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Full-Scale Side Impact Testing

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16. Abstract

This report describes the results of recent research conducted by the Federal Highway Administration (FHWA) on occupant injury due to single vehicle side impacts into roadside objects. Injuries and fatalities due to side impacts on our nation's highways are discussed, followed by a review of historic testing conducted by FHWA. Results from current research are then presented and conclusions stated. Recommendations are provided with regard to the strengthening and/or provision for energy absorption for vehicle sides, and with regard to test and evaluation criteria for future side impact research.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
in	inches	25.4	millimetres	mm
ft	feet	0.305	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km

AREA

Symbol	When You Know	Multiply By	To Find	Symbol
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.093	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometres squared	km^2

VOLUME

Symbol	When You Know	Multiply By	To Find	Symbol
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.028	metres cubed	m^3
yd^3	cubic yards	0.765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

MASS

Symbol	When You Know	Multiply By	To Find	Symbol
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°F	Fahrenheit temperature	5(F-32)/9	Celcius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi

AREA

Symbol	When You Know	Multiply By	To Find	Symbol
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometres squared	0.386	square miles	mi^2

VOLUME

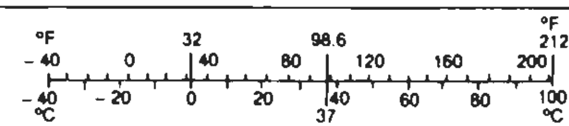
Symbol	When You Know	Multiply By	To Find	Symbol
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3

MASS

Symbol	When You Know	Multiply By	To Find	Symbol
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F



* SI is the symbol for the International System of Measurement

These factors conform to the requirement of FHWA Order 5190.1A.

(Revised April 1989)

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INTRODUCTION

This report documents the findings of a side impact research program conducted at the Federal Outdoor Impact Laboratory (FOIL).[1] The program consisted of a series of eight full-scale side impact tests using minisized sedans impacting two designs of luminaire supports. Both onboard electronic vehicle data and dummy data were collected for use in evaluation of the tests.

1. OBJECTIVE

The objective of this program was to investigate the impact severity of minicompact sedans during low-speed broadside collisions with breakaway luminaire supports. Determination of the types of occupant injury occurring during such collisions and injury causation mechanisms were principal objectives. The development of preliminary test evaluation criteria linking injury potential to vehicle rather than dummy results was another important objective.

2. REVIEW OF PRIOR RESEARCH

Side impact research is currently being pursued by both The Federal Highway Admnistration (FHWA) and the National Highway Traffic Safety Administration (NHTSA). NHTSA research primarily focuses on vehicle to vehicle collisions, whereas FHWA research focuses on vehicle collisions with fixed roadside objects and roadside features. To date, FHWA side impact research has focused on breakaway luminaire supports and other narrow fixed objects. The following discussion provides a review of past FHWA research related to side impact collisions and incorporates results from four NHTSA funded crash tests into a pole-like object.

a. Early Tests

Some early tests into a rigid instrumented pole were sponsored by NHTSA and conducted during the late 1984 time frame.[2-6] Four tests were conducted involving Volkswagen Rabbits weighing approximately 2600 lb (1180 kg), including dummies and cargo, "crabbed" at an angle of 45° and impacting at speeds of 20 mi/h (32.3 m/s) and 25 mi/h (11.2 m/s). These tests focused on intrusion during side impact and on possible vehicle structural and interior design changes to minimize occupant injury. Appurtenance design improvements to minimize injury were not considered.

Several impact tests have been conducted under FHWA sponsored research programs in the past. In one early test, conducted in 1976, a 1971 Chevrolet Vega weighing 2670 lb (1218 kg), with no dummy involved and including weight of side impact casters, impacted broadside into a breakaway slipbase luminaire support at 22 mi/h (9.8 m/s).[7,8] To perform this test, a set of large casters was fitted to the outboard portion of the vehicle and actually carried the vehicle. Just prior to impact, the casters were raised, allowing the vehicle to skid into the luminaire support. This concept worked well, but the casters made up a large portion of the vehicle test weight of approximately 400 lb (181.6 kg) due to the size of the wheels and their activation hardware.

Two additional early side impact tests were conducted in 1982, one impacting broadside at the occupant shoulder location and one impacting at 45° aligned with the vehicle A-pillar.[9] These tests were conducted to determine, in a preliminary manner, the magnitude of the side impact problem when narrow pole-like objects were involved in roadside collisions. The tests used Volkswagen Rabbits weighing 1850 lb (839.9 kg), exclusive of the side impact dummy, as test vehicles and a heavy (1000-lb)(454-kg) breakaway slipbase "surrogate" pole as the test article. In the broadside test, the vehicle impacted the pole at a point aligned with the instrumented dummy at 30.4 mi/h (13.6 m/s). The vehicle broke the pole away but the dummy incurred a severe to fatal injury due to head and thoracic trauma. The second test involved the use of a similar vehicle impacting the pole at 45° and 30 mi/h (13.4 m/s) at the vehicle A-pillar location. This test resulted in fairly minor impact severities with low predictors of injury.

b. Preliminary FOIL Tests

Following completion, in 1985, of the side impact test capability at the FOIL research and learning center, a series of eight full-scale tests was conducted to determine side crush characteristics of four different vehicles, as well as their safety performance during side impact collisions with slipbase luminaire supports.[9] Three of the vehicles configured for testing weighed 1850 lb (840 kg), exclusive of the side impact dummy, while the fourth, a Dodge St. Regis, weighed 4500 lb (2043 kg). A list of tests conducted and vehicles used is presented in table 1.

Table 1. Tests conducted during FOIL development.

Test Number	Vehicle	Structure	Speed
1469-SI-1-85	Honda Civic	Rigid Pole	25 mi/h
1469-SI-2-85	VW Rabbit	Rigid Pole	25 mi/h
1469-SI-3-85	Dodge Colt	Rigid Pole	25 mi/h
1469-SI-4-85	Honda Civic	Lum Support	30 mi/h
1469-SI-5-85	VW Rabbit	Lum Support	30 mi/h
1469-SI-6-85	Dodge Colt	Lum Support	30 mi/h
1469-SI-7-85	Dodge St Regis	Lum Support	30 mi/h
1469-SI-8-85	Dodge St Regis	Rigid Pole	10 mi/h

1 m/h = 0.447 m/s

(1). Rigid Pole Tests

The four rigid-pole tests involved impacting the vehicles broadside into a rigid instrumented pole at a point on the vehicle near the occupant's shoulder. However, no dummies were used for these tests. The impact forces were measured with the instrumented rigid pole. Additionally, vehicle responses were measured with accelerometers and rate gyros located at the vehicle center of gravity.

The instrumented pole collected data for the local forces acting on the sill structure, door, and the roof. These forces were summed, and the total force acting on the vehicle was determined. Figure 1 presents the force-displacement characteristics for all four vehicles. Test SI #8 was conducted with a full-sized vehicle with unknown stiffness. To prevent possible damage to the instrumented rigid pole, this test was conducted at a much lower speed. Deflection data for all vehicles were determined from high-speed film because the lateral accelerometer data, from the vehicle center of gravity, was biased due to contamination from vehicle yaw motion. As depicted in figure 1, the side stiffness of the lighter weight vehicles when tested at 25 mi/h (11.1 m/s) is somewhat similar regarding both peak force (15,300 to 17,800 lb) (6946 to 8081 kg) and maximum dynamic deflection (23.7 to 29.8 in) (602 to 757 mm).

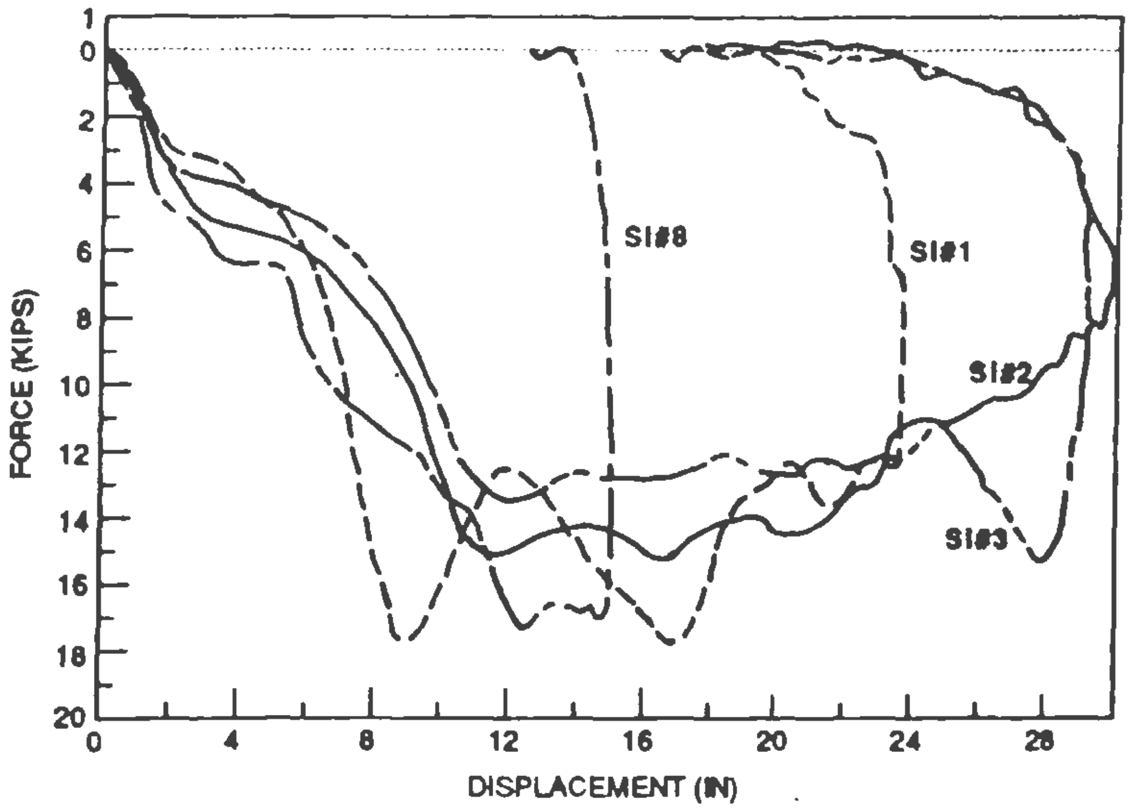


Figure 1. Side impact force deflection characteristics for four vehicles.

(2). Luminaire Tests

The same four vehicles were impacted into a breakaway slipbase luminaire support. This device was selected for testing because it was known to be one of the safer breakaway devices currently installed on our Nation's roadways. Previous tests produced vehicle velocity changes ranging from a low of approximately 8 ft/s (2.44 m/s) to a high approaching 12 ft/s (3.7 m/s) when tested under controlled frontal impact conditions at speeds of 60 and 20 mi/h (26.8 and 8.9 m/s), respectively. In all cases, the luminaire support broke away. However, for the lighter weight cars, prior to actuation of the support and rotation out of the path of the oncoming car, significant occupant compartment intrusion occurred resulting in severe head and thorax trauma. Table 2 provides details of some of the major observations from these tests.

Table 2. Results from breakaway tests.

Test	Impact Speed	Vehicle Delta V	Static Crush	Serious Injury or Fatality
SI #4	29.2 mi/h	15.8 ft/s	10.5 in	Yes
SI #5	28.4 mi/h	9.1 ft/s	11.1 in	Yes
SI #6	30.1 mi/h	9.8 ft/s	17.3 in	Yes
SI #7	31.8 mi/h	5.0 ft/s	8.5 in	Possible

1 mi/h = 0.447 m/s   1 in = 25.4 mm   1 ft/s = 0.3048 m/s

TEST PROGRAM

1. TEST MATRIX

The test matrix, shown in table 3 for this series of side impact tests conducted at the FOIL, consisted of eight tests. All tests were conducted with the vehicle aligned broadside with the line of travel, impacting at a speed of 30 mi/h (13.4 m/s). These test conditions, as well as the selection of a lightweight minisize vehicle were chosen based upon a preliminary review of several accident databases and a desire to select test conditions which lie somewhere between the median and the worst case regarding severity.[10] Two different types of luminaire supports commonly used on our Nation's roadways, slipbase and transformer base supports, were impacted.

Table 3. Test matrix for side impact test series.

Test Number	Angle	Impact Location	Test Article
1	90	0	Slipbase
2	90	0	Transformer base
3	90	0	Slipbase
4	90	0	Slipbase
5	90	-12 in (near B-pillar)	Slipbase
6	90	+12 in (near door center)	Slipbase
7	90	+24 in (near A-pillar)	Slipbase
8	90	0	Slipbase

90 = Broadside on Driver's Door
0 = Centered on Occupant
\+ = Forward of Occupant
\- = Rearward of Occupant

1 in = 25.4 mm

2. FOIL SIDE IMPACT SYSTEM

For this test series, the FOIL was set up in the side impact configuration. Basically, a dual rail guidance and delivery system is employed during side impact testing with the majority of the vehicle weight supported by the main rail and the remainder supported by an auxiliary outrigger rail. Just prior to impact, the dual rail system terminates with the result that as the vehicle approaches the test article, it travels off the end of the rail system, lands on the ground, and skids sideways on its tires until impact. This vehicle delivery system is depicted in figure 2. Vehicle acceleration is supplied using the FOIL's drop weight propulsion system.[1] Various impact locations on the vehicle are obtained by moving the luminaire support laterally across the test runway.

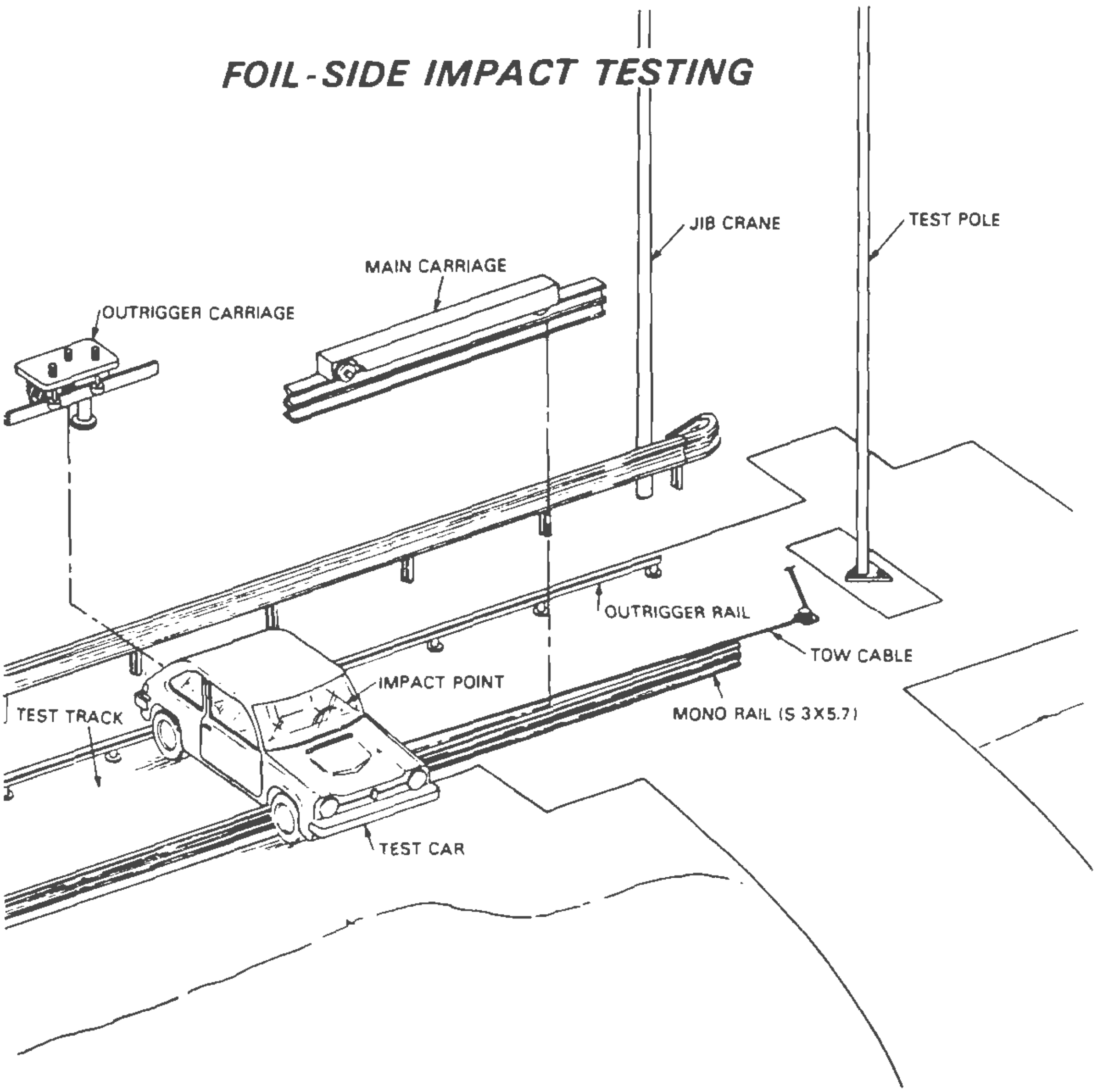


Figure 2. FOIL side impact layout.

APPURTENANCE DESCRIPTION

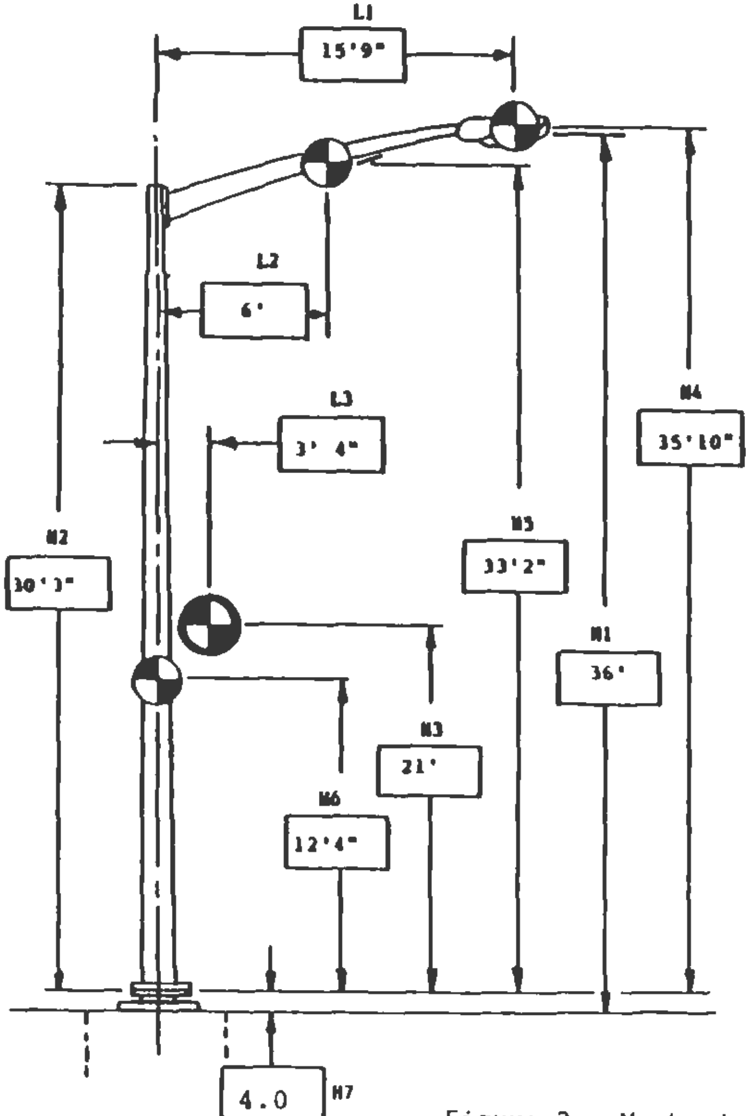
The physical properties of the breakaway luminaire supports are contained in table 4. The slipbase luminaire support incorporated a triangular three bolt slipbase which is based on a design of the California Type 31 support. The slipbase was positioned so impact would occur against an edge which had two bolts aligned. The luminaire support had a mast arm attached during this test as well as a steel weight attached to the end of the arm, simulating the luminaire. The slipbase was clamped together with three bolts which were tightened to 14 kips (6356 kg) for tests 1,3,4,5,6 and 7, while during test 8 they were loose. For test 2, the only transformer base test, the base was clamped to the base plate with studs and nuts which were tightened to 200 ft-lb (888 N·m) torque just prior to the test. Dimensional properties of slipbase and transformer base poles tested are shown in figures 3 and 4. Photographs of both types of base are shown in figures 5 and 6.

Table 4. Properties of test base & pole.

Type	Slipbase	Transformer Base
Material	Steel	Steel
Weight	416 lb	386 lb
Height, c.g.:	21 ft	23 ft, 10 in
Top diameter:	3.5 in	6 in
Bottom diameter	7.5 in	8 in
Mast Arm Length:	15 ft, 9 in	14 ft, 9 in
Luminaire Height:	35 ft, 10 in	39 ft
Luminaire Weight:	51 lb	51 lb
Base Type:	California Type 31 slipbase	Transformer
Number of bolts:	3	4
Size:	1 in diameter	1 in diameter
Type:	Instrumented to measure bolt load	Galvanized studs
Bolt Clamp Load:	14 kips tension (tests 1,3,4,5,6,7,) 0 kips tension (test 8)	200 ft-lb (test 2)

1 lb = 0.454 kg 1 in = 25.4 mm 1 ft = 0.305 m

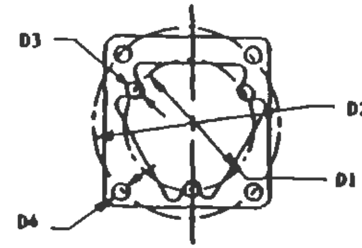
FHWA FOIL TEST FACILITY



LUMINAIRE SUPPORT PARAMETERS
SLIP BASE WITH TRUSS MAST ARM

Manufacturer: Ameron Part No: ____

Ref. FOIL Tests: ____



WEIGHTS (LB)

Pole: 275 (W1)

Mast Arm: 90 (W2)

Luminaire: 51 (W3)

Total Assy: 416 (WT)

MEASURED LENGTHS (IN)

Mounting Height: 36' (H1)

Pole Height: 30'3" (H2)

Pole CG Height: 12'4" (H6)

Mast Arm CG Ht: 33'2" (H5)

Mast Arm CG Offset: 6' (L2)

Lumin CG Ht: 35'10" (H4)

Lumin CG Offset: 15'9" (L1)

Stub Ht: 4.0 (H7)

SLIP BASE PARAMETERS

No. Slip Bolts: 3

Slip BC Dia (in): 14 (D1)

Dia of Slip Bolts (in) 1 (D3)

No. Foundation Bolts: 3

Found BC Dia (in): 14 (D2)

Dia Found Bolt (in): 1 (D4)

S Bolt Clamp Force (lb): Varies

Keeper Plate, Y/N: Y

Slip Base Thick (in): 1

POLE PARAMETERS

Base Dia (in): 7.5

Tip Dia (in): 3.5

Wall Thick (in): .125

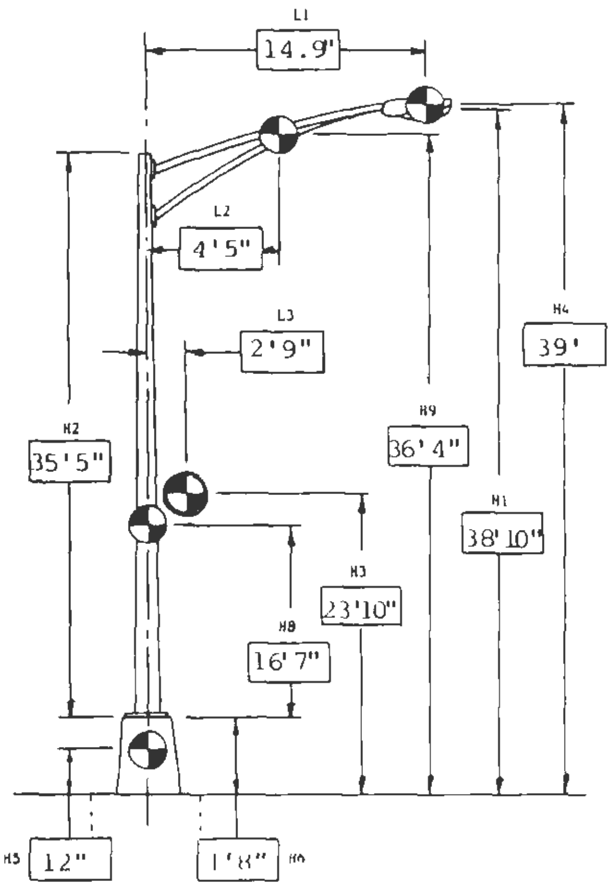
Material: Steel

TOTAL ASSEMBLY CG LOCATION (IN)

Total Assy CG Ht = 21' (H3)

Total Assy CG Offset = 3'4" (L3)

Figure 3. Mechanical properties of slipbase pole.



LUMINAIRE SUPPORT PARAMETERS
TRANSFORMER BASE AND TRUSS MAST

Manufacturer: Union Metal   Part No: -

Ref. FOIL Tests: 879096

WEIGHTS (LB)

Pole: 252 (W1)

T-Base: 28 (W2)

Mast Arm: 55 lbs (W3)

Luminaire: 51 (W4)

Total Assy: 386 (WT)

MEASURED LENGTH

Mounting Height: 38'10" (H1)

Pole Height: 35'5" (H2)

Pole CG Height: 16'7" (H8)

Mast Arm CG Ht: 36'4" (H9)

Mast Arm CG Offset: 4'5" (L2)

Lum CG Ht: 39' (H4)

Lum CG Offset: 14'9" (L1)

T-Base Height: 1'8" (H6)

POLE PARAMETERS

Base Dia (in): 8"

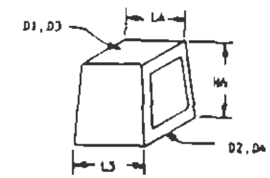
Tip Dia (in): 6"

B Plate Thick (in): 1 (H7)

TOTAL ASSEMBLY CG LOCATION

Total Assy CG Ht: 23'10" (H3)

Total Assy CG Offset: 2'9" (L3)



TRANSFORMER BASE PARAMETERS (IN)

Door Pos - F, R, LS, RS: R

T-Base CG Ht: 12" (H5)

Dia Pole Bolts: 1" (D3)

Pole BC Dia: 12" (D1)

Top TB Width: 13" (L4)

Found BC Dia: 15" (D2)

Dia Found Bolt: 1" (D4)

Lower TB Width: 15" (L5)

Wall Thick (in): .25

Material: AL

B Plate Width (in): 12"

Figure 4. Mechanical properties of transformer base pole.

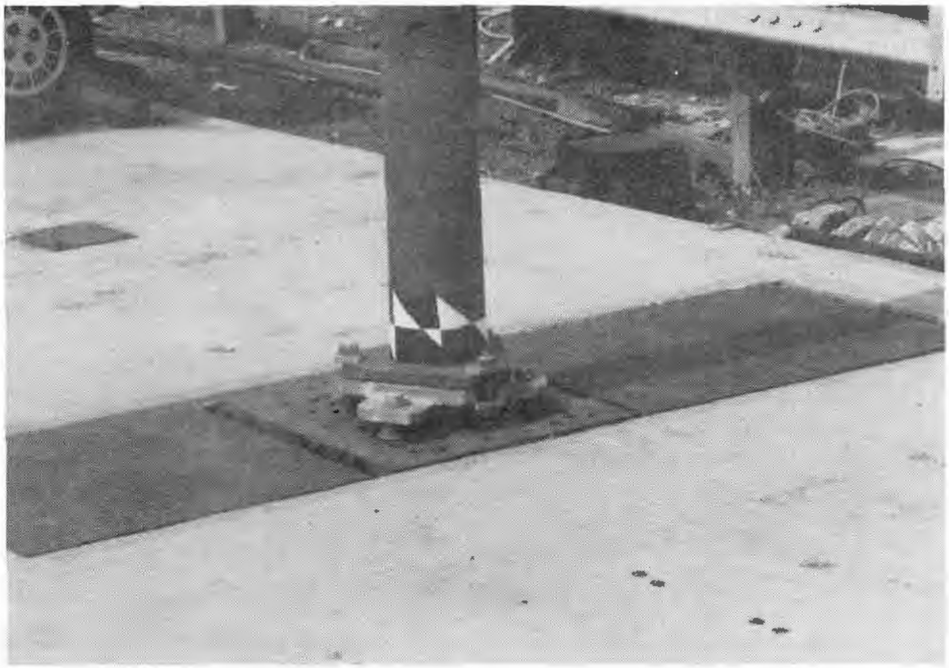


Figure 5. Slipbase luminaire support.

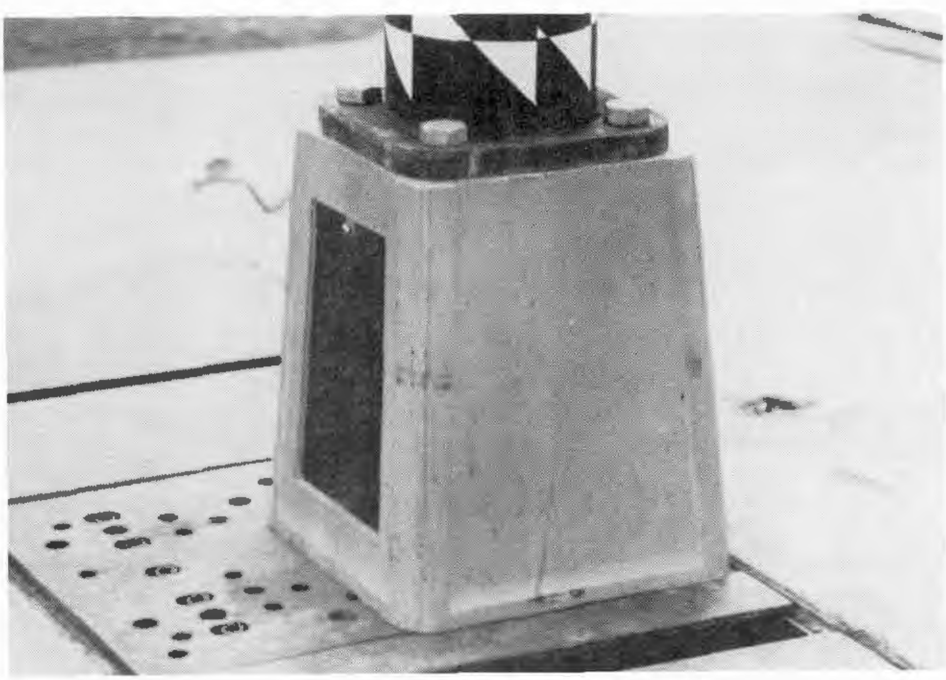


Figure 6. Transformer base luminaire support.

VEHICLE DESCRIPTION

The test vehicles were 1980 and 1981 Plymouth Champs and Dodge Colts. The test inertial vehicle weight, without the dummy, and the gross static weight, including the dummy, along with the year, make, and model are presented in table 5. The longitudinal center of gravity of each vehicle without the occupant was located approximately 32 in (813 mm) behind the centerline of the front axle. The inertial data of each vehicle in its as-delivered and as-tested configurations are given in table 6. Inertial data were measured using the FOIL Inertial Measuring Device (IMD).

Each vehicle was equipped with a triaxial accelerometer package mounted on the lateral centerline of the vehicle at the longitudinal location of the center of gravity. One rate gyro was also installed to the same mounting block to measure yaw rate. Vehicles were also equipped with a contact switch mounted on the left door to permit vehicle and occupant data to be measured relative to the time of impact. A second triaxial accelerometer package was attached to the floor board located in front of the front right hand seat. Two gyros were also attached to this block to measure yaw and roll rates. Table 7 lists the data channel assignments for the tests. The typical test vehicle is shown in figure 7.

Table 5. Vehicle data.

Test Number	SI#1	SI#2	SI#3	SI#4	SI#5	SI#6	SI#7	SI#8
Test Date	7/87	7/87	10/87	10/87	10/87	4/88	5/88	6/88
Vehicle	Plymouth	Dodge	Dodge	Plymouth	Plymouth	Plymouth	Dodge	Plymouth
Model	Champ	Colt	Colt	Champ	Champ	Champ	Colt	Champ
Year	1980	1980	1981	1980	1981	1980	1980	1981
$Weight_I$ (lb)	1849	1850	1847	1850	1850	1850	1847	1848
$Weight_G$ (lb)	2009	2010	2007	2010	2010	2010	2008	2008

Note: $Weight_I$ is test inertial weight,
$Weight_G$ is gross vehicle weight.

1 lb = 0.454 kg

Table 6. Vehicle inertial data.

Test Number	SI#1	SI#2	SI#3	SI#4	SI#5	SI#6	SI#7	SI#8
Inertial Data, as delivered								
Xcg (in)	-33	-32	-32	-32	-32	-32	-32	-32
Ycg (in)	0	0	0	0	0	0	0	0
Zcg (in)	21.4	20.1	20.0	20.6	21.4	19.3	19.8	19.8
Roll (slug-ft^2)	190	208	195	197	190	195	212	197
Pitch (slug-ft^2)	828	802	764	795	828	755	901	794
Yaw (slug-ft^2)	863	872	856	869	863	823	913	875
Inertial Data, as tested								
Xcg (in)	-33	-32	-32	-32	-32	-32	-32	-32
Ycg (in)	0	0	0	0	0	0	0	0
Zcg (in)	20.9	20.4	20.0	20.7	20.9	19.0	20.2	19.4
Roll (slug-ft^2	)205	205	189	205	205	201	195	217
Pitch (slug-ft^2)	742	778	769	793	743	704	762	823
Yaw (slug-ft^2)	838	845	842	852	838	823	843	846

Note: Xcg measured from front wheel centerline
Zcg measured from ground
Roll, Pitch and Yaw measured about cg

1 in = 25.4 mm   1 ft = 0.305 m

Table 7. Vehicle instrumentation.

Channel No.	Channel Description
19	Vehicle X Accel
20	Vehicle Y Accel
21	Vehicle Z Accel
22	Impact Switch
23	Vehicle Yaw Rate
24	Vehicle Roll Rate

Figure 7. Typical test vehicle.

DUMMY DESCRIPTION

A special dummy was used during this test program to measure occupant injury. The dummy was a Part 572 fitted with a special thorax which was designed especially for side impacts. The Side Impact Dummy (SID) was seated in the driver's seat for each test. The dummy was unrestrained except for a light string which held the dummy from sliding over during the vehicle acceleration phase. The dummy was equipped with a set of up to 18 accelerometers. In most tests, the accelerometer locations described in table 8 were used. Each of the instrumented ribs contained two accelerometers in the primary axis.

Table 8. Typical dummy data.

Channel No.	Channel Description
1	Head X
2	Head Y
3	Head Z
4	Upper Spine, T01XG1
5	Upper Spine, T01YG1
6	Upper Spine, T01ZG1
7	Lower Spine, T12XG1
8	Lower Spine, T12YG1
9	Lower Spine, T12ZG1
10	Left Upper Rib, LURYG1
11	Left Upper Rib, LURYGA
12	Left Lower Rib, LLRYG1
13	Left Lower Rib, LLRYGA
14	Upper Sternum, USTXG1
15	Lower Sternum, LSTXG1
16	Pelvis X
17	Pelvis Y
18	Pelvis Z

DATA ANALYSIS METHODOLOGY

Data from vehicle and dummy transducers were recorded on analog tape and subsequently digitized after completion of each test. Digitization was accomplished using a sampling rate of 8000 samples/s in conjunction with an SAE Class 1000 low pass filter (linear one-to-one output up to 1000 Hz, with the dB down 3 point at a frequency of 1650 Hz). The resultant digitized data were stored on digital data tape for subsequent processing.

Film documentation of each test, obtained from multiple high-speed cameras operating at minimum filming rates of 500 fps, was recorded on 100-ft (30.5-m) rolls of individual high-speed film. Subsequently, this documentation was developed, edited, combined into a single film record and copied for further data processing.

1. VEHICLE DATA ANALYSIS METHODOLOGY

Analysis of vehicle data can be separated into three distinct categories: vehicle speed calculations (impact, speed change, and exit speed), occupant impact velocity and acceleration determinations ("Flail Space" velocity change and "Ridedown" acceleration from NCHRP 230), and static crush measurements.

a. Vehicle Speed Calculations

To determine the impact speed of the test vehicle, redundant high-speed cameras (filming at a constant rate of 500 fps), located perpendicular to the vehicle's motion were employed. A series of frames from each film record immediately prior to impact were analyzed, frame by frame, using a film motion analyzer coupled with an IBM PC-AT computer to determine the displacements of the vehicle and the associated time intervals. Subsequently, a linear regression analysis was performed on the resulting displacement-time data to determine the line which best fit the data. The impact speed was determined from the slope of this line. Because redundant cameras were used to measure the displacement of the vehicle immediately prior to impact, the speeds calculated from the cameras were averaged to establish the reported impact speed.

To determine the vehicle's speed change during the impact event, the data obtained from the accelerometers located at the vehicle center of gravity (X, Y and Z) were filtered using an SAE Class 60 low pass filter (one-to-one output up to 60 Hz and a 3 dB point of 100 Hz). The resulting digitized acceleration data in the lateral direction (Y) were subsequently processed (by performing a simple integration) to determine the area under the acceleration curve (that is, the speed change) between impact and loss of contact with the support.

To compute the exit speed of the test vehicle after breakaway of the support and subsequent loss of contact, the speed change of the vehicle (calculated from Y acceleration data) was subtracted from the impact speed (determined from film analysis).

b. Occupant Impact Velocity and Acceleration Determinations

To determine the lateral impact velocity of a theoretical unrestrained occupant against the occupant compartment interior ("Flail Space" velocity change) and the occupant's subsequent acceleration while in contact with the interior surface following the impact ("Ridedown" acceleration), the resulting lateral acceleration data (Y direction) after filtering with the SAE Class 180 low pass filter was used. These two quantities were determined in accordance with the procedures outlined in NCHRP Report No. 230.[11] As specified in Report No. 230, a 1-ft (.305-m) flail distance (between the occupant and the interior door surface) was used even though the actual distance in the test vehicles was somewhat less.

c. Static Crush Measurements

The vehicle static crush was measured using the NHTSA specified six-point measurement technique.[18] As prescribed by this technique, a set of L, C and D values were determined from each tested vehicle along with the maximum resultant (static) crush. As depicted in figure 8, the L value indicates the overall length of the damage. The D value gives the distance from the vehicle center of gravity to the center of damage, with a negative number indicating the damage is rearward of the center of gravity. The C values define the actual deformation as measured at six equally spaced places along the damaged area, with C1 being the rear most and C6 the front most. Since the C values do not always indicate the maximum crush, particularly when narrow roadside objects are involved, maximum static crush was also measured.

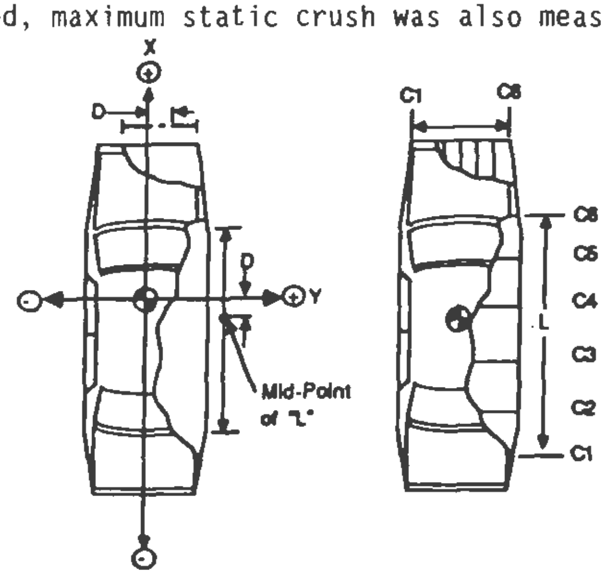


Figure 8. NHTSA crush guide.

2. SIDE IMPACT DUMMY (SID) DATA ANALYSIS METHODOLOGY

Analysis of dummy data can be separated into two distinct categories: Head Injury Criteria (HIC) calculations and thoracic injury determinations.

a. Head Injury Criteria (HIC) Calculations

The digitized data obtained from the three accelerometers located in the head of the occupant were combined to yield a resultant acceleration occurring during the impact event. The Head Injury Criteria (HIC) were determined in accordance with the procedures outlined in FMVSS 208.[13]

b. Thoracic Injury Determinations

The digitized data obtained from the lateral accelerometers (Y direction) mounted at the upper spine (T01Y), the lower spine (T12Y), the left upper rib (LURY) and the left lower rib (LLRY) locations within the thorax of the SID were again filtered, this time using the NHTSA developed Finite Impulse Response (FIR) filter.[15]

The Thoracic Trauma Index (TTI-86), a measure of the severity of the impact at the thorax, was computed using the following relationship:[15,16]

$$TTI\text{-}86 = 1.4*Age+0.5*[T12Y+MAX(LURY,LLRY)]*[Mass/165]$$

To obtain the required peak acceleration values for the left upper rib (LURY) or the left lower rib (LLRY) inputs to this equation, the two accelerometers at each respective location were averaged together. The TTI-86 was calculated for assumed occupant ages 0, 23, and 41. Age 23 is the median age for all injured occupants while age 41 is the median age for occupants receiving serious to fatal injuries.[2]

Once the TTI-86 values were determined for each age, the probability of injury was determined using the Injury Probability Scale proposed by NHTSA and depicted in figure 9.[15,16] This scale relates TTI-86 values to probabilities of injury for three injury severity classifications (AIS>3, AIS>4 and AIS>5) using the 1980 Abbreviated Injury Scale (AIS80).[19]

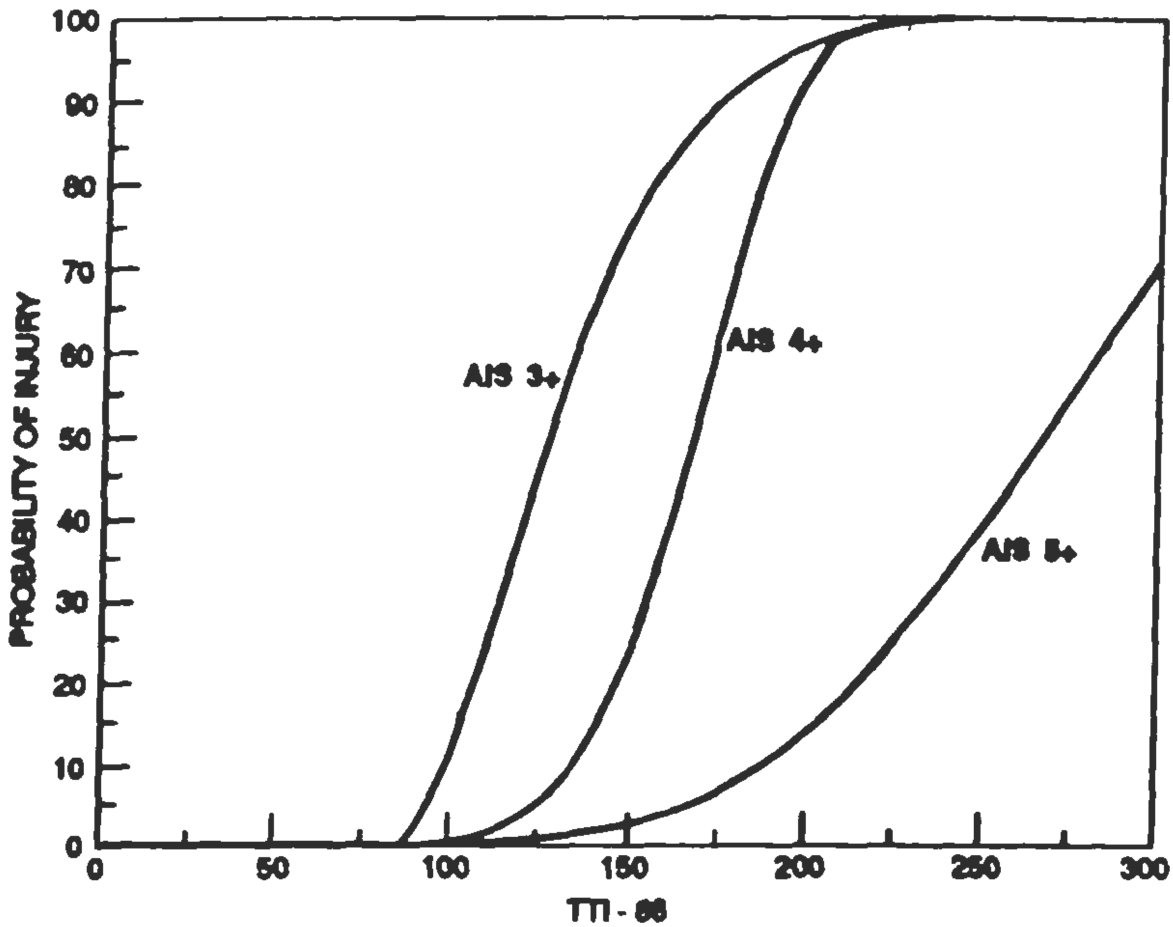


Figure 9. Thoracic injury probability scale.

TEST RESULTS

This section discusses each test property and measurement briefly. Brief results of each test are presented in the appendix. For detail results of each test the reader is referred to individual test reports which are available from NTIS (Report Nos. FHWA-RD-89-89 through FHWA-RD-89-97). All the tests are discussed together in this section by data type. Comparisons are made between the key findings.

1. VEHICLE DATA

Vehicle data are divided into three sections: vehicle speed data, NCHRP Report No. 230 Flail Space data, and vehicle crush data.

a. Vehicle Speed Data

The nominal impact speed for all tests was 30 mi/h (13.4 m/s). The speed was measured using high-speed film just prior to impact. Table 9 presents the vehicle speed data for each test. Also listed are speed reduction and the resulting exit speed. The latter are calculated using accelerometer data (in the direction of travel) and from a combination of high-speed film/accelerometer data.

Table 9. Vehicle speed results.

Test Number	SI #1	SI #2	SI #3	SI #4	SI #5	SI #6	SI #7	SI #8
Impact Speed(mi/h)	29.4	28.6	30.5	30.5	29.7	28.3	28.9	29.6
Speed Change (mi/h)	6.1	28.6	4.1	6.1	8.4	28.3	10.2	4.9
(ft/s)	(8.9)	(41.9)	(6.0)	(8.9)	(12.3)	(41.5)	(15.0)	(7.2)
Exit Speed (mi/h)	23.3	0.0	26.4	24.4	21.3	0.0	18.7	24.7

1 mi/h = 0.447 m/s 1 ft/s = 0.3048 m/s

b. NCHRP Report No. 230 Flail Space Data

Each test was evaluated to determine the flail space delta-V and ridedown acceleration of a theoretical occupant in accordance with the NCHRP 230 evaluation technique.[11] A 1-ft (0.305-m) flail distance was used for all tests. The results of this analysis are presented in table 10. The design goals for flail space velocity change and ridedown are 15 ft/s (4.572 m/s) and 15 g's for other types of highway appurtenances.

Table 10. Occupant impact lateral velocity and acceleration results.
(Flail space velocity change and ridedown acceleration)

Test Number	SI #1	SI #2	SI #3	SI #4	SI #5	SI #6	SI #7	SI #8
Velocity Change(ft/s)	9.7	26.7	6.1	9.1	11.4	28.8	14.7	7.1
Acceleration (g)	1.5	8.4	2.3	1.5	3.1	4.9	3.5	2.0

1 ft/s = 0.3048 m/s

No guidelines regarding recommended values of flail space velocity change and subsequent ridedown acceleration exist for side impacts into luminaire supports. However, NCHRP Report No. 230 does specify lateral recommended values for angled vehicle impacts into roadside barriers and into the sides of crash cushions. These recommended maximums are 15 ft/s (4.57 m/s) and 15 g's, respectively, for the theoretical occupant flail space velocity change and ridedown acceleration.

c. Vehicle Crush Data

The vehicle static crush was measured after each test using the NHTSA six-point technique.[18] A set of L, C and D values were measured for each test along with the maximum crush. The L value indicates the overall length of the damage. D gives the distance from the cg to the center of damage, with minus data indicating the center is behind the cg. The C values present the actual deformation as measured at six equally spaced places along the damaged area, with C1 being at the rear and C6 at the front. Since the C values do not always indicate the maximum crush, it is also indicated. These data are presented in table 11. Refer to figure 7 for definition of the values.

Table 11. Static crush results.

Test Number	SI #1	SI #2	SI #3	SI #4	SI #5	SI #6	SI #7	SI #8
Location	Crush Measurements (in)							
Maximum	10.0	26.0	9.5	10.0	13.0	36.0	7.7	7.5
C1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C2	1.0	6.5	2.5	1.5	2.0	5.0	4.0	2.5
C3	3.0	25.0	7.5	9.0	10.5	12.0	5.5	6.0
C4	8.8	4.0	7.2	6.2	4.0	10.0	7.5	5.0
C5	3.5	1.5	3.7	3.0	1.2	4.0	7.0	3.0
C6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
L	77.0	104.0	63.0	60.0	94.0	157.0	47.5	64.0
D	-22.5	-16.0	-16.0	-18.0	-23.0	-18.8	-9.8	-19.0

1 in = 25.4 mm

2. SIDE IMPACT DUMMY DATA

a. Head Injury Criteria Data

Head Injury Criteria (HIC) were calculated for all tests and are presented in table 12. The HIC values ranged from near 9000 to a low of 64. Generally those tests where the head impacted the pole directly generated the very high HIC values. Low HIC values resulted from pole impacts away from the dummy.

Table 12. Head injury criteria (HIC) values.

Test Number	SI #1	SI #2	SI #3	SI #4	SI #5	SI #6	SI #7	SI #8
HIC	1593	3385	8684	8026	64	2191	150	1996
Start (s)	0.02652	0.02553	0.01900	0.02075	0.01850	0.04513	0.04313	0.02613
Stop (s)	0.02940	0.03490	0.02200	0.02338	0.07663	0.06262	0.04688	0.02763
Delta t (s)	0.00288	0.00938	0.00300	0.00262	0.05813	0.01749	0.00375	0.00150

As previously stated, HIC values are calculated using the procedures outlined in FMVSS 208 for frontal impacts.[13] Because of the design of the dummy head, HIC values are only accurate when the impact is into the front of the head. Under frontal impact conditions, a HIC at or exceeding 1000 is considered to produce serious life threatening or fatal injury. Side impacts into the dummy head are less accurate and should be used for gross comparisons only. (Note: To aid in these comparisons, the same dummy was used for all tests, recalibrated as necessary.)

b. Occupant Severity Indices

The Chest Severity Index (CSI) algorithm and maximum resultant acceleration were used to determine severities for the T01 (upper spine), T12 (lower spine) and pelvis location. The data from each accelerometer in the three triaxial accelerometer packages were summed and processed in accordance with the procedures specified in FMVSS 208 and SAE Information Report J885a, respectively.[13,17] The results are presented in table 13.

Table 13. Occupant severity indices.

Test Number	SI #1	SI #2	SI #3	SI #4	SI #5	SI #6	SI #7	SI #8
Upper Spine (T01)								
CSI	1334	32862	1987	2244	506	190	46	230
Max g's	158	425	193	169	101	82	16	72
Time (s)	0.0247	0.0384	0.0216	0.0263	0.0256	0.0301	0.0587	0.0277
Lower Spine (T12)								
CSI	-	-	1819	2274	319	1017	34	124
Max g's	-	-	201	214	71	127	17	60
Time (s)	-	-	0.0198	0.0238	0.0264	0.0312	0.0377	0.0267
Pelvis								
CSI	244	2979	800	1469	214	2945	62	64
Max g's	71	199	157	198	44	158	43	25
Time (s)	0.0230	0.0210	0.0202	0.0233	0.0335	0.0264	0.0183	0.0293

The upper spine was selected to evaluate chest parameters since it was the closest transducer to the standard chest accelerometer used in the Part 572 frontal impact dummy. However, the upper spine, lower spine, and pelvis results should not be compared with the recommended limits of 1000 and 60 g's for the chest severity index and the maximum resultant chest acceleration, respectively, as specified in FMVSS 208. This is because none of these accelerometer packages are at the center of gravity of the upper thorax. They can be used, however, for gross comparisons between tests using the same side impact dummy.

c. Thoracic Injury

The lateral data from the upper spine (T01Y), lower spine (T12Y), upper rib (LURY) and lower rib (LLRY) were processed using the NHTSA FIR filter.[15] The peak values were then selected from each data trace and are presented in table 14.

Table 14. Lateral acceleration results (peak values).

Test Number	SI #1	SI #2	SI #3	SI #4	SI #5	SI #6	SI #7	SI #8
FIR Filtered Data (g's)								
T01Y	-	-	167	150	100	-	17	67
T12Y	151	-	172	160	68	101	15	48
LURY01	-	253	280	232	51	117	9	132
LURYGA	-	331	271	218	55	127	11	135
LLRY01	-	205	265	234	60	133	13	85
LLRYGA	-	220	169	218	61	171	16	87
Avg Upper	-	292	276	225	53	122	10	110
Avg Lower	-	213	217	226	60	152	15	86

The peak values were used in the equation for TTI using three selected ages: 0, 23 and 41. The TTI-86 process was used to determine the TTI value. The TTI was then used in conjunction with the TTI-86 curve, which relates probability of injury for AIS >3, AIS >4, and AIS >5.[19] The TTI-86 values for the three ages along with their associated probability of injury are presented in table 15.

Table 15. TTI values and probability of injury.

Test Number	SI #1	SI #2	SI #3	SI #4	SI #5	SI #6	SI #7	SI #8
TTI Values								
TTI-86, 0	151	291	224	193	64	126	14	91
TTI-86, 23	183	323	256	225	96	158	46	123
TTI-86, 41	208	348	281	250	121	183	71	148

Test Number	SI #1	SI #2	SI #3	SI #4	SI #5	SI #6	SI #7	SI #8
Thoracic Injury Probability								
				Age 0				
AIS > 3	75%	100%	100%	95%	0%	47%	0%	1%
AIS > 4	24%	100%	100%	87%	0%	5%	0%	0%
AIS > 5	2%	68%	25%	11%	0%	0%	0%	0%
				Age 23				
AIS > 3	93%	100%	100%	100%	6%	81%	0%	43%
AIS > 4	75%	100%	100%	100%	0%	34%	0%	4%
AIS > 5	8%	85%	45%	26%	0%	3%	0%	0%
				Age 41				
AIS > 3	98%	100%	100%	100%	40%	93%	0%	73%
AIS > 4	97%	100%	100%	100%	3%	75%	0%	21%
AIS > 5	17%	93%	62%	41%	0%	8%	0%	2%

DATA COMPARISONS

Potential correlations (cross-plots) between the various vehicle-based measures of injury severity and dummy based measures have been investigated. Several are discussed below. A linear regression has been obtained for each correlation. The linear regression line for the data is shown on each graph along with the R squared coefficient which indicates the degree of correlation between the data and the regression line. R squared values near one indicate excellent correlation while those near zero indicate very little correlation. No testing for statistical significance, regarding the regression curves obtained, has been attempted due to the limited number of data points available. Rather, the correlations are only intended to provide a gross indication of possible linkage between dummy-based measures and vehicle-based measures of injury severity.

1. THORACIC RESULTS

a. Impact Location

Before beginning this test series, it was anticipated that side impacts aligned directly on the dummy would produce more severe measures of occupant injury than when the impact was moved away from the dummy. To ascertain the validity of this expectation (or lack thereof), several of the tests were conducted at different locations along the side of the vehicle.

Figure 10 shows the TTI-86,41 values (TTI-86 for an assumed occupant 41 years old) versus impact location relative to the dummy for tests with essentially equal breakaway force (tests 1, 3 through 6 and 7). The test using a transformer base support (test 2) and the test using a slipbase support for which the clamp load at the slip plane was essentially zero (test 8) were eliminated from this comparison due to radically different test setup conditions. The absolute value of the impact location relative to the dummy was used to obtain a uniform curve. The R squared coefficient for the comparison was 0.85. This high value indicates significant correlation between impact location and TTI-86,41, with a decrease in thoracic injury levels as the impact point moves away from the dummy. This tends to confirm that impacts with the support aligned on the occupant location are the most severe, and that as the impact location moves away from the occupant location the severity decreases.

b. Flail Space Velocity Change

Flail space velocity change is a primary vehicle based measure of injury severity. When TTI-86,41 was compared with flail space velocity change for all tests, the R squared coefficient obtained was very low indicating a poor correlation (see figure 11). In figure 12, the comparison is limited to those tests with identical impact locations, that is, aligned with the dummy (tests 1 through 4 and 8). The R squared correlation coefficient is 0.53. This R squared value indicates a moderate correlation between the two measures when this partial data set is used. Additionally, the slope of the regression

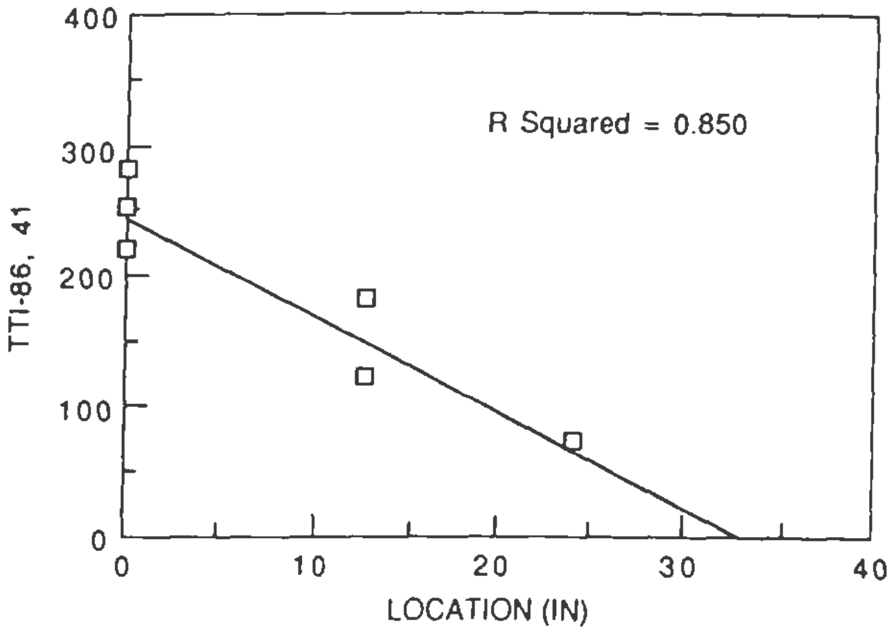


Figure 10. TTI-86,41 versus impact location.

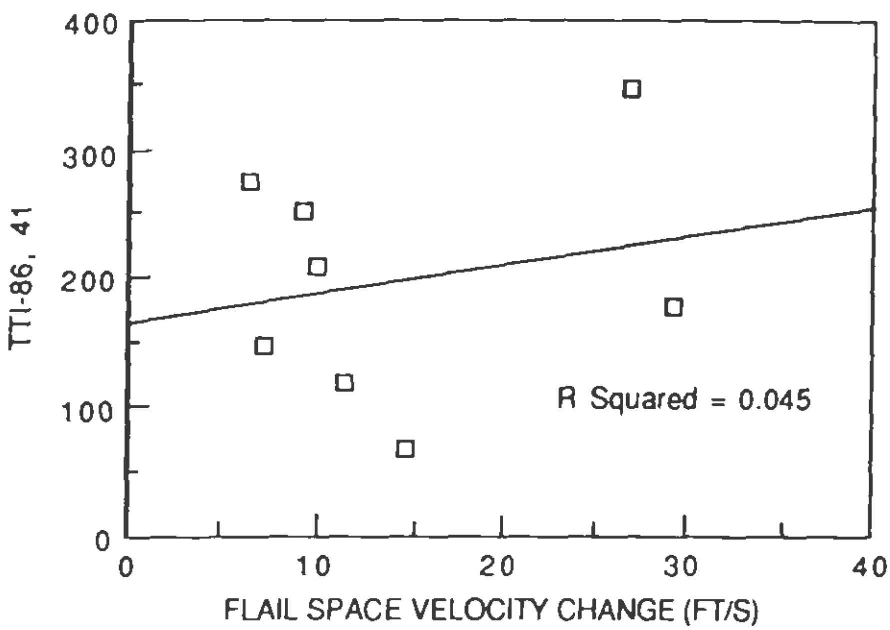


Figure 11. TTI-86,41 versus flail space velocity change for all tests.

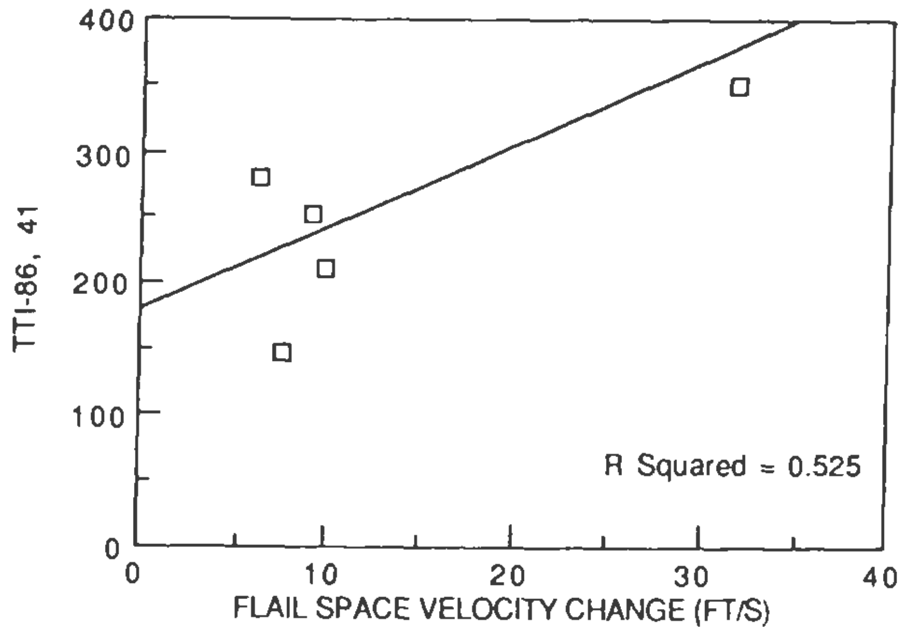


Figure 12. TTI-86,41 versus flail space velocity change for partial data set.

curve is positive, indicating that lower values of TTI-86,41 result in lower values of flail space velocity change, as is expected.

c. Static Crush Depth

Vehicle static crush depth is a secondary vehicle based measure of injury severity. When TTI-86,41 was compared with static crush depth for all tests, the R squared coefficient obtained was very low (as in the previous comparison), again indicating a poor correlation. This is shown in figure 13. The comparison was then limited to those tests where the impact was aligned with the dummy (tests 1 through 4 and 8). As shown in figure 14 (a plot of this partial data set) the R squared coefficient obtained was 0.66, also indicating moderate correlation between the two measures. As was the case with the previous data set, the slope of the regression curve is positive indicating lower values of TTI-86,41 for lower values of static crush depth, as expected.

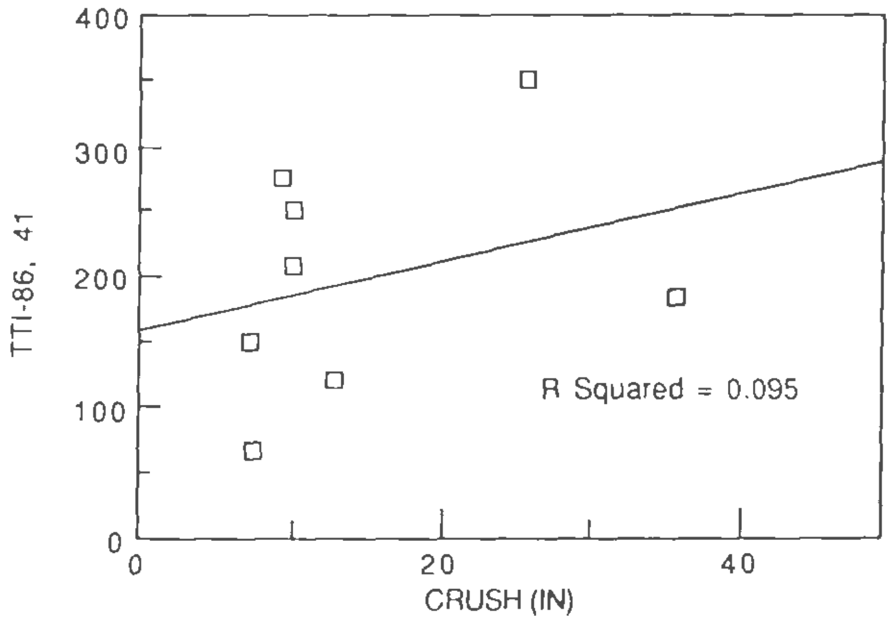


Figure 13. TTI-86,41 versus static crush depth for all tests.

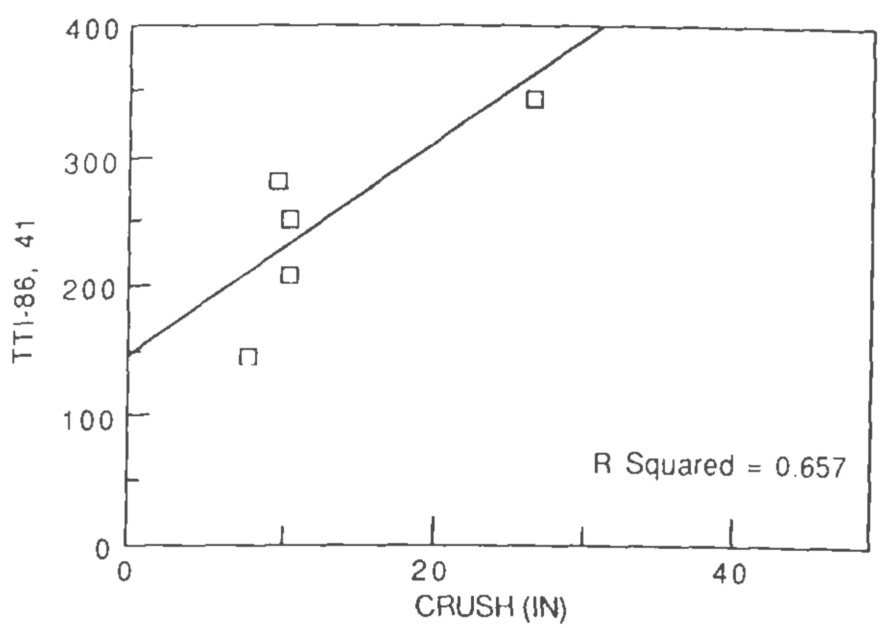


Figure 14. TTI-86,41 versus static crush depth for partial data set.

2. HEAD INJURY RESULTS

The Head Injury Criteria (HIC) computed for each test were compared in a similar manner (as TTI-86,41 the previous discussion) to investigate possible relationships between dummy and vehicle borne measures of injury.

a. Impact Location

The vehicle crush location was investigated to determine if the location of impact affected the HIC value. The data, plotted in figure 15, shows some relationship. Due to the extreme scatter of the HIC data at the on-occupant impact point, the data produced only a moderate correlation of 0.50.

b. Flail Space Velocity Change

HIC values were compared to flail space velocity change values for all tests. The associated R squared coefficient was 0.08. The complete data set is shown in figure 16. The partial set of tests (comprised of all impacts aligned with the dummy) is presented in figure 17. Again, the associated R squared value is low, 0.08. These low correlation values indicate almost no correlation between HIC and flail space velocity change measures for both comparisons. This is in contrast to TTI-86,41, where moderate correlation

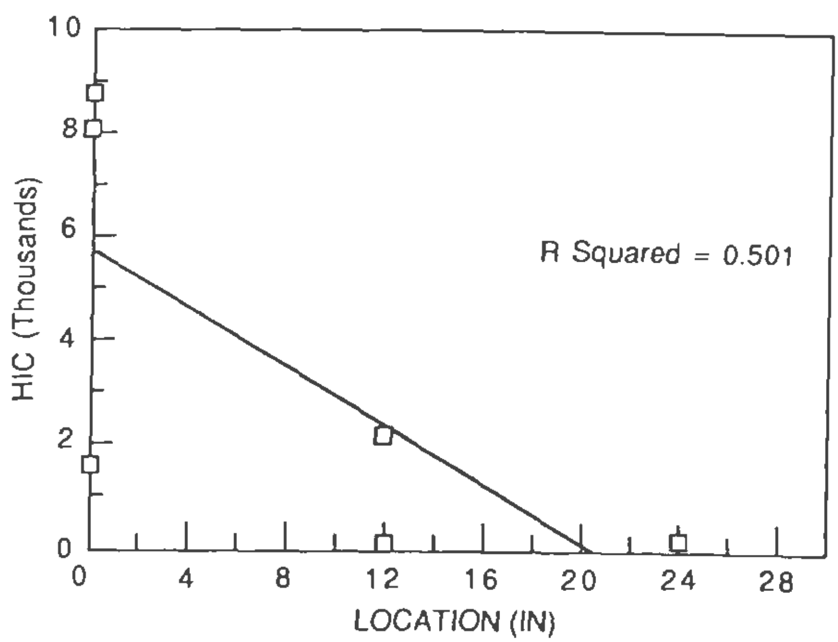


Figure 15. HIC versus crush location.

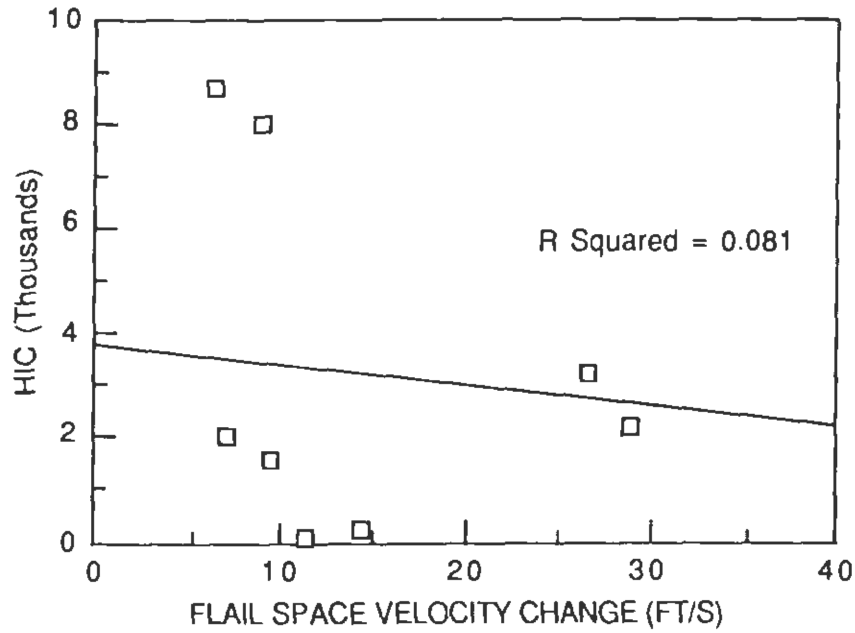


Figure 16. HIC versus flail space velocity change for all tests.

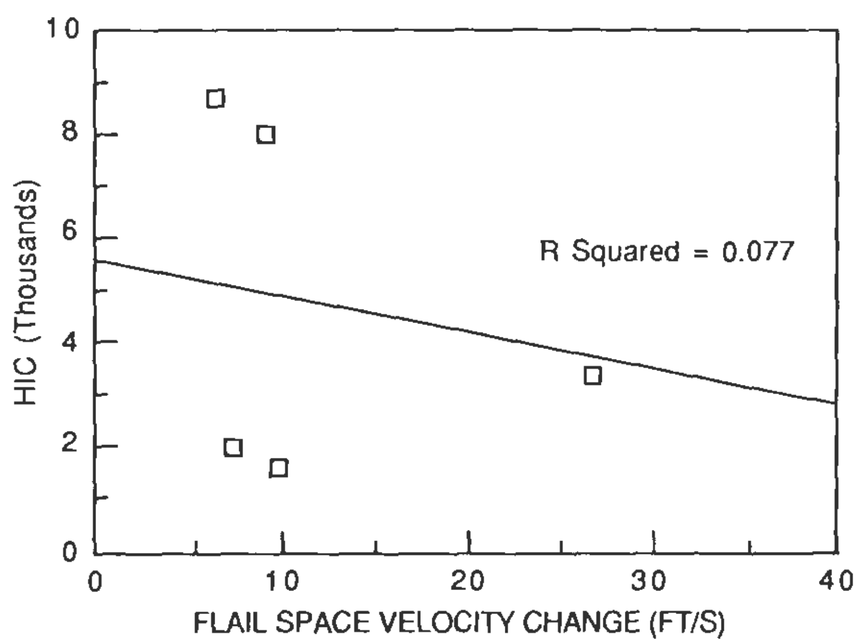


Figure 17. HIC versus flail space velocity change for partial data set.

exists for the partial set of tests. This perhaps reflects the fact that the side impact dummy head and neck have not been designed and validated for impacts into the side of the head. It definitely reflects the fact that HIC values varied over a wide range (from a low of near 1600 to a high near 8700) for four data points where the flail space velocity changes were similar. The reason for this wide variation and resulting low correlation is not well understood at this time.

c. Static Crush Depth

HIC values were compared with static crush depth for all tests. The resulting R squared coefficient was 0.01. This data is presented in figure 18. When using HIC values from the partial set of tests, the R squared value was 0.03, as shown in figure 19. As with the previously attempted correlation, HIC shows no correlation with static crush depth. Again, the reason for this is not well understood.

3. OTHER DATA COMPARISONS

Comparisons of data from the dummy such as HIC and TTI-86,41 were made with each other. This was done to determine if the two measurements of injury were tracking each other. This comparison is presented in figure 20. The correlation coefficient was 0.46, which indicates fair correlation between these two parameters.

In the vehicle, comparisons were made between crush and NCHRP 230 flail space velocity change and between speed reduction of the vehicle and flail space velocity change. These two relationships are shown in figures 21 and 22. The correlation coefficients for these comparisons were 0.86 and 0.98, respectively. These relationships show that the vehicle data is consistent within itself.

4. RECAP OF COMPARISONS

The above comparisons determined two potential candidates for use as vehicle based measures of thoracic injury severity, flail space velocity change and static crush depth. Comparisons of these two measures with TTI-86,41 revealed a moderate correlation, with the crush being slightly

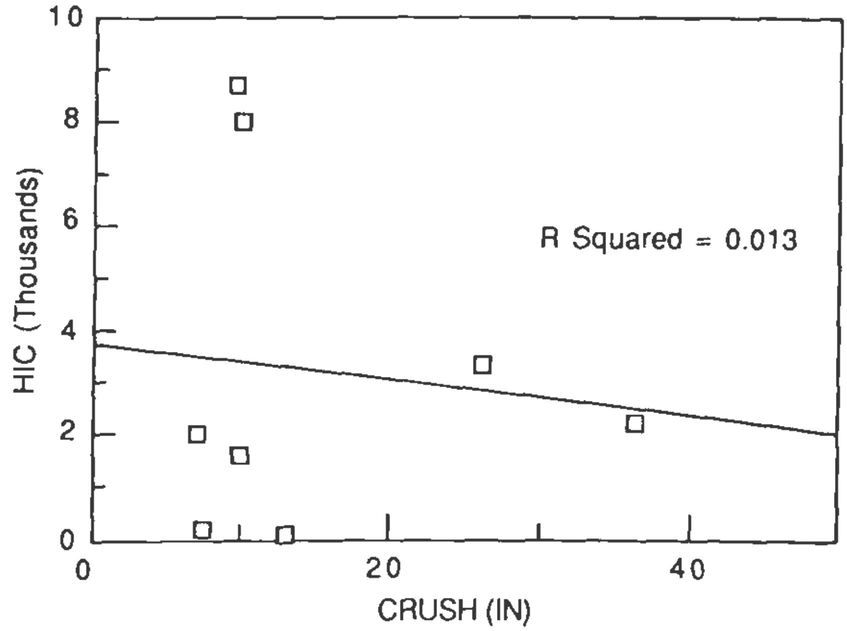


Figure 18. HIC versus crush for all tests.

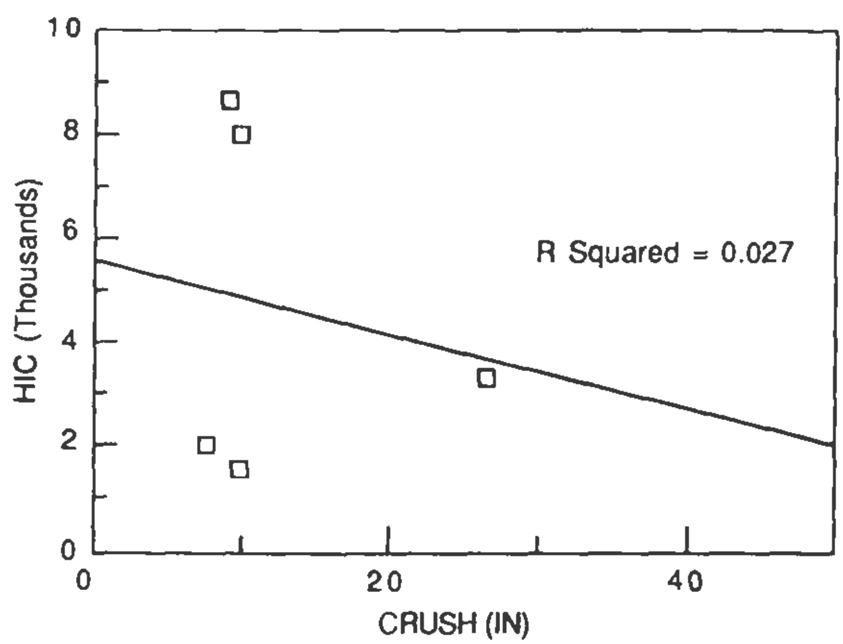


Figure 19. HIC versus crush for partial data set.

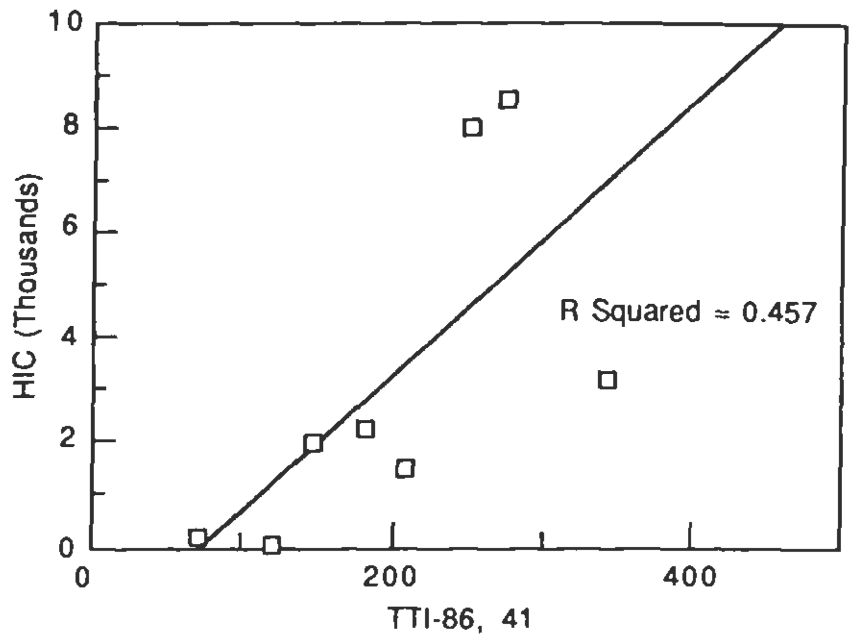


Figure 20. HIC versus TTI-86,41.

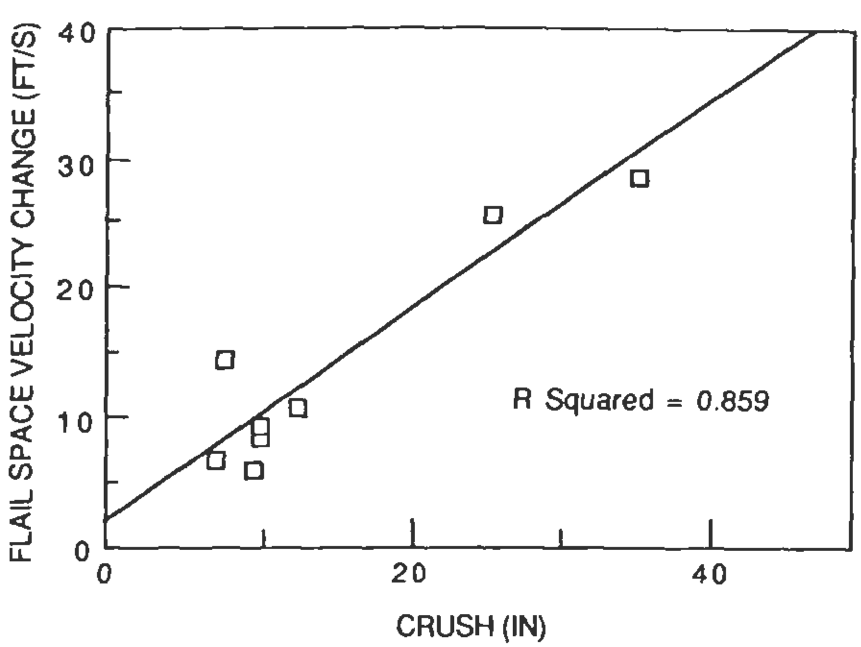


Figure 21. Crush versus flail space velocity change.

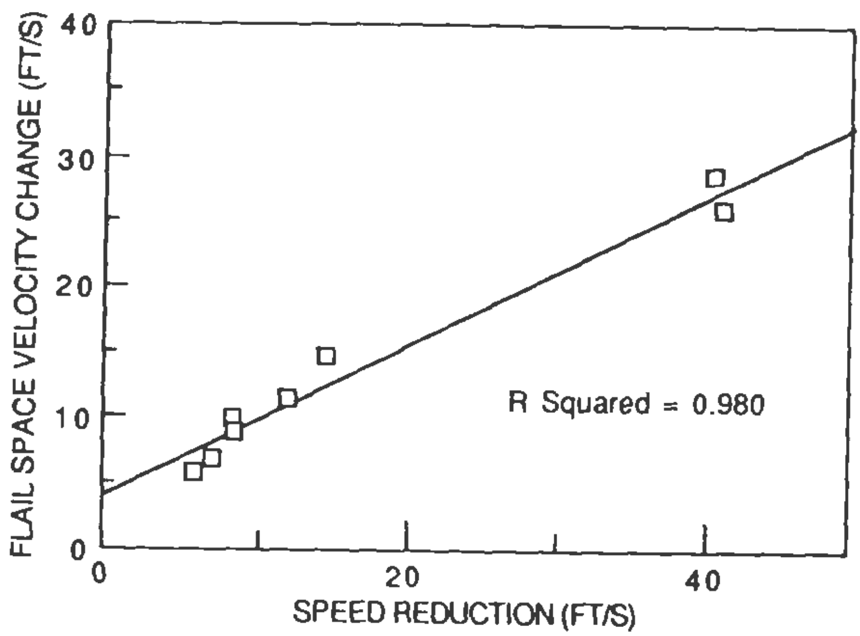


Figure 22. Vehicle speed reduction versus flail space velocity change.

higher. No tests for statistical significance were applied due to the limited amount of data. Comparisons between vehicle based measurements showed high correlations.

CONCLUSIONS

For "real world" side impact collisions into fixed roadside objects and roadside features, the impact point along the vehicle is random. It is as likely for the impact to occur at a point on the vehicle aligned with an occupant as any other place along the vehicle.[10] In addition, depending upon the accident data base queried, 60 to 90 percent of all fixed roadside object-side impact fatalities occur at speeds of 30 mi/h (13.4 m/s) or below.[10] With occupant protection the ultimate goal, it is reasonable to establish test criteria based on a worst case scenario, impacts aligned with the occupant, broadside at a speed of 30 mi/h (13.4 m/s).

Because occupant protection is the objective, the level of maximum injury allowable (the test evaluation criteria) must also be established. With regard to thoracic injury, the probability of exceeding an AIS value of 3, 4, and 5 must be specified, together with the age of the occupant. For this research program, the NHTSA developed relationship between AIS and TTI-86 values (figure 9) was selected and used. An occupant age of 41 years was used. It was felt that this age represented the median for vehicle occupants receiving serious to fatal injuries.[2]

Two preliminary relationships between dummy and vehicle based measures of injury severity were determined. They were TTI-86 versus flail space velocity change (impact velocity of a theoretical unbelted occupant into the vehicle interior) and TTI-86 versus resultant static crush depth. Figures 12 and 14 depict the preliminary curves obtained. Although not perfect, a moderate correlation between variables was obtained with the limited data available. As previously stated, the slope of the two curves is reasonable from a physical standpoint. The slopes of these curves are positive, indicating that lower values of TTI-86 correspond to lower values of flail space velocity change and static crush depth, respectively. However, the vertical axis intercept for the two regression curves ranges from TTI-86 values of approximately 150 to near 175 for zero values of flail space velocity change or static crush depth. From a physical standpoint, this lacks credibility.

One would expect lower probability of thoracic injury for zero values of velocity change or static crush. It is anticipated that the true relationships are nonlinear with the curves emanating from (or near to) the origin formed by each respective axis. In order to better characterize these two relationships and reduce statistical errors due to a limited number of samples, additional tests at both lower and higher severities are required. This test program must contain enough tests to quantify these relationships. With this information, a side impact injury predictor based upon vehicle response can be formulated.

RECOMMENDATIONS

Based upon the results of the side impact-narrow fixed roadside object research program described in this research report, the following recommendations are proposed:

1. To better characterize the relationships between TTI-86 and both flail space velocity change and static crush depth, additional testing at both lower and higher impact speeds into the slipbase and other luminaire supports is recommended. This will provide lower and higher severity data points needed to define these relationships. This will also provide a sufficient number of data points to obtain statistically significant relationships.

2. Because of the lack of stiffness present in the side structure of currently available small cars (weighing 2000 lb (908 kg) or less), it is felt that only a few inches of static crush may result in serious to fatal thoracic injury. Even with the best of breakaway supports currently available on our Nation's roadways, significant intrusion occurs before sufficient breakaway force is attained. Additionally, many of the side impact fatalities are due to collisions with trees and utility poles, both of which are nonbreakaway. It is therefore recommended that the side stiffness of such cars, particularly at the lower sill and the upper roof line, be increased.

3. Subsequent to additional side impact research, design improvements to breakaway luminaire supports are also necessary. With the exception of test 2, all tests conducted involved a breakaway luminaire support representative of the safest of such devices currently in use on our Nation's highways. Test 2, which involved a breakaway support more representative of the typical support currently in use, did not break away. Under side impact conditions, it behaved in a manner similar to a fixed, rigid narrow object. One test may not fully characterize any particular breakaway support's safety performance under side impact test conditions. However, it does tend to indicate that design improvements may be warranted. Even the slipbase breakaway support did not break away

during test 6, indicating that design improvements may be warranted for this support. The reason for this failure may have been due to substantial engagement between the lower car sill and the fixed base of the luminaire support (which is only 3 in (76.2 mm) high). This hypothesis was never conclusively proved. As a result of this, it is felt that stub heights for side impact compatible supports may need to be lower than the currently required 4 in (101.6 mm). During all tests conducted directly in line with the dummy, substantial head contact and high HIC values occurred. Therefore, techniques to limit head contact or to mitigate head trauma will be required if such injuries are to be reduced or eliminated. Finally, techniques to minimize or reduce intrusion of the narrow support into the occupant compartment are needed.

4. In any follow-up research program designed to better characterize the relationships between TTI-86 and either flail space velocity change or static crush depth, surrogate measures of estimating pelvic injury (based upon test vehicle responses) should be developed. This is to ensure that subsequently developed side impact compatible breakaway supports do not reduce thoracic injury potential at the expense of pelvic injury potential.

5. A test program (or programs) consisting of tests of increasing impact severity near, but not directly on, the dummy may be warranted. This would provide for a parallel curve (or series of curves) relating thoracic and pelvic injury to vehicle based surrogate measures of injury severity. The result would be to characterize the entire area around a vehicle occupant from an injury potential point of view. For example, a series of tests 6 or 12-in (152 or 305-mm) forward or rearward from the shoulder of the dummy may be appropriate. From this research, similar relationships would be developed for equally severe impacts with potentially less severe results on the vehicle occupant. The end result would be a better understanding of the side impact environment from an occupant injury potential point of view.

6. In the future, consideration should be given to developing a computer model (preferably PC compatible) simulating side impact into roadside

objects. Such simulations should be developed in stages. First, a relatively simple simulation should be formulated and validated to the extent feasible by existing test results. Improvements should be incorporated as understanding of the side impact/fixed roadside object accident environment increases. This simulation could include a lumped mass occupant model (inside the vehicle) if deemed desirable or necessary. In time, this simulation could be used for further refinements to surrogate measures for injury prediction, as well as for safety improvements to roadside hardware.

APPENDIX - TEST DESCRIPTIONS AND PHOTOGRAPHS

1. TEST SI #I

The test vehicle impacted at 29.36 mi/h (13.1 m/s) at a point on the left door in line with the occupant, 18 in (457.2 mm) behind the longitudinal location of the vehicle center of gravity as measured without the dummy in the vehicle. The vehicle had a 4° to 6° roll angle as it leaned toward the test pole, due to the side sliding forces acting on the tires. The maximum residual crush of the vehicle at the impact point was 10 in (254 mm). Pretest photographs of the vehicle and luminaire support are shown in figure 23.

After the initial separation from the vehicle, the luminaire support translated forward at a speed of 13.7 ft/s (4.1 m/s) with a rotation rate of 1.59 rad/s. The luminaire support rotated up and over the test vehicle. The top of the pole hit the ground approximately 1.08 s after impact. Just prior to impact with the ground, the center portion of the pole landed on the left rear corner of the car. As the support rotated away, the vehicle yawed counter clockwise and rolled to its left. The maximum roll angle was about 5°, based on film observations. The vehicle then became stable and continued forward away from the impact area after yawing a total of about 90°. The vehicle did not pitch or roll much, but remained stable during this transition. The final resting position of the vehicle was about 70 ft (21.3 m) downstream and 10 ft (3 m) to the right of the impact point. Posttest photographs are shown in figure 24.

2. TEST SI #2

The test vehicle impacted at 28.64 mi/h (12.8 m/s) at a point on the left door in line, with the occupant 19 in (482.6 mm) behind the longitudinal location of the vehicle center of gravity as measured without the dummy in the vehicle. The vehicle had a 6.4° roll angle as it leaned toward the test pole, due to the side sliding forces acting on the tires. The maximum residual crush of the vehicle at the impact point was 26 in (660 mm). Pretest photographs of the vehicle and luminaire support are shown in figure 25.

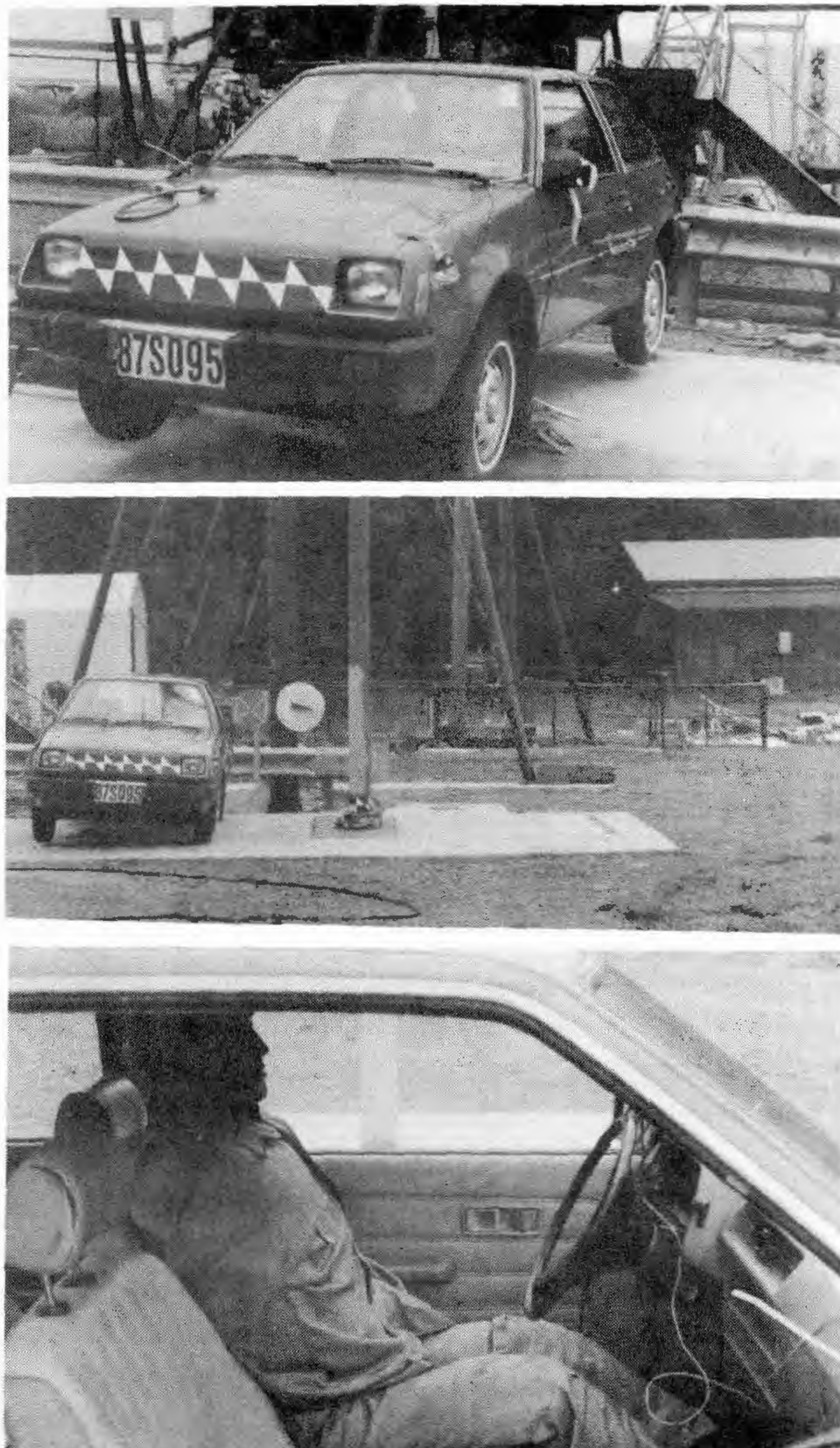


Figure 23. Pretest photographs of vehicle, test SI #1.

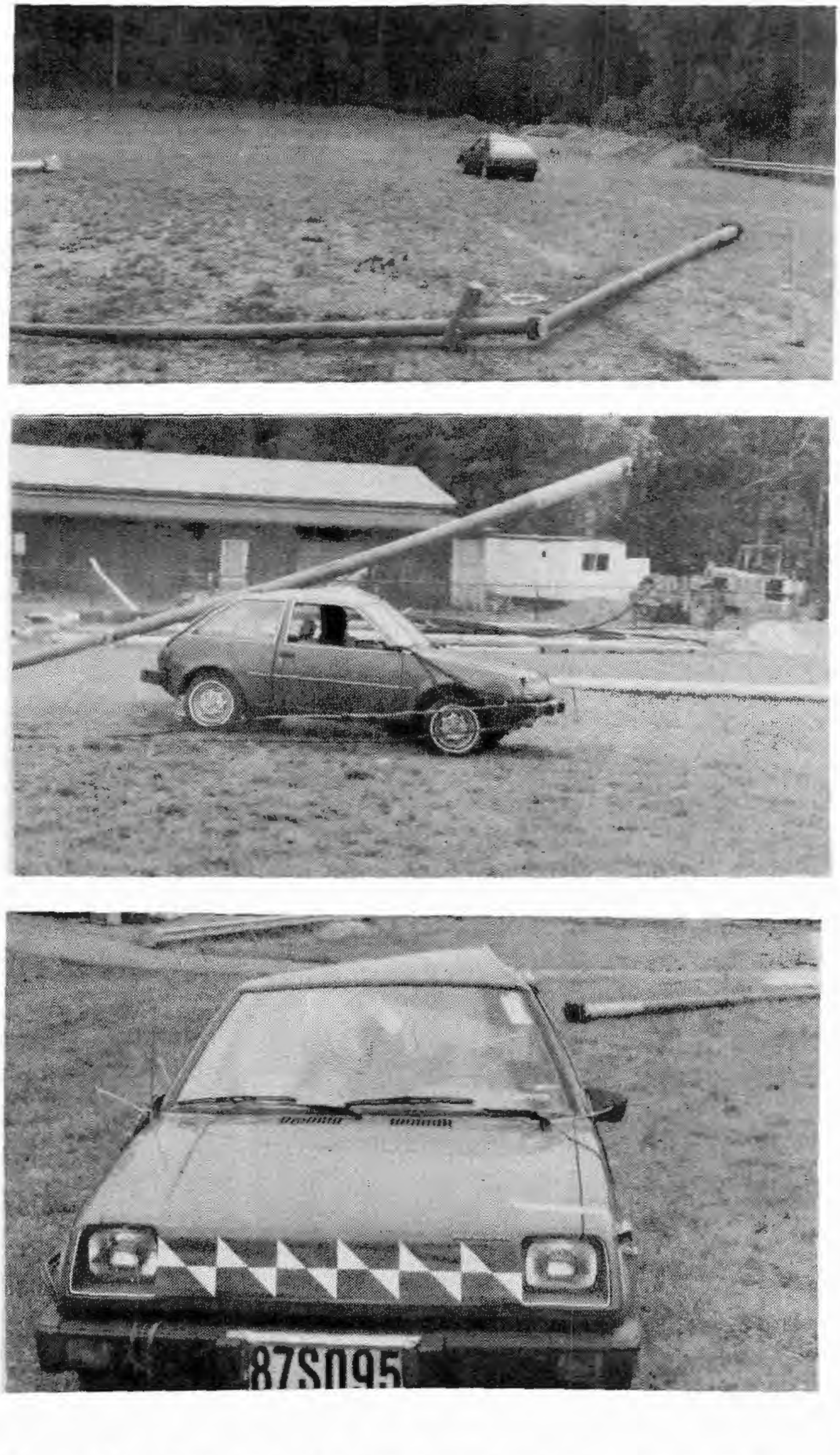


Figure 24. Posttest photographs of vehicle, test SI #I.

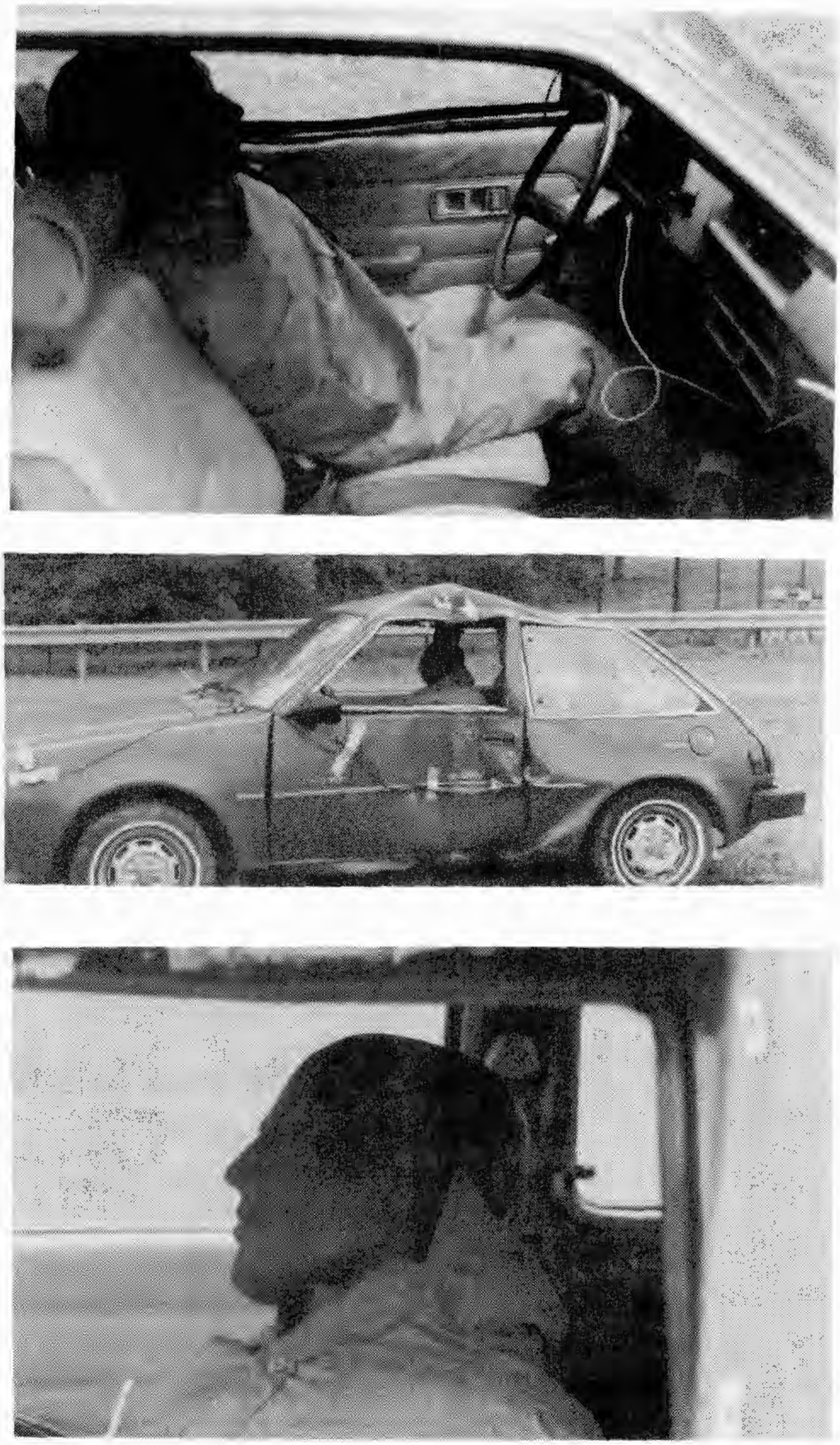


Figure 24. Posttest photographs of vehicle, test SI #1 (continued).

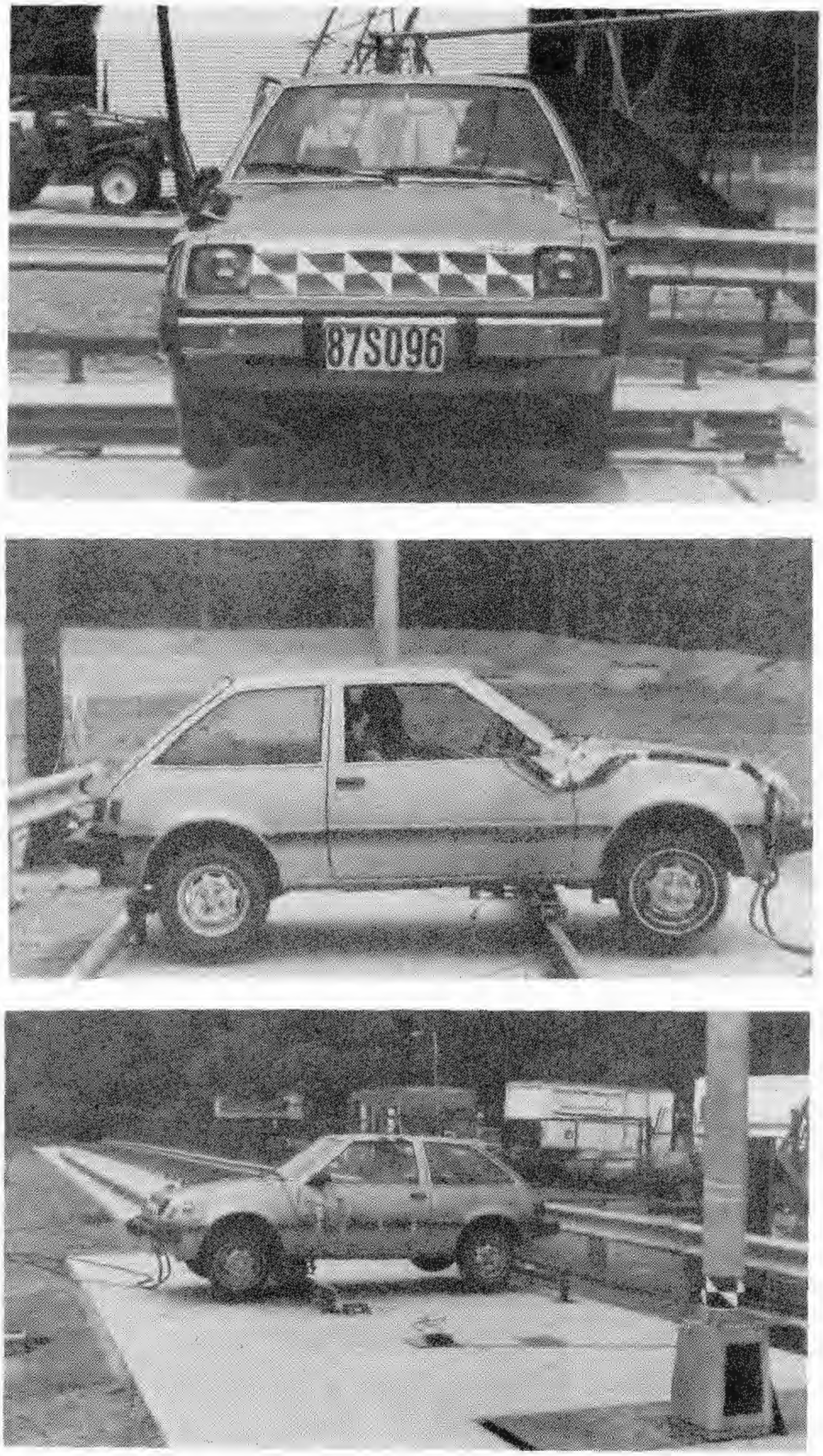


Figure 25. Pretest photos of vehicle & pole, test SI #2.

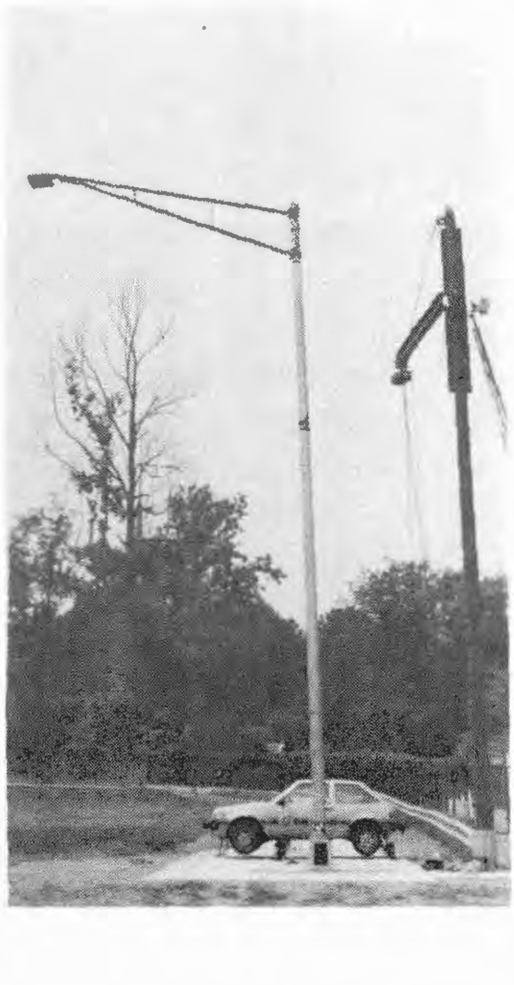


Figure 25. Pretest photographs of vehicle & pole, test SI #2 (continued).

Upon impact, the vehicle began to crush followed by the dummy's head striking the pole. Shortly after impact the vehicle began to yaw counter clockwise around the pole. The transformer base pole combination did not break away, although the T-base did have several cracks around the bottom. The vehicle continued to yaw coming to a rest after about 153° of total rotation. The final resting position was approximately 2 ft (610 mm) to the right of the pole. The vehicle was bent about the impact point with the wheel base shortened almost 20 in (508 mm) on the impact side. Posttest photographs are shown in figure 26.

3. TEST SI #3

The test vehicle impacted at 30.5 m/h (13.6 m/s) at a point on the left door in line with the occupant, 28 in (711 mm) behind the longitudinal location of the vehicle center of gravity as measured without the dummy in the vehicle. The vehicle had a 4.9° roll angle as it leaned toward the test pole, due to the side sliding forces acting on the tires. The maximum residual crush of the vehicle at the impact point was 9.5 in (34.9 mm). Pretest photographs of the vehicle and luminaire support are shown in figure 27.

After the initial separation from the vehicle, the luminaire support translated forward and rotated up and over the test vehicle with the top of the pole hitting the ground about 1.1 s after impact. Just prior to impact with the ground, the center portion of the pole impacted on the left rear corner of the car. As the support rotated away, the vehicle yawed counter clockwise and rolled to its left. The maximum roll angle was about 5°, based on film observations. The vehicle then became stable and continued forward away from the impact area after yawing a total of about 60°. The vehicle did not pitch or roll very much, but remained stable during this transition. The final resting position of the vehicle was about 55 ft (16.7 m) downstream and 35 ft (10.6 m) to the right of the impact point. Posttest photographs are shown in figure 28.

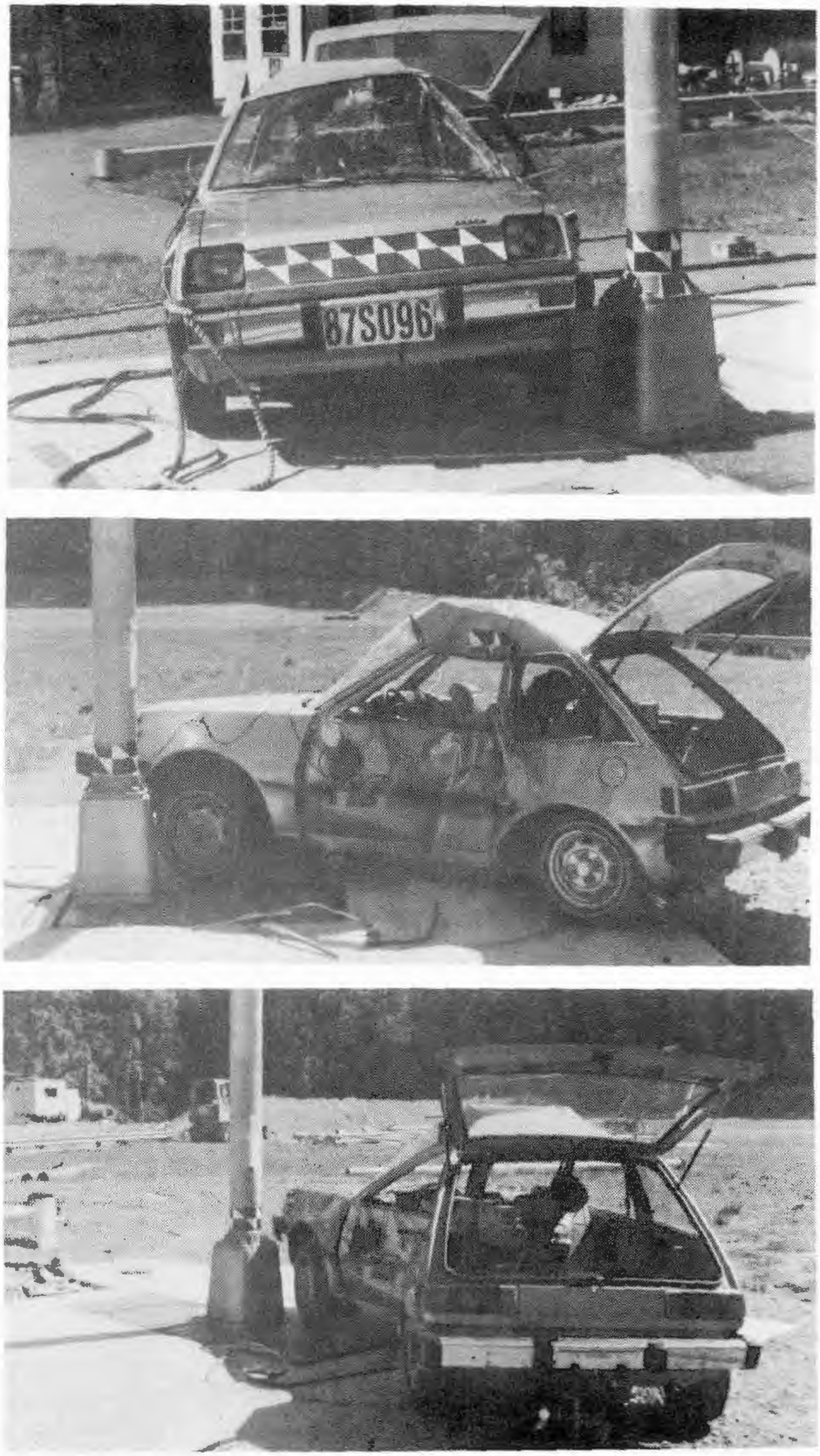


Figure 26. Posttest photographs of vehicle, test SI #2.

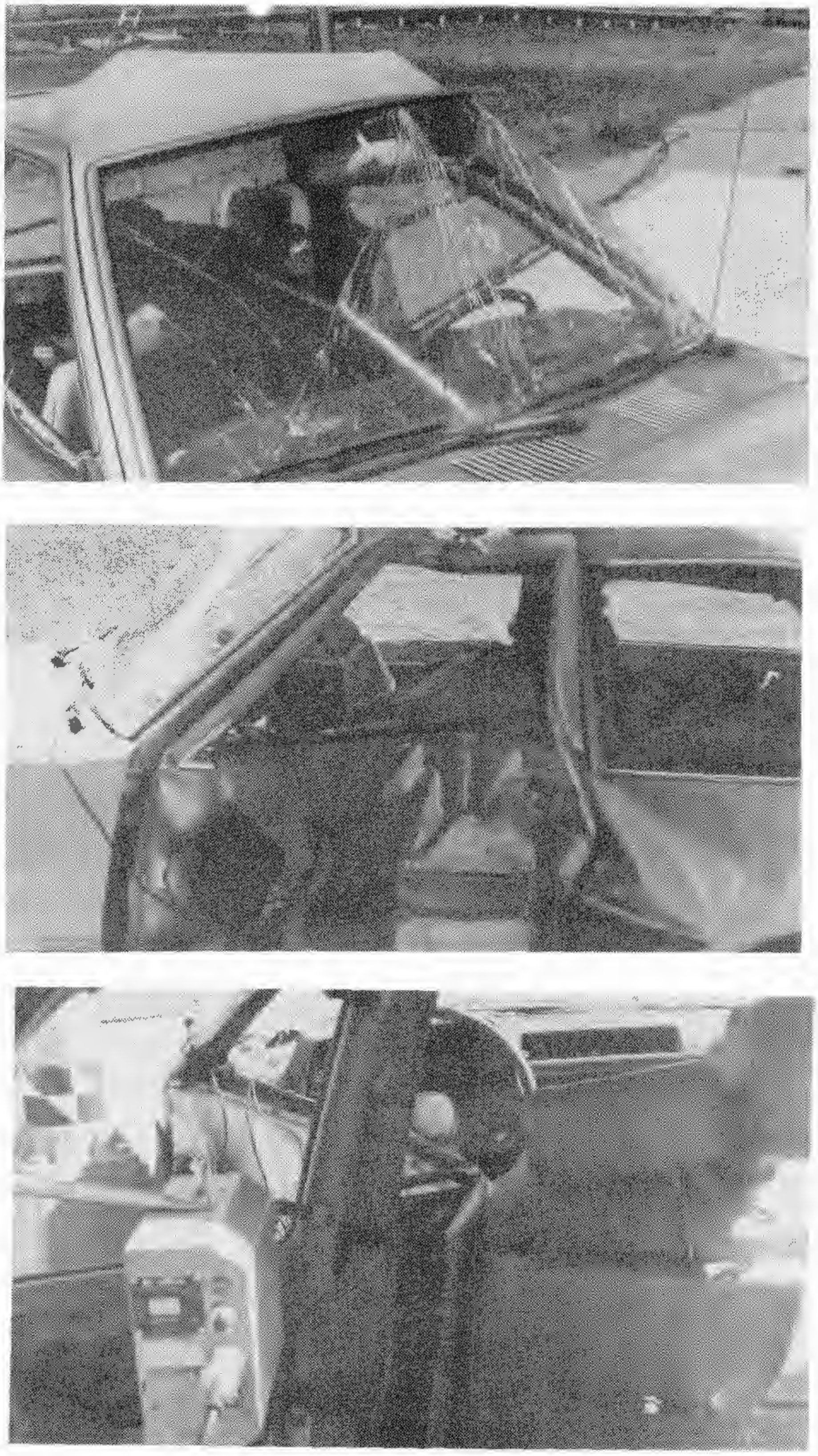


Figure 26. Posttest photographs of vehicle, test SI #2 (continued).

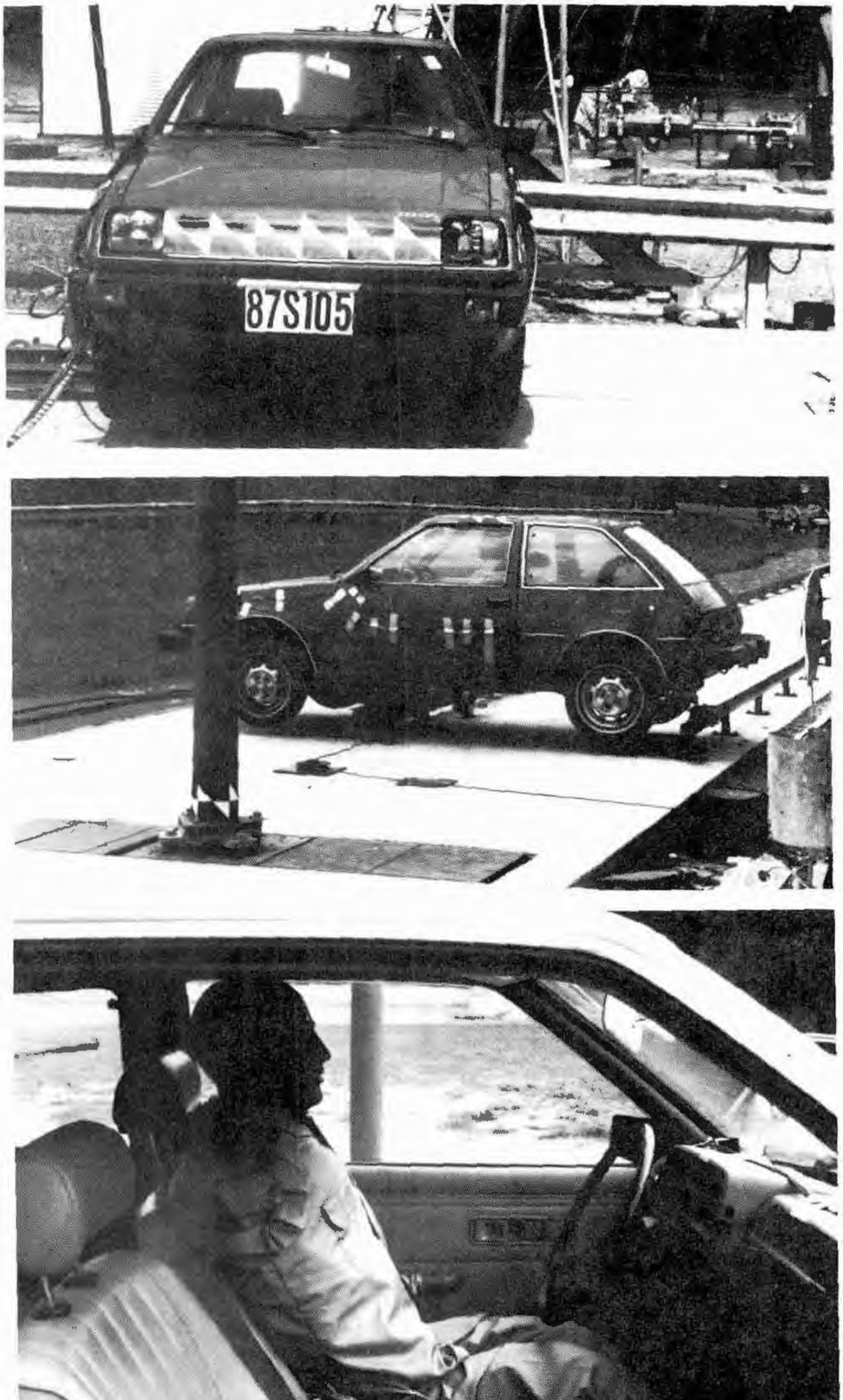


Figure 27. Pretest photographs of vehicle, test SI #3.

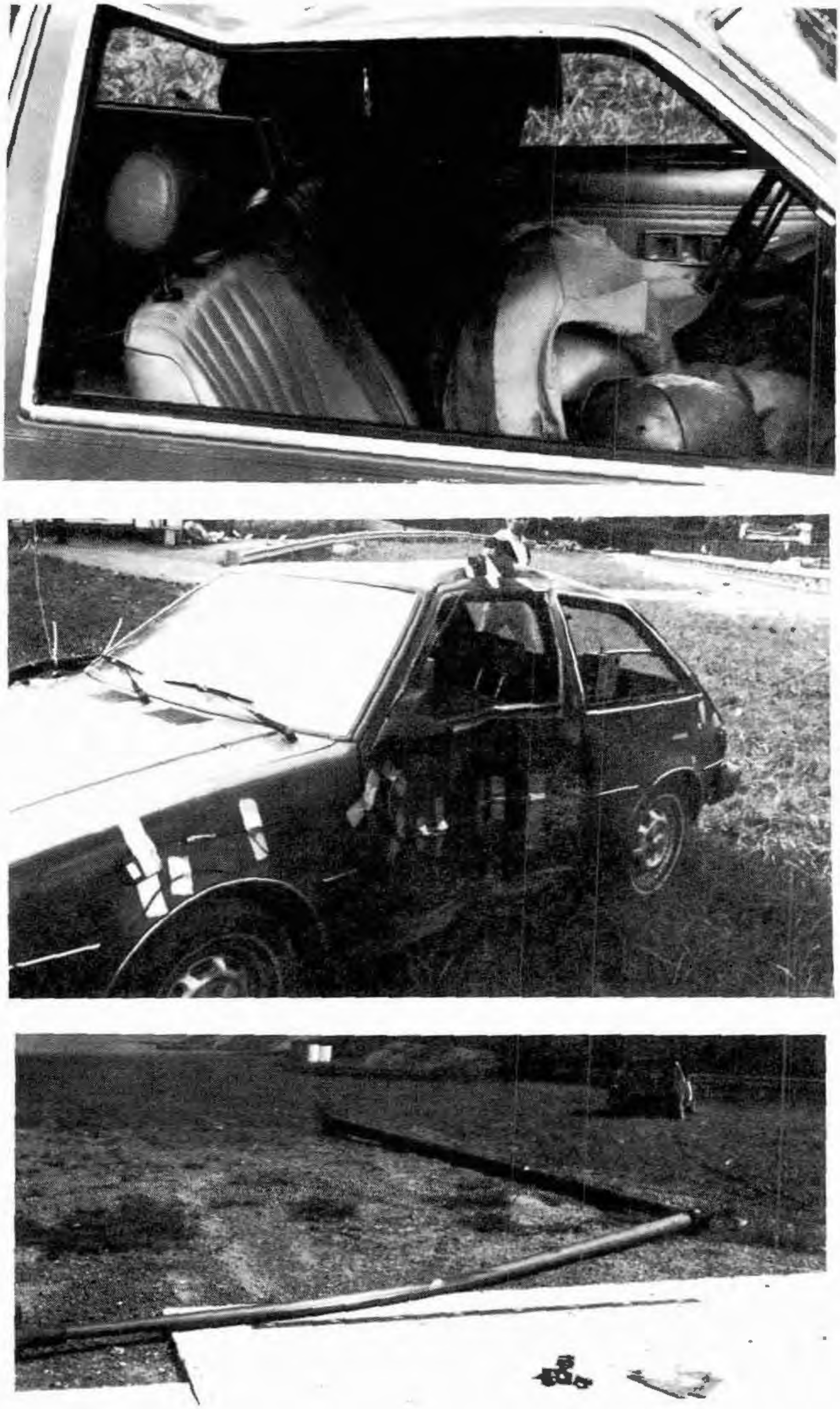


Figure 28. Posttest photographs of vehicle, test SI #3.

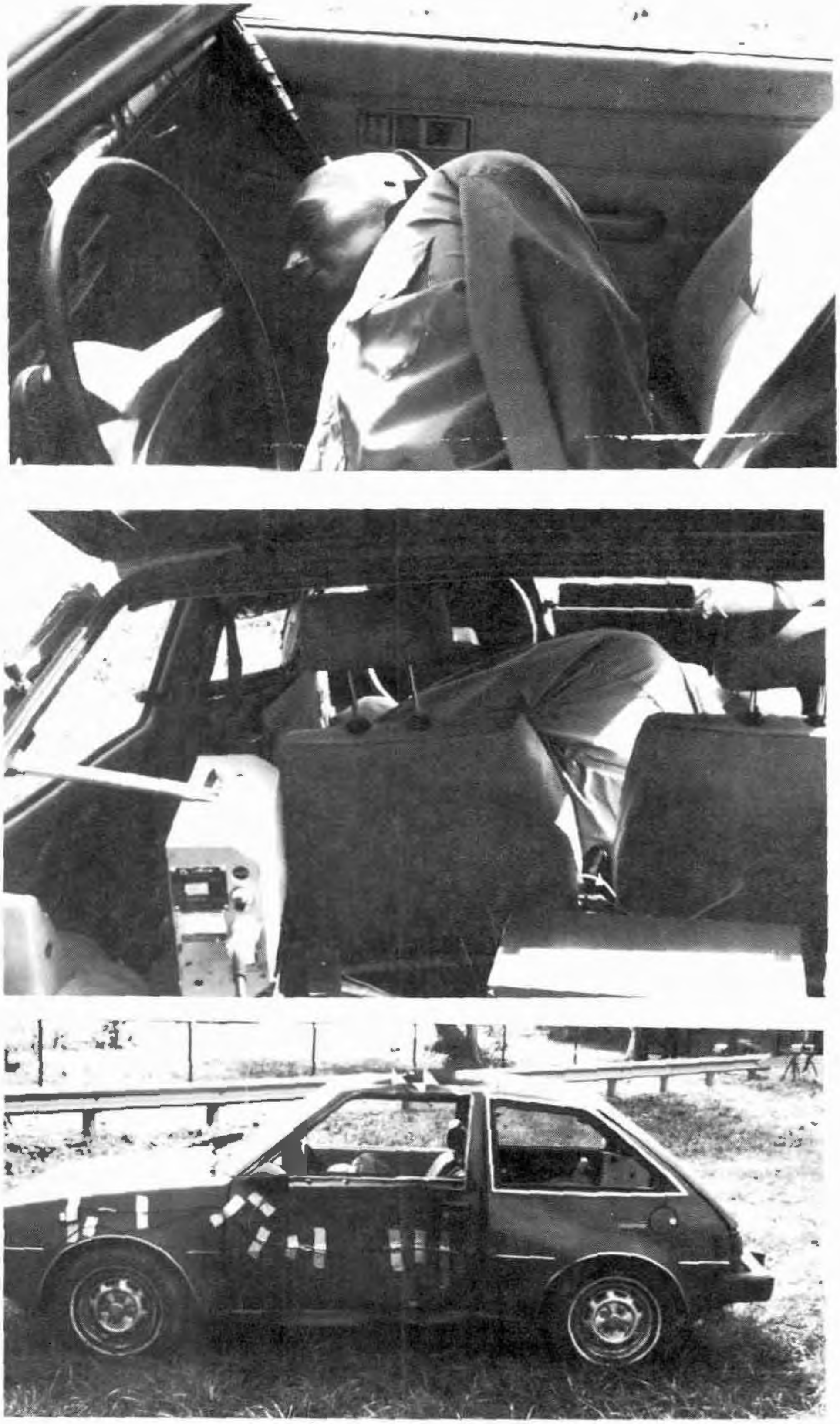


Figure 28. Posttest photographs of vehicle, test SI #3 (continued).

4. TEST SI #4

The test vehicle impacted at 29.45 mi/h (13.1 m/s) at a point on the left door in line with the occupant, 28 in (711 mm) behind the longitudinal location of the vehicle center of gravity as measured without the dummy in the vehicle. The vehicle had a 5.9° roll angle as it leaned toward the test pole, due to the side sliding forces acting on the tires. The maximum residual crush of the vehicle at the impact point was 10 in (254 mm). Pretest photographs of the vehicle and luminaire support are shown in figure 29.

After the initial separation from the vehicle, the luminaire support translated forward at a speed of 6.9 ft/s (2.1 m/s) with a rotation rate of 1.94 rad/s. The luminaire support rotated up and over the test vehicle with the top of the pole hitting the ground about 1.1 s after impact. Just prior to impact with the ground, the center portion of the pole impacted on the left rear corner of the car. As the support rotated away, vehicle yawed counter clockwise and rolled to its left. The maximum roll angle was about 5°, based on film observations. The vehicle total yaw angle was approximately 60°. The vehicle did not pitch or roll very much but remained stable during this transition. The final resting position of the vehicle was about 55 ft (16.7 m) downstream and 35 ft (10.6 m) to the right of the impact point. Posttest photographs are shown in figure 30.

5. TEST SI #5

The test vehicle impacted at 29.7 mi/h (13.2 m/s) at a point on the left door 12 in (305 mm) behind the occupant, 40 in (1016 mm) behind the longitudinal location of the vehicle center of gravity as measured without the dummy in the vehicle. The vehicle had a 6.1° roll angle as it leaned toward the test pole due to the side sliding forces acting on the tires. The maximum residual crush of the vehicle at the impact point was 13 in (330 mm). Pretest photographs of the vehicle and luminaire support are shown in figure 31.

After the initial separation from the vehicle, the luminaire support translated forward at a speed of 6.5 ft/s (1.98 m/s) with a rotation rate of 1.34 rad/s. The luminaire support rotated up and over the test vehicle with the top of the pole hitting the ground about 1.3 s after impact. Just prior

Figure 29. Pretest photographs of vehicle, test SI #4.

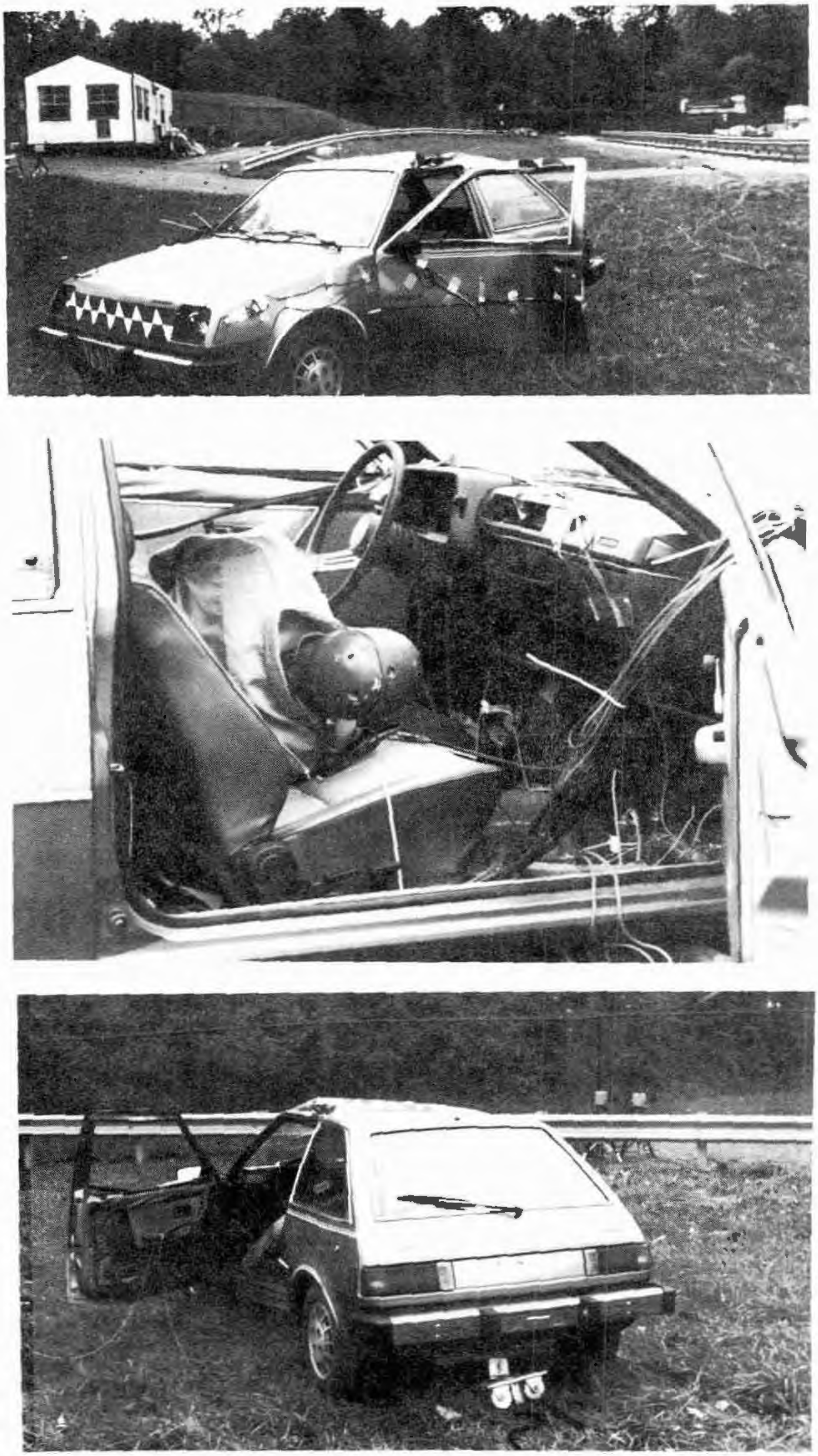


Figure 30. Posttest photographs of vehicle, test SI #4.

Figure 30. Posttest photographs of vehicle, test SI #4 (continued).

Figure 31. Pretest photographs of vehicle, test SI #5.

to impact with the ground, the center portion of the pole impacted on the left rear corner of the car. As the support rotated away, the vehicle yawed counter clockwise and rolled to its left. The vehicle then became stable and continued forward away from the impact area after yawing a total of about 90°. The vehicle did not pitch or roll very much but remained stable during this transition. The final resting position of the vehicle was about 60 ft (18.3 m) downstream and 15 ft (4.6 m) to the right of the impact point. During the impact, the driver's door latch area was deformed allowing the door to come open. As the vehicle left the impact area, the dummy slid out of the open door and fell to the ground. The dummy was then dragged along the ground by the dummy data cable. Posttest photographs are shown in figure 32.

6. TEST SI #6

The test vehicle impacted at 28.25 mi/h (12.6 m/s) at a point on the left door 12 in (305 mm) forward of the occupant, 16 in (406 mm) behind the longitudinal location of the vehicle center of gravity as measured without the dummy in the vehicle. The vehicle had a 6.1° roll angle as it leaned toward the test pole due to the side sliding forces acting on the tires. The maximum residual crush of the vehicle at the impact point was 36 in (914 mm). Crush was measured from a straight line cord running from front bumper to rear bumper on the impact side. This was done because the vehicle was bent very severely. Pretest photographs of the vehicle and luminaire support are shown in figure 33.

The vehicle impacted the pole in the desired location, 12 in (305 mm) forward of the driver's shoulder. The vehicle crushed inward as it slowed. The vehicle stopped without breaking away the pole, thus causing a very large deformation of the vehicle side. The vehicle yawed slightly as it came to a rest. Posttest photographs are shown in figure 34.

7. TEST SI #7

The test vehicle impacted at 28.9 mi/h (12.9 m/s) at a point on the left door 24 in (607 mm) forward of the occupant, coinciding approximately with the longitudinal location of the vehicle center of gravity as measured without the dummy in the vehicle. The vehicle had a 6.0° roll angle as it leaned toward

Figure 32. Posttest photographs of vehicle, test SI #5.

Figure 32. Posttest photographs of vehicle, test SI #5 (continued).

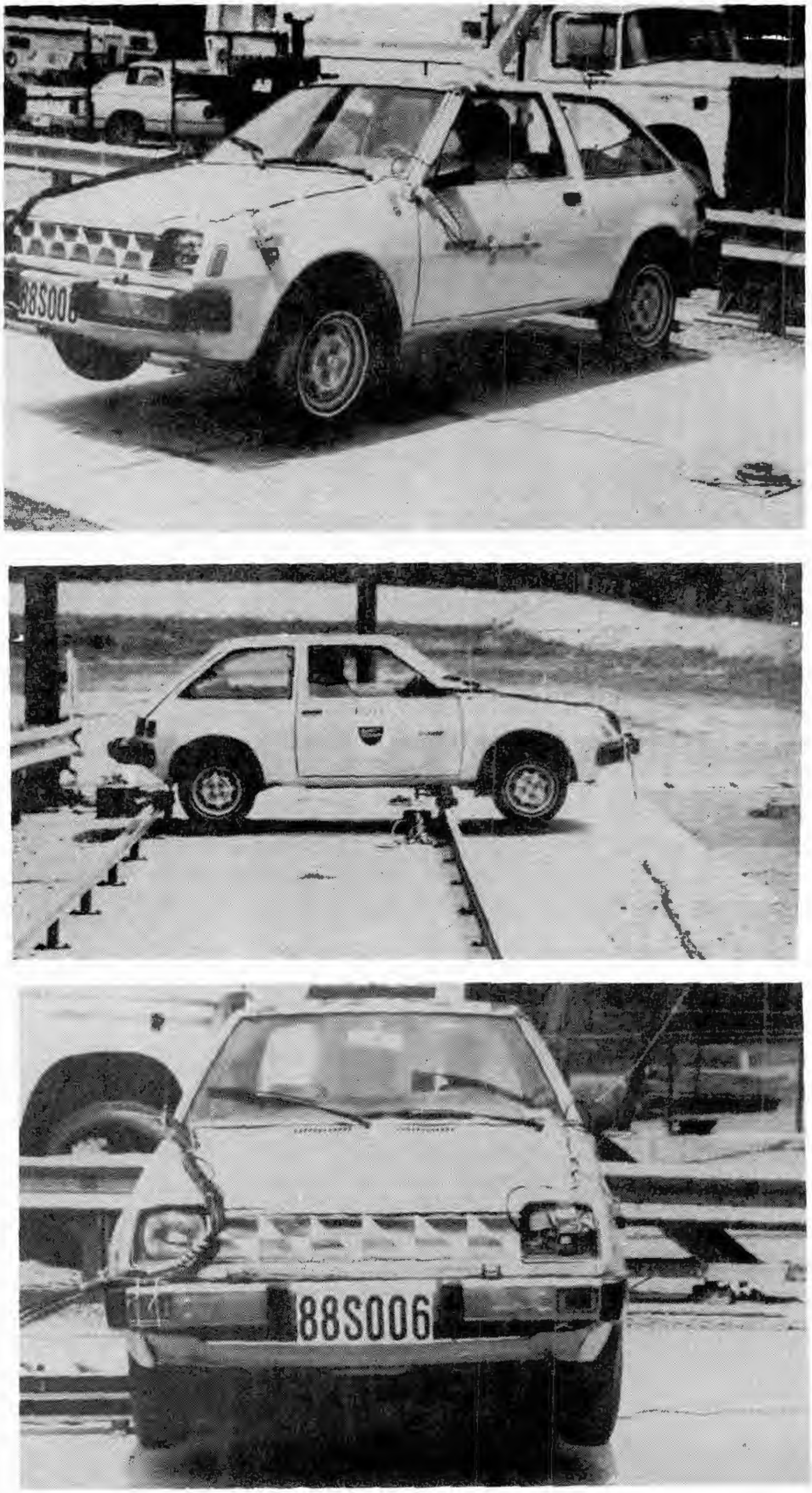


Figure 33. Pretest photographs of vehicle, test SI #6.

Figure 34. Posttest photographs of vehicle, test SI #6.

Figure 34. Posttest photographs of vehicle, test SI #6 (continued).

the test pole due to the side sliding forces acting on the tires. The maximum residual crush of the vehicle at the impact point was 7.5 in (190.5 mm). Pretest photographs of the vehicle and luminaire support are shown in figure 35.

After the initial separation from the vehicle, the luminaire support translated forward at a speed of 24.7 ft/s (7.5 m/s) with a rotation rate of 1.84 rad/s. The luminaire support rotated up and over the test vehicle, with the top of the pole hitting the ground about 1.07 s after impact. Just prior to impact with the ground, the center portion of the pole impacted on the hood of the car. At the time of impact of the pole with the hood, the vehicle had yawed clockwise. It continued yawing for a total yaw angle of 90°. The vehicle did not pitch or roll very much, but remained stable during this transition. The final resting position of the vehicle was about 36 ft (11 m) downstream and 8 ft (2.4 m) to the left of the impact point. The post base ended up next to the vehicle with the top near the impact point. Posttest photographs are shown in figure 36.

8. TEST SI #8

The test vehicle impacted at 29.59 mi/h (13.2 m/s) at a point on the left door 28 in (711 mm) behind with the longitudinal location of the vehicle center of gravity as measured without the dummy in the vehicle. The vehicle had a 5.5° roll angle as it leaned toward the test pole due to the side sliding forces acting on the tires. The maximum residual crush of the vehicle at the impact point was 7.5 in (190.5 mm). Pretest photographs of the vehicle and luminaire support are shown in figure 37.

After the initial separation from the vehicle, the luminaire support rotated up and over the test vehicle with the top of the pole hitting the ground about 1.08 s after impact. Just prior to impact with the ground, the center portion of the pole impacted the roof of the car. As the support rotated away, vehicle yawed counter clockwise, continue forward away from the impact area after yawing a total of about 45°. The vehicle did not pitch or roll very much, but remained stable during this transition. The final resting position of the vehicle was about 36 ft (11 m) downstream and 8 ft (2.4 m) to the right of the impact point, with the pole resting on the roof. The top of the pole was just past the end of the runway. Posttest photographs are shown in figure 38.

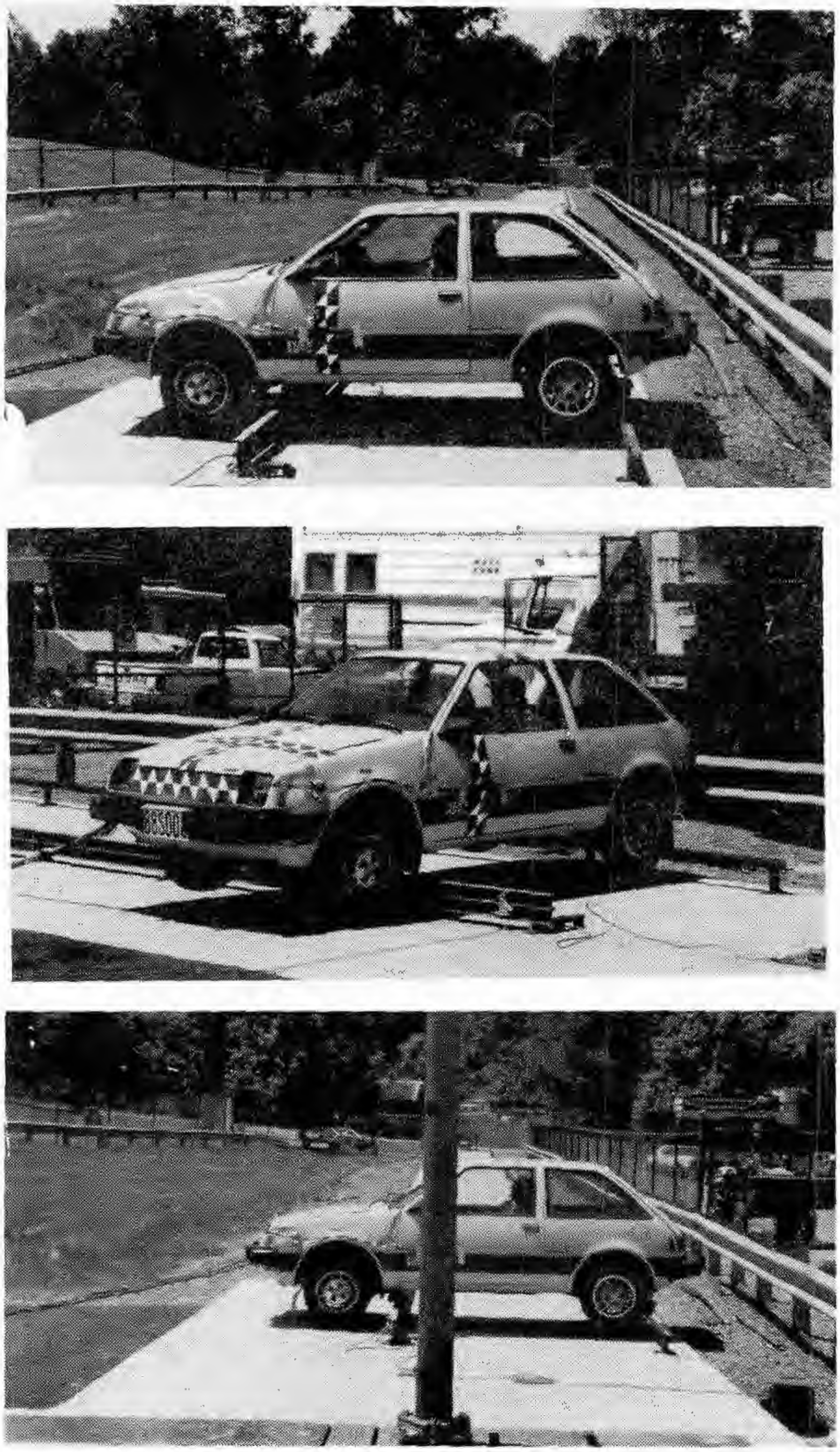


Figure 35. Pretest photographs of vehicle, test SI #7.

Figure 36. Posttest photographs of vehicle, test SI #7.

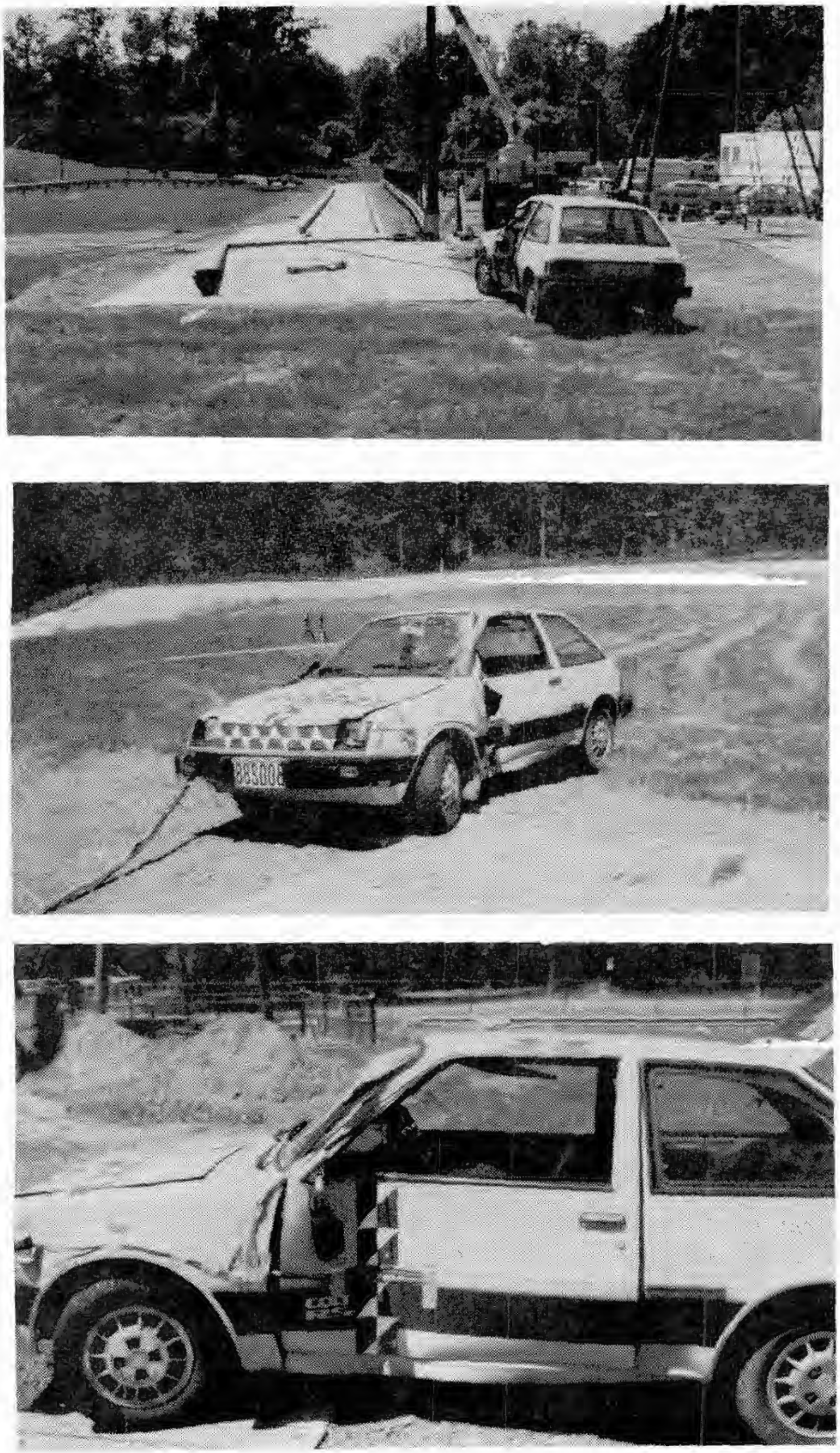


Figure 36. Posttest photographs of vehicle, test SI #7 (continued).

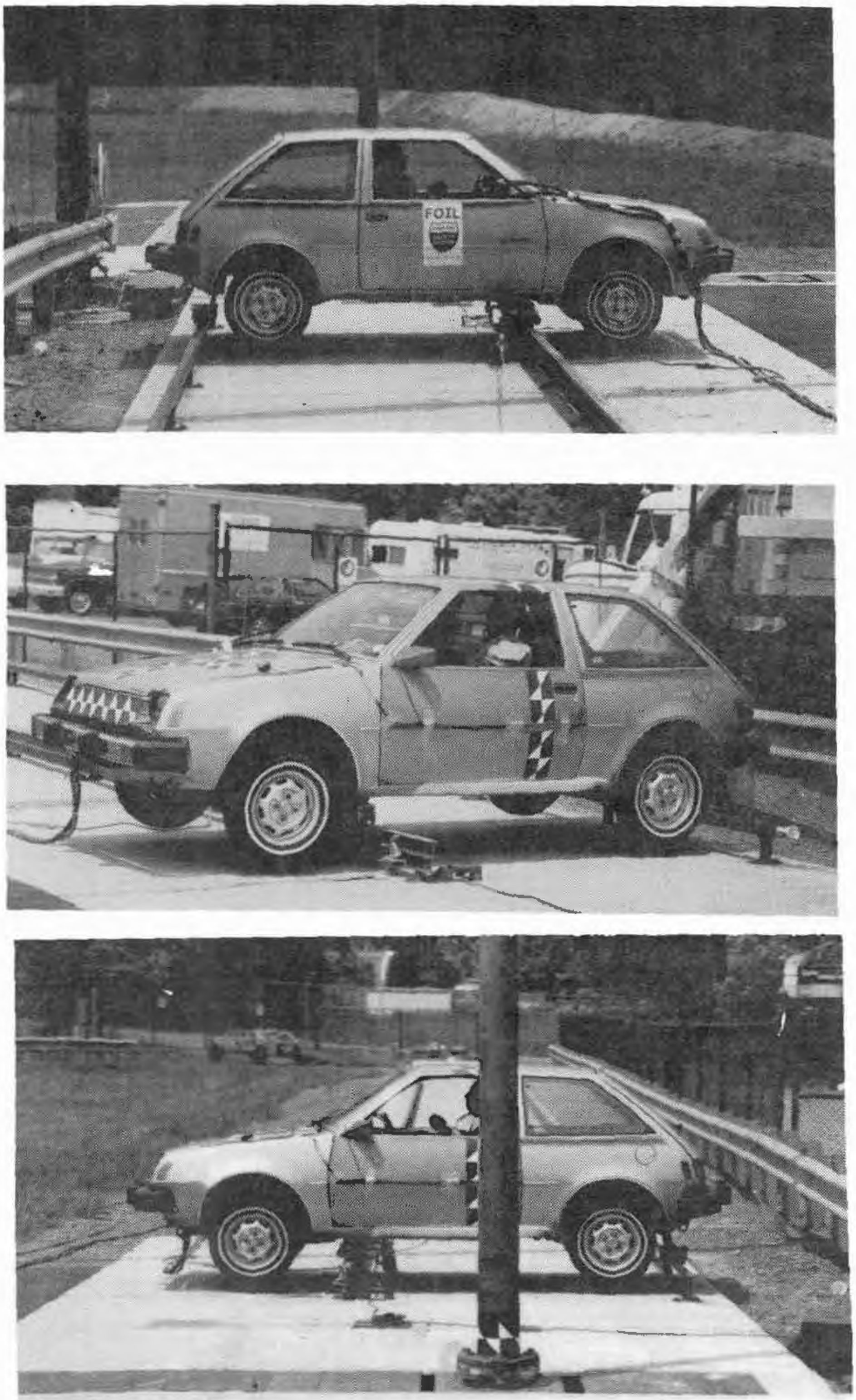


Figure 37. Pretest photographs of vehicle, test SI #8.

Figure 38. Posttest photographs of vehicle, test SI #8.

Figure 38. Posttest photographs of vehicle, test SI #8 (continued).

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