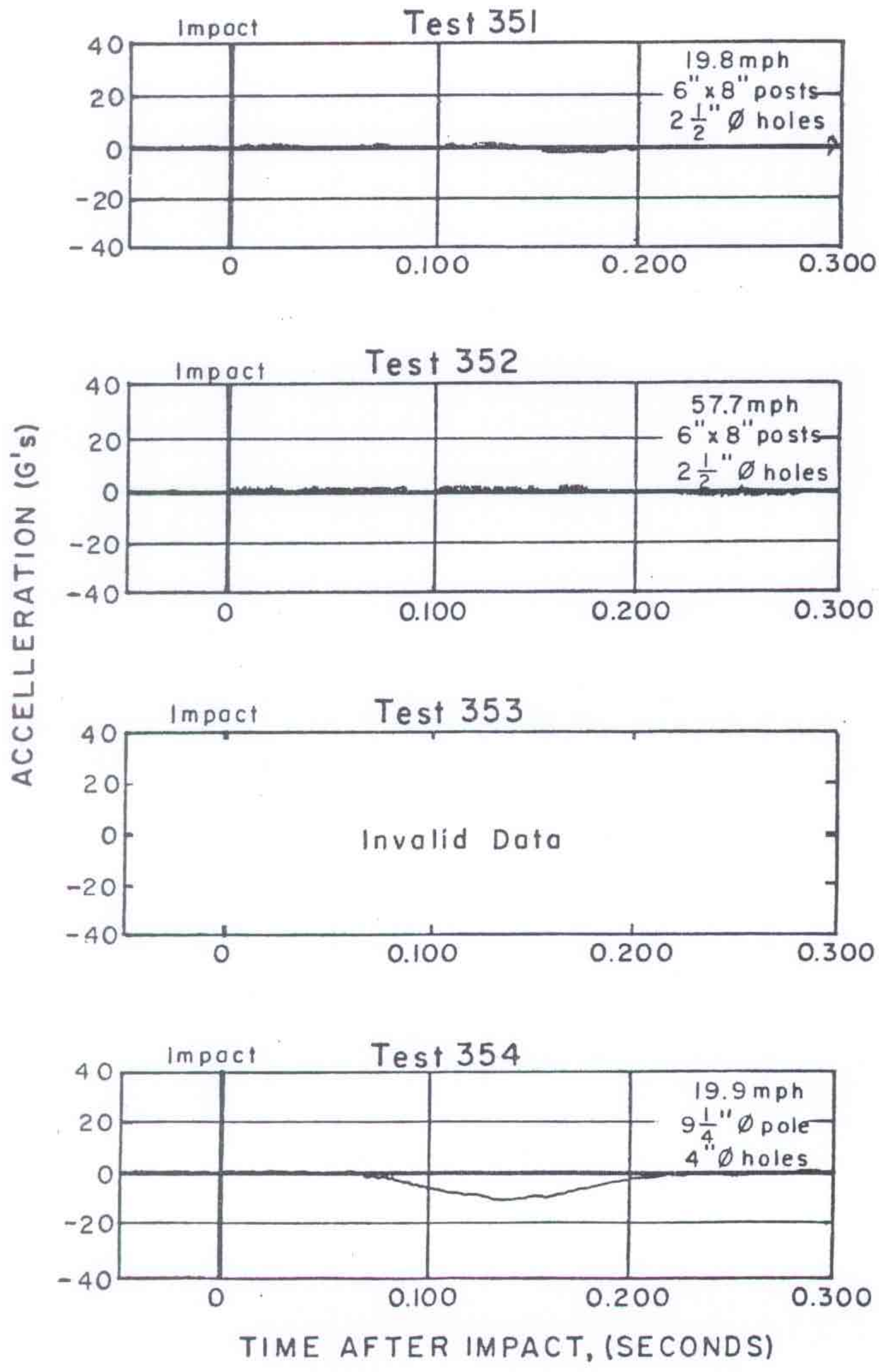
VERTICAL



All charts are unfiltered

Figure C6. DUMMY HEAD ACCELERATION VS TIME

LATERAL



All charts are unfiltered

FIGURE C7

TEST NUMBER

355.00

BOX SECTION

BREAKAWAY

WOOD POST

JAN 30 1981

MAX. 50 MS

AVER. ACCEL.

FOR CAR (G)-

VERTICAL---

-.82895

FROM TIME(S)

1.0000E-02

LONGITUDINAL

-4.1731

FROM TIME(S)

2.5000E-03

LONGITUDINAL

-4.4492

FROM TIME(S)

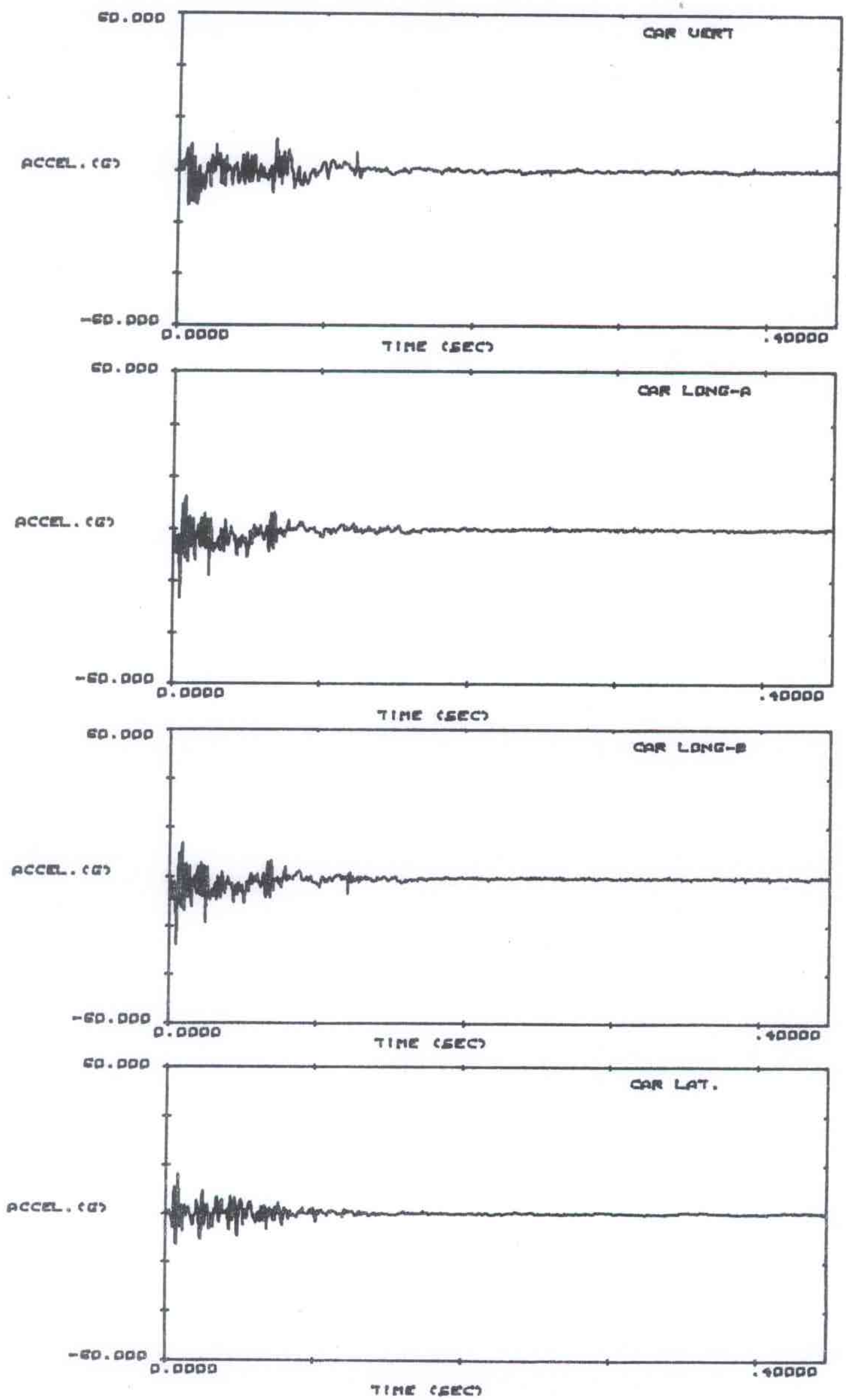
3.0000E-03

LATERAL---

.52326

FROM TIME(S)

8.5000E-03



TEST NUMBER
355.00
BOX SECTION
BREAKAWAY
WOOD POST
JAN 30 1981

CAR IMPACT
VELOCITY
(FPS)-
28.104

AT CAR
DISTANCE(FT)
5.1669
OCCUPANT
IMPACT
OCCURS

OCCUPANT
IMPACT
VELOCITY
(FPS)-
10.518
OCCURS AT
.25500
SEC. AFTER
CAR IMPACT

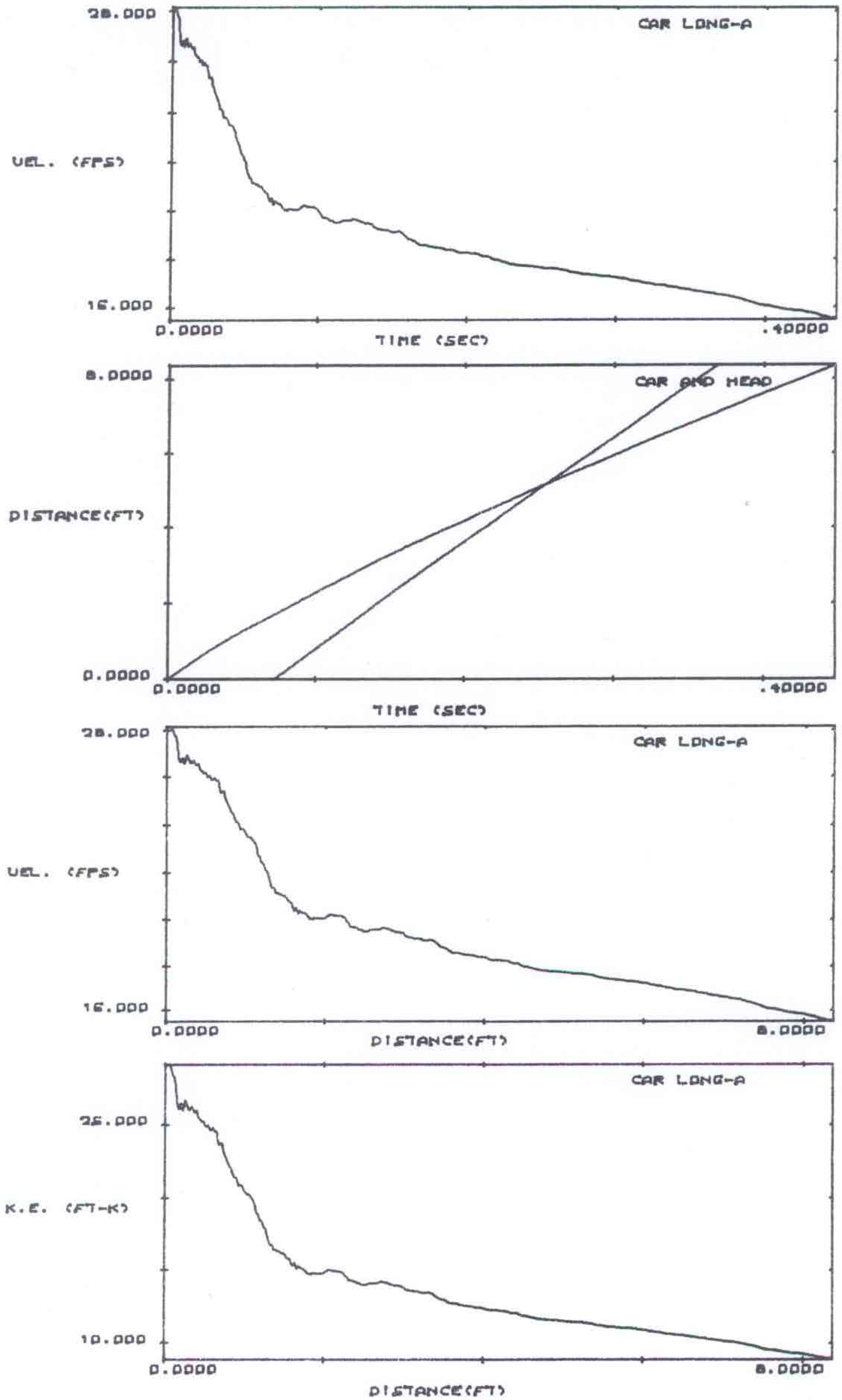


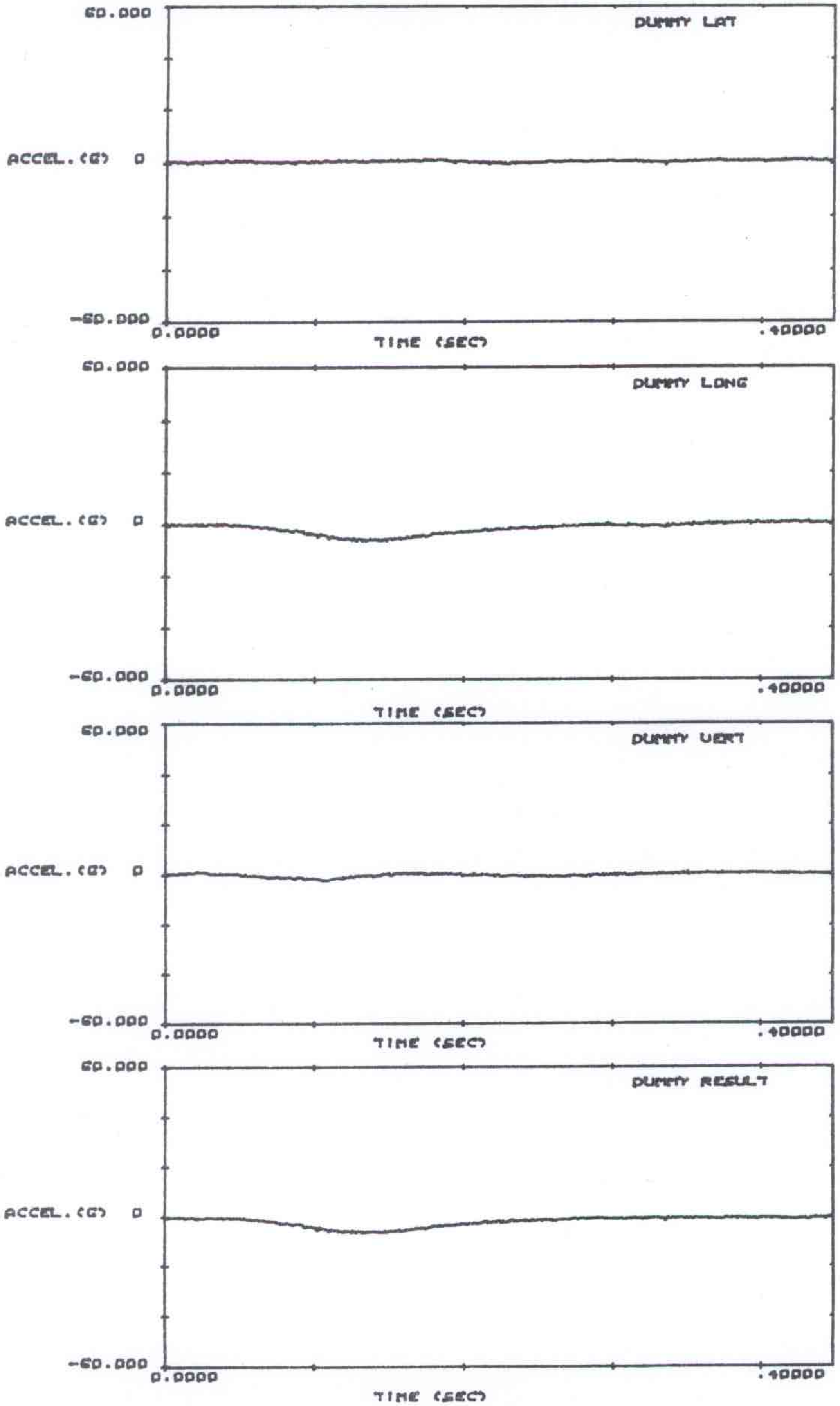
FIGURE C9

TEST NUMBER
355.00
BOX SECTION
BREAKAWAY
WOOD POST

JAN 30 1981

MAXIMUM
50 MS AVER.
DUMMY HEAD
RESULTANT
ACCEL. (G)-
6.1693
FROM TIME(S)
.10950
TO TIME(S)
.15950

HEAD INJURY
CRITEREON-
6.8981
FROM TIME(S)
8.3000E-02
TO TIME(S)
.20350



TEST NUMBER

356.00

LAMINATED

BOX SECTION

WOOD POST

MAR 12 1981

MAX. 50 MS

AVER. ACCEL.

FOR CAR (G)-

VERTICAL---

1.9469

FROM TIME(S)

1.9500E-02

LONGITUDINAL

-3.7126

FROM TIME(S)

1.5000E-03

LONGITUDINAL

-4.2280

FROM TIME(S)

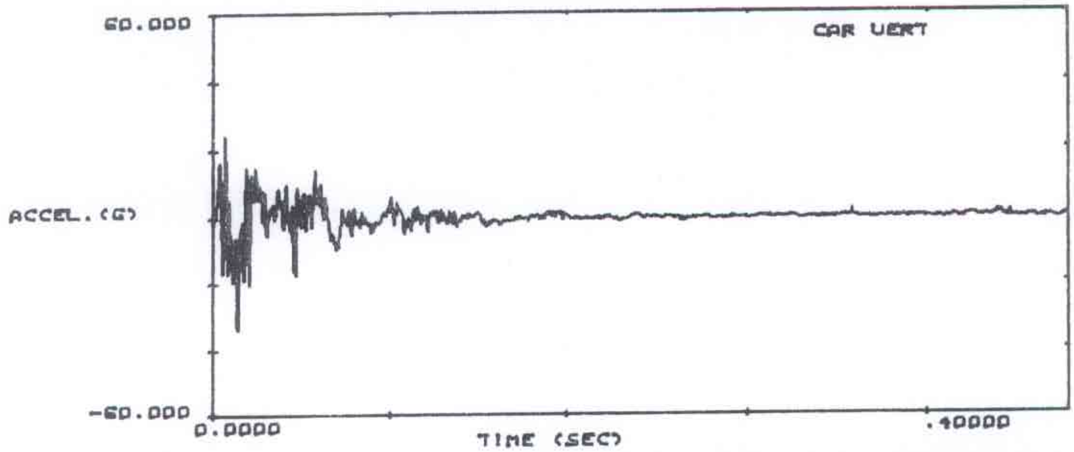
1.5000E-03

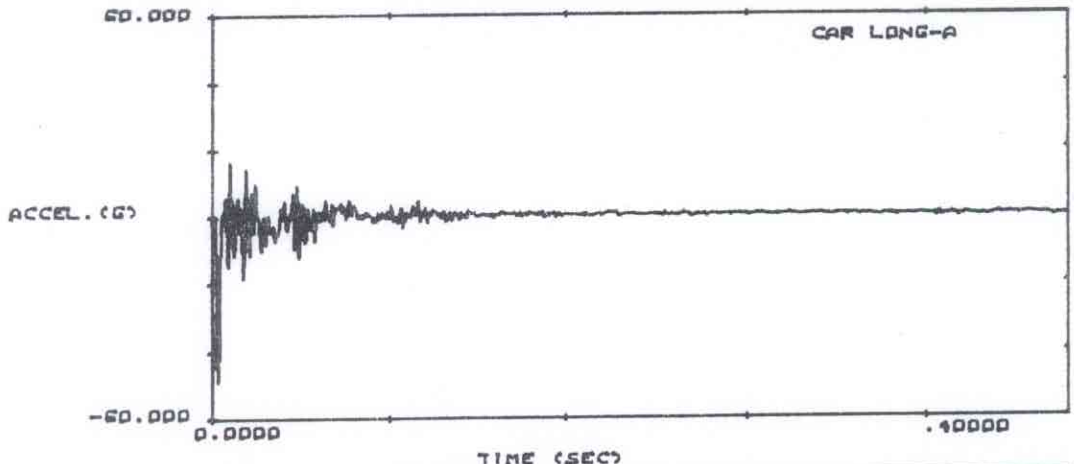
LATERAL---

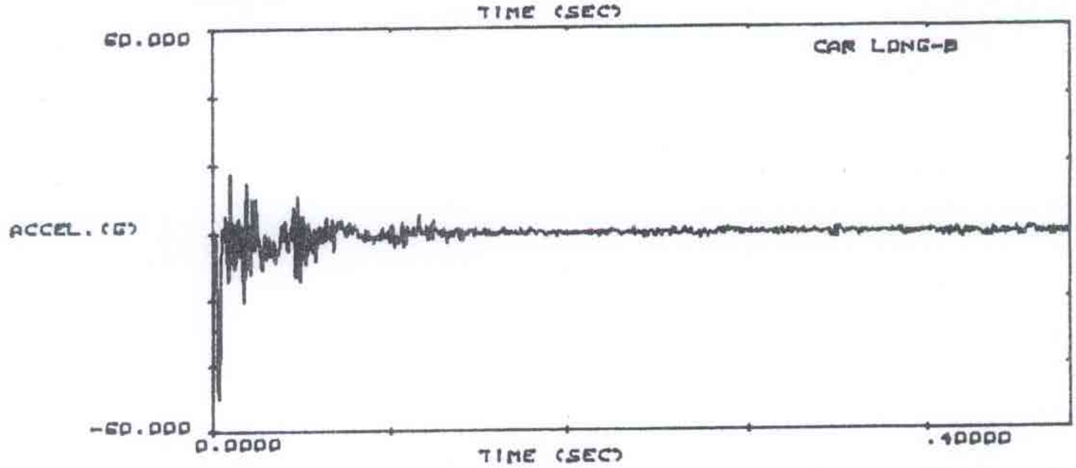
.47724

FROM TIME(S)

4.9500E-02







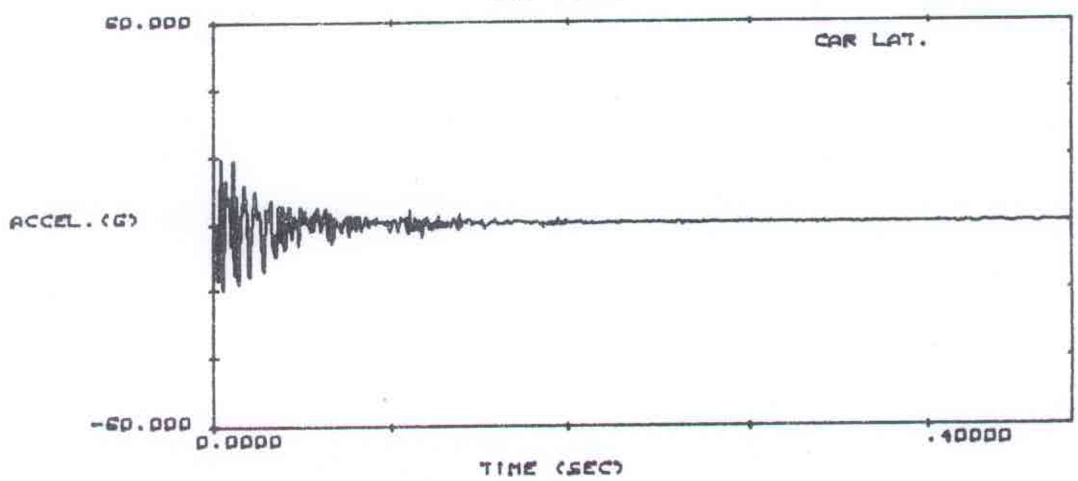


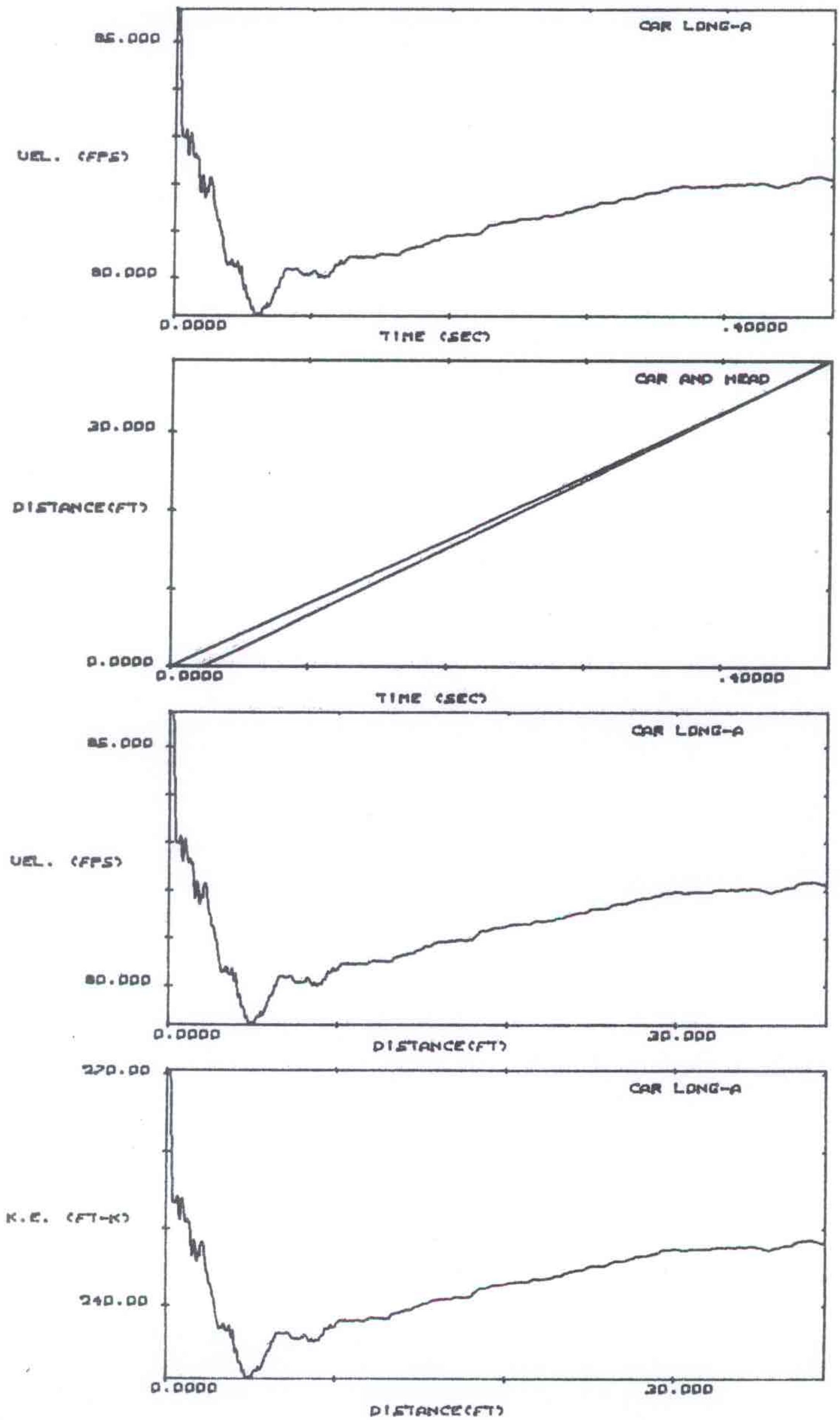
FIGURE C11

TEST NUMBER
356.00
LAMINATED
BOX SECTION
WOOD POST
MAR 12 1981

CAR IMPACT
VELOCITY
(FPS)-
85.715

AT CAR
DISTANCE(FT)
35.761
OCCUPANT
IMPACT
OCCURS

OCCUPANT
IMPACT
VELOCITY
(FPS)-
3.7448
OCCURS AT
.44050
SEC. AFTER
CAR IMPACT



TEST NUMBER

356.00

LAMINATED

BOX SECTION

WOOD POST

MAR 12 1981

MAXIMUM

50 MS AVER.

DUMMY HEAD

RESULTANT

ACCEL. (G)-

4.5264

FROM TIME(S)

9.5000E-02

TO TIME(S)

.14500

HEAD INJURY

CRITEREON-

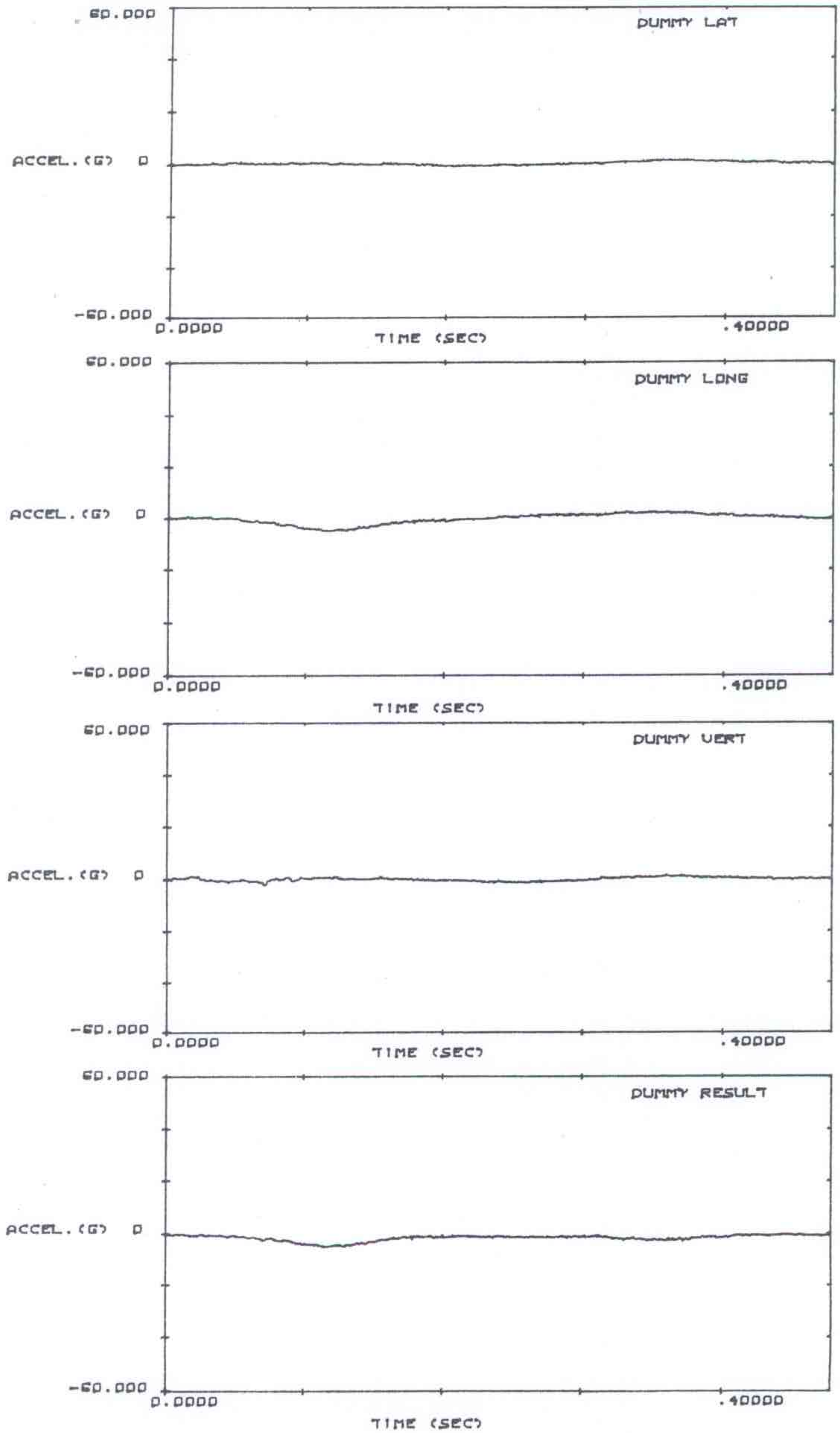
2.6138

FROM TIME(S)

5.3000E-02

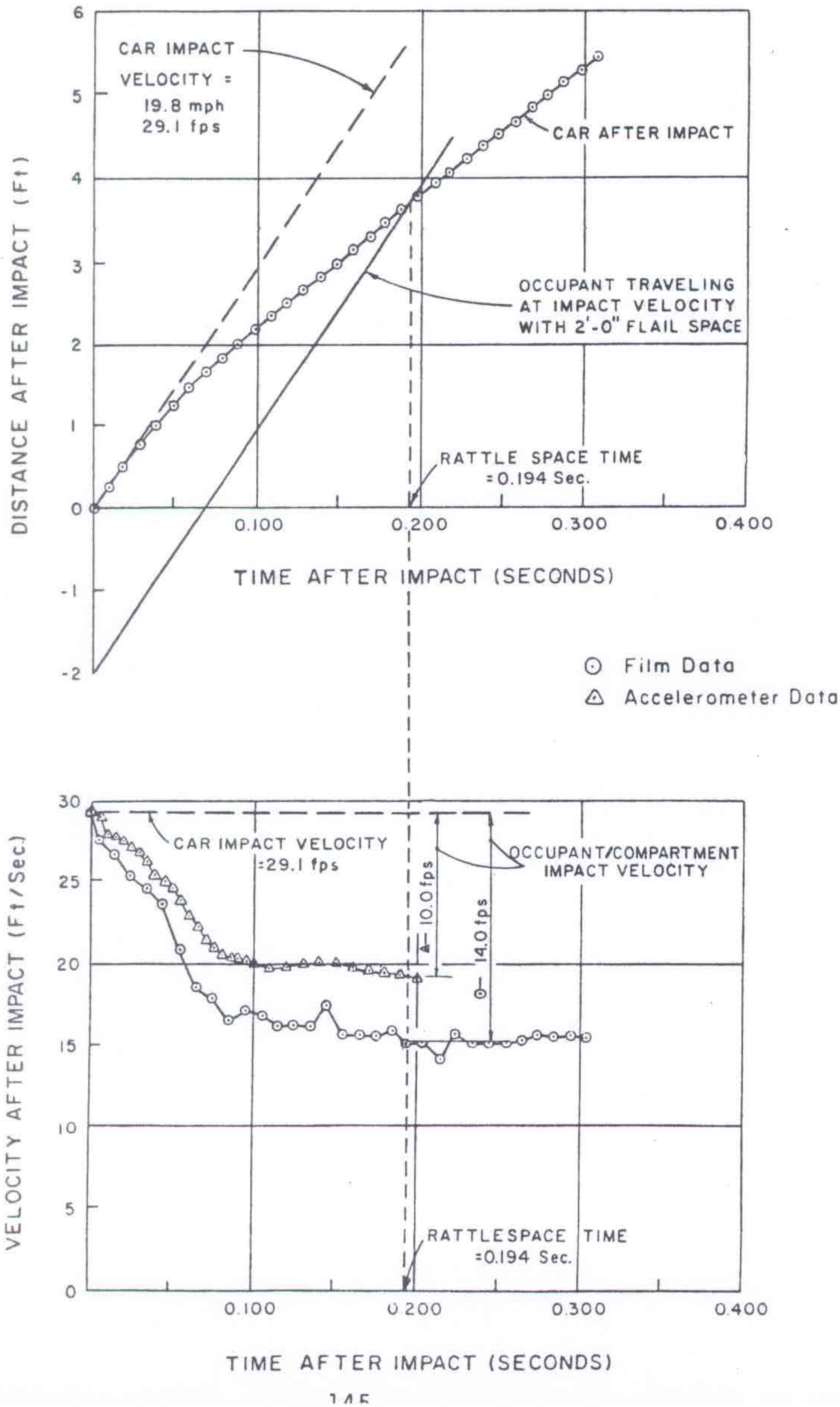
TO TIME(S)

.40550



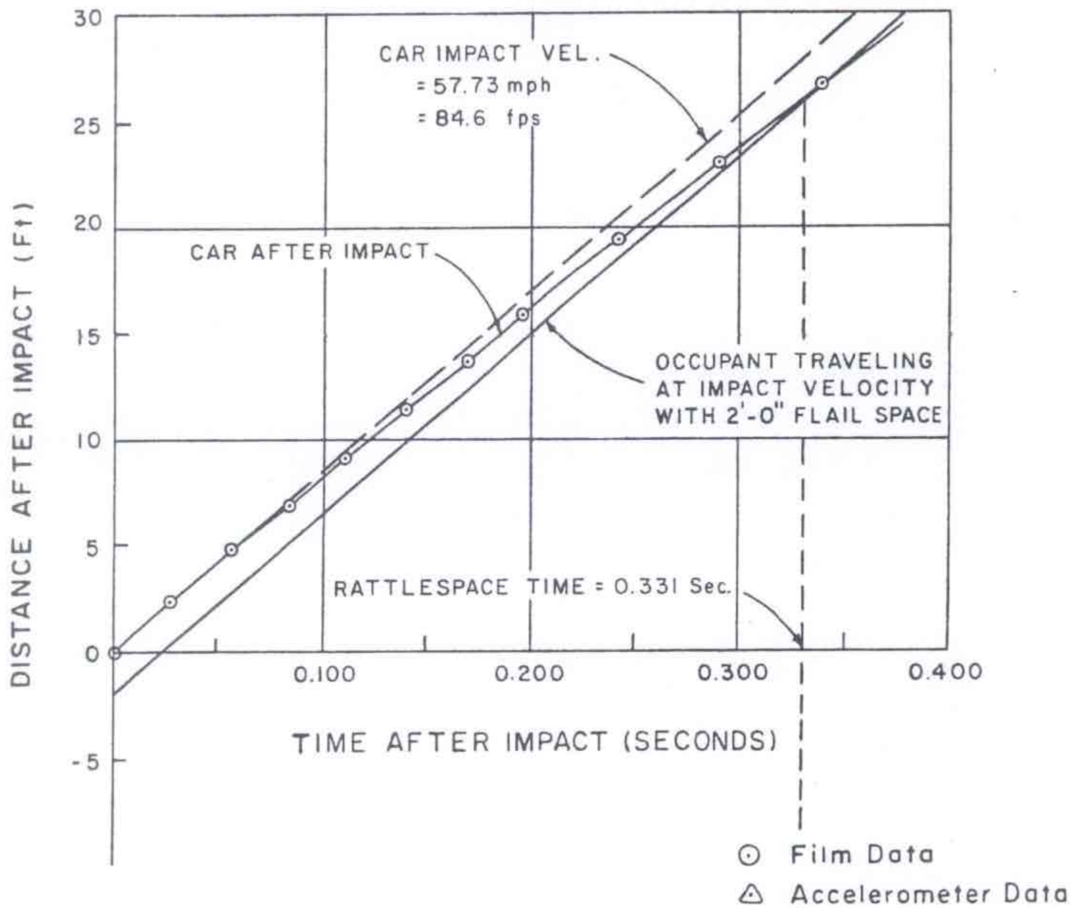
CAR DISTANCE AND VELOCITY VS TIME TEST 351

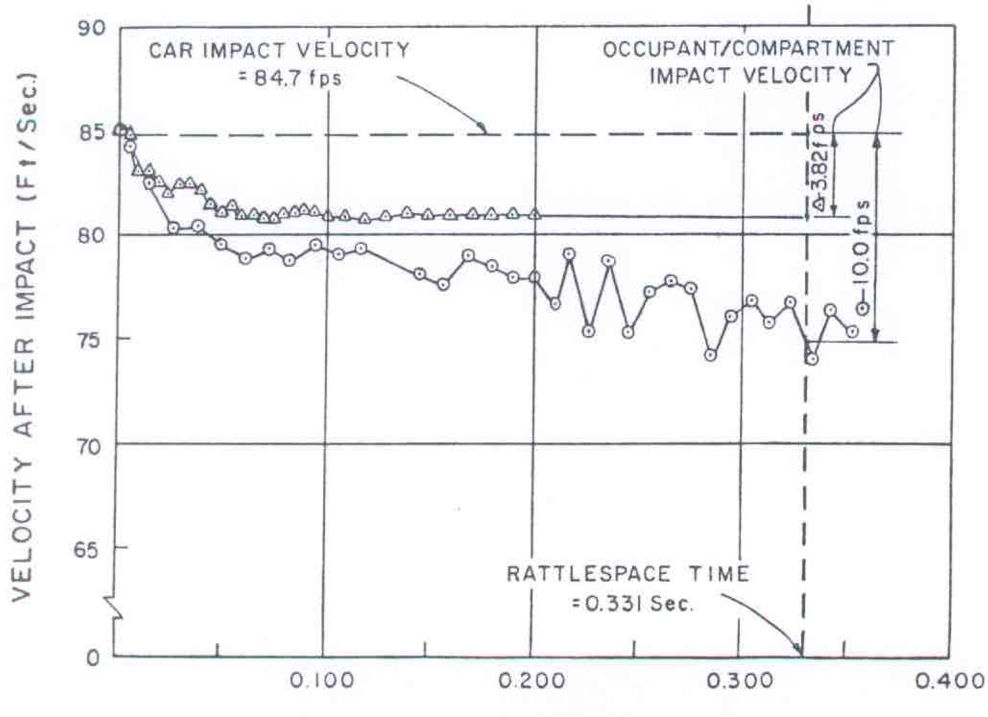
FIGURE C13



CAR DISTANCE AND VELOCITY VS TIME TEST 352

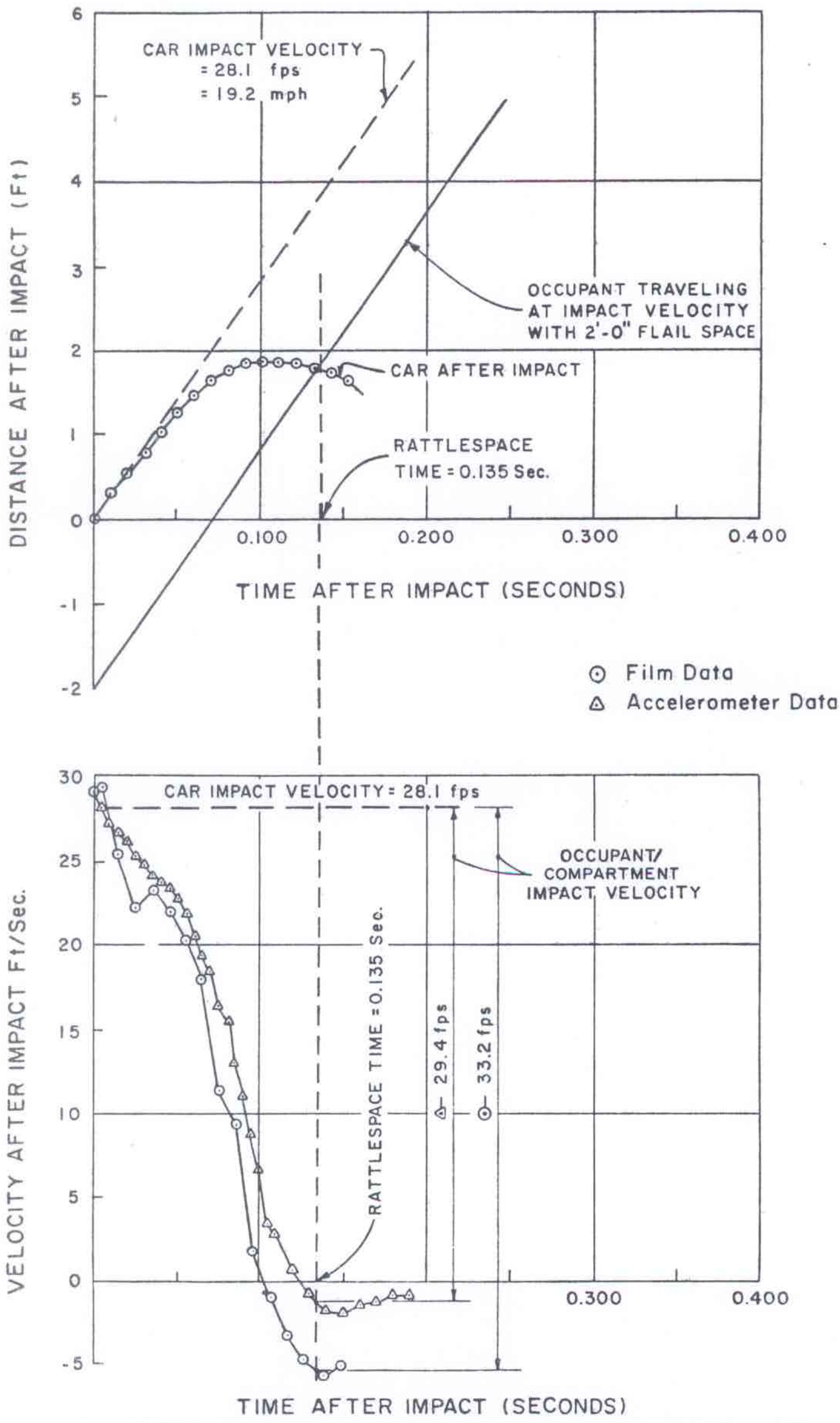
FIGURE C14





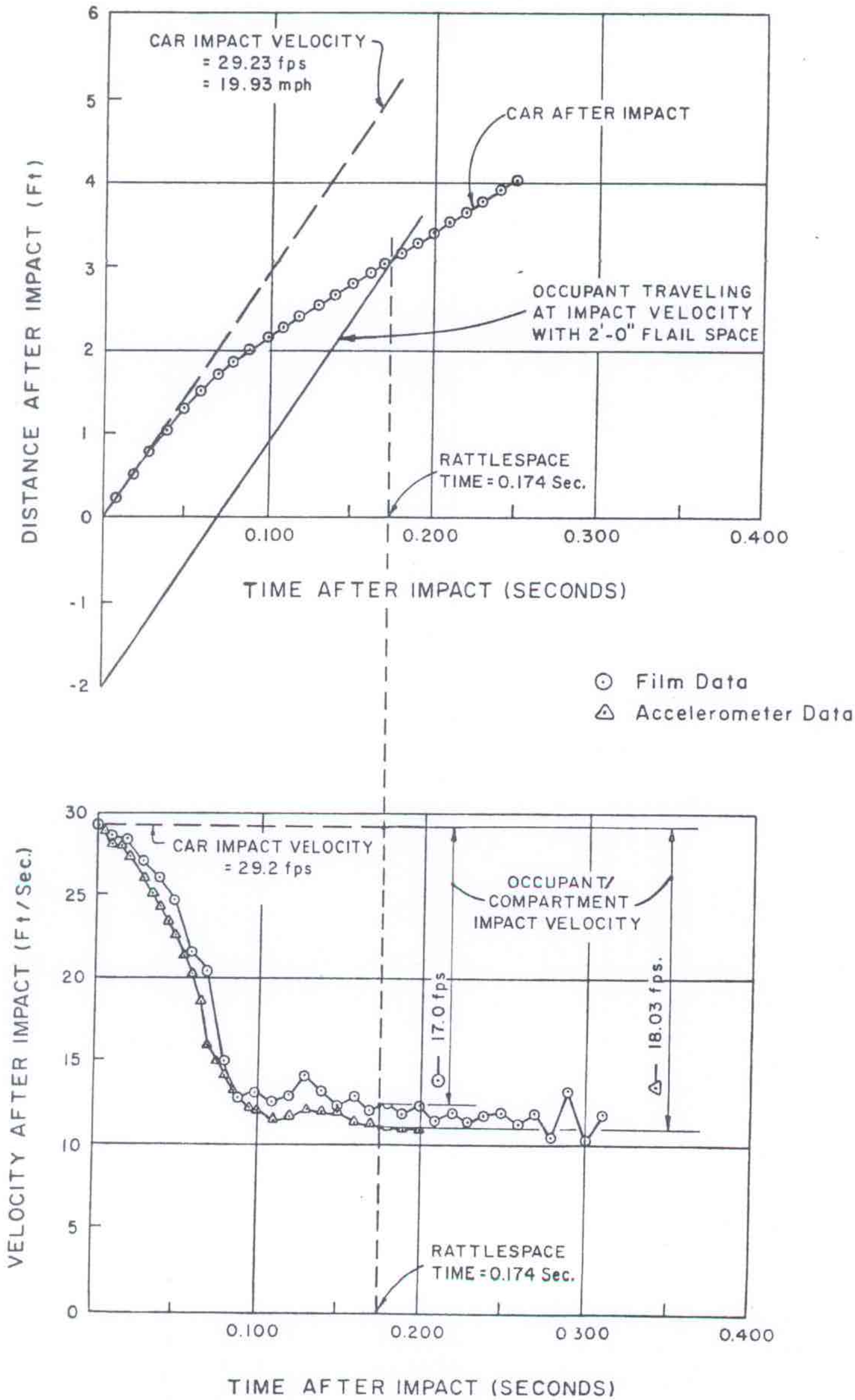
CAR DISTANCE AND VELOCITY VS TIME TEST 353

FIGURE C15



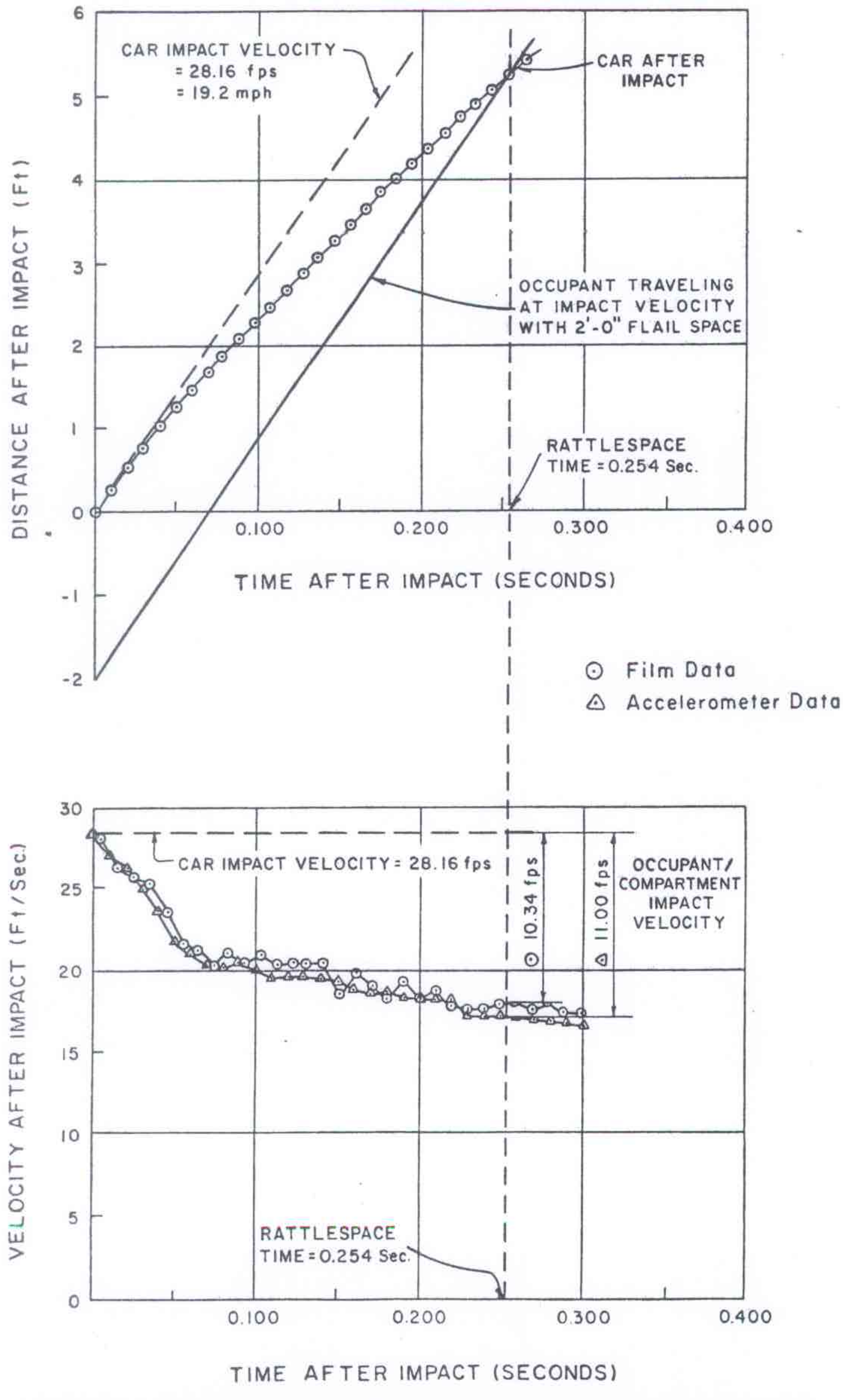
CAR DISTANCE AND VELOCITY VS TIME TEST 354

FIGURE C16



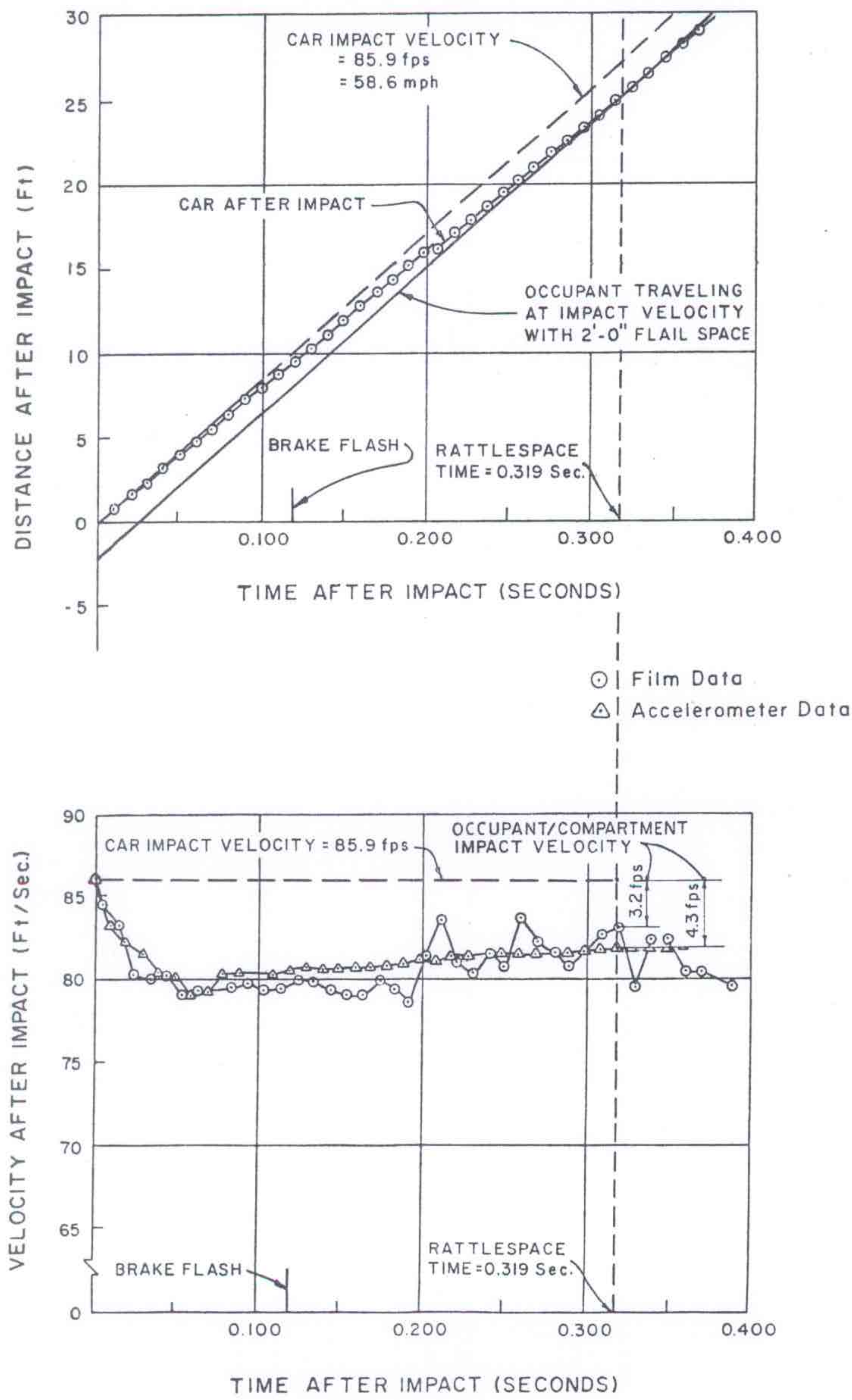
CAR DISTANCE AND VELOCITY VS TIME TEST 355

FIGURE C17



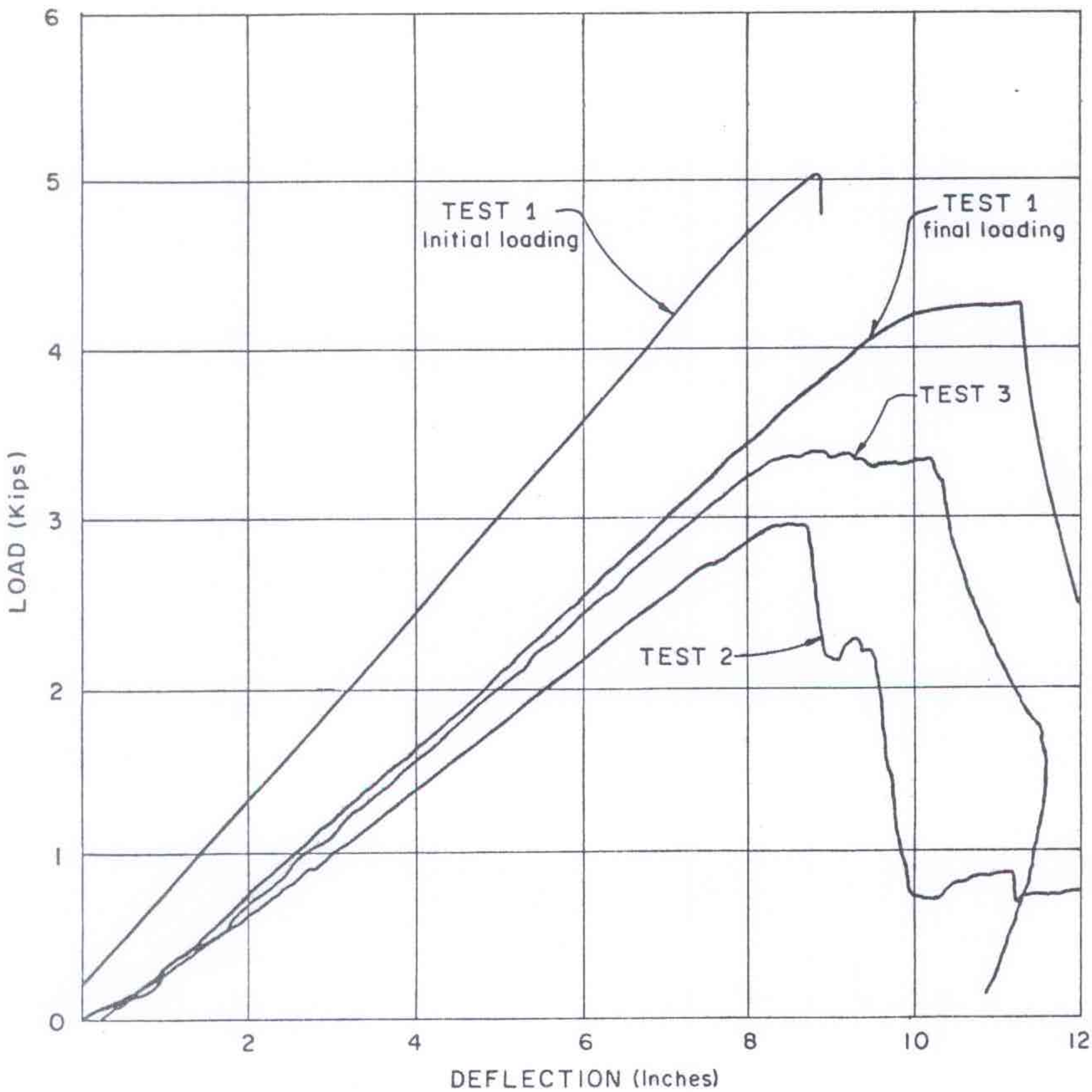
CAR DISTANCE AND VELOCITY VS TIME TEST 356

FIGURE C18



STATIC BEND TEST OF TIMBER POLES
LOAD VS DEFLECTION

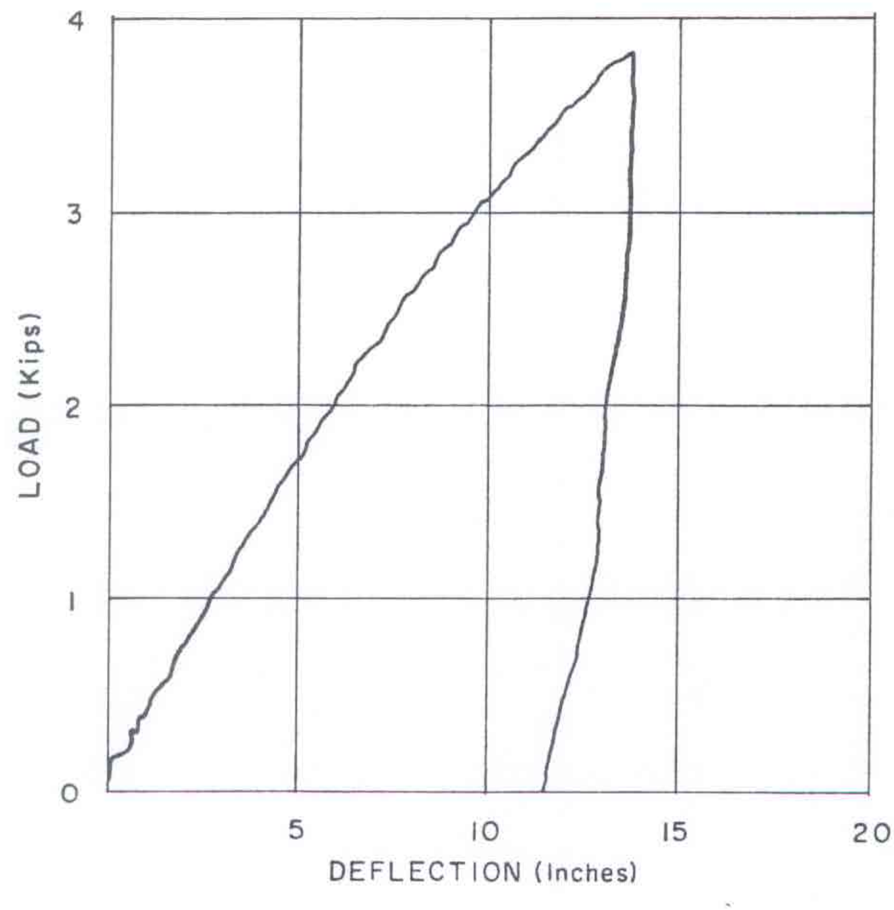
FIGURE C19



NOTES: 1. Mutiply load values on curve by 1.087 to obtain actual loads.
2. Deflection measured 11'-2" from clamp.

STATIC BEND TEST OF A LAMINATED WOOD VENEER BOX SECTION POST-LOAD VS DEFLECTION

FIGURE C20



NOTE : Deflection was measured at a point on the post 19'-0" above ground. Load was applied 21'-0" above ground..

APPENDIX D: Properties of Laminated Wood Veneer Lumber

D.1 Advantages

A number of studies of parallel-laminated veneer lumber have been conducted by the Forest Products Laboratory of the U.S. Forest Service (18 and 19). Some benefits cited for this type of material include: (1) a higher yield of material from logs than would be obtained with solid sawed lumber; (2) improvement in grade quality over solid sawed lumber from any given log due to dispersal of knots, minimizing of knot volumes, and elimination of the peeler core portion of the log; (3) consequent higher average strength with less variation in strength than solid sawed lumber; and (4) longer lengths of material that are more dimensionally stable than solid sawed lumber.

D.2 Fabrication

The laminated wood veneer lumber is built up from 1/8- or 1/10-inch thick C and D grade Douglas fir veneers that have been ultrasonically graded and combined to obtain a specific bending strength. The veneers are 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. They are dried to a moisture content of 6% or less. The veneers are the same as those used to fabricate plywood.

The lumber is laminated with glue lines parallel to the length in a continuous press. The glue is spread on one side of the veneers and they are fed into the press in the desired lay-up pattern. The press compresses the material to the required thickness and applies heat and pressure throughout the length. The material moves through the press at a constant rate determined by the cure time.

The material ranges in thickness from 3/4 to 2 1/2 inches. It is manufactured in billets that are two feet wide and up to 80 feet long. These billets are cut into the desired lumber piece sizes.

D.3 Strength

The manufacturer could supply material to provide allowable bending stress grades ranging from 2500 to 3150 psi. The comparable range in the modulus of elasticity was 1.8 to 2.3×10^6 psi. Material used in this project was rated at 2650 psi. The ultimate bending strength for the 2650 psi material was quoted as 7400 psi, and E was 2.0×10^6 psi. This stress was used both for bending in the built-up section as well as bending in the individual components. The value for bending strength in the specifications in Appendix E is slightly different. Shear stress is the same for all bending stress grades. For shear perpendicular to the glue lines the allowable stress used was 285 psi and the ultimate stress was 855 psi. This would be the stress used through the neutral axis of a web in a built up section. For shear parallel to the glue lines the allowable stress was 190 psi and the ultimate stress was 570 psi. This would be used to check shear at the joint between the flange and web of a built-up section. The coefficient of variation for all properties was quoted as 10% (standard deviation of the strength distribution expressed as a percentage of the mean of the distribution).

Other allowable stress values assigned to this material were: (1) tension - 2000 psi, (2) compression perpendicular to grain - 400 psi, and (3) compression parallel to grain - 2900 psi.

D.4 Allowable Stress Reduction Factors

The manufacturer recommended that the following allowable stress reduction factors be applied for wet conditions of use of the laminated wood veneer lumber:

Bending = 0.75
Shear = 0.84
Modulus of Elasticity = 0.89
Tension = 0.69
Compression parallel to grain = 0.61
Compression perpendicular to grain = 0.67

These factors were based on the manufacturer's own testing and knowledge with consideration given to factors used by the American Plywood Association. In checking the built up sections for wind loads, the researchers also modified allowable bending stresses with a form factor (box section) of 0.85, a wind factor of 1.33, and a factor to account for sawcuts in the web of 0.8 (suggested by the manufacturer).

D.5 Treatability

One of the beneficial properties claimed for laminated wood veneer lumber is its treatability. This property is related to the three dimensional network of lathe checks formed when the veneers are peeled from logs and flattened out (19). This improves penetration and retention of the preservative, particularly when the end grain is exposed which allows penetration for several feet. If water-borne preservatives are used, a strength reduction must be taken. Therefore, the test specimens for this project used only oil based preservatives (SWRI tests) or none at all (Caltrans tests). It is recommended that built up sections be treated after gluing rather than before gluing joints. All field installations should have the posts treated with oil based preservatives.

In a paper by the Forest Products Laboratory (19) it states:

"Treatability. -- The economics of any structural system must be calibrated not only in initial cost, but also in terms of its expected useful lifetime. Because wood fiber is produced by processes of nature, it is inevitable that it can also be decomposed by nature. Although some species are naturally decay resistant, most species will start to decay in 3 yr-5 yr if left unprotected under severe exposure.

"The use of preservative chemicals extends the service life of most wood species used in unfavorable conditions. Preservative treatment is essentially an impregnation of wood with a toxic chemical that prevents or retards wood attack by biological organisms. The effectiveness of a treatment depends on the depth of penetration and the amount of retention of a particular chemical.

"Research completed at FPL has shown that in treating laminated veneer components with nonaqueous-based preservatives, a broad range of preservative retentions can easily be achieved by variations in treatment schedules and that preservative penetration is independent of total uptake. The ease of treatability of PLV is directly related to the lathe checks that form a three-dimensional network within the laminated member and to the presence of butt joints, which occur every 4 ft in any one lamina and are spaced 12 in. apart between lamina.

"The level of retention and the completeness of cross-sectional penetration of preservative can be controlled by adjusting the initial air pressure of the treating schedule. Because of the excellent penetration evident immediately after treatment and because of minimal post-preservation checking, the decay resistance of treated Press-Lam from a species not easily treated should be superior to the decay resistance of a solid or laminated lumber beam of that species treated to the same retention. Deep checking after treatment should be less of a decay hazard in Press-Lam than in a solid or laminated lumber beam.

"The lathe checks in thick veneer are effective passageways for moving preservatives deeply into laminated veneer beams. Lathe checks are actually a series of short parallel checks with overlapping, offset ends. Flow along the checks in laminated veneer beams probably encounters substantial resistance at some of the overlapped ends and possibly also at intermittent glue dams. However, it appears from this research that these obstructions can be bypassed by the radial flow of preservative from one lamination to another if lathe checks in adjacent laminations cross at the gluelines. Coarsely lathe-checked veneer (from fast-growth or low-grade logs) is especially receptive to treatment."

D.6 Durability Tests of Glues and Preservatives

Two types of glue were used in the built up box and H-section members. The adhesive used to bond the veneers together was phenol-formaldehyde, an exterior type glue which complies with Uniform Building Code Standard No. 25-19. The flange and web elements of the built up sections were jointed with phenol-resorcinol glue. Following is a brief overview of several technical papers which describe tests of the durability of various glues and preservatives:

1. "Glue Joints Durable" (20) This paper states, "Resorcinol and phenol-resorcinol glues have shown excellent durability on untreated wood over the nearly one and a half decades they have been in use. Results are now available at the Forest Products Laboratory on laminated wood treated after gluing and aged up to 12 years before it was tested. The tests were conducted by the Laboratory for the specific purpose of determining whether preservatives have any deteriorating effects on synthetic-resin glues of the melamine, resorcinol, and phenol-resorcinol types over long periods of aging." Douglas fir was one of the species used for the laminated test specimens, and pentachlorophenol was one of the preservatives used.

Some of these specimens were stored in an unheated shed and never exposed to the weather in order to isolate the effects, if any, on the glue joints by the preservatives. Untreated control specimens as well as the treated specimens were tested for shear strength after treatment and after 2, 6, and 12 years of aging. Results of the shear tests on Douglas fir specimens treated with pentachlorophenol showed that the average strength of 1344 psi was close to that of 1390 psi for the untreated specimens. In these tests an average of 86% of the specimens failed in the wood rather than the glue joint which also indicates a strong glue bond.

Soaking and drying cycles on the treated specimens performed similar to the requirements of ASTM D1101-53 showed the glue joints had excellent resistance to delamination. The remaining specimens were allowed to weather naturally. Again, the percentage of glue joints separating was very small. Sections treated with oil-borne preservatives showed less delamination at the glue joints and more resistance to checking than those treated with water-borne preservatives. However, "In resistance to decay, the treated specimens were far superior" to the untreated ones after 12 years. Some of the weathered untreated specimens were in an advanced state of decay.

2. "Accelerated Aging of Adhesives in Plywood-Type Joints" (21) This paper describes tests that were conducted in an attempt to accelerate the aging process with the hope of predicing long-term durability. The tests included untreated specimens of Douglas fir made up of veneers bonded with phenol-formaldehyde resins, resorcinol-formaldehyde resins, and others. Some specimens were subjected to dry heat at 212°F, some were soaked in water at temperatures of 104°F, 158°F, or 212°F, and some were subjected to repeated boil-dry cycles. These specimens were all subjected to shear strength tests. Exposure time to the heat, water, etc. was varied for different specimens. Some conclusions were that:

a. "Dry heat caused a loss of shear strength controlled mainly by the properties of the wood substrates. All adhesives evaluated were more thermally stable than the wood itself."

b. "Water soaking caused much greater rates of strength loss with all adhesives than dry heat. During water soaking, specimens well bonded with phenol-resin or resorcinol-resin adhesives deteriorated in strength mainly in the wood."

c. "The development of internal stresses in the boil-cycle test increased the rate of strength loss over and above the maximum loss that would result from the effects of moisture and temperature along."

d. These tests appeared to be useful for their intended predictive purposes.

3. "Durability of Adhesives in Plywood" (22) Unpainted and untreated plywood panels and plywood shear test specimens were placed outdoors on an exposure fence in Madison, Wisonsin. They were left there for varying periods of time up to eight years. The specimens included Douglas fir plywood bonded with phenol and resorcinol adhesives as well as others. These specimens were compared with those subjected to accelerated aging described in the paper in No. 2 above. Conclusions were as follows:

a. "The most durable adhesives - hot press phenol, resorcinol, melamine, and catalyzed polyvinyl acetate - retained 60 to 70 percent of their wet strength after seven years of weathering. The changes were due to loss of strength in the wood, as high wood failures were noted throughout the exposure period."

b. "The high variability of the wet strength results after exposing plywood panels and specimens to weathering precluded any statistical evaluation of the significance of the differences noted. Only patterns and trends could be observed and related to the results obtained by accelerated aging in the laboratory."

c. "The results verified that differences among adhesives, which could be determined by accelerated aging in dry heat as well as in water soaking, were also observable in their performance during weathering."

It was noted that the exposure conditions of the specimens were more severe than those normally found in service environments.

4. "Synthetic-Resin Glues" (23) This paper is a general treatise on glues. It discusses glue classifications and components, the gluing process, properties of different types of glue, and the durability of glues. Following is a quote with "generalizations" based on numerous exposures, both laboratory-controlled and to the weather, at the Forest Products Laboratory.

"The durability of moderately alkaline phenol-resin, resorcinol-resin, and straight melamine-resin glues is very similar. These glues, when properly used, are capable of producing joints that, under all severe conditions studied, are as durable as the wood itself. Thus joints properly made with these glues will withstand, without delamination or significant loss in strength, prolonged exposure to cold and hot water, to alternate soaking and drying, to temperatures up to those that seriously damage the wood, to high relative humidities where many untreated species decay, and to outdoor weathering without paint or mechanical protection from the elements. The plies of plywood made with these glues will not separate when exposed to fire. The glues are not weakened by fungi, bacteria, and other micro-organisms and are avoided by termites. Despite this immunity of the glues themselves, they do not offer any significant protection to the adjacent wood. Consequently, wood products glued with these glues should be considered no more decay- or insect-resistant than solid wood of the same species. Completely cured phenol-resin glued joints are highly resistant to the action of solvents, oils, acids, alkalies, wood preservatives, and fire-retardant chemicals; similar properties of resorcinol- and melamine-resin glues have not been adequately evaluated. Thus, in general, well-made joints with phenol-, resorcinol-, and melamine-resin glues are difficult to destroy without destroying the wood itself. However, as with other types of glues, poorly made joints with these durable glues may fail in service under any of the aforementioned conditions. Based on available experience, the phenol-resorcinol-resin glues, when adequately cured, appear to have the same high-durability characteristics as straight phenol- or resorcinol-resin glues."

All of the above papers imply an established technology for wood members glued and treated for exterior use. Another standard along the same lines is American Wood Preservers Association Standard C-28-79, "Standard for Preservative Treatment of Structural Glued Laminated Members and Laminations Before Gluing of Southern Pine, Pacific Coast Douglas Fir, Hemfir and Western Hemlock by Pressure Processes" (24) This standard provides for treatment before or after gluing of laminations. It also outlines the penetration, retention, and sampling requirements for treated laminated members that will be in contact with soil.

D.7 Other Uses

Laminated wood veneer lumber has been used as flange and chord material for solid and open web joints, scaffold planking, truck and trailer beds, mobile home trusses, and decking. Recently it has been marketed for use in built up H-columns to support farm buildings. The columns are embedded in the ground.

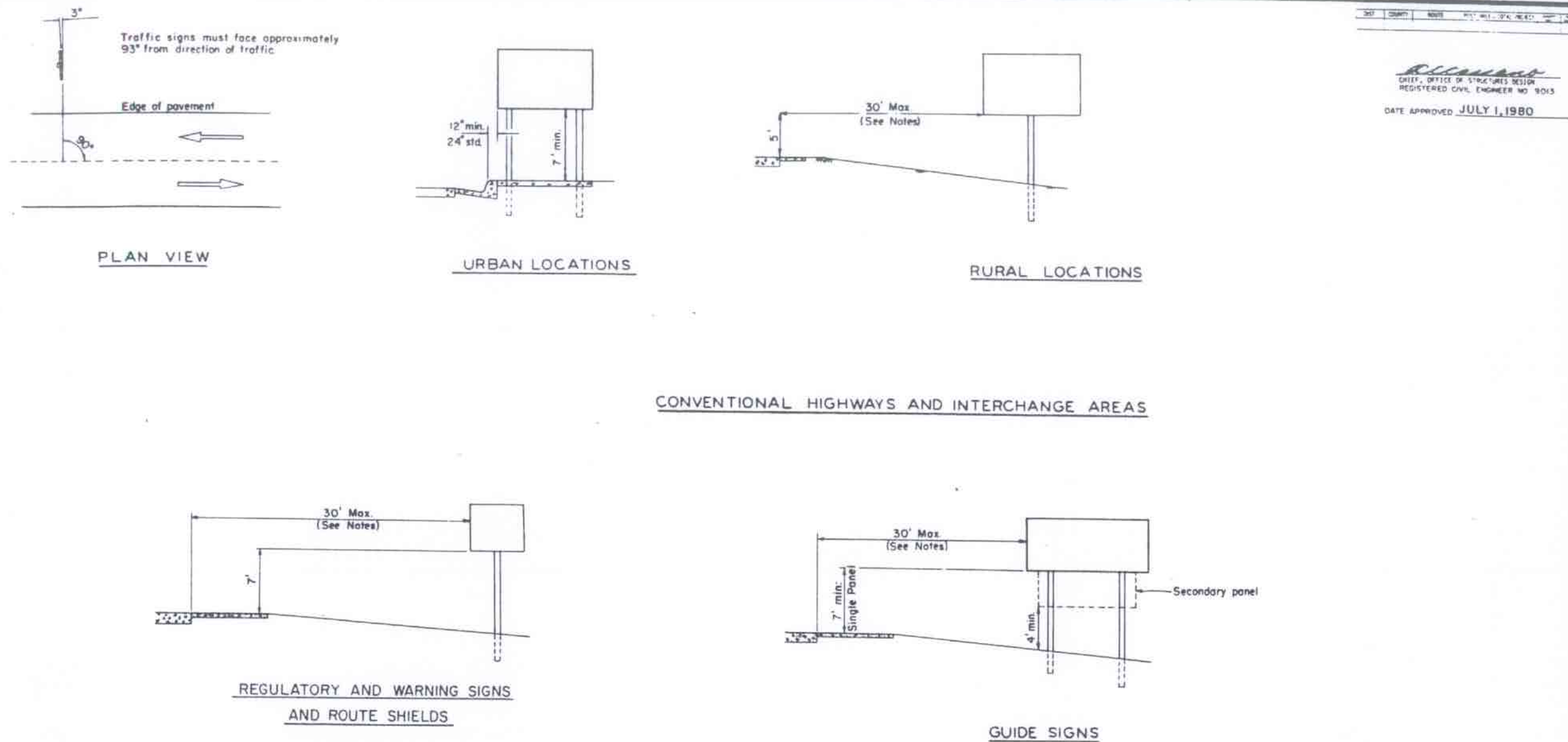
The wood veneer lumber product used in the built up sections for this project has been approved as an alternate method of construction in Research Committee Report No. 3155 dated February 1979 of the International Conference of Building Officials (25).

D.8 Sources

At the time of this project only one United States Manufacturer of laminated wood veneer was known to the researchers. A second west coast company may have the product commercially available in 1981. A company in Finland markets a similar product in the U.S. that is used principally for scaffold planking.

APPENDIX E: Breakaway Supports for Roadside Signs - Standard Plans and Specifications

The standard plans are from Reference 5.



FREEWAY AND EXPRESSWAY LOCATION

NOTES:

When clear roadside recovery areas are provided, signs shall be placed as far from the edge of traveled way as possible, up to a maximum of 30 feet. When possible they shall be placed in protected locations.

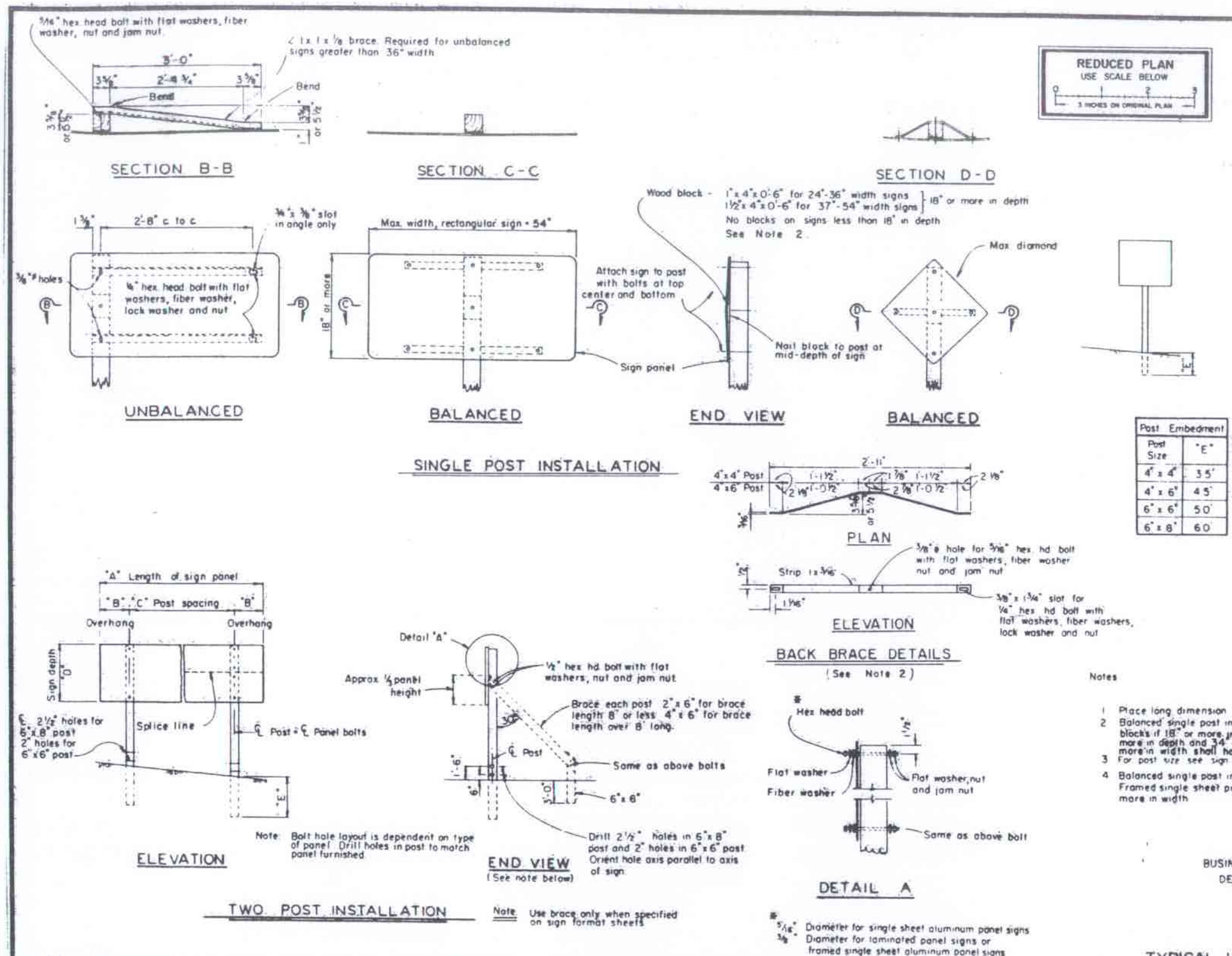
Signs in medians shall be placed at midpoint of median up to a maximum distance of 30' from edge of traveled way. When appropriate, signs for opposing directions shall be placed back to back.

REDUCED PLAN
USE SCALE BELOW
0 1 2 3
3 INCHES ON ORIGINAL PLAN

STATE OF CALIFORNIA
BUSINESS AND TRANSPORTATION AGENCY
DEPARTMENT OF TRANSPORTATION

ROADSIDE SIGNS
TYPICAL INSTALLATION DETAILS NO. 1 | S 41-3

FIGURE E1



Post Size	Post Embedment "E"
4" x 4"	3.5'
4" x 6"	4.5'
6" x 6"	5.0'
6" x 8"	6.0'

CHIEF, OFFICE OF STRUCTURES DESIGN
REGISTERED CIVIL ENGINEER NO 9013

DATE APPROVED JULY 1, 1980

POST SPACING TABLE

SIGN PANEL LENGTH "A"	SIGN PANEL OVERHANG "B"	POST SPACING "C"
4'-8", 5'-0" & 5'-6"	7", 9" & 12"	3'-6"
6'-0" & 6'-6"	12" & 15"	4'-0"
7'-0" & 7'-6"	15" & 18"	4'-6"
8'-0"	18"	5'-0"
8'-6"	20"	5'-2"
9'-0"	22"	5'-4"
9'-6"	23"	5'-8"
10'-0"	24"	6'-0"
10'-6"	24"	6'-6"
11'-0", 11'-6" & 12'-0"	24", 27" & 30"	7'-0"
12'-6"	30"	7'-6"
13'-0"	30"	8'-0"
13'-6" & 14'-6"	30" & 36"	8'-6"
14'-0" & 15'-0"	30" & 36"	9'-0"
15'-6" & 16'-0"	36" & 39"	9'-6"
16'-6"	39"	10'-0"
17'-0" & 17'-6"	39" & 42"	10'-6"
18'-0" & 18'-6"	42" & 45"	11'-0"
19'-0"	45"	11'-6"
19'-6" & 20'-0"	45" & 48"	12'-0"
20'-6" & 21'-0"	48" & 51"	12'-6"
21'-6"	51"	13'-0"
22'-0" & 22'-6"	51" & 54"	13'-6"
23'-0"	54"	14'-0"
23'-6" & 24'-0"	54" & 57"	14'-6"

Notes

1. Place long dimension of post cross section normal to sign axis.
2. Balanced single post installations of unframed single sheet aluminum panel signs shall have blocks if 18" or more in depth and a combination of blocks and back braces if 18" or more in depth and 34" or more in width. Signs panels less than 18" in depth and 34" or more in width shall have back braces only.
3. For post size see sign layout, format or quantity sheets
4. Balanced single post installations of Laminated Panel and Framed single sheet panel signs require back braces when 34" or more in width

STATE OF CALIFORNIA
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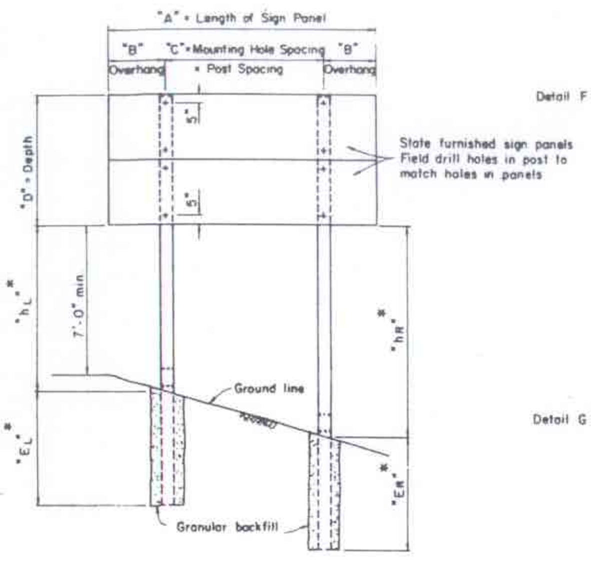
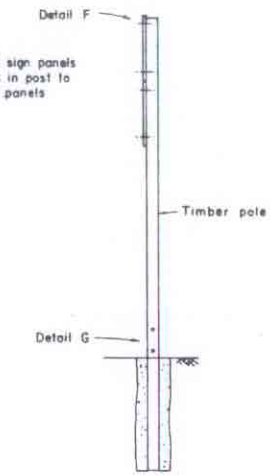
ROADSIDE SIGN
WOOD POSTS
TYPICAL INSTALLATION DETAILS NO. 2 S 42-15

FIGURE E2

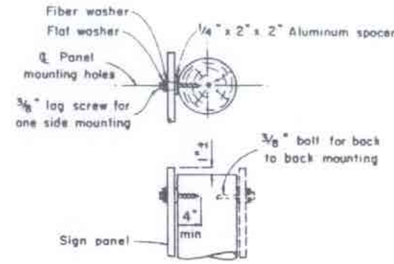


ELEVATION

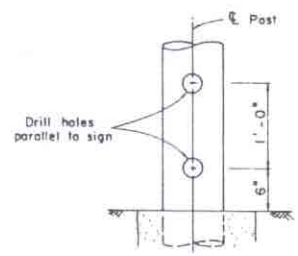
* Dimensions given on Project Plans are for fabrication. At time of installation adjust these dimensions to provide a level sign approximately 7' above roadway shoulder.



END VIEW



DETAIL F



DETAIL G

Pole Diameter at Ground Line	Hole Dia.
6" to less than 7"	2"
7" to less than 8"	2"
8" to less than 9"	2½"
9" to less than 10½"	3"
10½" to less than 12"	3½"
Over 12"	4"

SIGN PANEL LENGTH "A"	SIGN PANEL OVERHANG "B"	MOUNTING HOLE SPACING "C"
4' - 8"	7"	3' - 6"
5' - 0"	9"	3' - 6"
6' - 0"	12"	4' - 0"
7' - 0"	15"	4' - 6"
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"

LAMINATED PANELS

Notes: See Project plans for:

1. Station of each sign.
2. Distance from edge of pavement or other layout line.
3. Length of Sign "A".
4. Depth of Sign "D".
5. Height "h" of each pole above foundation.
6. Depth of embedment "E" for each pole.
7. Diameter of post hole.
8. Class of timber pole.

CHIEF, OFFICE OF STRUCTURES DESIGN
REGISTERED CIVIL ENGINEER NO.

APPROVED JULY 1, 1980

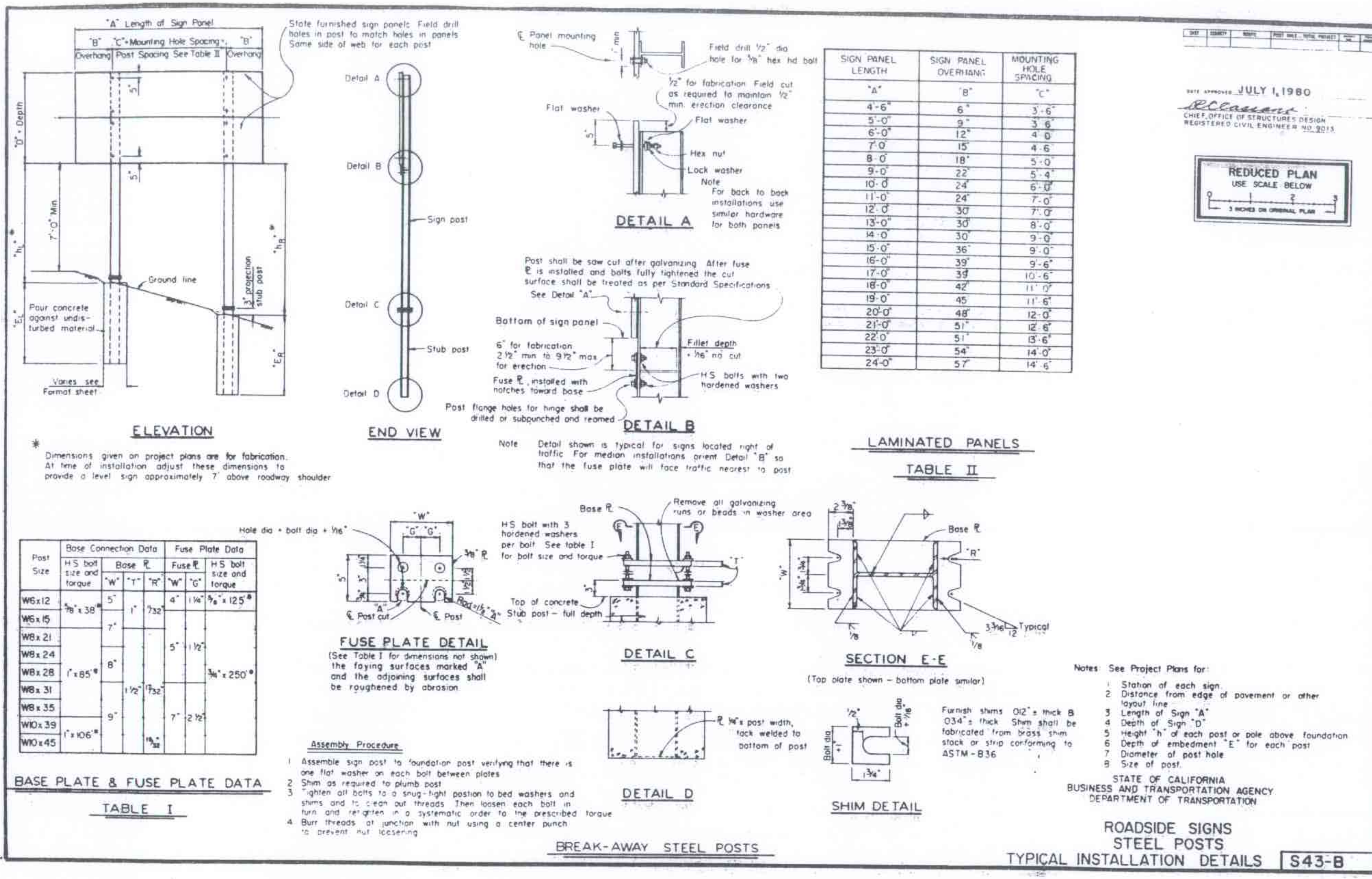
REDUCED PLAN
USE SCALE BELOW
0 1 2 3
3 INCHES ON ORIGINAL PLAN

STATE OF CALIFORNIA
BUSINESS AND TRANSPORTATION AGENCY
DEPARTMENT OF TRANSPORTATION

ROADSIDE SIGNS
TIMBER POLES
TYPICAL INSTALLATION DETAILS NO. 3

S43-A

FIGURE E3



BASE PLATE & FUSE PLATE DATA

TABLE I

Post Size	Base Connection Data: H.S. bolt size and torque	Base ℞ "W"	Base ℞ "T"	Base ℞ "R"	Fuse ℞ "W"	Fuse ℞ "G"	Fuse Plate Data: H.S. bolt size and torque
W6x12	⅝" x 38'*	5"	1"	7/32"	4"	1¼"	⅝" x 125'*
W6x15		7"			5"	1½"	¾" x 250'*
W8x21	1" x 85'*		1½"	17/32"			
W8x24		8"					
W8x28							
W8x31		9"			7"	2½"	
W8x35							
W10x39	1" x 106'*						
W10x45				19/32"			

LAMINATED PANELS

TABLE II

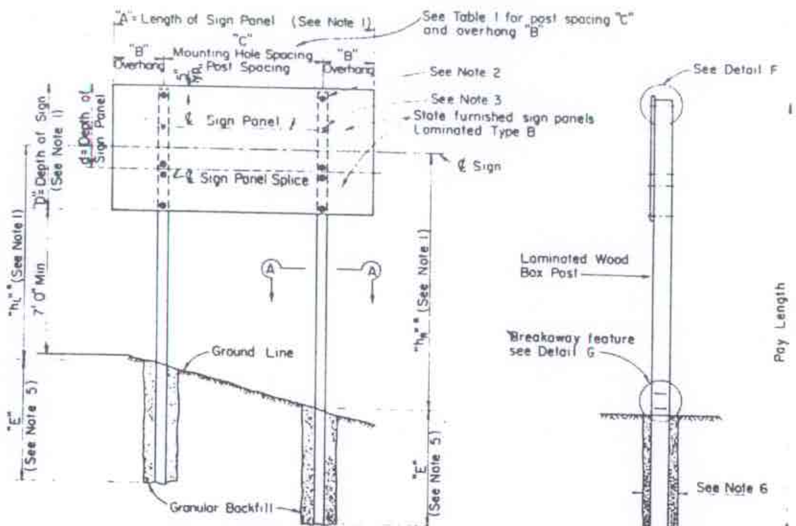
SIGN PANEL LENGTH "A"	SIGN PANEL OVERHANG "B"	MOUNTING HOLE SPACING "C"
4'-6"	6"	3'-6"
5'-0"	9"	3'-6"
6'-0"	12"	4'-0"
7'-0"	15"	4'-6"
8'-0"	18"	5'-0"
9'-0"	22"	5'-4"
10'-0"	24"	6'-0"
11'-0"	24"	7'-0"
12'-0"	30"	7'-0"
13'-0"	30"	8'-0"
14'-0"	30"	9'-0"
15'-0"	36"	9'-0"
16'-0"	39"	9'-6"
17'-0"	39"	10'-6"
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"

FIGURE E4

RSP-S43-A

To accompany plans dated

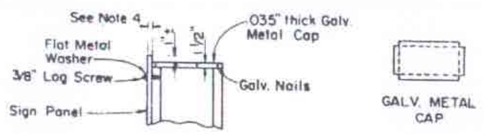
Date approved: June 18, 1981



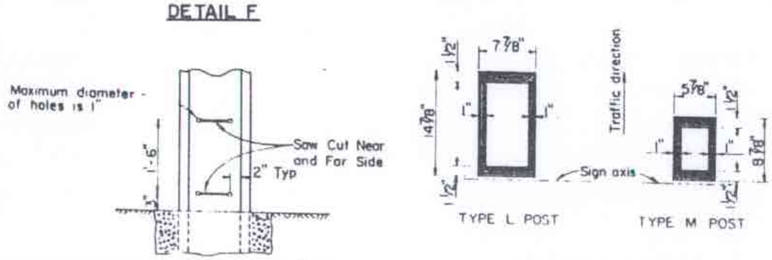
ELEVATION

END VIEW

* 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.



DETAIL F



DETAIL G

SECTION A-A

TABLE 1

SIGN PANEL LENGTH (See Note 1) "A"	SIGN PANEL OVERHANG "B"	MOUNTING HOLE SPACING "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"

TABLE 2

MINIMUM POST EMBEDMENT "E" FOR TYPE L POST

"h_L" or "h_R" (in feet)	TOTAL SIGN AREA (sq. ft.) 40 to 90	90+ to 140	140+ to 190	190+ to 240	240+ to 290
9 to 13	6'	6.5'	7.5'	8.5'	9'
13+ to 17	6'	7'	8'	9'	10'
17+ to 21	6'	7.5'	9'	9'	
21+ to 26	7'	8'	9'		

NOTES:

1. See Project Plans for:
   - Location of each sign.
   - Length of sign panel "A".
   - Depth of sign "D".
   - Height "h_L" and "h_R" of centerline of sign above ground line at each post.
   - Type of post, L or M.

   See Standard Plan S41-3 for other details.
2. "•" 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.
3. "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"

4. 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.
5. Embedment "E" for Type L posts shall conform to the requirements in Table 2. Embedment for Type M posts shall be 6 feet minimum.
6. 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.

REVISED STANDARD PLAN

Supersedes Plan Sheet S43-A Page 185 of the Standard Plan Book Dated January, 1981.

ROADSIDE SIGNS
LAMINATED WOOD BOX POST
TYPICAL INSTALLATION DETAILS NO. 3

Revised June, 1981

RSP-S43-A

FIGURE E5

(All new.)
(Add to SSP 56.50 when roadside signs are to be installed on Type L or Type M laminated wood box posts.)
(Use the following Item Code Nos. and Item Descriptions:
566020 Type L Laminated Wood Box Post (Roadside Sign)
566021 Type M Laminated Wood Box Post (Roadside Sign)
(Include Revised Standard Plan S-43A in project plans.)

56.55
7-27-81

Roadside signs consisting of State-furnished sign panels installed on laminated wood box posts shall be installed at the locations shown on the plans. The laminated wood box posts shall conform to the details shown on the plans and the following requirements, and shall be of the type or types designated in the Engineer's Estimate.

The 4 sides of each box post shall be made of laminated 1a
veneer lumber manufactured by gluing together 1/10 inch or 1/8 inch thick Douglas fir veneers in a continuous process with the grain parallel to the length of the post. The veneers shall be end jointed with a lap splice or butt joint. Each side shall have no joints other than those required for laminating and jointing the veneers.

The veneers shall be CD grade dried to a moisture content 1b
of 6 percent or less. Veneers shall be graded by ultrasonic or other approved nonvisual methods.

The adhesive used to laminate the veneers shall be phenol 1c
formaldehyde conforming to the requirements in ASTM Designation: D 2559. The adhesive shall be mixed and applied by a curtain coater or other approved mechanical method.

The laminated wood sides shall have a minimum mean modulus 1d
of rupture of 7,000 psi, based on 10 or more samples of each of the sizes shown on the plans. The moving average bending strength of 30 or more samples of 3 1/2 inch wide specimens shall be 8,500±850 psi. The average ultimate horizontal shear strength shall be 855±85 psi perpendicular to the glue line, and 570±57 psi parallel to the glue line. The above mechanical properties shall be determined in accordance with the requirements in ASTM Designation: D 198.

The laminated veneer lumber sides shall be glued together 1e
to fabricate the box posts. The adhesive used to fabricate the box section shall be phenol resorcinol conforming to the requirements in ASTM Designation: D 2559. The ultimate shear strength of each joint of the box section shall be 570±57 psi.

The lumber and posts shall be laminated and fabricated in a 1f
plant under a process approved by the National Research Board of the Council of American Building Officials. The posts

shall be treated, after fabrication, with pentachlorophenol Type A in accordance with the requirements in AWPA Standard C 28. The name and address of the manufacturer and approved quality control agency shall be stamped legibly on the exterior surface of each post.

The cross sectional dimensions of the completed posts shall 1g
be within 1/8 inch of those shown on the plans.

A Certificate of Compliance shall be furnished for each ship- 2
ment of laminated wood box posts in accordance with the provisions in Section 6-1.07, "Certificates of Compliance," of the Standard Specifications. The certificate shall state that representative samples of the lumber and posts have been tested and that the test results conform to the requirements herein. The certificate shall be accompanied by a certified copy of the results of tests performed by the manufacturer upon samples of the lumber and posts.

The metal cap at the top of each laminated wood box post shall 3
be made from commercial quality galvanized sheet metal.

If the laminated wood box posts are not immediately used, the 4
posts shall be neatly piled on skids. The posts shall be piled so they may be readily inspected and shall be handled in a manner that will avoid injury or damage to the posts.

Lag screws shall be installed by turning the lag screw into 5
pilot holes by use of a wrench. The pilot holes shall be bored with a bit not larger than the base of the lag screw thread.

The breakaway saw cuts and holes in the laminated wood box 6
posts shall be made after installation of the posts. Posts shall not be spliced and one trim cut at the top of the post will be allowed. Field cut surfaces shall be treated with a brush treatment of the same preservative used to treat the posts originally.

After the laminated wood box posts are installed in the 7
excavated holes, the space around the posts shall be backfilled in the same manner as specified for backfilling the space around timber poles in Section 56-2.03, "Construction," of the Standard Specifications.

Laminated wood box posts will be measured by the linear foot 8
from the actual lengths installed.

The contract price paid per linear foot for laminated wood box 9
posts of the type or types designated in the Engineer's Estimate shall include full compensation for furnishing all labor, materials (except State-furnished sign panels, blind rivets and closure inserts), tools, equipment and incidentals and for doing all the work involved in installing the roadside signs on laminated wood box posts, complete in place, as shown on the plans, as specified in the Standard Specifications and these special provisions, and as directed by the Engineer.

APPENDIX F: Miscellaneous

Lag screw pilot hole sizes were taken from Reference 26. The pilot holes in Tests 1-3, Table F1 were made too small inadvertently. Although the hammer driven screws in Tests 10-12 had surprising pullout resistance, the values from wrench turned screws were used for design purposes. In the field, screws are sometimes driven in with a hammer as a shortcut. Tests 13-15 indicate that lag screws spaced at 12 inch intervals along a box beam exhibit more strength than the joint between the web and flange of the box section which failed first in 2 out of 3 of these tests. The screws were offset from the box center-line in Tests 13-15 to match the screw location in Test 356. On the standard plan, Figure E5, it was decided to center the screws in the flange of the box section.

Table F2 is a knot count for the three pole specimens subjected to static bend tests by Caltrans.

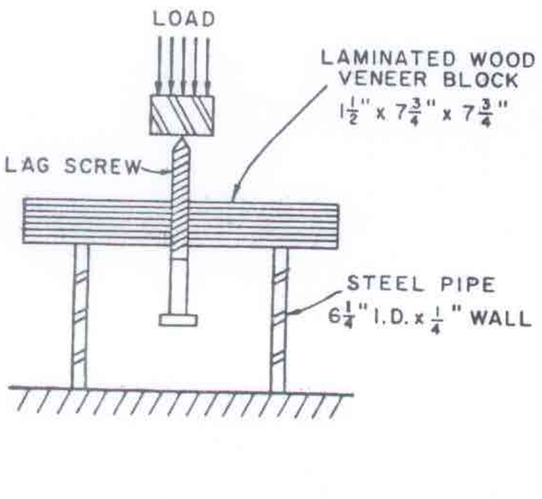
Tables F3-F7 summarize all crash tests by other agencies known to the researchers on dual-legged roadside signs with metal supports and various types of breakaway mechanisms. Tests with passenger vehicles and bogies are included. The values for occupant/compartment impact velocity were derived from the change of momentum values and do not necessarily represent a 2 ft-0 in. flail space as specified in Reference 6.

TABLE F1. STRENGTH OF LAG SCREWS IN LAMINATED WOOD VENEER MEMBERS

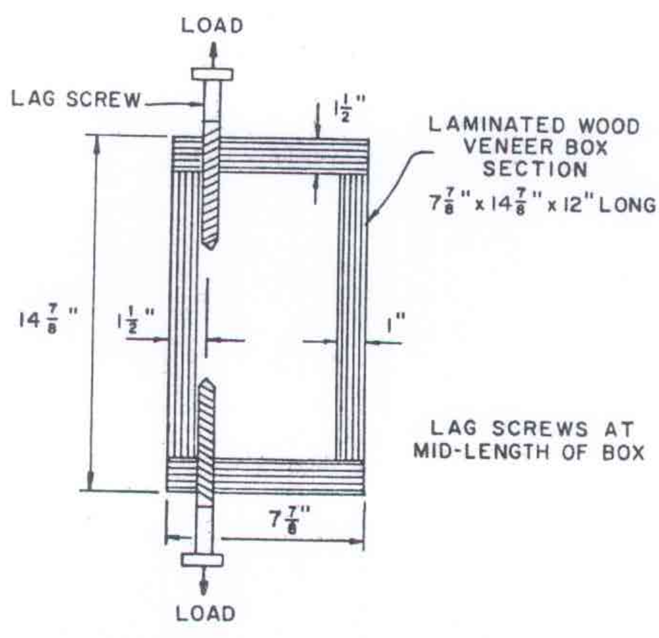
Specimen No.	Lag Screw Dia. (In.)	Pilot Hole Dia. (In.)	Method of Installation	Ultimate Load (Lbs)	
				First	Second
1	1/2	1/4	Wrench-Turned	1770	
2	1/2	1/4	"	1762	
3	1/2	1/4	"	1884	
4	1/2	5/16	"	2142	
5	1/2	5/16	"	1864	
6	1/2	5/16	"	2006	
7	3/8	1/4	"	1840	1610
8	3/8	1/4	"	1818	1640
9	3/8	1/4	"	1666	1674
10	3/8	1/4	Hammer-Driven	1164	
11	3/8	1/4	"	1096	
12	3/8	1/4	"	954	
13	1/2	5/16	Wrench-Turned	810	
14	1/2	5/16	"	1340	
15	1/2	5/16	"	1292	

Notes: 1. Lag screws were commercial quality steel, hot-dip galvanized and were 5 1/2 or 6 inches long.

2. In Tests 7-9 after the first loading to failure the screws were removed, a new pilot hole drilled 1/2 inch on center from the first hole, a lag screw inserted, and a second load test was conducted.



TEST SETUP-SPECIMENS 1-12



TEST SETUP-SPECIMEN 13-15

TABLE F2

STATIC BEND TESTS - TIMBER POLES

KNOT COUNT IN POLES

	Location on Pole (4-foot Sections)	Knot Diameters: Under 1/4"	1/4-1/2"	1/2-1"	Over 1"	Totals
TEST 1	Butt End - Top	3	13	1	0	17
	- Bottom	10	4	0	0	14
	Second - Top	2	9	0	0	11
	- Bottom	0	7	0	0	7
	Third - Top	2	4	2	0	8
	- Bottom	0	8	1	0	9
	Tip End - Top	1	2	3	0	6
	- Bottom	1	6	1	0	8
	Totals	19	53	8	0	80
TEST 2	Butt End - Top	0	0	3	7	10
	- Bottom	2	1	1	4	8
	Second - Top	0	0	0	5	5
	- Bottom	0	1	3	5	9
	Third - Top	0	0	1	8	9
	- Bottom	0	2	1	5	8
	Tip End - Top	0	0	0	6	6
	- Bottom	0	1	3	4	8
	Totals	2	5	12	44	63
TEST 3	Butt End - Top	2	1	1	3	7
	- Bottom	0	1	3	3	7
	Second - Top	1	2	1	3	7
	- Bottom	1	0	4	4	9
	Third - Top	0	4	0	2	6
	- Bottom	3	1	2	7	13
	Tip End - Top	1	1	1	4	7
	- Bottom	0	3	3	9	15
	Totals	8	13	15	35	71

Note: Top on compression side of pole, bottom on tension side.

DATA SUMMARY OF CRASH TESTS ON BREAKAWAY STEEL SUPPORTS FOR DUAL-LEGGED ROADSIDE SIGNS																					
TEST I.D.			BREAKAWAY SUPPORT					SIGN PANEL			VEHICLE			TEST RESULTS							
REF NO.	TEST NO.	TEST DATE	TYPE	BREAKAWAY MODIFICATION	HINGE BELOW SIGN PANEL	SPACING (ft.)	FOOTING (ft.)	CONNECTION TO SUPPORT	SIZE	GRND CLR. (ft)	TEST INER MASS (lbs)	IMPACT VELOC. FPS (MPH)	IMPACT ANGLE (Deg)	OCCUPANT/ COMPARTMENT IMPACT VELOCITY (FPS) FILM	ACCEL.	INITIAL MOMENTUM MV (lb-sec)	CHANGE OF MOMENTUM ΔMV (lb-sec) FILM	ACCEL.	INIT VEH KINET. ENER. KE (ft-K)	CHANGE IN KIN ENER ΔKE (ft-K)	MAX FRONT VEH CRUSH (in)
27 TTI	32	3/65	W5x16 ASTM A36	None	None	3.5	2'Ø x 3.0' Deep	Clamped	5' x 6' x 5/8" Plywood	7.0	3230	57.5 (39.2)	0	57.5		5768	5768		166	166	24
"	33	3/65	W8x20 ASTM A441	Slip Base 4 bolts	Cast Iron Fuse Plate		8'x24' Con-crete pad	"	8' x 16' x 5/8" Plywood	"	3130	76.3 (52.0)	0	2.54		7417	247		283	19	
"	35	4/65	"	"	"		"	"	"	"	3215	76.0 (51.8)	0	2.68		7588	268		288	20	
"	39	7/65	W8x20 ASTM A36	None	None		"	"	"	"	3240	64.5 (44.0)	0	64.5		6490	6490		209	209	
"	40	7/65	W8x20 ASTM A441	Slip Base 4 bolts	Cast Iron Fuse Plate		"	Bolted	"	"	3240	65.4 (44.6)	0	3.41		6581	343		215	22	
"	41	7/65	W8x20 ASTM A36	"	Notched Steel Fuse Plate		"	"	"	"	3620	62.3 (42.5)	0	1.47		7004	165		218	10	
28 TTI	C1	71-75	W12x45	Slip Base 4 bolts	Notched Steel Fuse Plate		2'Ø x 6.0' Deep				2360	29.8 (20.3)	0	7.80		2182	572		32	15	
"	C2	71-75	"	"	"		"				4500	60.4 (41.2)	0	6.13		8444	857		255	49	
29 Calif	201	4/68	2 1/2"Ø w/2"Ø Braces	Slip Base 4 bolts Braces -1 bolt inclined	Notched Steel Fuse Plate	9.5	1.5'Ø x 3.5' Deep	U-bolts	8' x 16" Sneet metal	7.0	4600	60.9 (41.5)	15	1.91		8695	272		265	16	
"	202	5/68	"	"		"	"	"	"	"	4600	60.7 (41.4)	15	3.37		8674	482		263	28	

TABLE F3

DATA SUMMARY OF CRASH TESTS ON BREAKAWAY METAL SUPPORTS FOR DUAL-LEGGED ROADSIDE SIGNS

TEST I.D.			BREAKAWAY SUPPORT					SIGN PANEL			VEHICLE			TEST RESULTS							
REF. NO.	TEST NO.	TEST DATE	TYPE	BREAKAWAY MODIFICATION	HINGE BELOW SIGN PANEL	SPACING (ft.)	FOOTING (ft.)	CONNECTION TO SUPPORT	SIZE	GRND. CLR. (ft.)	TEST INER. MASS (lbs)	IMPACT VELOC. FPS (MPH)	IMPACT ANGLE (Deg)	OCCUPANT/ COMPARTMENT IMPACT VELOCITY (FPS)		INITIAL MOMENTUM MV (lb-sec)	CHANGE OF MOMENTUM ΔMV (lb-sec)		INIT VEH KINET. ENER. KE (ft-K)	CHANGE IN KIN ENER ΔKE (ft-K)	MAX FRONT VEH CRUSH (in)
														FILM	ACCEL.		FILM	ACCEL.			
30 CAL	1	1969	12"Ø Alum. 1/4" Wall	N.J. Load Concentrated Coupling	None	14.0	Large Concrete Found.	Pin conn. Split collar	24' x 14' x 2" Alum.	7.5	1990	35.8 (24.4)	0	6.75		2212	417		40	14	7
"	2	1969	"	"	"	"	"	"	"	"	"	54.6 (37.2)	20	6.60		3372		483	92	21	9
"	3	1969	"	"	"	"	"	"	"	"	4400	30.8 (21.0)	10	*		4209	*		65	*	1
"	4	1969	"	"	"	"	"	"	"	"	4320	65.1 (44.4)	"	3.96		8737	533		285	34	6
31 NY	69	--	W6x8.5	Slip Base 4 bolts	Notched Steel Fuse Plate	8.0			13.5' x 5.5'	7.0	3100	88 (60)	90	2.93		8472	282		373	24	*
"	70	--	"	Slip Base 4 bolts at corners of R	" (Double Two Hinges)	"			"	"	"	"	"	2.64		8472	254		"	22	*
32 TTI	1	12/74	W12x45	Slip Base 4 bolts	Notched Steel Fuse Plate	14.3	2' x 2' x 8.5' deep	2-3/8"Ø bolts into wind beams	12' x 24' x 5/8" Plywood	8.5	2360	28.8 (19.6)	0	7.23	6.62	2107	530	485	30	13/12	12
"	2	"	"	"	"	"	"	"	"	"	4500	60.1 (41.0)	0	6.30	5.47	8404	880	765	252	50/44	15
33 ENSCO	801A	11/78	W8x20	Slip Base 4 bolts	2 Fuse Plates 1-Slots 1-Not	10.0	Large Concrete Found.	1/2"Ø bolts Alum. clips	10' x 15' x 5/8" Plywood	7.0	2275	86.5 (59.0)	0	7.30	8.05	6114	516	569	265	43/47	16
"	802	12/78	"	"	"	"	"	"	"	"	2445	33.7 (23.0)	0	5.19	4.20	2561	394	319	43	12/10	12
"	803	2/79	"	"	"	"	"	"	"	"			0				652	467			18

*No Data

TABLE F4

DATA SUMMARY OF CRASH TESTS ON BREAKAWAY SUPPORTS FOR DUAL-LEGGED ROADSIDE SIGNS

TEST I.D.			BREAKAWAY SUPPORT					SIGN PANEL			VEHICLE			TEST RESULTS							
REF. NO.	TEST NO.	TEST DATE	TYPE	BREAKAWAY MODIFICATION	HINGE BELOW SIGN PANEL	SPACING (ft.)	FOOTING	CONNECTION TO SUPPORT	SIZE	GRND. CLR. (ft.)	TEST INER. MASS (lbs.)	IMPACT VELOC. FPS (MPH)	IMPACT ANGLE (Deg)	OCCUPANT/ COMPARTMENT IMPACT VELOCITY (FPS) FILM	OCCUPANT/ COMPARTMENT IMPACT VELOCITY (FPS) ACCEL.	INITIAL MOMENTUM MV (lb-sec)	CHANGE OF MOMENTUM ΔMV (lb-sec) FILM	CHANGE OF MOMENTUM ΔMV (lb-sec) ACCEL.	INIT VEH KINET. ENER. KE (ft-K)	CHANGE IN KIN. ENER ΔKE (ft-K)	MAX FRONT VEH CRUSH (in)
34 Swe-den	F6	1978	2.36"Ø One piece ⊓ frame	None	None	6.6	Concrete 5' x 2'	Bolted Clips	6.6' x 6.6'	3.3	Bogie 2205	45.6 (31.1)	0	15.5		3120	1747		71	57	No Data
"	F7	"	"	"	"	"	"	"	"	"	"	"	0	18.2		"	"		"	"	"
"	F8	"	4.5"Ø One piece ⊓ frame	"	"	"	"	"	"	"	"	"	0	13.7		"	998		"	38	"
"	F9	"	"	Slip Base 3 bolts	"	"	"	"	"	"	"	"	0	5.47		"	374		"	55	"
"	F10	"	3.15" x 3.15" Posts & 2.36" x 1.57" Braces	None	"	"	"	Bolted	9.8' x 9.8'	7.2	"	63.8 (43.5)	0	18.2		4368	1872		139	94	"
"	F11	"	2.37"Ø Truss Posts & 1.33"Ø Lattice Bars	None	"	"	"	"	"	"	"	"	0	9.11		4368	936		"	53	"
"	F12	"	IPE 16 Wide flange	Slip Base 4 bolts	Notched Steel Fuse Plate	"	"	"	"	"	"	45.6 (31.1)	0	6.38		3120	437		71	19	"
"	F13	"	IPE 18 Wide Flange	"	"	"	"	"	18' x 8.2'	"	"	63.8 (43.5)	0	5.47		4368	374		139	23	"
"	F14	"	IPE 22 Wide flange (3 sup-ports)	"	"	"	"	"	13.1' x 14.4'	"	"	"	0	7.29		4368	499		"	30	"

TABLE F5

DATA SUMMARY OF CRASH TESTS ON BREAKAWAY SUPPORTS FOR DUAL-LEGGED ROADSIDE SIGNS

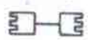
TEST I.D.			BREAKAWAY SUPPORT					SIGN PANEL			VEHICLE			TEST RESULTS							
REF. NO.	TEST NO.	TEST DATE	TYPE	BREAKAWAY MODIFICATION	HINGE BELOW SIGN PANEL	SPACING (ft.)	FOOTING	CONNECTION TO SUPPORT	SIZE	GRND. CLR. (ft.)	TEST INER MASS (lbs.)	IMPACT VELOC. FPS (MPH)	IMPACT ANGLE (Deg)	OCCUPANT/COMPARTMENT IMPACT VELOCITY (FPS) FILM	OCCUPANT/COMPARTMENT IMPACT VELOCITY (FPS) ACCEL.	INITIAL MOMENTUM MV (lb-sec)	CHANGE OF MOMENTUM ΔMV (lb-sec) FILM	CHANGE OF MOMENTUM ΔMV (lb-sec) ACCEL.	INIT VEH. KINET ENER. KE (ft-K)	CHANGE IN KIN ENER ΔKE (ft-K)	MAX FRONT VEH CRUSH (in)
33 ENSCO	1001	4/79	W12x45	Slip Base 4 bolts 	2 Steel Fuse Plates 1-Slots 1-Not	15.0	Large Concrete Found.	Bolts, Alum. Clips	12'x 24' x 5/8" Plywood	8.5	2425	27.9 (19.0)	0	10.5	9.43	2099	790	710	29	16/18	13.5
"	1002	"	"	"	"	"	"	"	"	"	2360	29.7 (20.3)	0	29.7	29.7	2177	2177	2177	32	32	17.5
"	1003	"	"	"	"	"	"	"	"	"	"	29.4 (20.0)	0	8.54	9.37	2155	626	687	32	16/15	17
"	1004	"	"	"	"	"	"	"	"	"	2260	30.7 (20.9)	15	9.35	9.97	2155	656	700	33	17/18	
"	1005	"	"	"	"	"	"	"	"	"	"	32.9 (22.4)	30	10.0	9.65	2309	704	677	38	4/3	
"	1006	5/79	"	"	Balanced Hinge, Pivot & Shear Pins	"	"	Shear Pin	"	"	"	31.3 (21.3)	0	10.42	9.93	2197	731	697	34	4/3	17
"	1007	"	"	"	"		"	Alum. Clips	"	"	"	28.4 (19.4)	0	10.0	9.47	1993	702	665	28	4/3	17
"	1008	"	"	"	2 Steel Fuse Plates 1-Slots 1-Not	"	"	"	"	"	2478	85.1 (58.0)	0	8.15	8.73	6546	627	672	278	54/51	15
"	1009	6/79	"	"	"	"	"	"	"	"	1516	89.5 (61.0)	0	10.8	7.84	4212	508	369	188	32/43	15
"	1010	"	"	"	"	"	"	"	"	"	1617	30.2 (20.6)	0		9.88	1517		496	22	11	10
"	1011	"	"	"	"	"	"	"	"	"	1738	28.9 (19.7)	0	14.0	11.4	1560	756	614	23	14	12

TABLE F6

DATA SUMMARY OF CRASH TESTS ON BREAKAWAY SUPPORTS FOR DUAL-LEGGED ROADSIDE SIGNS

TEST I.D.			BREAKAWAY SUPPORT					SIGN PANEL			VEHICLE			TEST RESULTS							
REF NO	TEST NO	TEST DATE	TYPE	BREAKAWAY MODIFICATION	HINGE BELOW SIGN PANEL	SPACING (ft.)	FOOTING	CONNECTION TO SUPPORT	SIZE	GRND CLR. (ft)	TEST INER MASS (lbs)	IMPACT VELOC. FPS (MPH)	IMPACT ANGLE (Deg)	OCCUPANT/ COMPARTMENT IMPACT VELOCITY (FPS) FILM	OCCUPANT/ COMPARTMENT IMPACT VELOCITY (FPS) ACCEL.	INITIAL MOMENTUM MV (lb-sec)	CHANGE OF MOMENTUM ΔMV (lb-sec) FILM	CHANGE OF MOMENTUM ΔMV (lb-sec) ACCEL.	INIT VEH KINET. ENER. KE (ft-K)	CHANGE IN KIN. ENER. ΔKE (ft-K)	MAX FRONT VEH CRUSH (in)
35 Germany	1	1980	2-2.37"Ø Truss Posts 21.65" apart w/ 1.06"Ø Lattice Bars	None	None	5.9	Steel plates /concrete slab	Alum. "Clamshell Rings"	6.56' x 9.84'	3.3	1929	82.9 (56.5)	0	13.7		4968	1037		206	77	No Data
"	2	"	2-6.49"Ø Posts	"	"	"	"	Clamp Rings	"	"	"	79.3 (54.1)	0	50.1		4760	3003		188	163	"
"	3	"	Same as Test 1	"	"	"	"	Alum. "Clamshell Rings"	"	"	"	54.7 (37.3)	0	33.7		3276	2020		90	76	"
"	4	"	2-2.36"Ø Truss Posts 39.37" apart w/1.33"Ø Lattice Bars	"	"	"	"	"	13.1' x 9.84'	"	"	33.3 (22.7)	0	33.3		2020	2020		34	34	"
"	5	"	"	"	"	"	"	"	"	4.9	"	86.6 (59.0)	0	41.0		5187	2457		225	162	"
"	6	"	2-2.99"Ø Posts	"	"	"	"	"	2.69' x 10.4'	3.3	"	39.2 (26.7)	0			2348			46		"
"	7	"	2-7.63"Ø Posts (masts)	"	"	"	"	"	13.1' x 9.84'	"	"	36.5 (24.9)	0	36.5		2184	2184		40	40	"
"	8	"	2-4.76"Ø Posts	"	"	"	"	Steel "Clamshell Rings"	6.56' x 9.84'	"	"	95.7 (65.2)	0			5733			274		"
"	9	"	Same as Test 1	"	"	"	"	Alum. "Clamshell Rings"	"	4.9	"	90.2 (61.5)	0	17.3		5405	1037		244	85	"
"	10	"	2-3.00"Ø Truss Posts 25.59" apart w/1.06"Ø Lattice Bars	"	"	"	"	"	13.1' x 9.84'	"	"	38.3 (26.1)	0	38.3		2293	2293		44	44	"
"	11	"	"	"	"	"	"	"	"	"	"	104.8 (71.5)	0	31.9		6279	1911		329	170	"
"	12	"	2-2.38"Ø Truss Posts 39.37" apart w/1.06"Ø Lattice Bars	"	"	"	"	"	"	"	"	84.8 (57.8)	0	15.5		5078	929		215	144	"

TABLE F7