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EVALUATION OF DESIGN ANALYSIS PROCEDURES AND ACCEPTANCE CRITERIA FOR ROADSIDE HARDWARE

Volume II: The Effect of Soil Strength On Longitudinal Barrier Performance

August 1987
Final Report

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16. Abstract

This research was conducted to identify and investigate aspects of NCHRP Report 230 which require additional technical research. This report deals with five broad areas of concern: (1) the importance and effect of soil conditions on the dynamic performance of barriers, (2) methods for re-evaluating pre-Report 230 test results in light of the current Report 230 criteria, (3) linking the occupant risk factor to "real-world" accident cases, (4) assessing the potential hazards of the redirected vehicle, and (5) replacement of the 4500-lb test car.

This is the second of a six-volume report dealing with specific technical topics in NCHRP Report 230. The others in the series are:

Vol. No.	FHWA No.	Title
I	RD-87/096	Executive Summary
II	RD-87/097	The Effect of Soil Strength on Longitudinal Barrier Performance
III	RD-87/098	Evaluating Pre-Report 230 Crash Tests
IV	RD-87/099	The Importance of the Occupant Risk Criteria
V	RD-87/100	Hazards of the Redirected Car
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METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
in	inches	2.54	millimetres	mm
ft	feet	0.3048	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	0.0929	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
mi^2	square miles	2.59	kilometres squared	km^2
ac	acres	0.395	hectares	ha

MASS (weight)

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

VOLUME

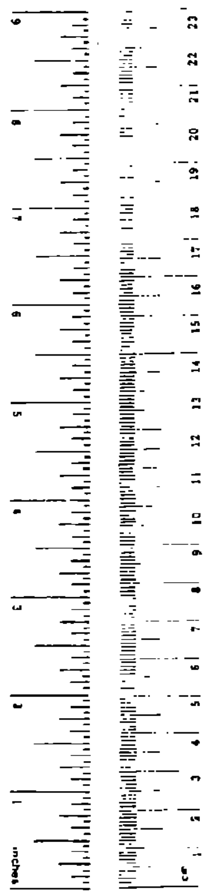
Symbol	When You Know	Multiply By	To Find	Symbol
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.0328	metres cubed	m^3
yd^3	cubic yards	0.0765	metres cubed	m^3

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

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

* SI is the symbol for the International System of Measurements



APPROXIMATE CONVERSIONS TO 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
km^2	kilometres squared	0.39	square miles	mi^2
ha	hectares (10 000 m^2)	2.53	acres	ac

MASS (weight)

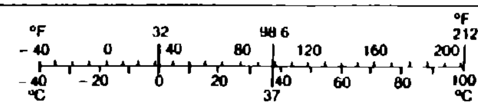
Symbol	When You Know	Multiply By	To Find	Symbol
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T

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

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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

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Objectives

The primary purpose of a guardrail system is to redirect an errant vehicle away from a roadside hazard and thus prevent a more serious collision. This is accomplished by transforming a portion of the kinetic energy of the impacting vehicle into barrier deformations. One of the important energy absorption components of such a system is the soil in which the system is anchored.

NCHRP Report 230(1) specifies that the soil used to anchor appurtenance test articles conform to the gradation curve of figure 1 and that it be compacted to at least 95 percent of its standard proctor density. These standards were chosen because most tests performed at Southwest Research Institute before Report 230 conformed to these conditions. It was not known how sensitive barrier performance was to the particular type of soil and the degree of compaction. The objective of this the research was to determine a rationally based specification for the soil conditions during a full-scale crash test and, more generally, to determine how sensitive barrier performance is to changes in soil strength.

There are two distinct types of guardrail behavior typically observed during dynamic impacts. When the soil strength is greater than the flexural capacity of the post, the guardrail system will behave like a cantilever beam with nearly rigid support. In this situation, the post will fail before the soil. For example, "weak post" systems have been designed to increase the bearing surface on the soil by using reaction plates and larger embedment lengths to develop the full flexure strength of the post in even the poorest of soils. Energy is absorbed by flexural deformation of the post rather than rigid-body displacement of the post in the soil. The complement of this situation is one in which the soil is weak with respect to post strength. During impact the post will behave as a nearly rigid body and the soil shear strength will be exceeded before that of the post.

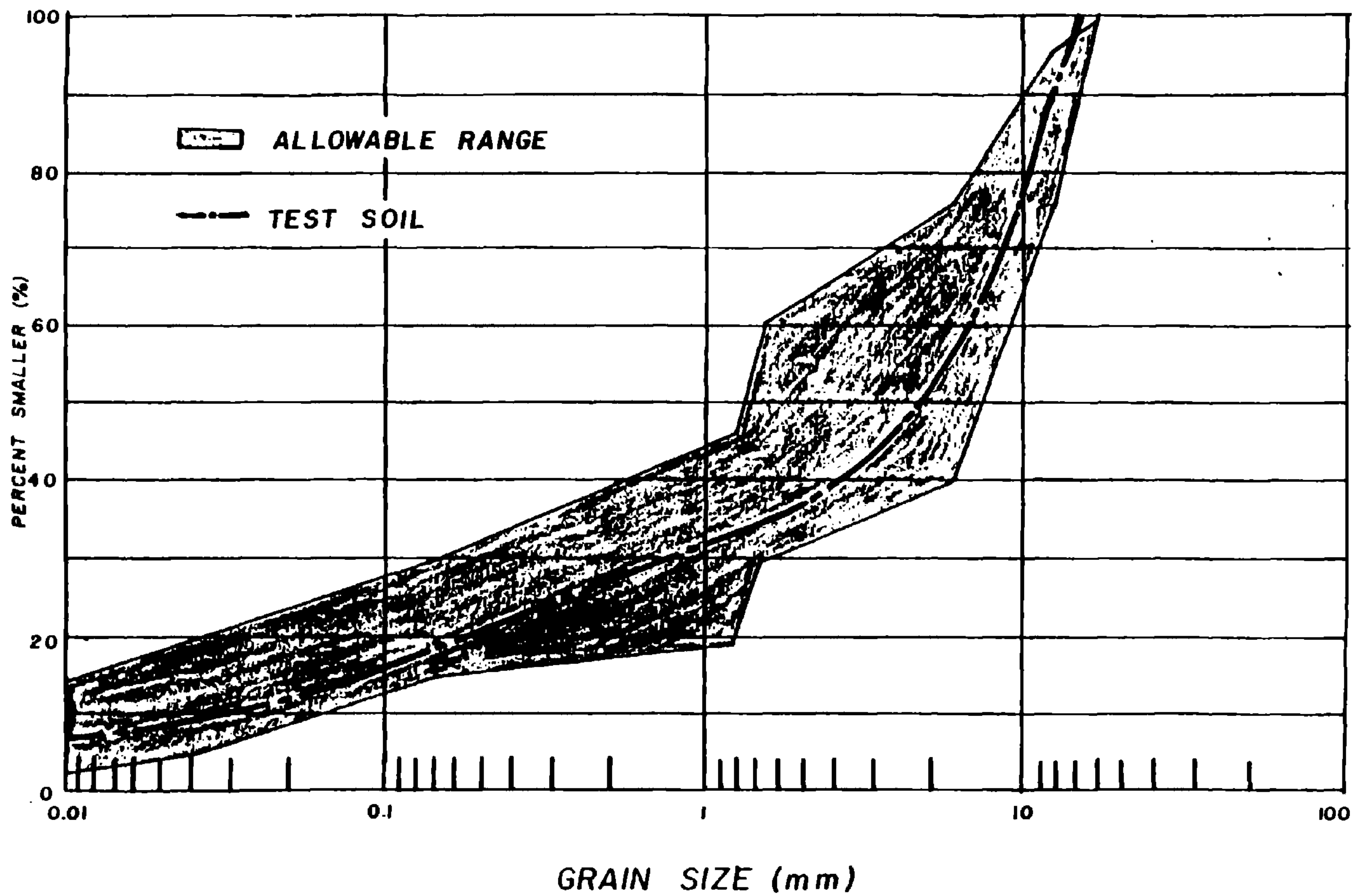


Figure 1. Grain size distribution of Report 230 Type S1 soil.

Characterizing the Force-Deflection Properties of Posts in Soil

Many parameters affect soil strength. Density, moisture content, angle of internal friction, cohesion, and grain size distribution are some of the important factors that affect the dynamic behavior of soils. The analysis of the contribution of all of these factors was clearly beyond the scope and resources of this research. Soil density, therefore, was chosen as the sole variable for study for the following reasons:

- Density is perhaps the single most important parameter. Soil resistance is primarily a function of the lateral earth pressure, which is itself linearly dependent on density.
- Density is both easy to vary and easy to measure in the field.

A series of pendulum tests were performed where the soil density was varied and the post resistance was calculated from pendulum-mass accelerations. Table 1 is a summary of these tests and appendix A of this volume contains detailed information about each individual test.

The dynamic behavior of the laterally loaded post can be divided into two distinct phases; an elastic and a plastic phase. These phases are shown in figures 2 and 3. During the elastic phase the force-deflection curve is linear. Once the ultimate load is reached, the soil continues to deform plastically. In figure 3, the load decreases from the ultimate value because the post is pulled radially out of the soil at the same time it is being rotated.

Table 1 shows that the post/soil stiffness, amount of energy absorbed, and the ultimate load all increase with increasing soil densities. Figure 4 shows the variation of the ultimate post/soil strength with soil density.

Figure 4 also demonstrates another interesting phenomena. Ultimate post/soil strength is a function of the gross <u>in-situ</u> density and not the

Table 1. Pendulum test summary.

Test Number	Dry Density (pcf)	Water Content (%)	Percent Proctor Density (%)	Energy Absorbed by the Soil (in-kips)	Ultimate Load (kips)	Stiffness (kpi)	Zero Load Deflection (in).
SD6*	100.4	3.5	77			Post Broke	
SD7	111.3	3.5	86	181.8	8.4	3.8	34.6
SD8	118.8	3.5	92	250.8	13.7	8.6	25.5
SD9	123.9	3.5	96	260.0	20.6	12.1	18.8
SD10		- Incorrect Soil Placement -			11.6	4.6	35.0
SD11	115.7	6.9	89	212.5	8.3	3.5	32.8
SD12	125.5	8.1	97	102.4		- Pendulum Ramped -	

* All remaining tests used a 6 x 8 steel box beam post

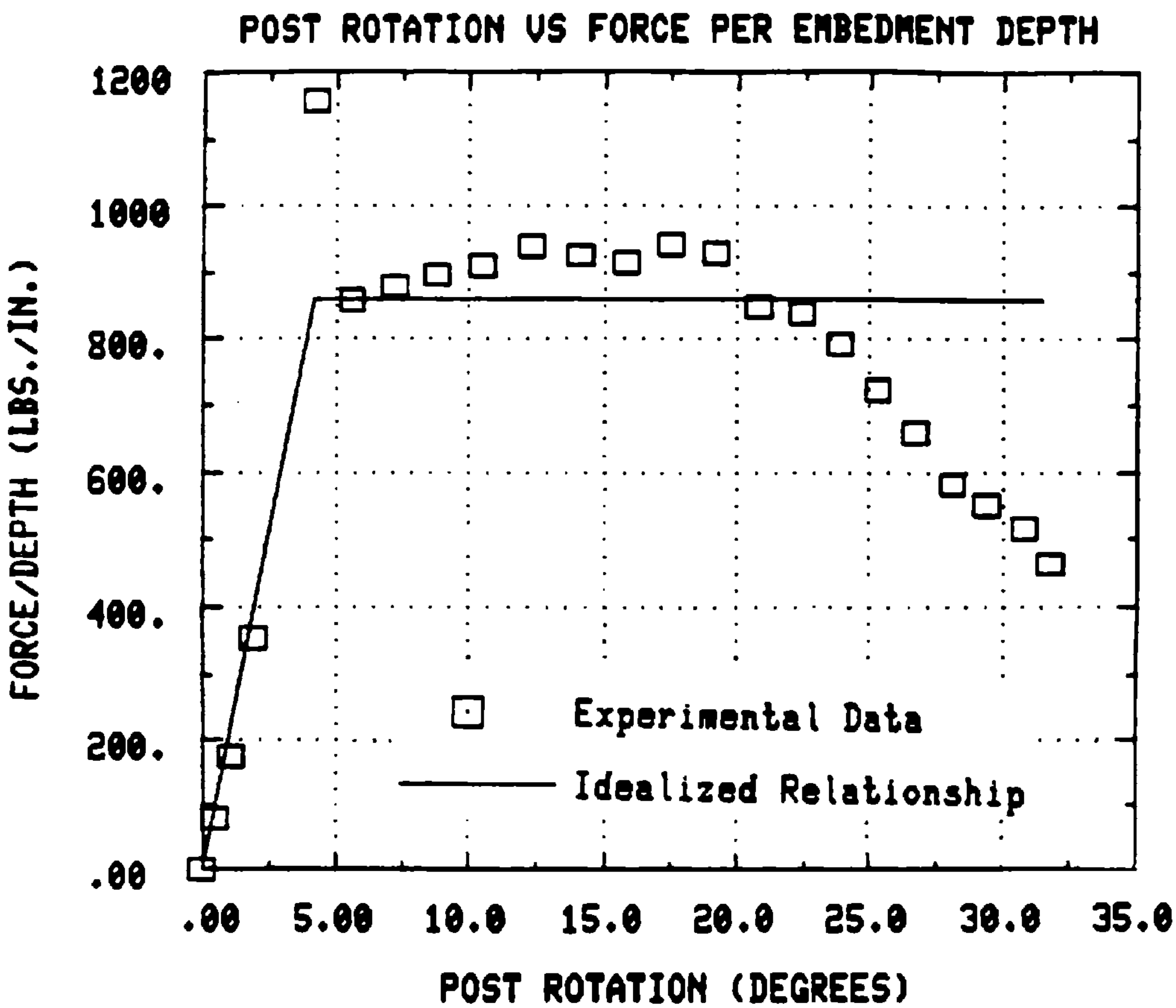


Figure 2. Force-rotation curve, test SD-9.

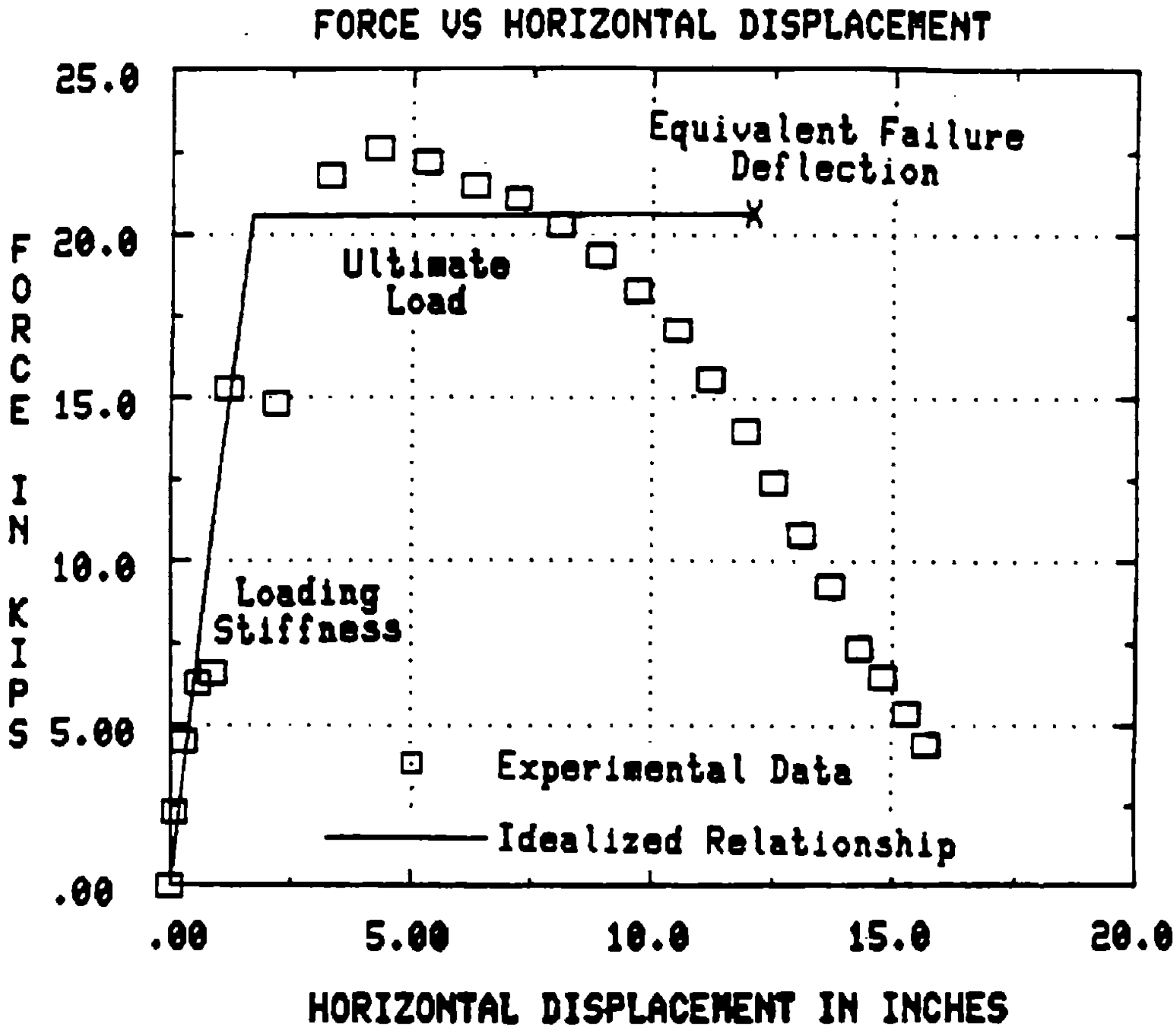


Figure 3. Force-horizontal deflection curve, test SD-9.

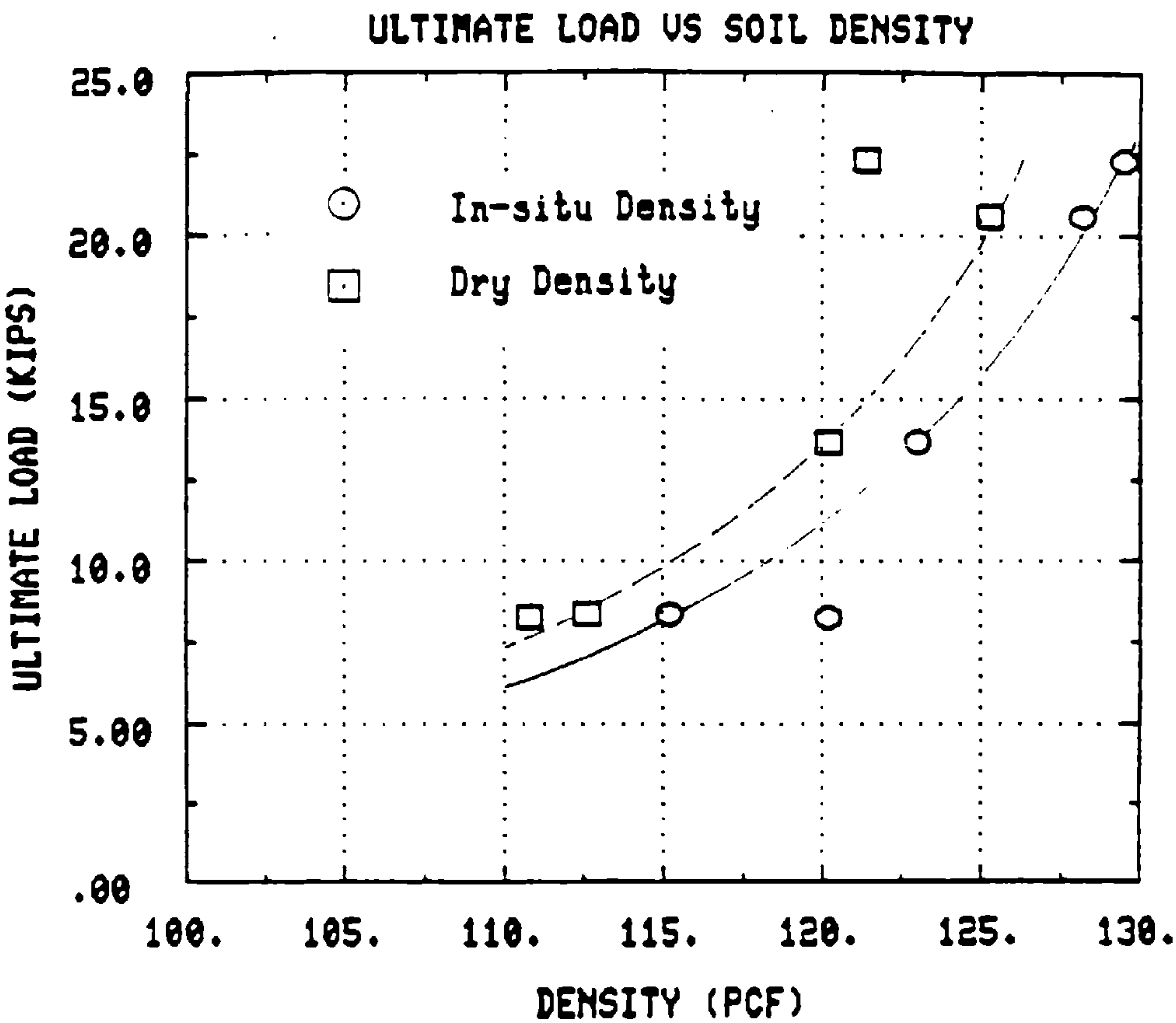


Figure 4. Ultimate load as a function of soil density.

dry density. The three points lying on the dashed line all represent tests with moisture contents of 3.5 percent. The two points lying off the line represent tests at other moisture contents. The solid line in figure 4 shows that when gross in-situ density, the density including the density of water, is used as the independent variable, the five data points will lie along the same line. This trend persists until soil saturation occurs. At saturation the effective density becomes the buoyant density and the soil quickly weakens. For example, if a soil having a gross density of 140 pcf (2243 kg/m^3) were saturated with water, the density effective in resisting post deflection is the gross density minus the density of water, 62.4 pcf (1000 kg/m^3); therefore, a saturated soil with a density of 140 pcf (2243 kg/m^3) is only as strong as a dry soil weighing 77.6 pcf (1243 kg/m^3).

Effect of Soil Strength on Barrier Performance

Computer Simulations.

Knowing the behavior of the post-soil subsystem, the effect of soil strength on the guardrail system as a whole was investigated using the BARRIER VII(2) computer simulation program.

BARRIER VII is a general purpose computer program for analyzing the interaction between vehicles and highway safety appurtenances. Appurtenances are modeled as a series of simple structural members such as springs, elasto-plastic posts, beams, links and hinges. Using these different elements many typical barriers can be accurately modeled.

A G4(1S) guardrail system was chosen as a test system for several reasons:

- The G4(1S) is one of the most popular strong post systems.
- The G4(1S) and the G4(2W) are generally thought to exhibit similar behavior.

- A strong post system is capable of developing much more flexural capacity; thus it is more difficult to provide a rigid support for the strong post than for the weak.

- The G4(1S) has been in service for many years and its performance is well understood.

A G4(1S) guardrail system was therefore chosen as a representative system which still posed a worst-case situation. Table 2 shows the post properties used for the BARRIER VII simulations. Once the ultimate moment is reached the post will fail because of high soil-shear or excessive deflection. A very large ultimate shear was specified so the post would deform plastically. The failure distance, Δ_F, was calculated to correspond to the energy dissipated in the actual pendulum tests shown in table 1. The energy is given by the area under the force deflection curve. Therefore, referring to figure 3,

$$E = P_U \Delta_F - \frac{1}{2} \left(\frac{P_U}{K} \right) P_U \quad (1)$$

$$\Delta_F = \frac{E}{P_U} + \frac{P_U}{2K} \quad (2)$$

where

P_U = ultimate load

Δ_F = equivalent failure deflection

K = loading stiffness

E = energy dissipated

Table 2. BARRIER VII post properties.

	Stiffness (kpi)	Ultimate Moment (in-k)	Ultimate Shear (kips)	Deflection at Failure (in)
Weak axis	0.9 k	0.9(21 P_U)	100	0.9 Δ_F
Strong axis	k	21 P_U	100	Δ_F

Values of k, P_U and Δ_F are the values idealized from the pendulum test data.

The values taken from the pendulum test were all strong axis values. Calcote(3) shows data which suggest that the weak axis develops about 90 percent of the strong axis strength for 6x8-inch (15.2x20.3-cm) steel posts. All the weak axis parameters were simply scaled-down to 90 percent of the strong axis value. Of course, the weak axis is not critical in a strong-post barrier like the G4(1S) therefore, this empirical approximation was deemed sufficient for the purpose of this simulation.

Using the above rationale and the pendulum data, eight simulations were performed; figure 5 shows a plot of the results. The dashed line represents the hypothetical case where the post is perfectly rigid. The post, however, is not rigid; it has some ultimate flexural capacity. The solid line represents this more realistic case. When the S1 soil is compacted to a density greater than 115 pcf (1842 kg/m^3), the soil provides rigid support and the post will fail in flexure. Below 115 pcf (1842 kg/m^3) the post will behave as a rigid body and the soil will fail.

One primary reason for providing a test specification is to allow comparisons of test data between testing agencies. As figure 5 shows, the barrier is very sensitive to small changes in soil density until 115 pcf (1842 kg/m^3), nearly 90 percent of the standard proctor density, is achieved. After this point the barrier performance is identical regardless of whether the compaction is 90 or 120 percent of the standard proctor density.

Full-Scale Crash Tests.

In order to validate the findings shown in figure 5, three full-scale crash tests were performed. The tests are summarized in table 3 and the full test reports appear in appendix B.

Dynamic barrier deflection is generally the most repeatable characteristic of a longitudinal barrier collision. A barrier impact is a combination of many smaller impact events and many of the measurable variables are not repeatable. An analogous situation is the measurement

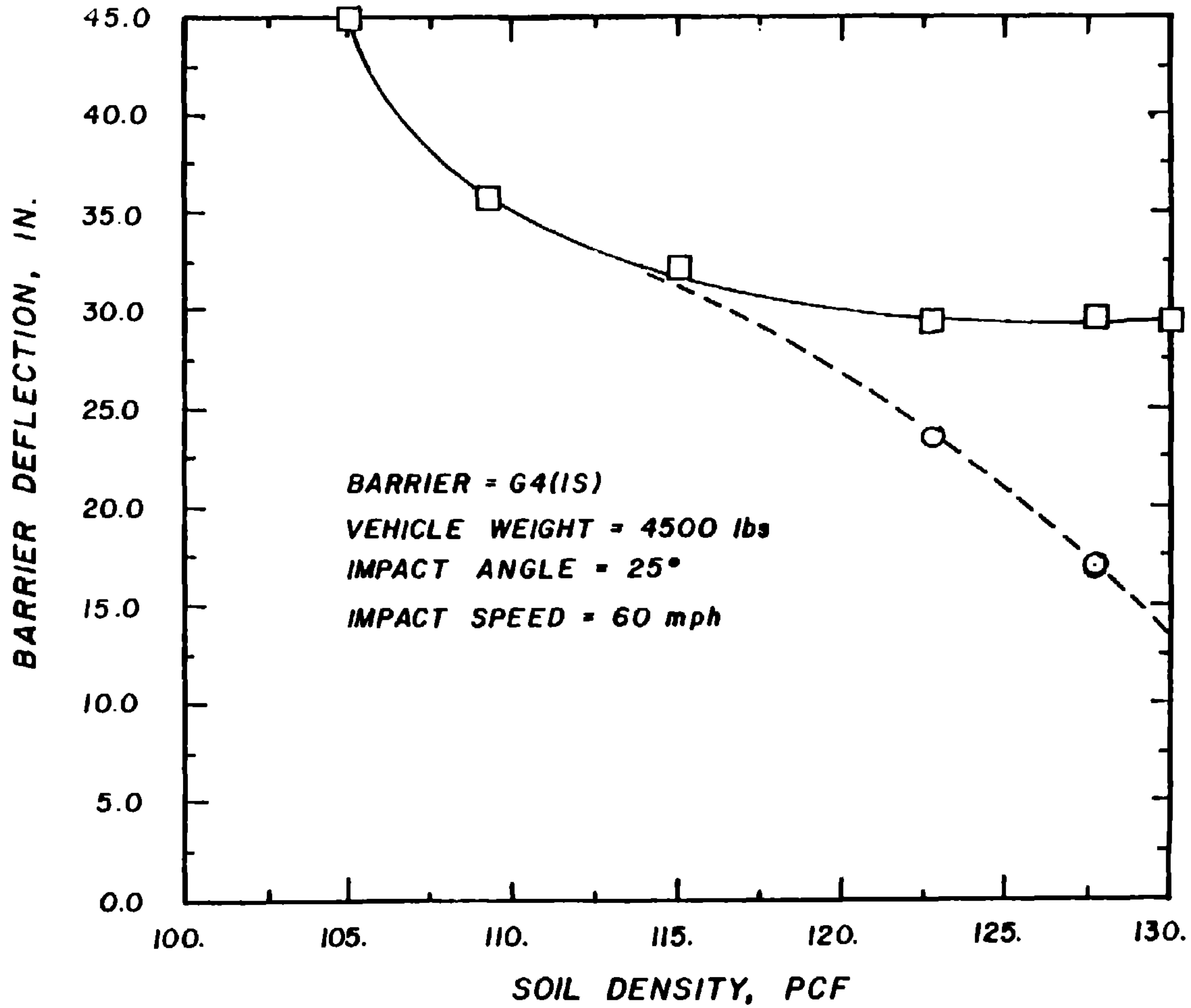


Figure 5. Effect of soil compaction on G4(1S) deflection.

Table 3. Comparison of soil-post interaction crash tests.

	Test		
	SPI-1	SPI-2	SPI-3
Soil Conditions			
Natural Soil Density (pcf)	148	108	121
Standard Proctor Compaction (%)	110	80	90
Moisture Content (%)	3.7	3.7	3.5
Dynamic Deflections			
Simulated (in.)	30	44	30
Actual (in.)	35.6	45.1	29.6
Evaluation Criteria (film data)			
Lateral Occupant Risk (fps)	14.6	16.0	15.9
Lateral Ridedown Accel (g's)	5.2	5.5	6.4
Lateral 50 msec Accel (g's)	5.2	5.5	6.4
Barrier Damage			
Number of Deflected Posts	6	9	8
Number of Deformed Beams	2	2	2
Number of Beam/Post Separations	0	1	1

of vehicle accelerations. Each local structural event makes its mark on the instantaneous acceleration so that any two traces differ at any particular instant; the area enclosed by the acceleration-displacement curve, the change in velocity, however, is repeatable. The change in velocity is a measure of the total transfer of energy whereas the instantaneous acceleration only represents the collision interaction at that instant. All the forces applied to the barrier will result in barrier displacements; the dynamic deflection was therefore used to assess the total performance of the guardrail system.

The soil compaction in tests SPI-1 and SPI-3 was 110 and 90 percent standard proctor compaction, respectively. In terms of figure 5, both tests lie along the flat portion of the solid line; they were expected to yield identical results. As table 3 shows, the dynamic barrier deflections were quite similar. The BARRIER VII simulation was only 1/2 inch (1.3 cm) different from test SPI-3 and 5.6 inches (14.2 cm) more than expected in test SPI-1.

In both test SPI-1 and SPI-3, the post failed in flexure as shown in figure 6. The soil remained undeformed, providing a rigid support which allowed the post to develop its ultimate strength.

In contrast, the posts in test SPI-2 remained undeformed and the soil failed as shown in figure 7. In this case the soil was not capable of providing a rigid support and before the steel post could develop its ultimate moment, the soil failed. Because the post never reached its ultimate moment, it experienced only elastic deflections and not the permanent plastic deformations experienced in tests SPI-1 and SPI-3.

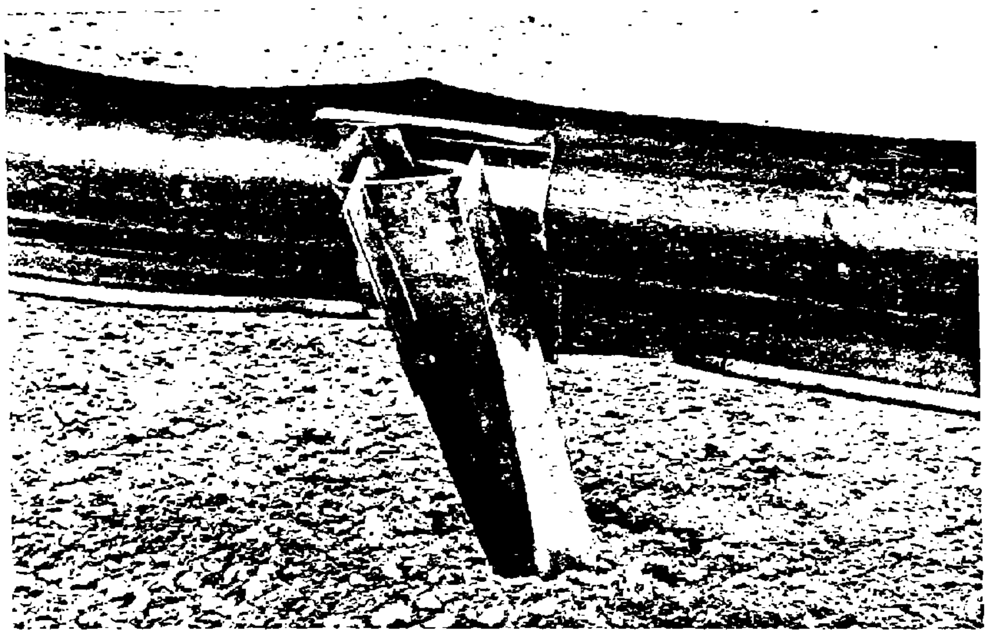


Figure 6. Post failure, SPI-1.

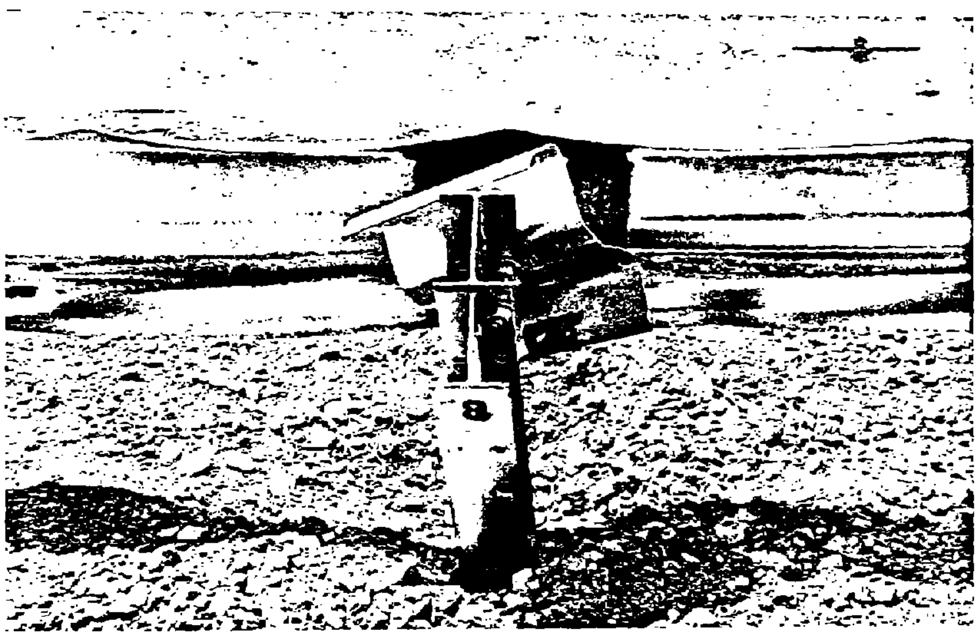


Figure 7. Soil failure, SPI-2.

Conclusions and Recommendations

Conclusions.

The full-scale crash tests indicate that the behavior of a strong post guardrail system is similar to that predicted by the curves in figure 5. The most important single conclusion of this work is that soil must be placed such that the ultimate strength of the posts is achieved.

Soil compaction is only one of the many parameters which effect the strength of soils. Other research is now in progress which will try to quantify further the effects of many different soil properties on guardrail post strength. What this present research demonstrates is that the soil must develop the full strength of the post to ensure that some standard barrier performance is achieved.

Although this research was directed at assessing the Report 230 specification the results are also applicable to field installations. It is as important to place the soil in the field as it is in research and testing applications. The barrier will not perform as desired if, for example, the soil is not sufficiently compacted to develop full post strength.

Recommendations.

In general, the present soil specification is very good. A specification should be specific enough to provide uniformity yet simple enough to implement. Therefore, the following specific observations are enumerated below.

Soil Type. Although only the S1 soil specified in Report 230 was used and no work was done with other soils, it may help simplify procedures if a less specific soil was designated. Report 230 specifies that "the embedment soil should be a low-cohesion, well-graded crushed stone or broken gravel with particle size distribution given in [Report 230] Table 1."[1] It is probably not necessary to specify the particle size distribution as long as the soil is well graded, low-cohesion and a crushed stone.

Moisture Content. Report 230 makes no mention of soil moisture other than that a test should not be performed in frozen or saturated soil. As mentioned previously, soil moisture increases strength when the moisture content is less than saturated. Therefore the specification is probably adequate as written since any additional soil moisture will improve performance.

Compaction. Currently a density of 95 percent standard proctor density is specified in Report 230. As was shown in figure 5, the point where a rigid foundation is provided seems to occur near 90 percent. To provide some factor of safety in the specification, 95 percent standard proctor should be retained as the minimum soil compaction specified.

References

(1) Michie, J.D., "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances," NCHRP Report 230 Transportation Research Board, Washington, DC, March 1981.

(2) Powell, G.H., "Computer Evaluations of Automobile Barrier Systems," FHWA-RD-73-73, Federal Highway Adm., Washington, DC, August 1970.

Appendix A. Pendulum Tests

Test Procedures-

In order to determine what the properties of dynamically loaded soil were, a number of pendulum tests were performed and are summarized in table 4. An NCHRP Report 230 S-1 soil was placed in a 5-ft (1.5-m) wide by 5-ft (1.5-m) deep and 12-ft (3.7-m) long soil pit and compacted in lifts by a hand-held pneumatic tamper until the desired level of consolidation had been acnieved. Soil density was varied between tests by altering the lift heights; smaller lifts resulting in soils with greater compaction. The final density of the placed material was determined from the weight of material placed divided by the volume of the test pit.

The moisture content of the delivered material varied from 2.3 percent to 8.1 percent. For tests at other moisture contents, the delivered material was placed as before and a measured amount of water was added to each lift of soil.

The test post was a 6x8-inch (15.2x20.3-cm) steel box beam 72 inches (182.9 cm) in length. Embedment depth was 40 inches (101.6 cm) with the 6-inch (15.2-cm) beam width reacting against the soil. In tests SD-1 through SD-6 a 6 x 8-inch wooden post was used. At high levels of compaction the soil strength exceeded the post strength thus fracturing the wooden post. A steel box beam was therefore used in the remaining tests due to its increased bending strength.

A 6x8-inch (15.2x20.3-cm) honeycomb pyramid-shaped element was attached to the post in the contact area. The purpose of the crushable nose was to attenuate the otherwise too rapid buildup of force in the post and to more closely simulate the force-time history of a guardrail post.

The data system included accelerometers on the post, a uniaxial accelerometer on the pendulum mass, and high speed photography. The biaxial accelerometer device was mounted 24 inches above the ground on the

Table 4. Soil condition summary.

Test	In-Situ Density (lbs/ft^3)	Moisture Content (%)	Dry Density (lbs/ft^3)	Compaction (%)	Comments
SD6	103.9	3.5	100.4	77.5	Wooden Post - Broke
SD7	115.2	3.5	111.3	85.8	Steel Post
SD8	123.0	3.5	118.8	91.6	Steel Post
SD9	128.2	3.5	123.9	95.5	Steel Post
SD10		INCORRECT SOIL PLACEMENT			
SD11	123.7	6.9	115.7	89.2	Steel Post
SD12	135.7	8.1	125.5	96.8	Steel Post - Pendulum Ramped
SD13	129.5	6.7	121.4	93.6	Steel Post

post opposite the point of impact as shown in figure 8. The initial orientation of the accelerometers was vertical and horizontal. To record the angular displacement off the post the displacements at each time stop of two reference points attached to the post were acquired from high speed (500 frames/sec) film analysis. The single accelerometer mounted horizontally on the 4000-lb (1814-kg) pendulum mass measured the amount of force delivered to the post-soil system.

The electronic data were recorded on magnetic tape for subsequent processing. The high speed film was processed and then analyzed to determine the post rotation-time plot. With the rotation-time data, the biaxial post accelerometer data were resolved into horizontal and vertical components and then integrated for velocity and displacement.

After the post had been installed in the test pit, the pendulum mass was raised to a height of 13.4 ft (4.1 m) and released. The drop height produces an impact velocity of 20 mph or 29.33 fps (8.9 m/s) when impacting the guardrail post.

Test Data

Tables 5 through 12 contain the accelerometer data for tests SD-6 through SD-13 and the force deflection plots appear in figures 9 through 16.

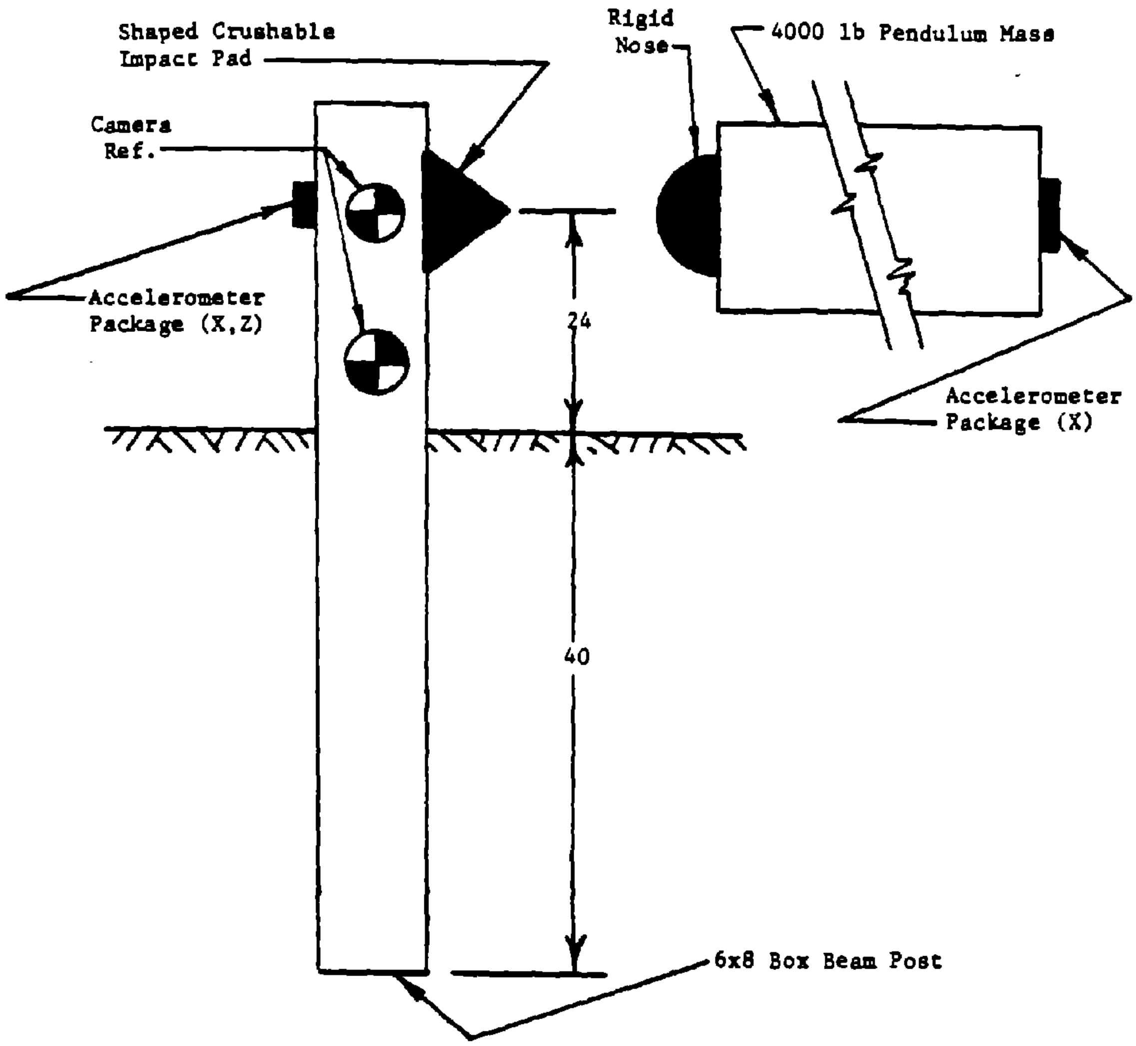


Figure 8. Pendulum test details.

Table 5. Accelerometer data, test SD-6.

TEST ID ----- SD-6-5
TEST DATE --- 08-29-84

PENDULUM KINETICS SUMMARY
NOTE: VALUES ARE INSTANEOUS AT TIME

TIME (SEC)	(-------MASS A (G'S)	V (FPS)	F (LBS) ---------)(AX (G'S)	AY (G'S)	VX (FPS)	---------POST--------- VY (FPS)	ANGLE (DEG)	DX (IN)	DY (IN) ---------)
0.000	.1	29.3	-440.	2.5	-.5	0.0	0.0	0.0	0.0	0.0
.005	-.5	29.3	1861.	41.3	6.2	3.1	.5	.4	.1	.0
.010	-.8	29.2	3319.	67.9	9.2	12.6	1.6	1.8	.5	.1
.015	-.9	29.0	3778.	59.7	8.0	23.6	2.9	3.4	1.6	.2
.020	-.5	28.9	2107.	10.1	4.6	29.2	4.1	5.2	3.2	.4
.025	-.3	28.9	1066.	-4.4	4.6	28.9	4.8	7.2	5.0	.7
.030	-.3	28.8	1126.	-2.8	1.7	28.4	5.3	9.3	6.7	1.0
.035	-.3	28.8	1224.	-5.9	1.6	27.8	5.8	11.4	8.4	1.3
.040	-.3	28.7	1238.	-1.0	9.6	27.2	6.5	13.6	10.0	1.7
.045	-.3	28.7	1382.	-3.2	6.5	26.5	7.2	15.7	11.7	2.1
.050	-.4	28.6	1517.	-3.6	-.1	26.3	8.1	17.8	13.2	2.6
.055	-.4	28.6	1578.	.4	8.1	26.1	8.8	19.9	14.8	3.1
.060	-.4	28.5	1435.	-3.8	8.1	25.4	9.6	21.9	16.3	3.6
.065	-.4	28.4	1552.	-5.9	1.8	24.7	10.4	23.8	17.9	4.2
.070	-.4	28.4	1613.	-4.1	3.6	23.9	11.0	25.8	19.3	4.9
.075	-.5	28.3	2174.	3.8	1.6	23.9	11.0	27.6	20.7	5.5
.080	-.3	28.2	1337.	-2.9	2.2	23.3	11.5	29.5	22.2	6.2

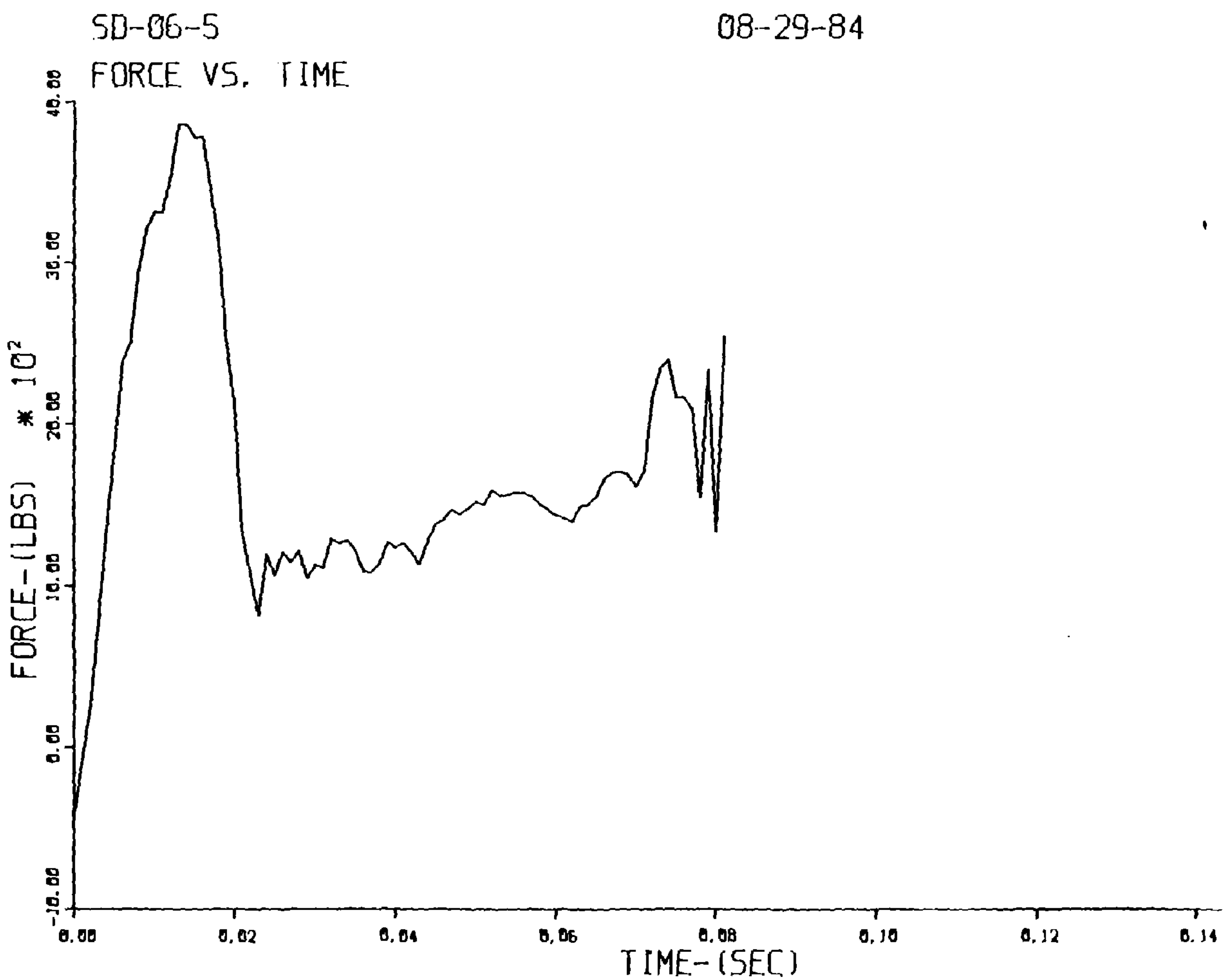


Figure 9. Force-deflection curve, test SD-6.

Table 6. Accelerometer data, test SD-7.

TEST ID ----- SD-7-5
TEST DATE --- 08-30-84

PENDULUM KINETICS SUMMARY
NOTE: VALUES ARE INSTANEOUS AT TIME

	(--------MASS--------)			(--------------------POST-------------------)						
TIME (SEC)	A (G'S)	V (FPS)	F (LBS)	AX (G'S)	AY (G'S)	VX (FPS)	VY (FPS)	ANGLE (DEG)	DX (IN)	DY (IN)
0.000	.1	29.3	-486.	.6	-.0	0.0	0.0	0.0	0.0	0.0
.005	-.4	29.3	1452.	20.5	2.1	1.5	.2	.3	.0	.0
.010	-.8	29.2	3339.	26.1	2.5	5.3	.6	.6	.2	.0
.015	-1.2	29.1	4572.	23.5	-.1	9.5	1.0	1.0	.7	.1
.020	-1.3	28.8	5139.	3.2	-5.8	12.2	.8	1.8	1.3	.1
.025	-1.0	28.7	4082.	-16.0	-3.9	10.3	-.3	2.7	2.0	.1
.030	-2.9	28.4	11696.	102.9	9.7	16.1	.3	4.0	2.7	.1
.035	-1.5	27.9	6168.	-48.3	2.3	26.9	1.0	5.5	4.1	.2
.040	-2.5	27.6	10070.	21.2	-9.2	24.4	.9	7.1	5.6	.2
.045	-2.1	27.2	8572.	.1	3.4	23.5	.7	8.9	7.0	.3
.050	-2.1	26.9	8213.	-6.7	2.0	23.6	.9	10.8	8.5	.3
.055	-2.1	26.5	8361.	-4.0	.9	23.1	1.2	12.7	9.9	.4
.060	-2.0	26.2	7929.	-.5	3.6	22.7	1.5	14.6	11.2	.5
.065	-1.9	25.9	7497.	-5.4	2.5	22.3	2.0	16.4	12.6	.6
.070	-1.8	25.6	7076.	1.6	8.1	21.9	3.0	18.2	13.9	.7
.075	-1.6	25.3	6402.	.8	12.2	21.7	4.6	20.0	15.2	1.0
.080	-1.5	25.1	5897.	-3.6	7.4	21.9	6.1	21.6	16.5	1.3
.085	-1.4	24.9	5772.	4.1	9.3	21.7	7.6	23.3	17.8	1.7
.090	-1.3	24.6	5109.	-1.4	9.8	21.4	9.1	24.8	19.1	2.2
.095	-1.2	24.4	4615.	-1.5	5.9	21.2	10.5	26.4	20.4	2.8
.100	-1.0	24.3	4143.	-3.7	10.7	21.0	11.8	27.9	21.7	3.5
.105	-1.0	24.1	3966.	-5.7	1.4	20.3	12.7	29.4	22.9	4.2
.110	-.9	24.0	3420.	-4.9	8.5	19.6	13.5	31.0	24.1	5.0
.115	-.8	23.8	3169.	-3.1	2.5	19.3	14.3	32.5	25.3	5.8
.120	-.7	23.7	2665.	-4.1	7.4	18.8	15.1	33.9	26.4	6.7
.125	-.7	23.6	2647.	4.1	1.3	18.4	15.9	35.1	27.5	7.6
.130	-.4	23.5	1753.	-1.7	2.9	18.1	16.6	36.1	28.6	8.6
.135	-.4	23.4	1451.	-3.2	5.4	17.7	17.3	36.5	29.7	9.6
.140	-.3	23.4	1264.	1.5	5.4	17.3	18.0	36.1	30.8	10.7
.145	-.3	23.3	1035.	.6	4.9	17.4	19.1	34.5	31.8	11.8
.150	-.2	23.3	722.	-3.1	4.3	17.2	19.8	31.3	32.8	12.9

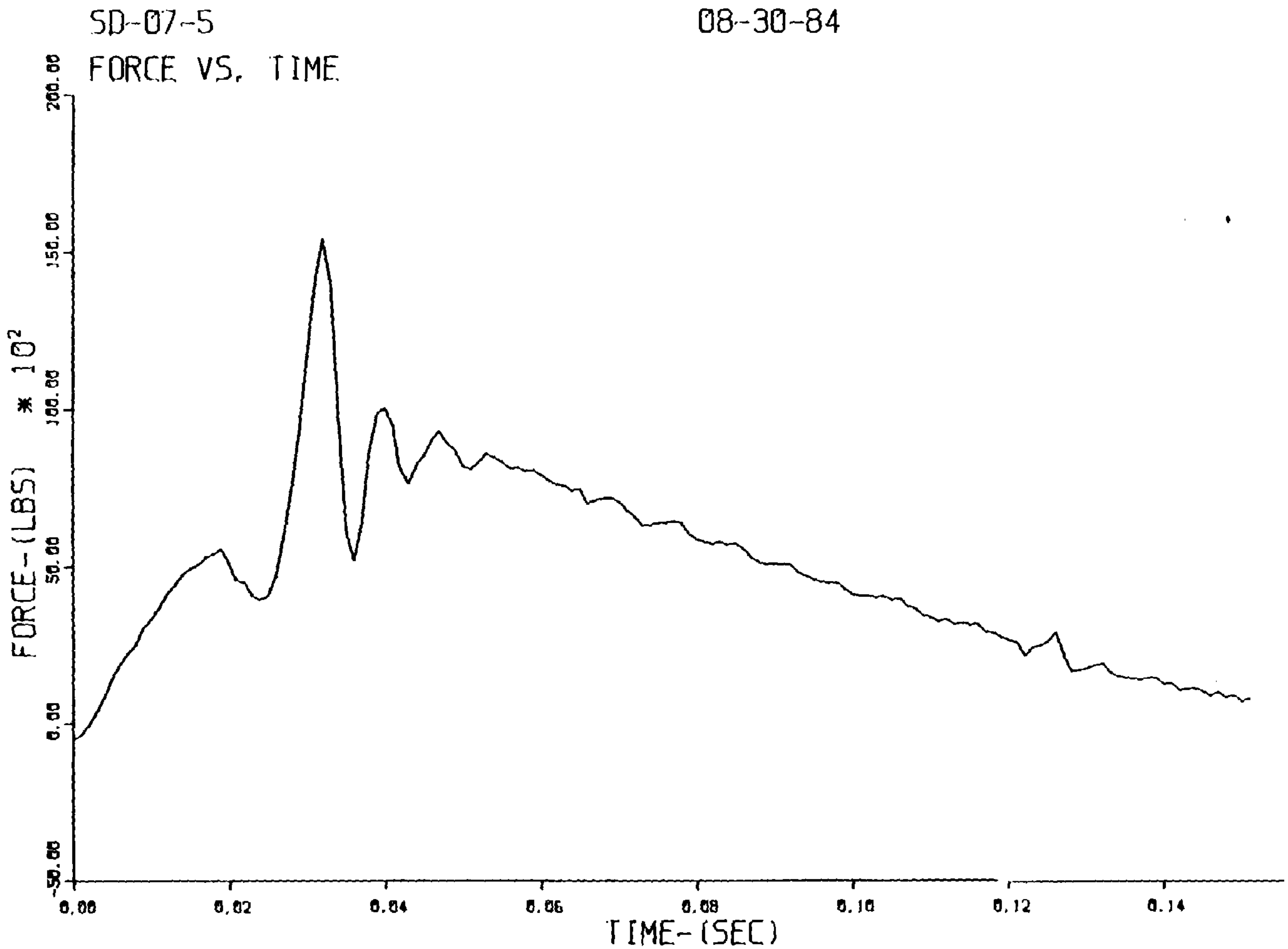


Figure 10. Force-deflection curve, test SD-7.

Table 7. Accelerometer data, test SD-8.

TEST ID ----- SD-8-5
TEST DATE --- 09-13-84

PENDULUM KINETICS SUMMARY
NOTE: VALUES ARE INSTANEOUS AT TIME

	(-------PASS--------)			(--------------------POST--------------------)						
TIME (SEC)	A (G'S)	V (FPS)	F (LBS)	AX (G'S)	AY (G'S)	VX (FPS)	VY (FPS)	ANGLE (DEG)	DX (IN)	DY (IN)
0.000	-.5	29.3	2013.	20.3	3.7	0.0	0.0	0.0	0.0	0.0
.005	-1.0	29.2	3944.	19.4	2.9	3.1	.3	.2	.1	.0
.010	-1.4	29.0	5883.	13.3	-5.2	6.2	.1	.5	.4	.0
.015	-1.6	28.8	6276.	-2.1	-4.7	7.3	-.4	1.0	.8	.0
.020	-2.0	28.5	8144.	43.9	6.3	6.4	-.7	1.7	1.2	-.0
.025	-4.9	27.9	13695.	110.3	17.9	21.8	1.1	2.7	2.0	-.0
.030	-3.6	27.4	14343.	17.0	8.7	19.9	.6	3.9	3.3	.1
.035	-3.5	26.8	14194.	-8.8	12.4	20.3	.1	5.3	4.6	.1
.040	-3.8	26.2	15044.	-1.7	13.8	20.1	.5	6.8	5.8	.1
.045	-3.7	25.6	14663.	-.1	7.7	19.4	.9	8.5	6.9	.2
.050	-3.7	25.0	14706.	-3.3	-1.4	18.8	1.3	10.3	8.1	.2
.055	-3.4	24.5	13540.	-4.4	1.1	18.2	1.7	12.1	9.2	.3
.060	-3.4	23.9	13648.	-2.7	7.9	17.7	2.4	14.0	10.3	.4
.065	-3.3	23.4	13184.	-2.9	5.1	17.3	3.3	15.8	11.3	.6
.070	-3.2	22.9	12677.	-2.4	3.7	16.8	4.3	17.6	12.4	.8
.075	-3.0	22.4	12033.	.6	6.1	16.4	5.3	19.3	13.4	1.1
.080	-3.0	21.9	11857.	-1.3	8.3	16.1	6.4	21.0	14.3	1.5
.085	-2.8	21.4	11033.	-1.0	5.8	15.6	7.5	22.6	15.3	1.9
.090	-2.6	21.0	10443.	-7.2	6.1	15.0	8.3	24.2	16.2	2.4
.095	-2.4	20.6	9683.	-5.5	3.6	14.2	9.2	25.7	17.1	2.9
.100	-2.1	20.2	8542.	-6.8	5.5	13.3	10.0	27.2	17.9	3.5
.105	-1.9	19.9	7656.	-5.7	7.3	12.4	11.1	28.6	18.7	4.1
.110	-1.6	19.6	6494.	-5.6	5.6	11.5	12.1	30.0	19.4	4.8
.115	-1.4	19.4	5586.	-6.7	5.4	10.6	13.1	31.4	20.1	5.6
.120	-1.1	19.2	4404.	-6.3	6.2	9.6	14.1	32.8	20.7	6.4
.125	-.9	19.0	3518.	-4.7	6.1	8.6	15.0	34.1	21.2	7.2
.130	-.8	18.8	3026.	-16.5	15.2	9.5	14.9	35.4	21.8	8.1
.135	-.5	18.7	2151.	-11.7	1.0	8.8	15.6	36.7	22.3	9.0
.140	-.7	18.6	2710.	-15.6	-13.5	8.8	16.0	38.0	22.8	10.0
.145	-.6	18.5	2271.	-9.2	-7.1	8.4	16.5	39.2	23.4	11.0
.150	-.4	18.4	1790.	-5.6	3.4	7.8	17.1	40.4	23.8	12.0
.155	-.4	18.3	1627.	-5.0	2.8	7.4	17.5	41.4	24.3	13.0
.160	-.4	18.3	1401.	-8.4	17.0	6.5	18.6	42.4	24.7	14.1
.165	-.3	18.2	1259.	-.2	2.2	6.0	19.3	43.3	25.1	15.2
.170	-.1	18.2	354.	-11.3	11.1	4.7	20.3	44.0	25.4	16.4
.175	.1	18.2	-382.	-11.7	10.0	2.7	22.1	44.7	25.6	17.7
.180	.2	18.2	-693.	-5.9	4.5	.8	23.6	45.3	25.7	19.1

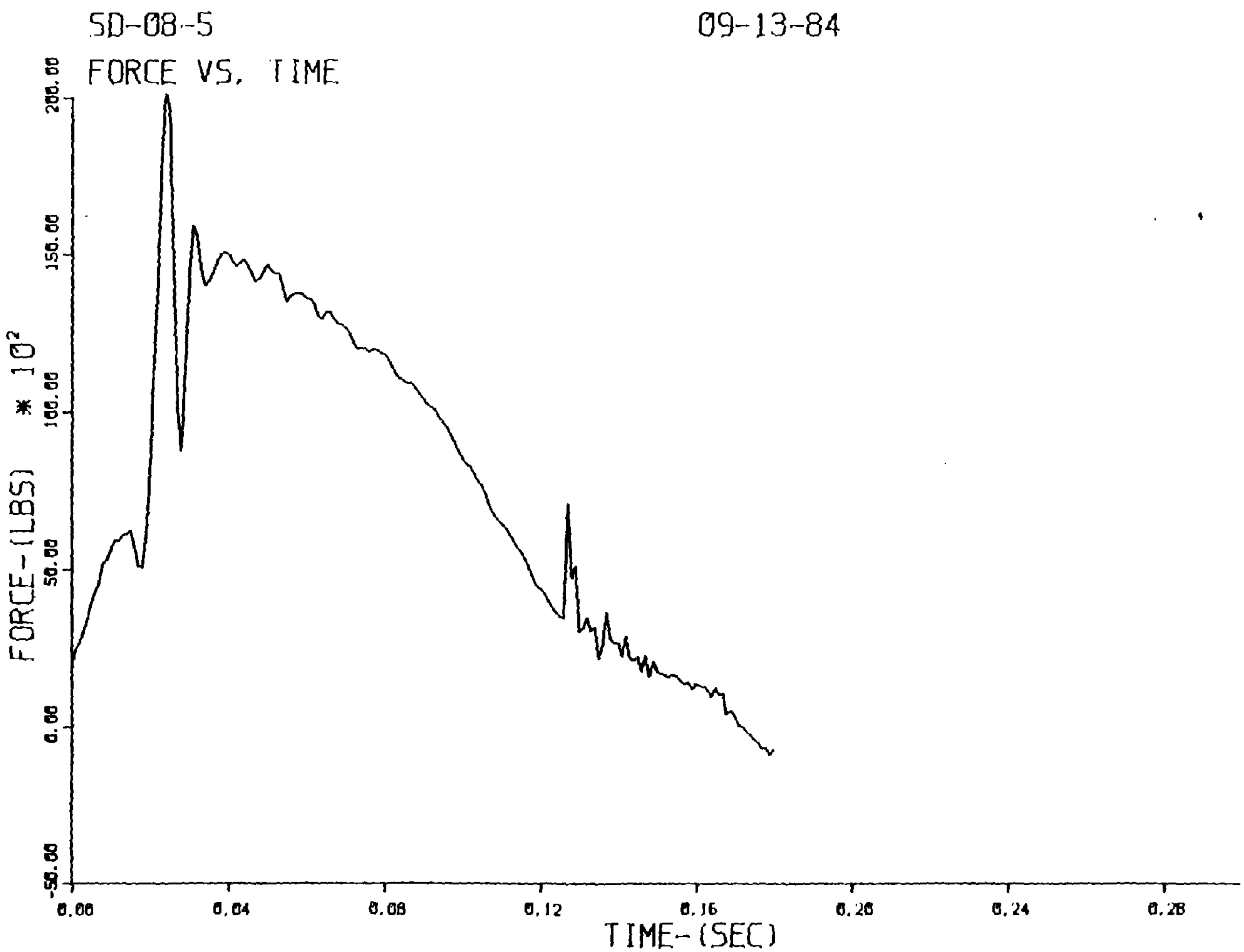


Figure 11. Force-deflection curve, test SD-8.

Table 8. Accelerometer data, test SD-9.

TEST ID ----- SD-9-5
TEST DATE --- 09-13-84

PENDULUM KINETICS SUMMARY
NOTE: VALUES ARE INSTANEOUS AT TIME

	(--------PASS	---------	---------)(	-------------------	--------------	--------	----POST----	--------------	--------------	---------)
TIME (SEC)	A (G'S)	V (FPS)	F (LBS)	AX (G'S)	AY (G'S)	VX (FPS)	VY (FPS)	ANGLE (DEG)	DX (IN)	DY (IN)
0.000	.1	29.3	-523.	2.2	.2	0.0	0.0	0.0	0.0	0.0
.005	-.6	29.3	2345.	20.3	1.9	2.2	.3	.1	.1	.0
.010	-1.1	29.2	4525.	6.3	-.1	4.5	.5	.5	.3	.0
.015	-1.6	28.9	6323.	3.1	.5	5.6	.5	1.1	.6	.1
.020	-1.6	28.7	6545.	-15.3	.0	5.6	.4	1.9	.9	.1
.025	-3.8	28.3	15269.	108.5	9.6	8.4	1.0	3.0	1.2	.1
.030	-3.7	27.5	14793.	-65.2	.2	20.4	2.6	4.2	2.2	.2
.035	-5.5	26.7	21840.	-8.5	-6.6	18.1	1.8	5.6	3.3	.4
.040	-5.7	25.8	22630.	-4.5	1.7	17.1	2.0	7.2	4.3	.5
.045	-5.6	24.9	22243.	-4.1	7.5	16.3	2.3	8.8	5.3	.6
.050	-5.4	24.0	21520.	-4.6	2.7	15.7	2.9	10.5	6.3	.8
.055	-5.3	23.1	21134.	-5.2	5.3	15.0	3.9	12.3	7.2	1.0
.060	-5.1	22.3	20275.	-3.5	7.5	14.3	4.9	14.1	8.1	1.2
.065	-4.8	21.5	19355.	-3.6	5.7	13.6	5.7	15.8	8.9	1.6
.070	-4.6	20.7	18268.	-5.1	2.7	12.9	6.5	17.5	9.7	1.9
.075	-4.3	20.0	17104.	-4.5	4.5	12.3	7.4	19.2	10.5	2.3
.080	-3.9	19.4	15574.	-2.4	6.3	11.8	8.2	20.6	11.2	2.8
.085	-3.5	18.8	13963.	-4.4	5.1	11.1	8.9	22.4	11.9	3.3
.090	-3.1	18.2	12378.	-4.5	4.7	10.5	9.7	23.9	12.5	3.9
.095	-2.7	17.8	10773.	-3.8	4.8	9.9	10.5	25.3	13.1	4.5
.100	-2.3	17.4	9260.	-3.6	5.7	9.3	11.5	26.7	13.7	5.1
.105	-1.9	17.0	7410.	-3.1	6.0	8.9	12.4	28.1	14.3	5.9
.110	-1.6	16.8	6540.	-4.1	5.0	8.3	13.3	29.4	14.8	6.6
.115	-1.3	16.5	5380.	-4.9	5.8	7.7	14.2	30.6	15.3	7.5
.120	-1.1	16.3	4388.	-4.1	3.9	6.9	15.0	31.8	15.7	8.3
.125	-.9	16.2	3580.	-3.7	5.4	6.3	15.9	33.0	16.1	9.3
.130	-.6	16.0	2542.	-6.7	5.4	5.4	16.8	34.1	16.4	10.2
.135	-.4	15.9	1581.	-14.2	10.0	6.4	16.5	35.2	16.8	11.2
.140	-.6	15.8	2548.	-6.1	7.5	5.9	17.2	36.2	17.2	12.3
.145	-.6	15.7	2536.	-1.6	-.7	5.4	17.6	37.1	17.5	13.3
.150	-.5	15.6	2157.	1.0	2.7	5.1	18.1	37.9	17.8	14.4
.155	-.5	15.5	1855.	-5.4	4.9	4.8	18.5	38.7	18.1	15.5
.160	-.4	15.5	1644.	-1.7	.4	4.6	19.0	39.3	18.4	16.6
.165	-.5	15.4	1862.	.3	5.0	4.2	18.9	39.8	18.7	17.7
.170	-.3	15.3	1330.	-3.4	-.0	3.9	19.0	40.2	18.9	18.9
.175	-.4	15.3	1502.	-3.6	.6	3.6	19.3	40.5	19.1	20.0
.180	-.2	15.2	832.	-3.5	5.5	3.1	19.8	40.8	19.3	21.2
.185	.0	15.2	-128.	-10.1	6.2	1.9	20.5	41.1	19.5	22.4
.190	.1	15.2	-323.	-9.3	4.9	.3	21.6	41.6	19.6	23.7
.195	.2	15.2	-855.	-5.1	2.1	-.9	22.6	42.4	19.5	25.0
.200	.1	15.3	-392.	-1.6	1.2	-1.4	23.1	43.8	19.5	26.4

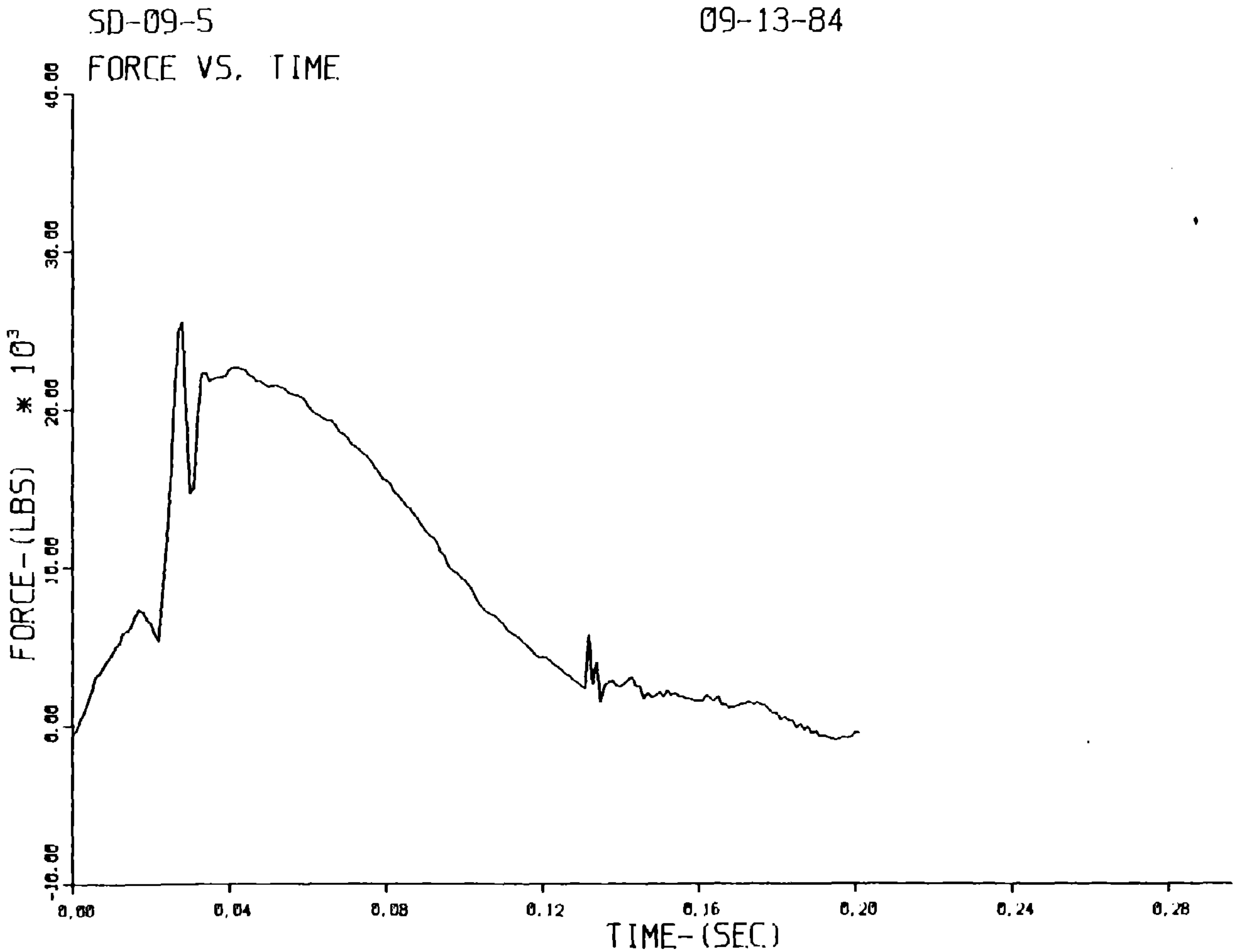


Figure 12. Force-deflection curve, test SD-9.

Table 9. Accelerometer data, test SD-10.

TEST ID ----- SD-10-5
TEST DATE --- 09-26-84

PENDULUM KINETICS SUMMARY
NOTE: VALUES ARE INSTANEOUS AT TIME

	(-------PASS	--------)	(	--------	--------	POST	--------	--------	--------	)
TIME (SEC)	A (G'S)	V (FPS)	F (LBS)	AX (G'S)	AY (G'S)	VX (FPS)	VY (FPS)	ANGLE (DEG)	DX (IN)	DY (IN)
0.000	.1	29.3	-576.	.6	.2	0.0	0.0	0.0	0.0	0.0
.005	-.4	29.3	1648.	24.2	2.4	2.0	.3	.6	.0	.0
.010	-1.0	29.2	4133.	27.0	1.4	6.6	.8	1.0	.3	.0
.015	-1.5	29.0	5818.	19.6	-2.9	10.2	.6	1.5	.8	.1
.020	-1.7	28.7	6642.	7.7	-.9	12.6	.2	2.2	1.5	.1
.025	-1.5	28.5	6111.	-12.4	.6	12.1	.4	3.1	2.3	.1
.030	-3.2	28.2	12721.	77.7	1.6	14.9	.8	4.2	3.0	.2
.035	-3.2	27.5	12730.	-1.9	.2	28.4	1.4	5.5	4.3	.2
.040	-3.3	27.1	13370.	13.1	-4.5	25.9	1.6	6.9	5.9	.3
.045	-3.1	26.6	12518.	-2.7	1.8	25.1	1.2	8.5	7.5	.4
.050	-3.2	26.1	12636.	-3.4	-1.3	24.8	1.4	10.2	9.0	.5
.055	-3.0	25.6	11877.	-5.8	2.3	24.5	2.1	11.9	10.5	.6
.060	-3.0	25.1	11672.	-3.0	4.6	24.2	3.4	13.8	11.9	.7
.065	-2.9	24.6	11407.	-2.4	5.1	23.6	4.6	15.6	13.3	1.0
.070	-2.8	24.2	11249.	-.4	5.1	23.2	5.1	17.5	14.7	1.3
.075	-2.7	23.7	10830.	-3.8	9.1	22.5	5.7	19.3	16.1	1.6
.080	-2.7	23.3	10781.	.7	10.3	22.2	6.6	21.2	17.5	1.9
.085	-2.6	22.9	10271.	-4.6	7.7	21.8	7.6	22.9	18.8	2.4
.090	-2.5	22.4	10145.	-1.2	9.5	21.5	8.8	24.6	20.1	2.9
.095	-2.4	22.0	9666.	-1.0	9.3	21.3	10.5	26.2	21.4	3.4
.100	-2.2	21.7	8816.	-4.7	9.0	20.7	11.8	27.8	22.6	4.1
.105	-2.0	21.3	7971.	-6.2	7.7	19.6	12.9	29.1	23.8	4.9
.110	-1.8	21.0	7123.	-7.3	6.7	18.7	14.0	30.4	25.0	5.7
.115	-1.6	20.8	6368.	-6.3	3.4	17.6	15.0	31.5	26.1	6.5
.120	-1.4	20.5	5429.	-5.7	5.2	16.8	15.7	32.5	27.1	7.5
.125	-2.6	20.3	10507.	46.0	-20.0	17.1	16.2	33.3	28.1	8.4
.130	-1.1	20.1	4490.	8.0	10.6	16.5	15.4	34.1	29.1	9.4
.135	-.9	19.9	3705.	-16.2	-1.5	16.2	16.4	34.8	30.1	10.3
.140	-.7	19.8	2859.	-17.1	-10.8	15.6	17.1	35.7	31.0	11.3
.145	-.6	19.7	2490.	-6.0	-3.0	14.9	17.6	36.9	32.0	12.4
.150	-.5	19.6	1921.	-1.4	3.8	14.6	18.4	38.5	32.8	13.4
.155	-.3	19.5	1198.	3.5	10.4	14.3	18.9	40.9	33.7	14.6
.160	-.3	19.5	1167.	2.8	7.0	14.2	19.7	44.6	34.6	15.7

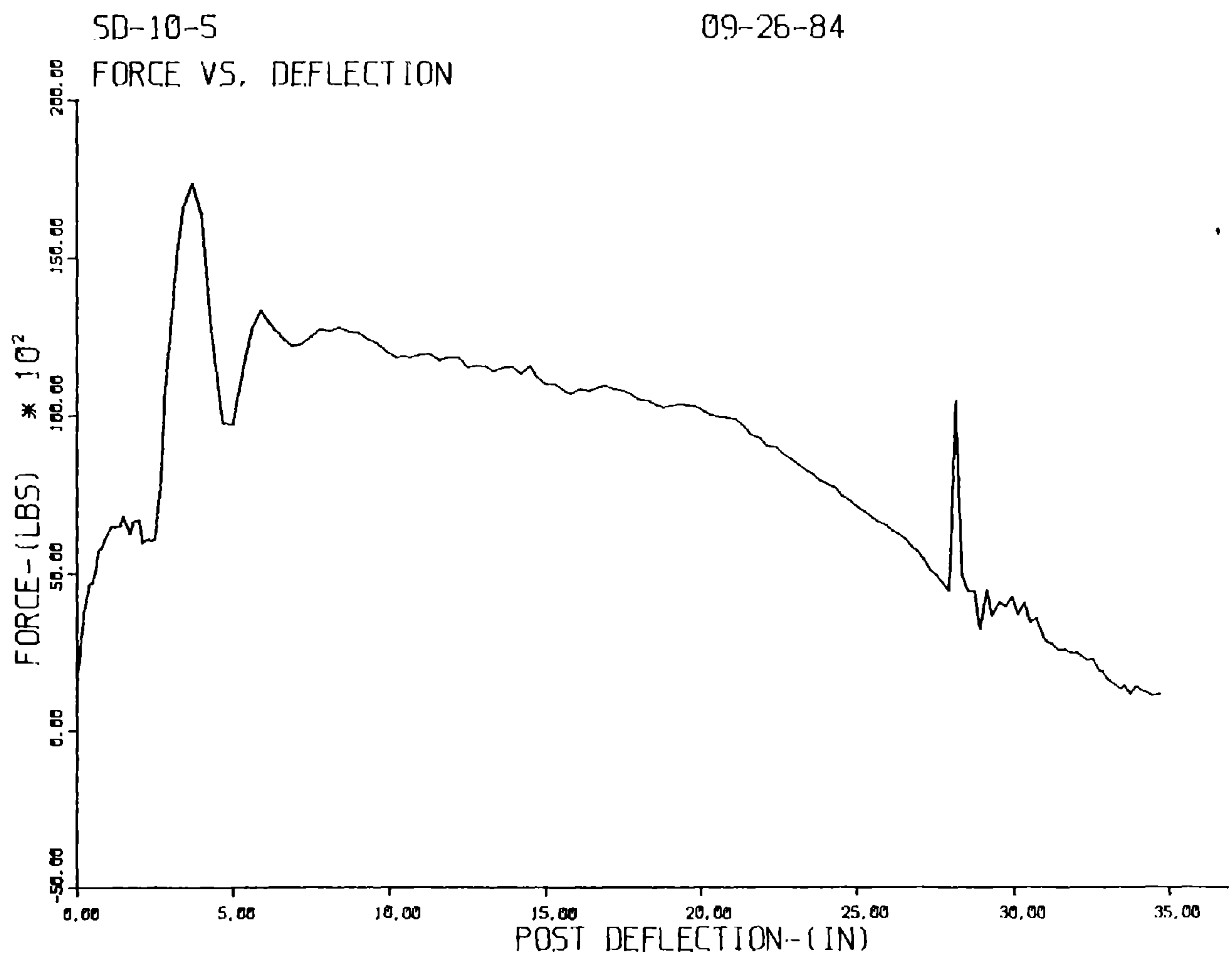


Figure 13. Force-deflection curve, test SD-10.

Table 10. Accelerometer data, test SD-11.

```
TEST ID ------ SD-11-5
TEST DATE --- 09-28-84

PENDULUM KINETICS SUMMARY
NOTE: VALUES ARE INSTANEOUS AT TIME
```

	(-------PASS--------)			(--------------------POST--------------------)						
TIME (SEC)	A (G'S)	V (FPS)	F (LBS)	AX (G'S)	AY (G'S)	VX (FPS)	VY (FPS)	ANGLE (DEG)	DX (IN)	DY (IN)
0.000	.2	29.3	-654.	1.6	.0	0.0	0.0	0.0	0.0	0.0
.005	-.5	29.3	2051.	28.4	3.2	2.3	.3	.1	.0	.0
.010	-1.0	29.2	4130.	25.7	2.4	7.3	.7	.6	.3	.0
.015	-1.6	29.0	6309.	30.7	2.3	11.7	1.0	1.4	.9	.1
.020	-1.8	28.7	7223.	17.5	-.8	15.7	1.1	2.4	1.7	.2
.025	-1.7	28.4	6962.	2.6	4.5	17.0	1.0	3.7	2.7	.2
.030	-1.7	28.2	6866.	-.8	.1	16.7	1.2	5.1	3.7	.3
.035	-3.0	27.8	12028.	62.6	3.5	21.7	1.7	6.8	4.8	.4
.040	-1.9	27.3	7562.	-24.1	8.4	28.2	2.0	8.6	6.4	.5
.045	-2.4	27.0	9676.	6.5	.2	26.6	2.3	10.5	8.0	.6
.050	-2.1	26.6	8457.	-3.3	6.8	26.3	2.6	12.4	9.6	.8
.055	-2.1	26.3	8501.	-3.0	5.1	26.1	3.2	14.4	11.2	.9
.060	-2.1	25.9	8349.	-.4	5.6	25.6	3.8	16.4	12.7	1.1
.065	-2.0	25.6	7811.	-1.8	9.7	25.4	4.6	18.3	14.3	1.4
.070	-1.9	25.3	7421.	-1.5	8.7	25.1	6.1	20.2	15.8	1.7
.075	-1.7	25.0	6876.	-2.4	7.4	24.8	7.0	22.1	17.3	2.1
.080	-1.6	24.7	6396.	-1.4	7.2	24.5	7.9	23.9	18.7	2.5
.085	-1.5	24.5	5859.	-2.8	6.4	24.4	8.7	25.6	20.2	3.0
.090	-1.3	24.3	5208.	-3.2	6.5	23.8	9.7	27.3	21.7	3.6
.095	-1.2	24.1	4647.	-1.6	7.1	23.5	10.8	29.0	23.1	4.2
.100	-1.0	23.9	3930.	-3.5	8.4	22.8	12.1	30.6	24.5	4.9
.105	-.8	23.8	3278.	-3.6	7.7	22.5	13.3	32.3	25.8	5.7
.110	-.7	23.6	2800.	-2.3	7.1	22.0	14.4	34.0	27.2	6.5
.115	-.5	23.5	1993.	-3.9	7.4	21.5	15.6	35.7	28.5	7.4
.120	-.3	23.5	1268.	-5.6	8.7	20.8	16.9	37.5	29.7	8.4
.125	-.2	23.4	782.	-6.2	8.6	19.9	18.3	39.2	31.0	9.4
.130	-.1	23.4	213.	-7.5	8.6	18.9	19.7	41.0	32.1	10.6
.135	.0	23.4	-150.	-3.5	12.5	17.8	21.2	42.6	33.2	11.8
.140	-.4	23.4	1463.	11.5	-32.7	16.7	22.3	44.1	34.3	13.1
.145	.4	23.4	-1755.	-33.4	-6.1	16.2	23.0	45.3	35.3	14.4
.150	.0	23.4	-23.	4.0	-13.2	15.5	23.6	46.0	36.2	15.8

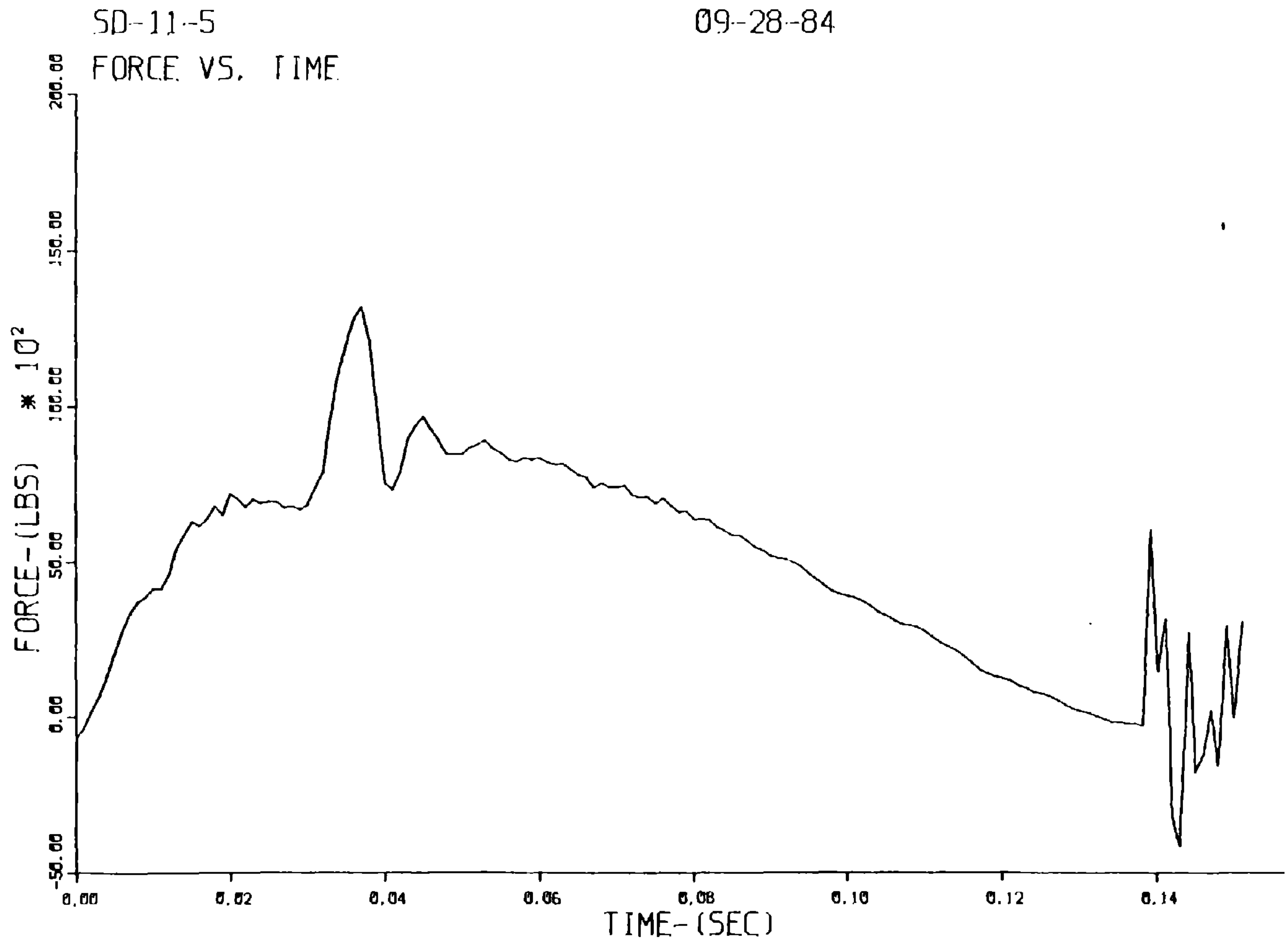


Figure 14. Force-deflection curve, test SD-11.

Table 11. Accelerometer data, test SD-12.

TEST ID ----- SD-12-5
TEST DATE --- 11-14-84

PENDULUM KINETICS SUMMARY
NOTE: VALUES ARE INSTANEOUS AT TIME

	(-------MASS-------)			(------------------------POST------------------------)						
TIME (SEC)	A (G'S)	V (FPS)	F (LBS)	AX (G'S)	AY (G'S)	VX (FPS)	VY (FPS)	ANGLE (DEG)	DX (IN)	DY (IN)
0.000	.1	29.3	-270.	.2	.0	0.0	0.0	0.0	0.0	0.0
.005	-.6	29.3	2247.	22.8	3.8	2.0	.3	-.1	.0	.0
.010	-1.2	29.2	4711.	11.2	-1.7	5.1	.6	-.0	.3	.0
.015	-1.5	28.9	6093.	4.9	-.7	6.0	.4	.5	.6	.1
.020	-1.8	28.7	7259.	-9.0	1.8	5.8	.3	1.5	1.0	.1
.025	-2.8	28.4	11129.	32.0	20.6	6.0	1.0	2.9	1.3	.1
.030	-9.2	27.4	36620.	11.9	-14.7	13.2	2.7	4.7	1.9	.3
.035	-5.7	26.6	22707.	9.4	-17.0	11.3	2.2	6.8	2.6	.4
.040	-5.3	25.8	21011.	-1.5	-1.9	10.2	2.0	8.9	3.2	.5
.045	-5.2	24.9	20775.	-8.3	1.0	9.2	2.1	11.0	3.8	.6
.050	-5.5	24.0	21945.	-4.0	4.4	8.3	2.8	13.0	4.3	.8
.055	-5.0	23.1	20088.	-4.1	4.2	7.5	3.8	14.8	4.8	1.0
.060	-4.9	22.3	19530.	-1.6	6.5	7.0	5.5	16.5	5.2	1.3
.065	-4.7	21.6	18918.	-6.5	3.8	6.0	6.5	18.1	5.6	1.6
.070	-4.6	20.8	18415.	-4.4	2.7	5.4	7.3	19.5	6.0	2.0
.075	-4.4	20.1	17534.	-5.5	4.5	4.5	8.1	20.8	6.3	2.5
.080	-4.2	19.4	16978.	-4.6	5.6	3.8	9.1	22.1	6.5	3.0
.085	-3.8	18.7	15341.	-6.2	7.3	2.9	10.2	23.4	6.7	3.6
.090	-3.6	18.1	14354.	-7.4	6.4	1.9	11.3	24.7	6.9	4.2
.095	-3.3	17.6	13097.	-7.3	4.9	.7	12.2	26.1	7.0	4.9
.100	-3.0	17.1	11840.	-7.2	5.1	-.3	13.1	27.4	7.0	5.7
.105	-2.7	16.6	10962.	-4.0	4.0	-1.0	13.7	28.6	6.9	6.5
.110	-2.3	16.2	9382.	-6.1	7.3	-2.0	14.5	29.8	6.8	7.4
.115	-2.3	15.9	9099.	4.1	-.0	-2.3	15.2	30.8	6.7	8.3
.120	-1.9	15.5	7790.	1.6	.3	-3.0	15.6	31.6	6.5	9.2
.125	-1.7	15.2	6913.	-3.7	-.8	-3.5	16.0	32.3	6.3	10.1
.130	-1.5	15.0	6036.	-4.2	-1.4	-4.2	16.6	32.9	6.1	11.1
.135	-1.2	14.8	4998.	-6.1	.2	-4.9	17.1	33.9	5.8	12.1
.140	-1.1	14.6	4338.	-4.6	2.4	-5.4	17.5	35.5	5.5	13.2
.145	-.9	14.4	3516.	-2.7	4.2	-5.8	18.0	38.7	5.2	14.2
.150	-.8	14.3	3181.	-.8	4.5	-6.3	18.5	44.6	4.8	15.3

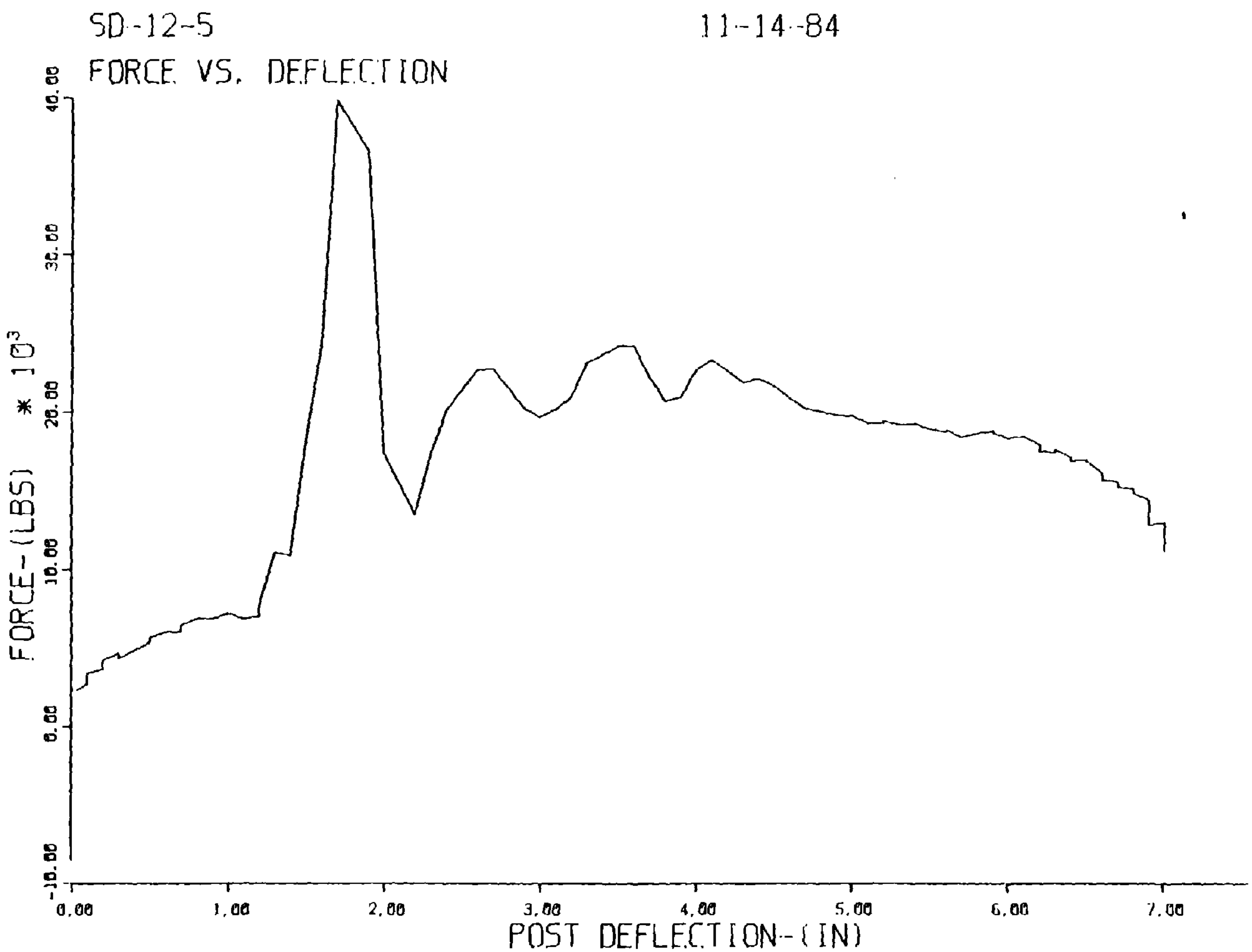


Figure 15. Force-deflection curve, test SD-12.

Table 12. Accelerometer data, test SD-13.

TEST ID ----- SD-13
TEST DATE --- 01-30-85

PENDULUM KINETICS SUMMARY
NOTE: VALUES ARE INSTANEOUS AT TIME

	(-------MASS-------)			(--------------------POST						--------------------)
TIME (SEC)	A (G'S)	V (FPS)	F (LBS)	AX (G'S)	AY (G'S)	VX (FPS)	VY (FPS)	ANGLE (DEG)	DX (IN)	DY (IN)
0.000	-.0	29.3	168.	11.1	2.3	0.0	0.0	0.0	0.0	0.0
.005	-1.0	29.2	4106.	29.0	2.2	3.5	.4	-.0	.1	.0
.010	-1.7	29.0	6710.	8.2	-3.7	6.8	.4	.1	.4	.0
.015	-2.0	28.7	7883.	-3.0	-3.6	7.4	.1	.7	.9	.1
.020	-1.6	28.4	6568.	-28.6	-.5	4.5	-.1	1.6	1.2	.1
.025	-5.4	28.0	21537.	77.0	19.1	9.5	1.5	2.9	1.5	.1
.030	-3.4	27.2	13470.	-64.3	-.6	8.1	2.5	4.4	2.2	.2
.035	-5.2	26.3	20599.	-21.9	-2.0	8.5	2.4	6.1	2.7	.4
.040	-5.7	25.4	22739.	-6.7	2.0	7.6	2.6	7.8	3.1	.5
.045	-5.8	24.5	23242.	-6.3	4.0	6.6	3.0	9.6	3.6	.7
.050	-5.9	23.5	23705.	-2.3	6.6	6.0	4.0	11.4	3.9	.9
.055	-5.8	22.6	23370.	-4.6	6.7	5.3	5.0	13.1	4.3	1.2
.060	-5.8	21.7	23360.	-3.7	7.8	4.7	6.1	14.8	4.6	1.5
.065	-5.6	20.7	22580.	-4.0	5.6	4.0	7.1	16.4	4.8	1.9
.070	-5.5	19.8	21972.	-6.0	4.1	3.2	7.9	17.9	5.1	2.4
.075	-5.2	19.0	20912.	-3.9	5.2	2.5	8.6	19.4	5.2	2.9
.080	-5.0	18.1	19907.	-4.1	4.0	1.8	9.4	20.8	5.4	3.4
.085	-4.6	17.4	18229.	-4.5	6.1	1.1	10.1	22.3	5.5	4.0
.090	-4.1	16.7	16552.	-4.9	4.3	.5	10.9	23.7	5.5	4.6
.095	-3.7	16.0	14641.	-5.4	6.5	-.2	11.8	25.1	5.5	5.3
.100	-3.1	15.5	12359.	-4.4	6.0	-1.0	12.7	26.6	5.5	6.0
.105	-2.6	15.0	10573.	-5.0	4.6	-1.8	13.6	28.0	5.4	6.8
.110	-2.2	14.7	8664.	-4.4	4.5	-2.5	14.4	29.3	5.3	7.7
.115	-1.8	14.3	7332.	-2.2	4.1	-3.1	15.1	30.7	5.1	8.5
.120	-1.4	14.1	5561.	-3.8	3.9	-3.6	15.7	31.9	4.9	9.5
.125	-1.0	13.9	3927.	-3.7	4.3	-4.1	16.5	33.1	4.7	10.4
.130	-.7	13.8	2802.	-4.1	5.8	-4.7	17.3	34.3	4.4	11.5
.135	-.5	13.7	2132.	3.9	-1.7	-4.9	17.9	35.3	4.1	12.5
.140	-.4	13.6	1486.	-4.4	1.1	-5.0	18.2	36.2	3.8	13.6
.145	-.3	13.5	1368.	-1.3	2.7	-5.3	18.6	37.1	3.5	14.7
.150	-.2	13.5	904.	.0	3.9	-5.8	19.1	37.9	3.2	15.8
.155	-.1	13.5	357.	-1.1	2.3	-6.0	19.6	38.5	2.8	17.0
.160	-.1	13.4	347.	-2.2	-2.0	-6.1	20.0	39.3	2.4	18.2
.165	-.0	13.4	199.	3.0	7.7	-6.3	20.5	40.0	2.1	19.4
.170	.0	13.4	-114.	-3.7	.1	-6.4	21.0	40.8	1.7	20.6
.175	.0	13.4	-55.	-2.6	.1	-6.6	21.4	41.5	1.3	21.9
.180	.1	12.4	-230.	.4	4.4	-6.6	21.8	42.3	.9	23.2

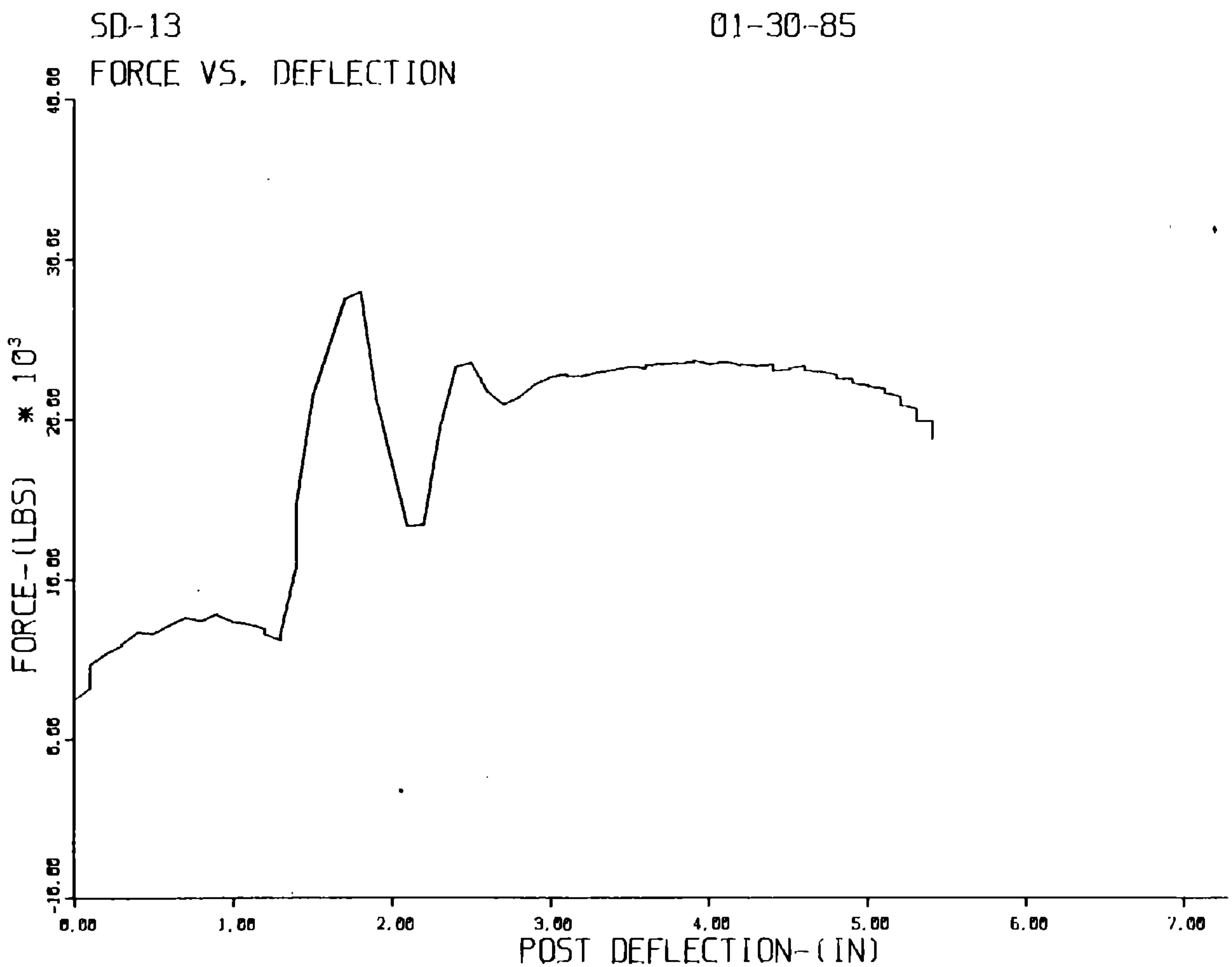


Figure 16. Force-deflection curve, test SD-13.

Appendix B. Soil-Post Interaction Crash Tests

Introduction

The purpose of this test series was to determine the importance of various soil parameters on the behavior of guardrail systems.

Pendulum tests discussed in appendix A indicated that post deflections did decrease with increasing soil strength. Computer simulations of a typical guardrail system, the G4(1S), were made using the pendulum data to assess the barrier's sensitivity to various soil strengths. Figure 17 is the result of those simulations. There are two limiting conditions shown in figure 17; (1) post strength limit and (2) soil strength limit.

Test SPI-1, at 110 percent standard proctor compaction, was well into the post strength limit region. In this region the soil provides a perfectly rigid base; the post-soil system is limited by the flexural strength of the guardrail post.

Test SPI-2, at 80 percent standard proctor compaction, was in the soil strength limited region. In this region the soil is not strong enough to provide a fixed support; therefore, the soil experiences a shear failure and the post rotates without being deformed.

Test SPI-3, at 90 percent standard proctor compaction, was at the boundary between these reactions. The transition between these regions appears to be very crisp with the post developing its ultimate strength as soon as the density is greater than 120 pcf (1922 kg/m^3).

Table 13 compares the performance of these three tests and the three soil conditions represented. The simulated performance corresponds quite well to the observed performance. This indicates that figure 17 appears to be valid at least between 100 pcf (1602 kg/m^3) and 150 pcf (2403 kg/m^3). Vehicle and barrier damage was nearly identical for all three tests although in test SPI-2 the vehicle vaulted over the barrier.

Vaulting occurred because the excessive rotations of the post formed as a ramp that the vehicle could easily climb.

Conclusion

Test SPI-2 demonstrates the importance of achieving at least the minimum required compaction. Excessive barrier deflections can cause the vehicle to ramp and possibly roll over.

The method for modeling guardrail posts using computer simulations developed earlier appears to be a good predictor of barrier deflections as shown in table 13. In addition the effect of soil compaction of the performance of a G4(1S) appears to resemble figure 17.

Once the minimum compaction is reached barrier performance remains the same regardless of the degree of compaction. In such cases the post strength is the limiting factor as long as the soil provides enough strength to develop the ultimate post strength. A comparison of the deflections in tests SPI-1 and SPI-3 show that performance was nearly identical although test SPI-1 was more heavily compacted.

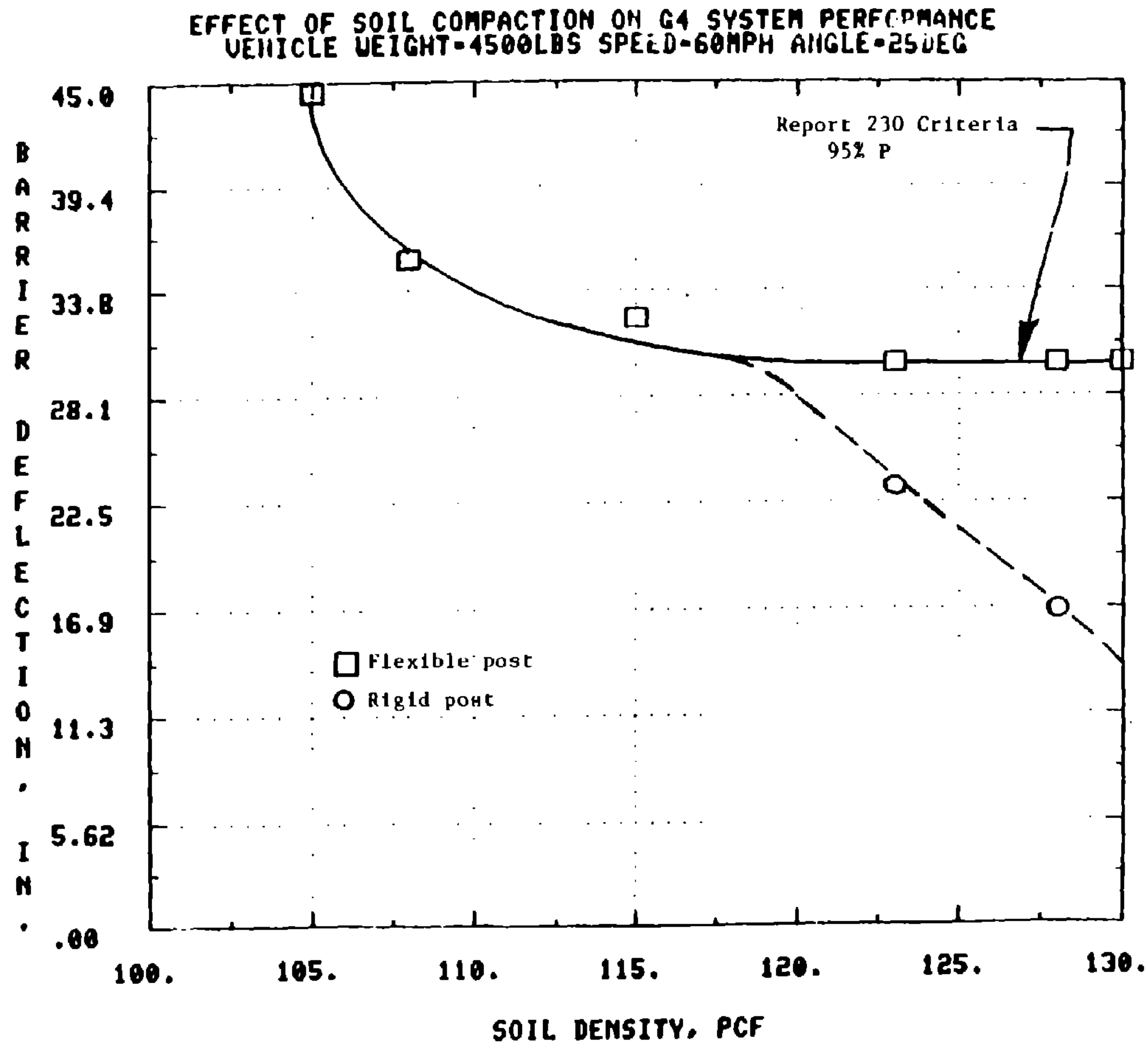


Figure 17. Barrier deflection of a G4 system as a function of soil density.

Table 13. Comparison of soil-post interaction crash tests.

	Test		
	SPI-1	SPI-2	SPI-3
Soil Conditions			
Natural Soil Density (pcf)	148	108	121
Standard Proctor Compaction (%)	110	80	90
Moisture Content (%)	3.7	3.7	3.5
Dynamic Deflections			
Simulated (in.)	30	44	30
Actual (in.)	35.6	45.1	29.6
Evaluation Criteria (film data)			
Lateral Occupant Risk (fps)	14.6	16.0	15.9
Lateral Ridedown Accel (g's)	5.2	5.5	6.4
Lateral 50 msec Accel (g's)	5.2	5.5	6.4
Barrier Damage			
Number of Deflected Posts	6	9	8
Number of Deformed Beams	2	2	2
Number of Beam/Post Separations	0	1	1

Test SPI-1

Purpose

The objective of test SPI-1 was to serve as a baseline test for both the replacement of the 4500-lb (2043-kg) car crash tests and the soil-post interaction tests.

Barrier Installation

The barrier for this test was a standard G4(1S) system as depicted in figure 18. The height to the top of the W-beam was 27 inches as shown. This barrier system was used because of its popularity in the field and the long history of experience with this system.

NCHRP Report 230 specifies that the soil must be compacted to 95 percent standard proctor compaction or greater. The soil was found to be 110 percent of the standard proctor density with a moisture content of 3.7 percent.

Impact Conditions

This test was intended to be a standard strength test; hence, the desired impact conditions were 60 mph (96.5 kph) and 25 degrees.

Test Vehicle

The test vehicle was a 1978 Plymouth Fury ballasted with steel plates to 4490 lbs (2039 kg). The ballast was added to the front floor pans at about the height of the vertical c.g. Anthropometric dummies were not used in this test. The bumper height was found to be 21.5 inches (53.5 cm) and the yaw moment of inertia was 37,370 in-lb-sec^2 (4218 kg-m^2). The vehicle is shown in figure 19.

Performance

Figure 20 shows sequential photographs of the collision event. Actual impact conditions were 59.6 mph (95.9 kph) and 25.3 degrees. The point of impact was at post number 5. The vehicle was smoothly redirected with no rolling or wheel involvement coming to rest 155 ft (47.24 m) downstream of impact and 12 ft (3.66 m) into the traveled way. The time and length of barrier contact were 620 msec and 24.33 ft (7.42 m).

Maximum 50 msec average accelerations measured by film analysis were 2.9 g (longitudinal) and 5.2 g (lateral). Figure 21 presents a summary of test results. Table 14 contains permanent rail deflections. Table 15 contains vehicle kinetic data as well as occupant risk data from film analysis. Analog to digital conversion from on-board transducers is tabulated in table 16. Figure 22 contains photographs of barrier and vehicle damage. Plots of transducer data are presented in figure 23.

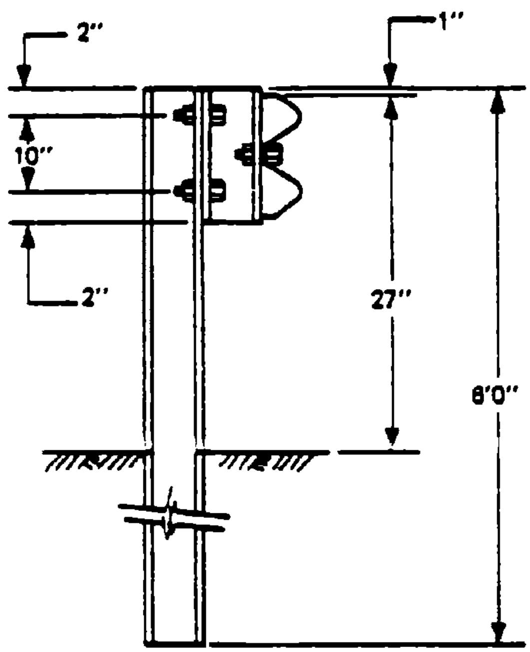
Barrier Damage

Two sections of W-beam were deformed and posts 4 through 9 were deflected laterally as shown in table 14. All beams and posts remained attached.

Figure 22 shows the mechanism of post failure. Because the soil provided a fixed support, the post web crippled indicating a flexure failure. The posts developed their full strength and the soil remained undeformed.

Vehicle Damage

The vehicle damage consisted of sheet metal deformation of the left front fender, left side and grill. The left front and rear tires were blown out from underriding the beam. The front bumper was damaged but it remained connected to the frame horn.



DESIGN G4S

Beam:	12 ga. W
Blockout:	W6 X 8.5
Post:	W6 X 8.5
Post Spacing:	6 ft-3 in.
Bolts:	5/8-in. dia

Figure 18. Barrier system for tests SPI-1, SPI-2, SPI-3.

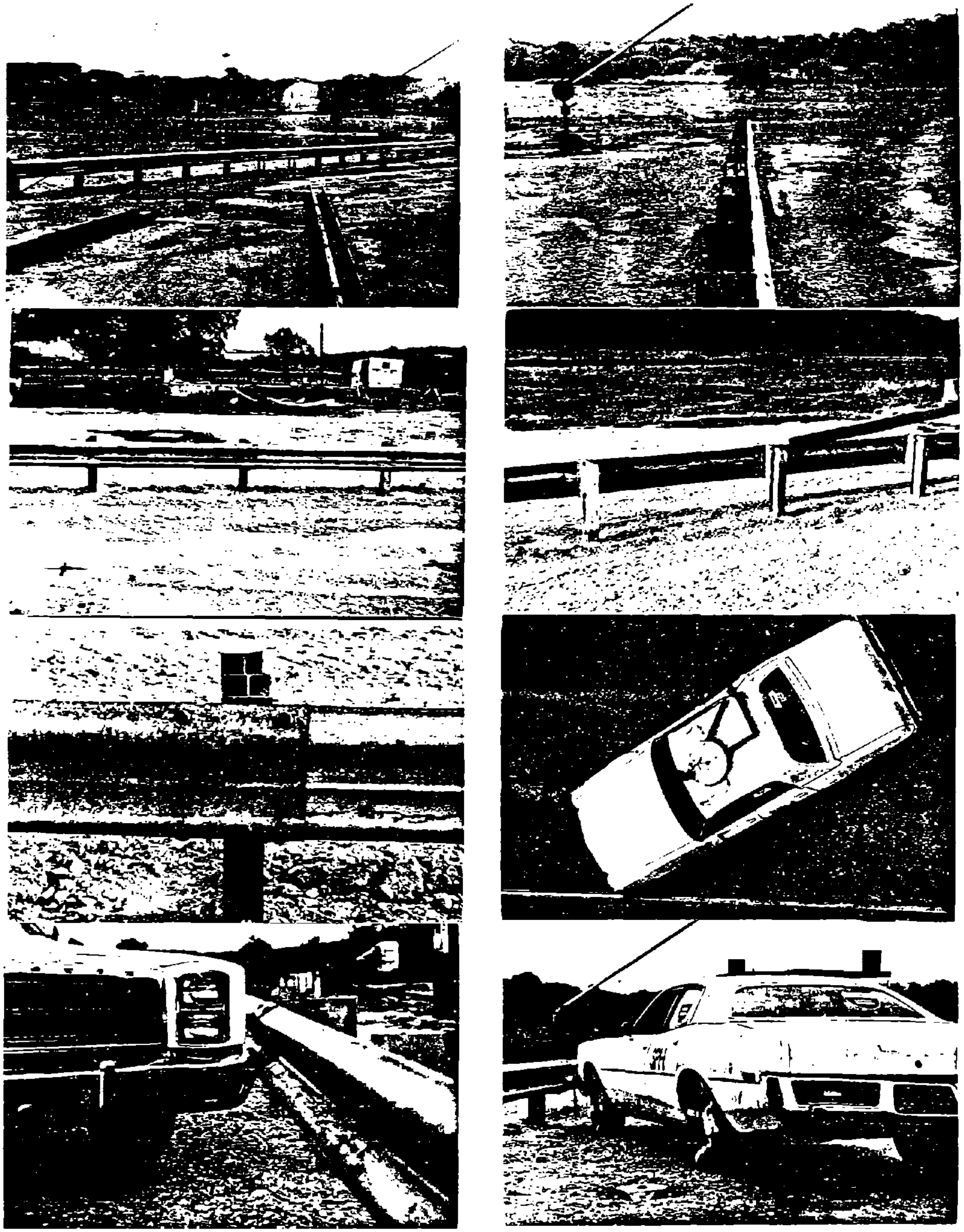


Figure 19. Barrier and vehicle pretest details, test SPI-1.

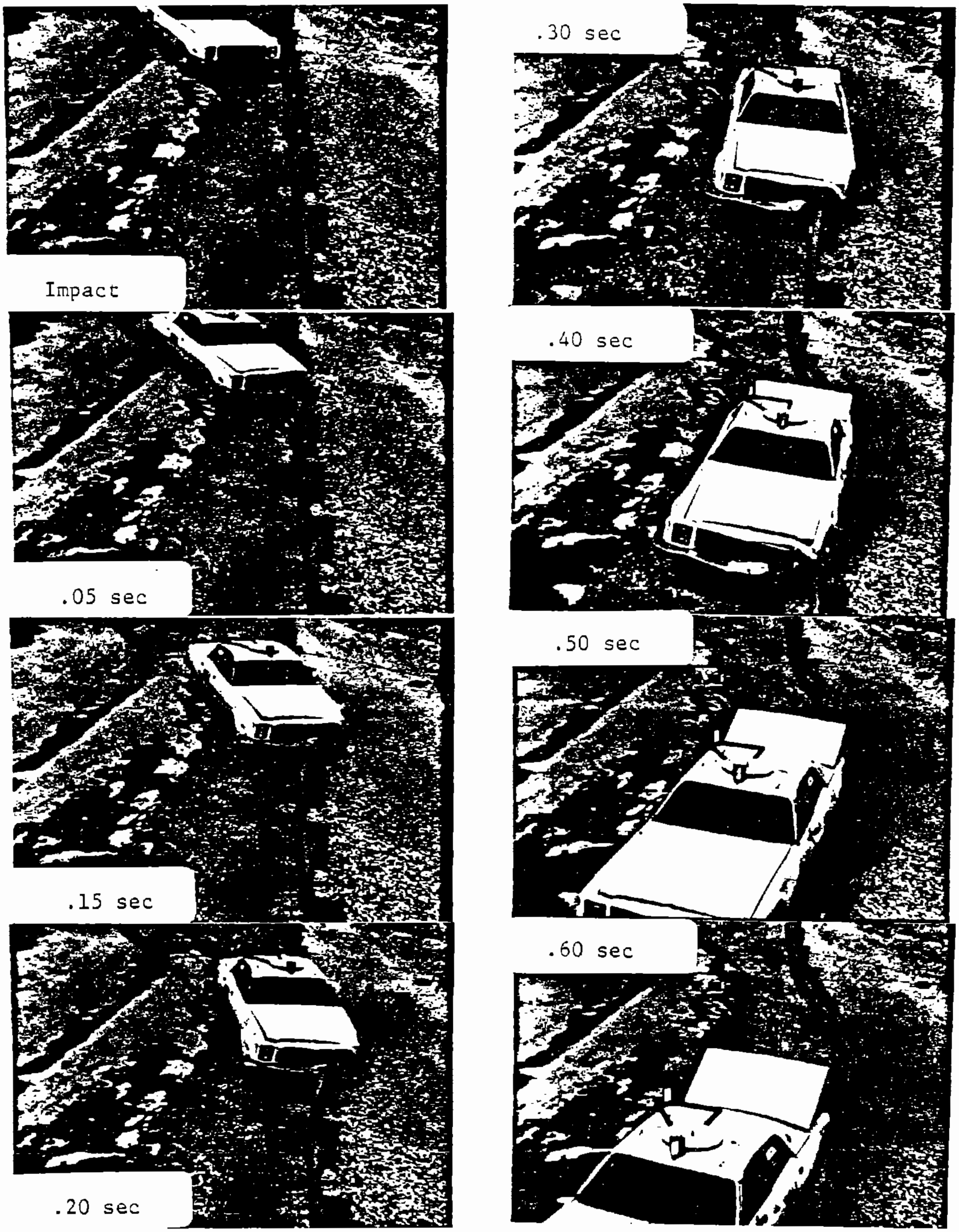
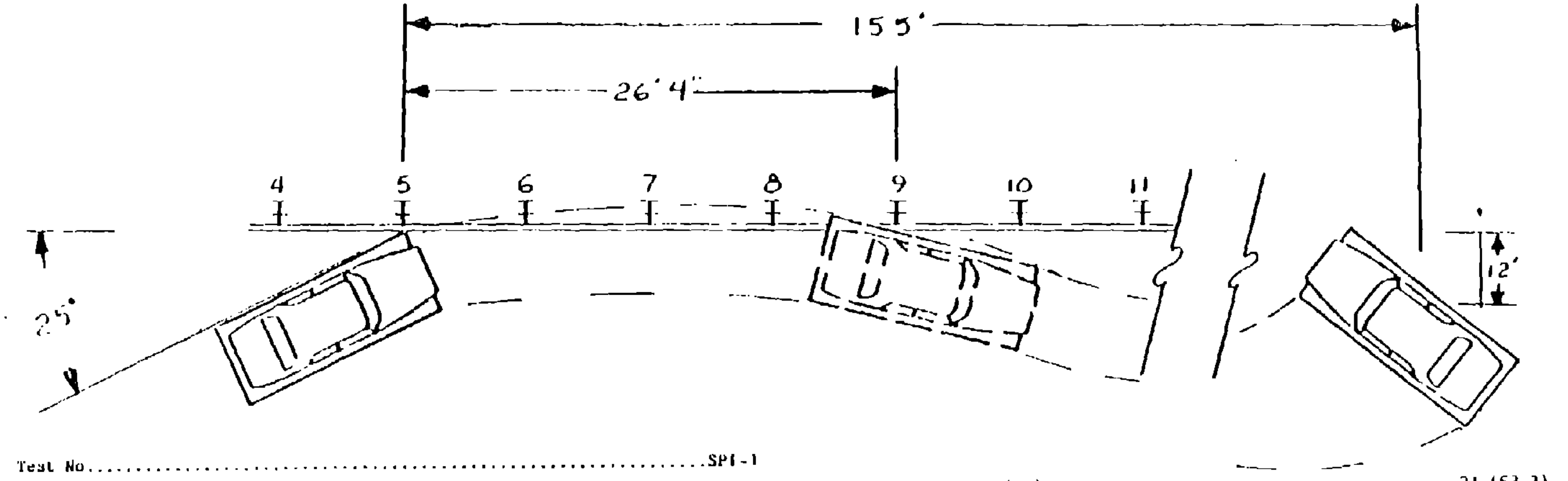


Figure 20. Sequential photographs, test SPI-1.



Test No	SPI-1
Date	7/3/85
Installatin Length - ft (m)	87.5 (26.7)
Beam	
Member	W-beam
Length - ft (m)	12 (3.7)
Maximum Deflections - in. (cm)	
Dynamic	35.6 (90.4)
Permanent	27.3 (69.3)
Post	
Material	steel
Description	W6x8.5
Embedment -ft (m)	3.7 (1.1)
Spacing -ft (m)	6.3 (1.9)
Soil	
Soil Type	S1
Moisture Content (%)	3.7
Standard Proctor Compaction (%)	110
Vehicle	1978 Plymouth Fury
Mass - lb (kg)	4490 (2037)

Bumper Height - in. (cm)	21 (53.3)
Yaw Inertia - in-lb-sec^2 (kg-m^2)	37,370 ( )
Speed - mph (kph)	
Impact	59.6 (95.9)
Exit	41.7 (67.1)
Angle - deg	
Impact	25.3
Exit	18.2
Occupant Impact Velocity - fps (m/s)	
Forward (film/accel)	7.3/12.9 (2.23/3.93)
Lateral (film/accel)	14.6/15.3 (4.45/4.66)
Occupant Ridedown Accelerations -g's	
Forward (accel)	
Lateral (accel)	5.2/7.6
Maximum 50 msec Avg Accelerations - g's	
Longitudinal (film/accel)	2.9/3.4
Lateral (film/accel)	5.2/5.5
Damage	
VDI	11FLES8

Figure 21. Summary of results, test SPI-1.

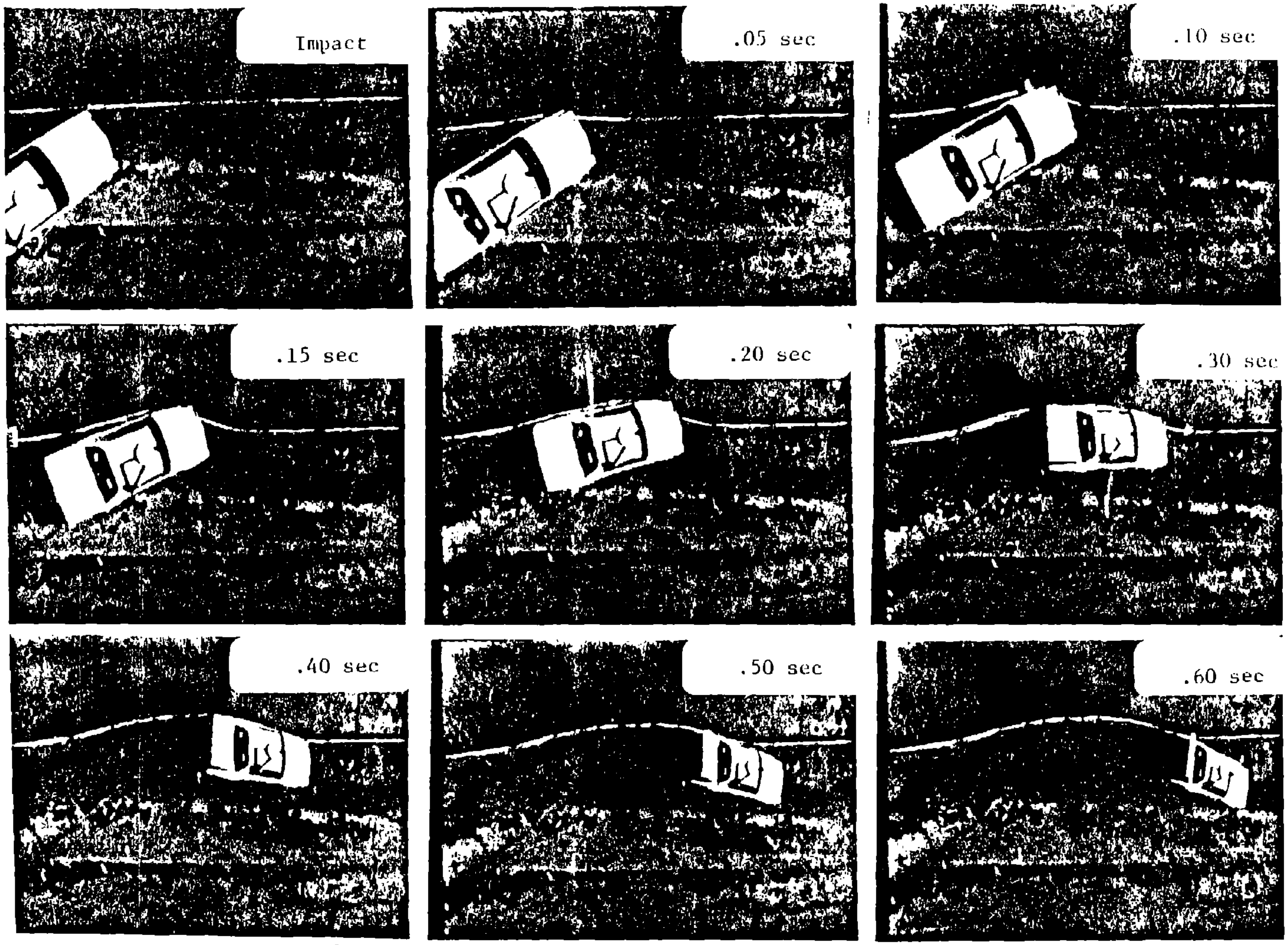


Figure 21. Summary of results, test SP1-1 (Continued).

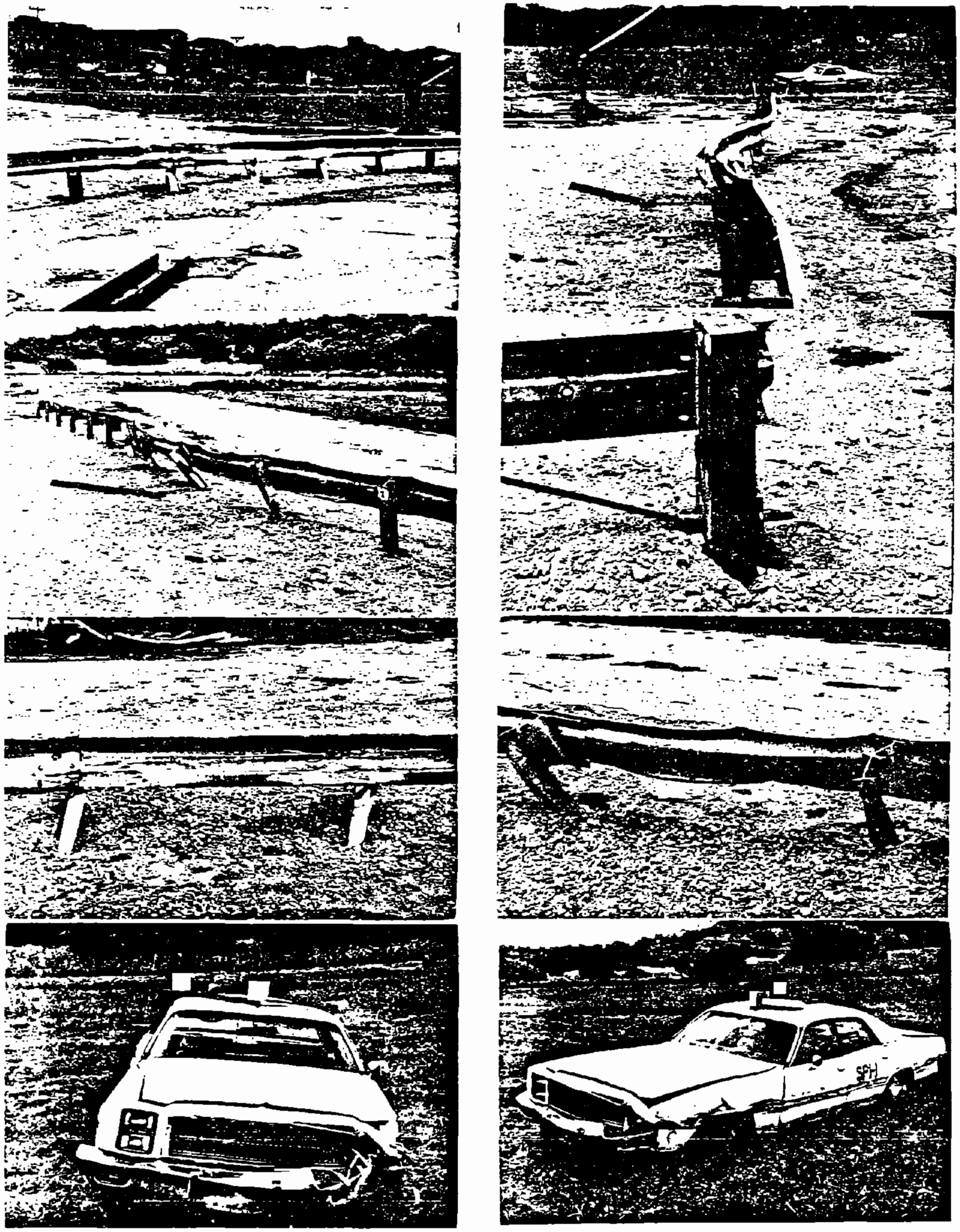


Figure 22. Vehicle and barrier damage, test SPI-1.

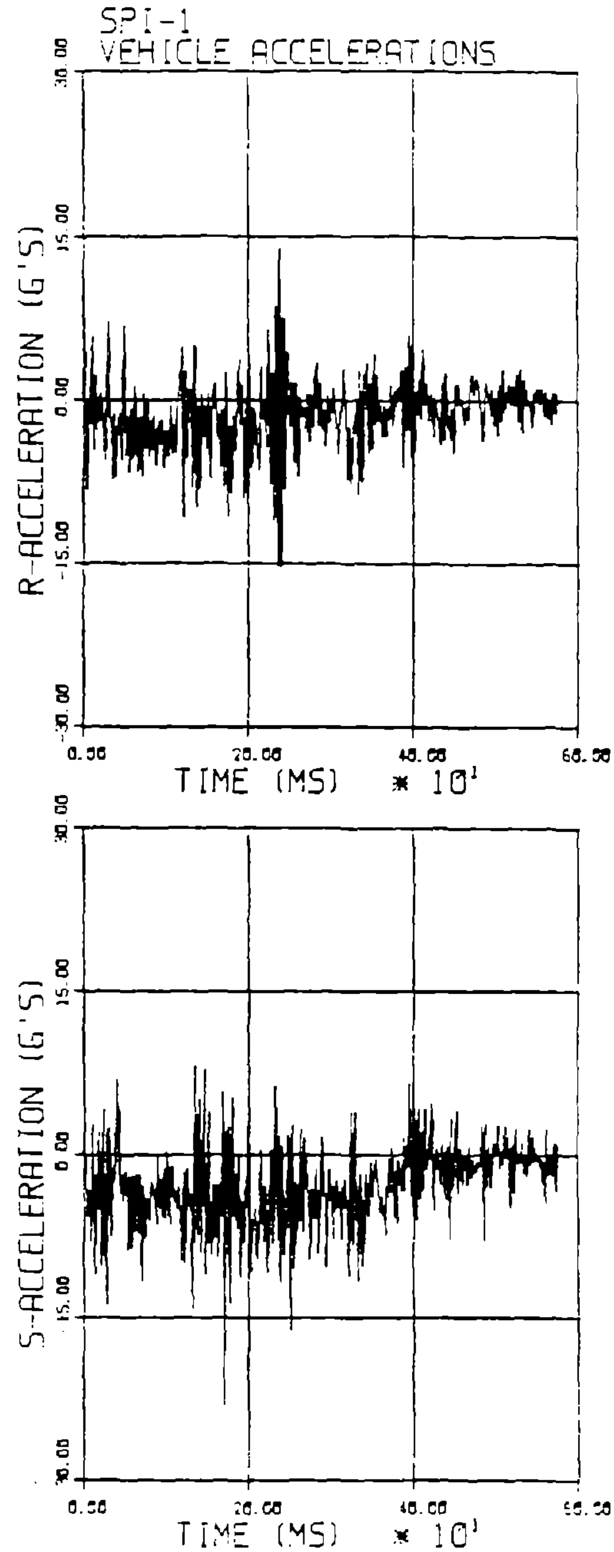


Figure 23. Vehicle accelerations, Test SPI-1.

Table 14. Permanent barrier deflections, test SPI-1.

Post Number	Deflection (inches)
3	0
4	1.5
5	8.0
6	21.3
7	27.3
8	24.5
9	8.0
10	0.75
11	0

Table 15. Film analysis data, test SPI-1.

SOIL POST INTERACTION SPI-1 7-3-85

VEHICLE KINETICS SUMMARY--FROM FILM ANALYSIS

TIME (S)	VEH. ACCEL.(G'S) LONG.	LAT.	HEADING ANGLE (DEG)	VEH. VEL.(FPS) LONG.	LAT.	VEH. DISP.(F) X	Y
0.000	-1.22	-1.60	25.25	86.19	-.67	-17.75	-5.54
.010	-1.40	-1.74	25.22	85.77	-1.16	-16.97	-5.18
.020	-1.58	-1.87	25.12	85.29	-1.60	-16.19	-4.83
.030	-1.75	-2.00	24.95	84.76	-1.98	-15.41	-4.49
.040	-1.91	-2.13	24.70	84.18	-2.27	-14.64	-4.15
.050	-2.06	-2.27	24.36	83.55	-2.46	-13.87	-3.82
.060	-2.21	-2.40	23.93	82.89	-2.61	-13.10	-3.51
.070	-2.35	-2.54	23.40	82.18	-2.65	-12.33	-3.20
.080	-2.47	-2.69	22.78	81.43	-2.60	-11.57	-2.90
.090	-2.59	-2.85	22.07	80.64	-2.49	-10.81	-2.62
.100	-2.69	-3.02	21.27	79.83	-2.31	-10.05	-2.34
.110	-2.78	-3.20	20.38	78.98	-2.08	-9.30	-2.08
.120	-2.86	-3.38	19.41	78.10	-1.81	-8.56	-1.83
.130	-2.92	-3.57	18.37	77.20	-1.52	-7.82	-1.60
.140	-2.96	-3.76	17.27	76.28	-1.23	-7.08	-1.37
.150	-2.98	-3.96	16.11	75.34	-.94	-6.35	-1.17
.160	-2.99	-4.15	14.91	74.40	-.67	-5.63	-.98
.170	-2.97	-4.34	13.67	73.45	-.44	-4.91	-.80
.180	-2.94	-4.51	12.41	72.51	-.26	-4.20	-.64
.190	-2.89	-4.68	11.14	71.57	-.14	-3.50	-.49
.200	-2.83	-4.82	9.86	70.65	-.09	-2.80	-.36
.210	-2.75	-4.95	8.59	69.76	-.11	-2.10	-.25
.220	-2.65	-5.05	7.34	68.89	-.20	-1.42	-.16
.230	-2.55	-5.13	6.11	68.06	-.37	-.74	-.08
.240	-2.43	-5.16	4.91	67.27	-.61	-.06	-.02
.250	-2.31	-5.19	3.75	66.52	-.92	.61	.02
.260	-2.19	-5.18	2.63	65.81	-1.30	1.27	.05
.270	-2.06	-5.13	1.56	65.16	-1.74	1.92	.06
.280	-1.93	-5.05	.54	64.55	-2.23	2.57	.05
.290	-1.81	-4.94	-.43	63.99	-2.75	3.21	.03
.300	-1.69	-4.79	-1.34	63.48	-3.31	3.85	-.01
.310	-1.57	-4.61	-2.20	63.01	-3.88	4.48	-.07
.320	-1.45	-4.41	-3.00	62.58	-4.45	5.11	-.14
.330	-1.34	-4.18	-3.75	62.19	-5.01	5.73	-.22
.340	-1.24	-3.93	-4.46	61.84	-5.56	6.34	-.32
.350	-1.14	-3.65	-5.12	61.52	-6.07	6.95	-.43
.360	-1.05	-3.37	-5.74	61.24	-6.53	7.56	-.55
.370	-.96	-3.05	-6.32	60.99	-6.94	8.16	-.68
.380	-.88	-2.75	-6.88	60.76	-7.25	8.75	-.82
.390	-.80	-2.44	-7.41	60.56	-7.56	9.35	-.97

Table 15. Film analysis data, test SPI-1 (continued).

.400	-.72	-2.12	-7.92	60.35	-7.76	9.93	-1.13
.410	-.65	-1.81	-8.42	60.23	-7.87	10.52	-1.29
.420	-.57	-1.51	-8.90	60.10	-7.89	11.10	-1.46
.430	-.50	-1.21	-9.39	59.99	-7.83	11.68	-1.63
.440	-.43	-.93	-9.87	59.91	-7.67	12.26	-1.81
.450	-.37	-.67	-10.35	59.84	-7.42	12.84	-1.99
.460	-.30	-.42	-10.83	59.80	-7.09	13.41	-2.17
.470	-.23	-.20	-11.33	59.77	-6.68	13.99	-2.35
.480	-.16	.00	-11.82	59.76	-6.19	14.56	-2.54
.490	-.09	.18	-12.33	59.73	-5.63	15.13	-2.72
.500	-.02	.33	-12.84	59.80	-5.02	15.70	-2.90
.510	.05	.46	-13.35	59.85	-4.36	16.27	-3.08
.520	.11	.56	-13.86	59.91	-3.66	16.85	-3.26
.530	.18	.65	-14.37	59.99	-2.93	17.42	-3.44
.540	.25	.71	-14.87	60.06	-2.18	17.99	-3.62
.550	.31	.76	-15.36	60.19	-1.43	18.57	-3.79
.560	.38	.80	-15.84	60.31	-.66	19.15	-3.96
.570	.43	.82	-16.30	60.44	.07	19.73	-4.13
.580	.48	.84	-16.73	60.58	.79	20.31	-4.30
.590	.52	.86	-17.14	60.74	1.50	20.89	-4.47
.600	.56	.88	-17.52	60.90	2.19	21.48	-4.63
.610	.58	.91	-17.88	61.07	2.85	22.07	-4.79
.620	.58	.94	-18.20	61.24	3.49	22.66	-4.95
.630	.57	.99	-18.49	61.40	4.12	23.25	-5.11
.640	.54	1.05	-18.76	61.56	4.73	23.85	-5.26
.650	.49	1.12	-19.01	61.70	5.35	24.45	-5.42
.660	.42	1.20	-19.25	61.83	5.96	25.05	-5.56
.670	.34	1.29	-19.47	61.92	6.62	25.65	-5.71
.680	.23	1.37	-19.70	61.99	7.29	26.26	-5.85
.690	.11	1.45	-19.94	62.01	8.00	26.87	-5.99
.700	-.01	1.49	-20.19	61.99	8.75	27.48	-6.12
.710	-.14	1.48	-20.46	61.93	9.52	28.10	-6.25
.720	-.26	1.39	-20.75	61.81	10.30	28.71	-6.38
.730	-.38	1.19	-21.06	61.55	11.07	29.32	-6.50

HIGHEST 50-MS AVG.ACCEL.

		TIME (SEC)	
	G'S	START	END
LONG.	-2.94	.1350	.1850
LAT.	-5.18	.2250	.2750

Table 15. Film analysis data, test SPI-1 (continued).

```
SOIL POST INTERACTION SPI-1      7-3-85
OCCUPANT RISK SUMMARY -- FROM FILM ANALYSIS
NOTE: AVG. ACCEL. FOR PRIOR 0.010 SEC. CALCULATED
FROM VEHICLE VELOCITY CHANGE
RELATIVE VALUES-(OCCUPANT W.R.T. VEHICLE)
```

	(------- VEHICLE	--------)(		----------- OCCUPANT	-----------		)
TIME	ACCEL. (G'S)		ANG. VEL	VEL. (FPS)		DISP. (F)	
(S)	LONG.	LAT.	(RAD/S)	LONG.	LAT.	LONG.	LAT.
0.000	-1.22	-1.60	.44	0.00	0.00	0.00	0.00
.010	-1.40	-1.74	.44	.29	.41	.00	.00
.020	-1.58	-1.87	.44	.52	.84	.01	.01
.030	-1.75	-2.00	.44	.97	1.29	.01	.02
.040	-1.91	-2.13	.43	1.37	1.78	.03	.03
.050	-2.06	-2.27	.43	1.79	2.31	.04	.05
.060	-2.21	-2.40	.42	2.25	2.88	.06	.08
.070	-2.35	-2.54	.41	2.74	3.51	.08	.11
.080	-2.47	-2.69	.40	3.25	4.19	.11	.15
.090	-2.59	-2.83	.39	3.79	4.95	.15	.20
.100	-2.69	-3.02	.37	4.35	5.79	.18	.26
.110	-2.78	-3.20	.36	4.93	6.71	.23	.32
.120	-2.86	-3.38	.34	5.52	7.73	.27	.40
.130	-2.92	-3.57	.32	6.11	8.85	.32	.49
.140	-2.96	-3.76	.30	6.70	10.03	.38	.59
.150	-2.98	-3.96	.28	7.29	11.40	.43	.70
.160	-2.99	-4.15	.26	7.85	12.84	.49	.83
.170	-2.97	-4.34	.24	8.39	14.37	.55	.98
.180	-2.94	-4.51	.22	8.91	16.01	.62	1.15
.190	-2.89	-4.68	.19	9.40	17.74	.68	1.33
.200	-2.83	-4.82	.17	9.85	19.55	.75	1.53
.210	-2.75	-4.95	.15	10.25	21.43	.81	1.75
.220	-2.65	-5.05	.13	10.61	23.37	.87	2.00
.230	-2.55	-5.13	.11	10.93	25.36	.93	2.26
.240	-2.43	-5.18	.09	11.20	27.38	1.00	2.54
.250	-2.31	-5.19	.07	11.43	29.42	1.05	2.85
.260	-2.19	-5.18	.05	11.61	31.46	1.11	3.17
.270	-2.06	-5.13	.03	11.75	33.49	1.17	3.52
.280	-1.93	-5.05	.01	11.85	35.50	1.22	3.89
.290	-1.81	-4.94	-.01	11.93	37.46	1.27	4.27
.300	-1.69	-4.79	-.02	11.97	39.35	1.32	4.68
.310	-1.57	-4.61	-.04	11.98	41.20	1.36	5.10
.320	-1.45	-4.41	-.05	11.97	42.96	1.41	5.54
.330	-1.34	-4.18	-.07	11.93	44.63	1.45	6.00
.340	-1.24	-3.93	-.08	11.87	46.20	1.49	6.47
.350	-1.14	-3.65	-.09	11.79	47.67	1.54	6.96
.360	-1.05	-3.37	-.10	11.69	49.02	1.57	7.46

Table 15. Film analysis data, test SPI-1 (continued).

.370	-.96	-3.06	-.11	11.55	50.26	1.61	7.97
.380	-.88	-2.75	-.12	11.41	51.38	1.65	8.49
.390	-.80	-2.44	-.13	11.24	52.38	1.68	9.03
.400	-.72	-2.12	-.14	11.04	53.25	1.71	9.57
.410	-.65	-1.81	-.15	10.81	54.02	1.73	10.12
.420	-.57	-1.51	-.16	10.55	54.67	1.75	10.68
.430	-.50	-1.21	-.16	10.26	55.22	1.76	11.24
.440	-.43	-.92	-.17	9.93	55.65	1.77	11.81
.450	-.37	-.67	-.18	9.58	55.99	1.76	12.39
.460	-.30	-.42	-.19	9.14	56.25	1.75	12.96
.470	-.23	-.20	-.20	8.77	56.42	1.72	13.54
.480	-.16	.00	-.21	8.32	56.52	1.69	14.12
.490	-.09	.19	-.22	7.54	56.56	1.64	14.70
.500	-.02	.35	-.22	7.34+	56.55	1.59+	15.28

OCCUP. RISK FACTORS		TIME (S)	VELOCITY (FPS)
LONG. VEL. AFTER 2.0 FT. DISP.	--	.500	7.34
LAT. VEL. AFTER 1.0 FT. DISP.	--	.171	14.56

MAX. ACCEL. AFTER OCCUPANT IMPACT		TIME(S)	ACC.(G'S)
LAT. ACCELERATION	--	.250	-5.19

Table 16. Transducer data, test SPI-1.

```
TEST ID ------- SPI-1
TEST DATE ----- 07-03-85
VEHICLE CLASS - STANDARD
IMPACT SPEED --    86.19 FPS
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VEHICLE KINETICS SUMMARY
NOTE: VALUES ARE INSTANTANEOUS AT TIME
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TIME	ACCEL.(G'S)		HEAD.ANG.	VELOCITY(FPS),		DISP.(F)	
S.	LONG.	LAT.	DEG	LONG.	LAT.	X	Y
0.000	.67	.26	25.25	86.19	-.67	-17.75	-5.54
.010	4.07	-3.36	25.04	85.90	-1.22	-16.97	-5.16
.020	-1.94	-1.45	24.69	85.90	-1.59	-16.18	-4.83
.030	7.26	-.09	24.32	85.45	-2.70	-15.39	-4.50
.040	-6.96	5.05	23.70	84.74	-2.30	-14.60	-4.17
.050	5.17	-1.95	23.05	84.38	-1.85	-13.82	-3.85
.060	-5.29	-1.95	22.33	83.43	-2.02	-13.04	-3.55
.070	-2.82	-3.06	21.51	82.53	-2.31	-12.26	-3.26
.080	-5.13	-4.30	20.56	81.82	-2.86	-11.49	-2.99
.090	-3.72	-2.73	19.45	80.49	-2.41	-10.72	-2.73
.100	-2.36	.34	18.31	79.43	-1.92	-9.95	-2.50
.110	-2.36	-3.23	17.03	78.38	-1.10	-9.19	-2.27
.120	-1.53	-5.30	15.55	78.36	-.89	-8.44	-2.06
.130	.77	-6.37	14.04	77.58	-.22	-7.69	-1.87
.140	-2.57	5.13	12.41	75.73	.39	-6.94	-1.69
.150	-1.53	-8.09	10.74	75.70	2.23	-6.20	-1.52
.160	1.56	-3.45	8.95	75.20	3.01	-5.46	-1.36
.170	-7.90	-23.07	7.06	74.27	4.02	-4.72	-1.23
.180	-5.47	5.27	5.09	72.52	4.91	-4.00	-1.11
.190	-.11	-11.15	3.08	71.77	6.03	-3.28	-1.00
.200	.96	4.91	1.13	70.75	6.95	-2.57	-.91
.210	-2.99	-8.94	-.76	70.00	7.22	-1.87	-.84
.220	-.06	-2.95	-2.71	69.01	7.75	-1.17	-.78
.230	-4.29	-3.09	-4.60	68.30	8.29	-.48	-.75
.240	-15.21	-.36	-6.43	67.70	9.49	.20	-.72
.250	-.11	-11.94	-8.01	66.97	10.11	.88	-.71
.260	-4.97	-2.95	-9.37	66.36	9.82	1.56	-.71
.270	-2.26	-2.38	-10.60	65.50	10.37	2.22	-.73
.280	-1.53	-5.59	-11.81	64.82	10.15	2.88	-.75
.290	-2.67	.45	-12.78	64.30	10.09	3.54	-.79
.300	-.17	-4.09	-13.78	64.13	9.91	4.19	-.84
.310	-3.62	-3.52	-14.74	63.53	9.82	4.83	-.91
.320	-7.17	-7.59	-15.75	63.13	9.24	5.46	-.98
.330	-2.76	.91	-16.64	61.55	9.09	6.09	-1.07
.340	-4.82	-3.09	-17.53	60.32	7.90	6.70	-1.17
.350	-1.32	-2.80	-18.35	60.19	7.73	7.29	-1.28
.360	-1.11	-5.09	-19.20	60.06	7.77	7.59	-1.40
.370	-.59	-.29	-20.15	59.34	7.31	8.40	-1.53

Table 16. Transducer data, test SPI-1 (continued).

.380	-.38	-6.18	-21.01	59.03	7.58	9.06	-1.67
.390	3.18	-3.30	-21.95	58.92	8.02	9.83	-1.81
.400	4.54	2.98	-22.84	58.94	8.91	10.21	-1.98
.410	-1.53	.91	-23.70	58.54	9.72	10.79	-2.10
.420	-1.73	-.24	-24.62	58.72	10.30	11.27	-2.25
.430	-1.21	.05	-25.38	58.32	11.31	11.95	-2.40
.440	2.55	-1.88	-26.11	57.81	11.86	12.52	-2.54
.450	-4.35	-1.23	-26.80	56.93	12.02	13.09	-2.69
.460	.15	-2.38	-27.51	56.81	12.88	13.85	-2.84
.470	.98	-1.75	-28.21	56.30	13.08	14.21	-2.99
.480	1.51	-1.09	-28.89	56.55	13.38	14.77	-3.14
.490	1.72	-2.50	-29.51	56.23	13.70	15.35	-3.30
.500	-1.94	.91	-30.20	56.05	14.36	15.88	-3.46
.510	2.37	-.52	-30.90	55.70	15.13	16.44	-3.61
.520	-.27	.46	-31.57	55.70	15.75	17.00	-3.77
.530	.38	-.45	-32.23	55.67	16.35	17.55	-3.93
.540	.15	-.31	-32.97	55.54	16.75	18.11	-4.09
.550	.38	-.24	-33.59	55.18	17.47	18.87	-4.25
.560	-1.42	-3.23	-34.25	55.07	17.75	19.22	-4.41
.570	-.17	-.52	-34.82	54.59	17.91	19.78	-4.57

TEST ID ------- SPI-1
TEST DATE ----- 07-03-85
VEHICLE CLASS - STANDARD
IMPACT SPEED -- 38.19 FPS

HIGHEST 50.0-MS AVG. ACCEL.

		TIME (SEC)	
	G'S	START	END
LONG.	-3.33	.054	.104
LAT.	-5.31	.175	.225

Table 16. Transducer data, test SPI-1 (continued).

TEST ID ------- SPI-1
TEST DATE ----- 07-03-85
VEHICLE CLASS - STANDARD
IMPACT SPEED -- 56.19 FPS

OCCUPANT RISK SUMMARY
NOTE: INSTANTANEOUS 10-MS AVERAGE ACCELERATIONS

	(------- VEHICLE	--------)		(------------ OCCUPANT			------------)
TIME	ACCEL. (G'S)		ANG. VEL	VEL. (FPS)		DISP. (F)	
(S)	LONG.	LAT.	(RAD/S)	LONG.	LAT.	LONG.	LAT.
0.000	.67	.20	-.73	0.00	0.00	0.00	0.00
.010	-.56	-4.63	-.58	.43	1.05	.00	.01
.020	-1.00	-3.50	-.73	.23	1.75	.01	.02
.030	-1.03	-3.65	-.77	.59	3.40	.01	.05
.040	-3.66	.10	-1.02	1.06	3.63	.02	.08
.050	-.97	-3.77	-1.13	1.25	3.35	.03	.12
.060	-2.72	-4.29	-1.43	1.77	4.93	.04	.16
.070	-3.63	-5.94	-1.61	2.30	6.24	.06	.22
.080	-3.04	-3.93	-1.61	2.91	7.99	.08	.29
.090	-3.26	-3.06	-1.74	3.97	9.29	.11	.38
.100	-3.91	-3.47	-2.15	4.32	10.02	.14	.48
.110	-2.57	-3.16	-2.47	4.72	10.74	.18	.59
.120	-.95	-5.96	-2.64	4.15	12.52	.21	.71
.130	-.91	-4.29	-2.06	4.50	14.07	.23	.84
.140	-3.76	-1.91	-2.74	4.67	15.30	.25	1.00
.150	-2.66	-3.72	-3.16	4.62	15.91	.27	1.16
.160	-.74	-5.77	-3.17	4.33	17.73	.27	1.34
.170	-3.53	-4.30	-3.76	3.71	19.74	.27	1.53
.180	-5.31	-3.93	-3.34	4.99	21.19	.26	1.74
.190	-.60	-6.33	-3.21	4.79	23.04	.24	1.97
.200	-2.29	-4.27	-3.69	4.04	24.30	.21	2.22
.210	-3.42	-6.07	-3.22	4.15	27.20	.18	2.48
.220	.50	-6.35	-3.33	3.35	29.13	.13	2.77
.230	-1.47	-2.06	-3.26	2.33	31.20	.06	3.07
.240	-2.72	-5.09	-3.07	2.47	32.65	-.01	3.39
.250	-.46	-4.09	-2.05	3.17	35.33	-.05	3.73
.260	-2.26	-4.01	-2.35	2.29	36.95	-.15	4.09
.270	-1.47	-4.32	-2.20	2.22	38.12	-.22	4.46
.280	.11	-4.55	-1.63	2.31	40.52	-.29	4.84
.290	-1.34	-3.69	-1.63	1.53	41.75	-.36	5.25
.300	-.31	-3.96	-1.95	.91	42.58	-.44	5.67
.310	-1.92	-4.46	-1.58	1.03	44.59	-.53	6.10
.320	-2.58	-4.36	-1.63	.37	45.08	-.64	6.54
.330	-3.79	-4.58	-1.55	1.20	47.33	-.73	7.00
.340	-.99	-4.65	-1.57	1.49	49.42	-.83	7.47
.350	-.87	-2.56	-1.56	.75	50.55	-.93	7.96
.360	-.95	-4.04	-1.52	.35	51.51	-1.05	8.45

Table 16. Transducer data, test SPI-1 (continued).

.370	-.57	-2.47	-1.99	-.84	52.42	-1.15	8.96
.380	.05	-2.23	-1.03	-1.07	53.49	-1.24	9.47
.390	-.02	-.24	-1.40	-1.75	54.23	-1.31	9.99
.400	-.14	-.47	-1.58	-2.91	54.12	-1.70	10.50
.410	.09	.33	-1.48	-3.45	54.30	-1.89	11.02
.420	-.33	.22	-1.25	-4.32	54.40	-2.11	11.52
.430	-1.54	-1.14	-1.24	-4.73	54.53	-2.31	12.04
.440	-.59	-1.94	-1.15	-4.55	54.91	-2.52	12.55
.450	-1.53	-.22	-1.57	-5.51	54.67	-2.73	13.07
.460	-.47	-.94	-1.18	-5.77	55.37	-2.95	13.59
.470	.43	-1.09	-1.37	-6.34	55.37	-3.17	14.10
.480	.29	-.37	-1.14	-7.25	55.97	-3.41	14.62
.490	-.23	-1.04	-1.14	-7.63	56.07	-3.65	15.15
.500	-.93	.47	-1.28	-8.45	55.94	-3.91	15.66
.510	.34	.23	-1.31	-9.01	55.72	-4.19	16.17
.520	.57	-.33	-1.24	-9.73	55.75	-4.45	16.68
.530	.11	-.20	-1.30	-10.73	55.66	-4.79	17.18
.540	.05	-.37	-1.05	-11.13	56.12	-5.11	17.67
.550	-.06	-.05	-1.09	-11.38	55.85	-5.42	18.18
.560	-.33	-1.49	-.92	-12.20	55.17	-5.74	18.67
.570	-.49	-.50	-.90	-12.55	56.51	-6.06	19.18

OCCUP. RISK FACTORS

	TIME (S)	VELOCITY (FPS)
LONG. VEL. AFTER 2.0 FT. DISP. --	.575	-12.94
LAT. VEL. AFTER 1.0 FT. DISP. --	.140	15.30

MAX. ACCEL. AFTER OCCUPANT IMPACT	TIME(S)	ACC.(GS)
LAT. ACCELERATION --	.337	-7.62

Test SPI-2

Purpose

Test SPI-2 was a test of the G4(1S) barrier with substandard 80-percent soil compaction. The importance of meeting the NCHRP Report 230 guideline for soil compaction was made manifest in this test.

Barrier Installation

The same G4(1S) barrier system was used in this test as was used for test SPI-1; the barrier schematic is shown in figure 18 and pretest photographs appear in figure 24. The barrier was 50 ft longer to ensure proper anchorage with the larger expected deflections.

The soil was placed at 80 percent proctor density and 3.7 percent moisture content.

Target Impact Conditions

The strength test conditions of 60 mph (96.5 kph) and 25 degrees were the target impact conditions.

Test Vehicle

A 1978 Plymouth Fury ballasted to 4490 lb was the test vehicle. This vehicle was identical to the test vehicle used in SPI-1. No anthropometric dummies were used.

Performance

Actual impact conditions were 60.0 mph (96.5 kph) at 25.5 degrees. The point of impact was 16 inches downstream of post 7. Sequential photographs of the test appear in figure 25.

The vehicle began to redirect smoothly but because of excessive post rotations the vehicle pocketed and then ramped on post 10. The vehicle was launched and very nearly rolled over attaining a maximum roll angle of 49.5 degrees before coming to rest 195 ft (59.4 m) downstream of impact and 12 ft (3.7 m) into the traveled way.

Maximum 50 msec average accelerations measured by film analysis were 3.6 g (longitudinal) and 5.5 g (lateral). Transducer data indicated 50 msec averages of 2.5 g (longitudinal) and -6.0 g (lateral). Figure 26 presents a summary of test results. Table 17 contains permanent rail deflections. Table 18 contains vehicle kinetic data as well as occupant risk data from film analysis. Analog to digital conversion from on-board transducers is tabulated in table 19. Figure 27 contains photographs of barrier and vehicle damage. Plots of transducer data are presented in figure 28.

Barrier Damage

Two sections of W-beam were deformed and posts 5 through 13 were deflected laterally as shown in table 19. The beam was detached from the post at post 18. The post, though rotated in the soil, remained undeformed as figure 27 shows. With such poorly compacted soil the soil failed before the posts reached their ultimate strength.

Vehicle Damage

The vehicle damage consisted of sheet metal deformation of the left front fender, left side, and grill. The left front and rear tires were blown out from underriding the beam. The front bumper was damaged but it remained connected to the frame horn.

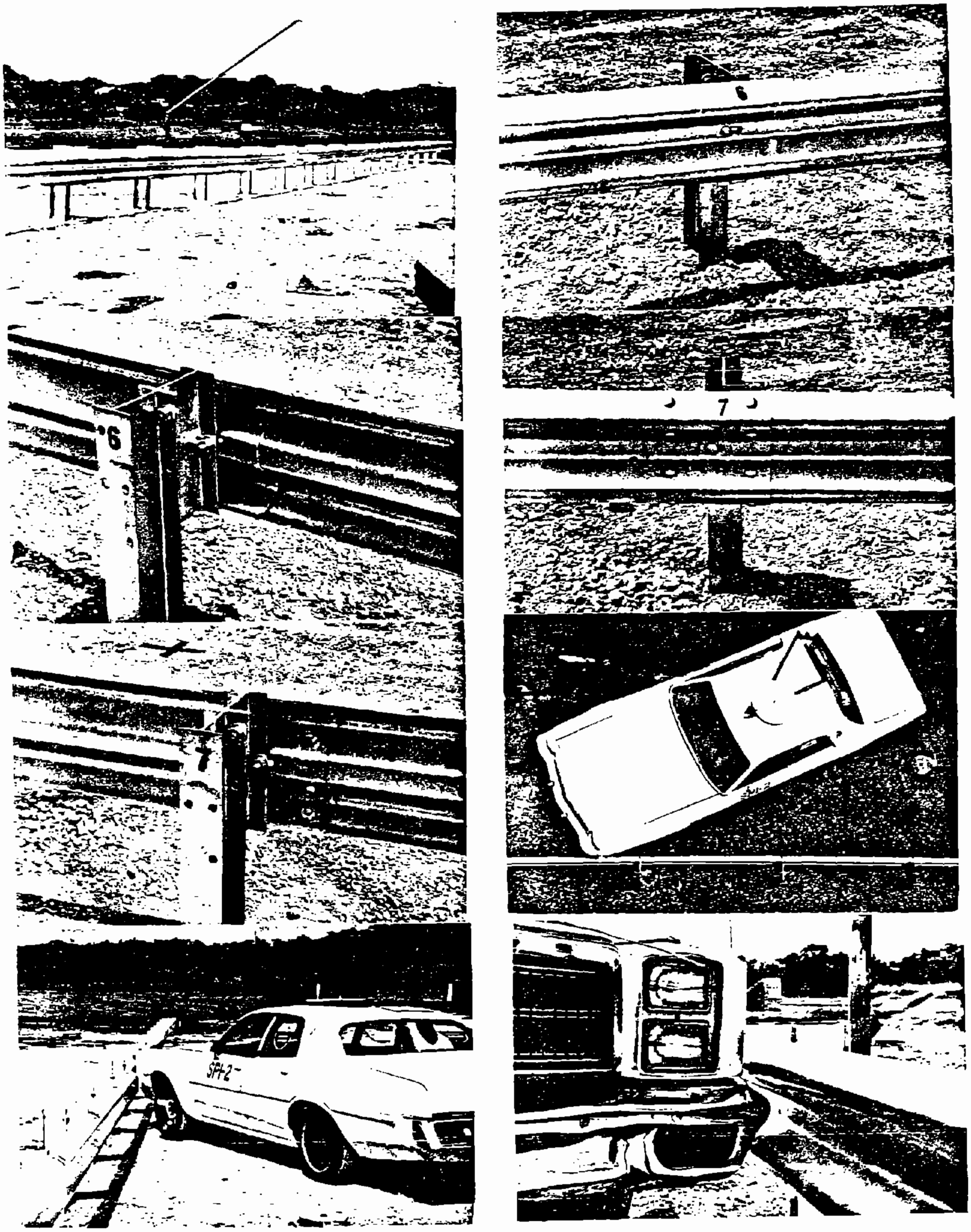


Figure 24. Pre-impact vehicle and barrier details, test SPI-2.

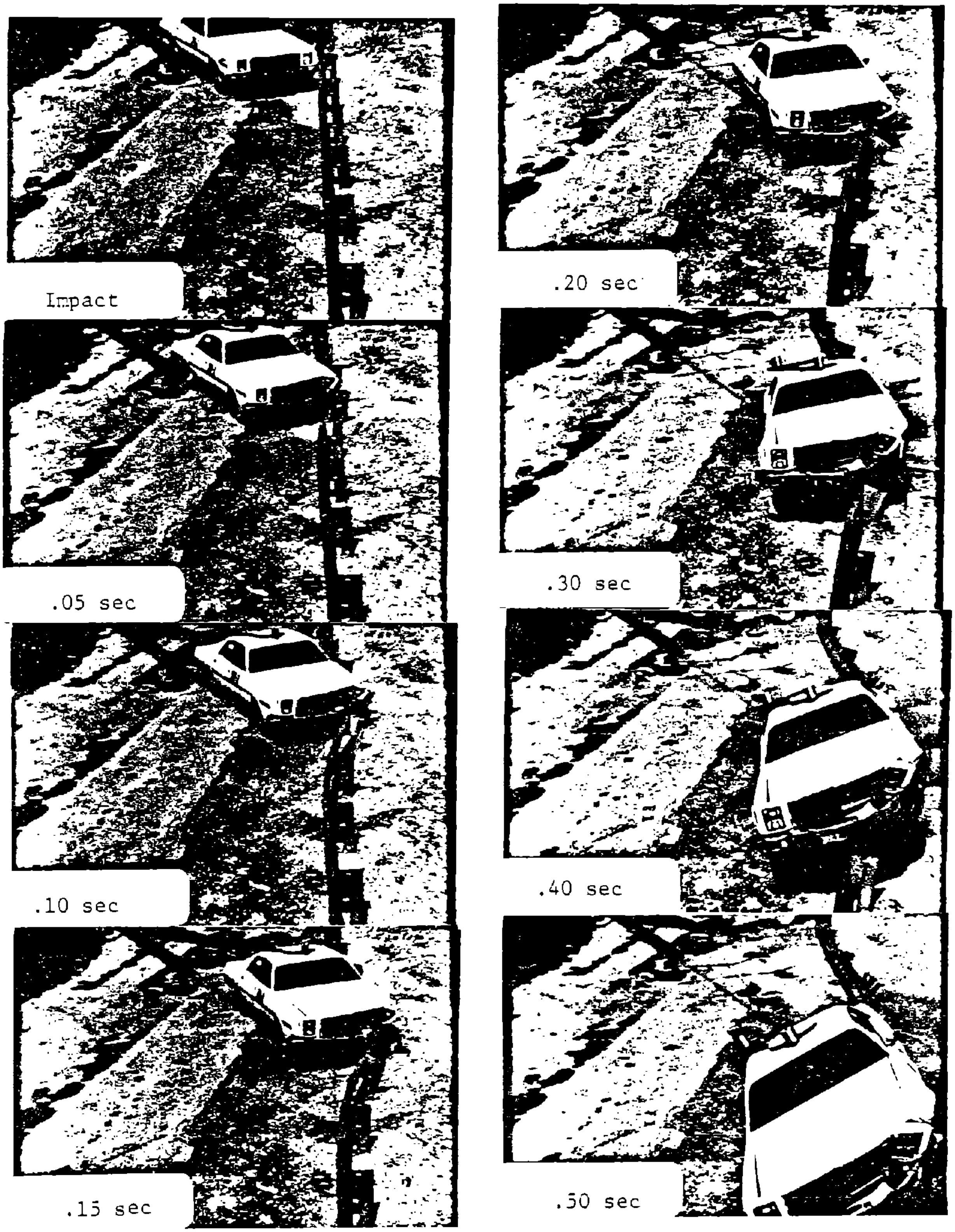
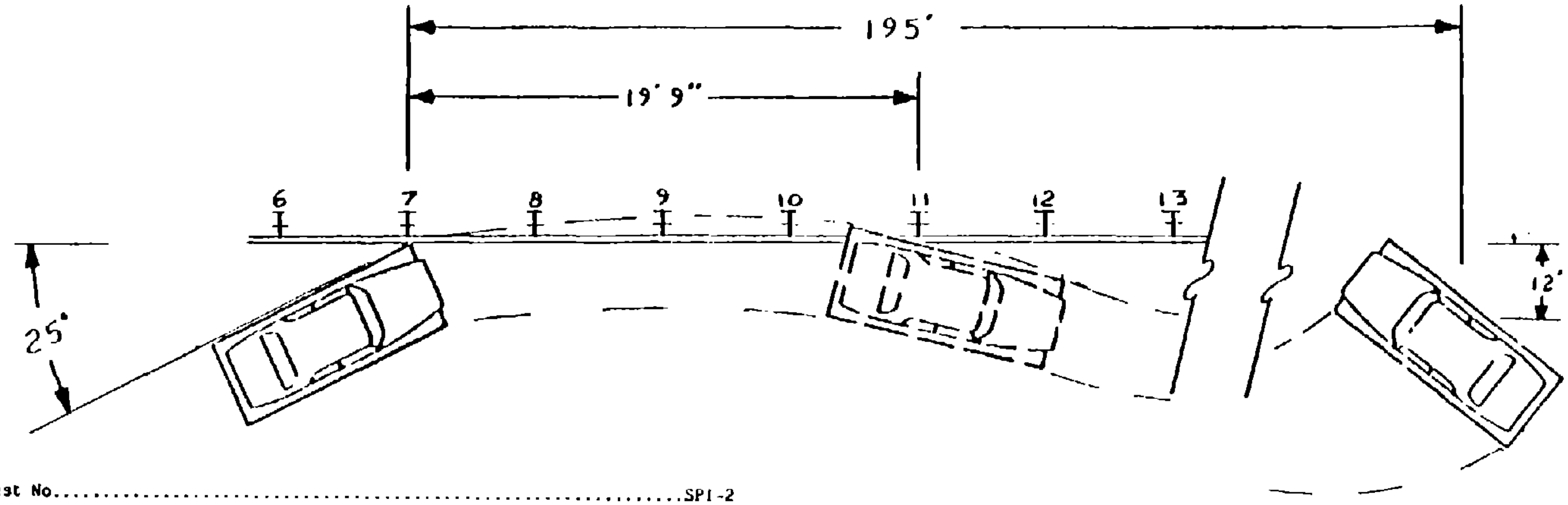


Figure 25. Sequential photographs, test SPI-2.



Test No. SPT-2

Date 7/12/85

Installatin Length - ft (m) 137.5 (41.9)

Beam
Member .... W-beam
Length - ft (m) 12 (3.7)

Maximum Deflections - in. (cm)
Dynamic 45.1 (114.6)
Permanent 27.3 (69.3)

Post
Material .... steel
Description W6x8.5
Embedment -ft (m) 3.7 (1.1)
Spacing -ft (m) 6.3 (1.9)

Soil
Soil Type S1
Moisture Content (%) 3.7
Standard Proctor Compaction (%) 80

Vehicle .... 1978 Plymouth Fury

Mass - lb (kg) 4490 (2037)

Bumper Height - in. (cm) 21.5 (54.6)

Speed - mph (kph)
Impact 58.6 (94.3)
Exit 47.3 (76.1)

Angle - deg
Impact 23.6
Exit 1.1

Occupant Impact Velocity - fps (m/s)
Forward (film/accel) 13.3/10.2 (4.05/3.11)
Lateral (film/accel) 16.0/14.2 (4.88/4.33)

Occupant Ridedown Accelerations -g's
Forward (accel) 1.3/0.6
Lateral (accel) 5.5/10.2

Maximum 50 msec Avg Accelerations - g's
Longitudinal (film/accel) 3.6/2.5
Lateral (film/accel) 5.5/6.0

Damage
VDI 11FLEN3

Figure 26. Summary of results, test SPT-2.

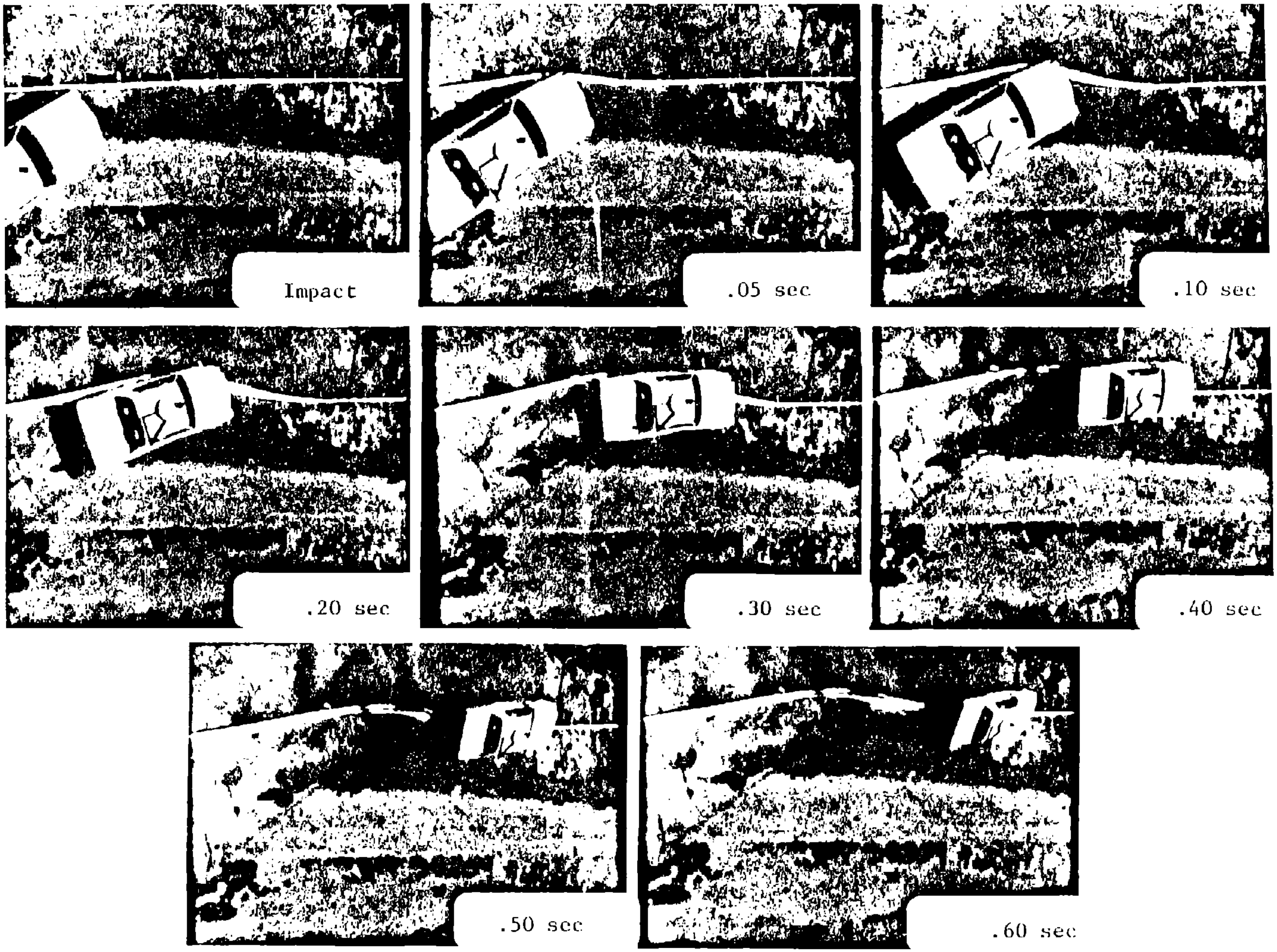


Figure 26. Summary of results, test SPT-2 (Continued).

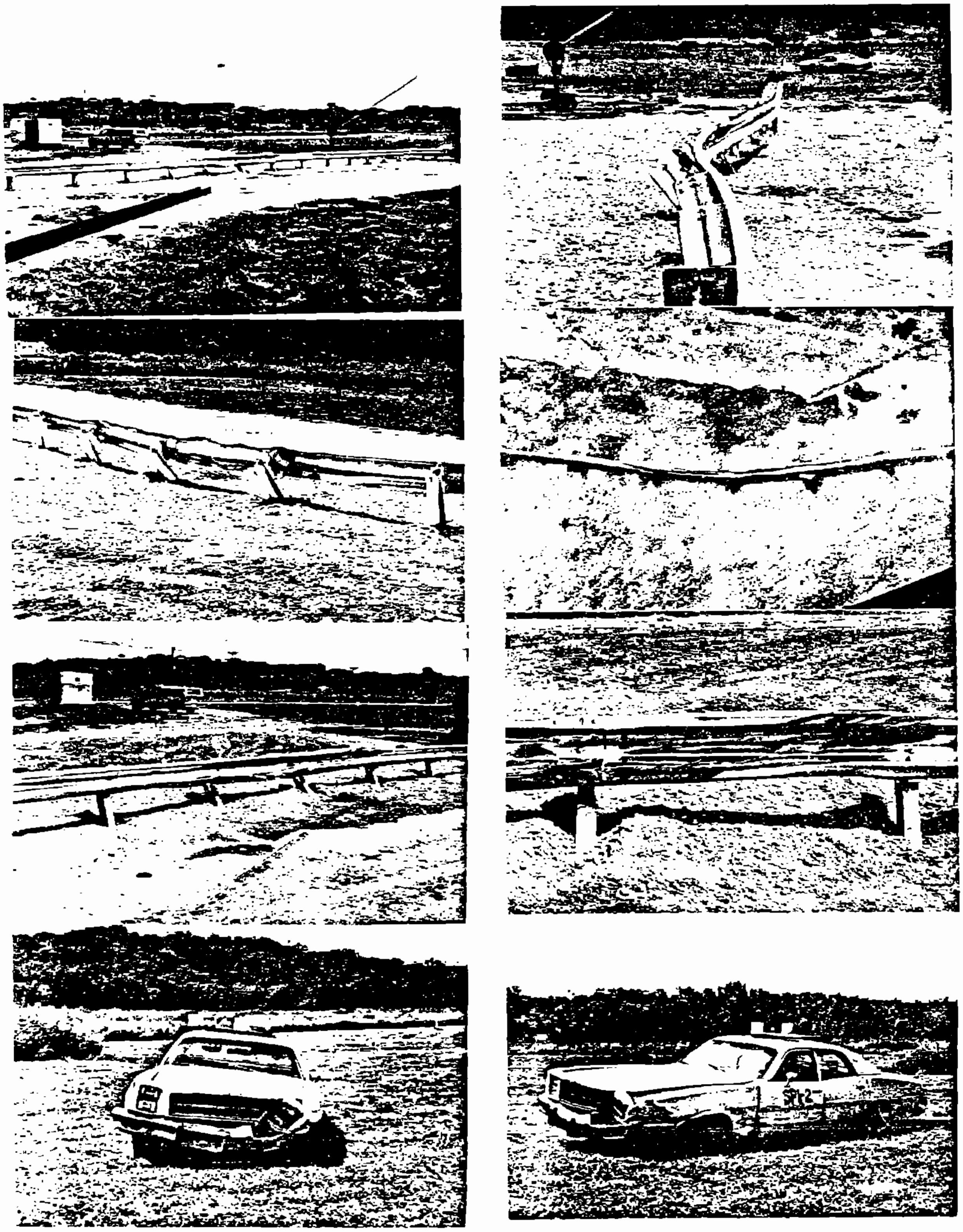


Figure 27. Vehicle and barrier damage, test SPI-2.

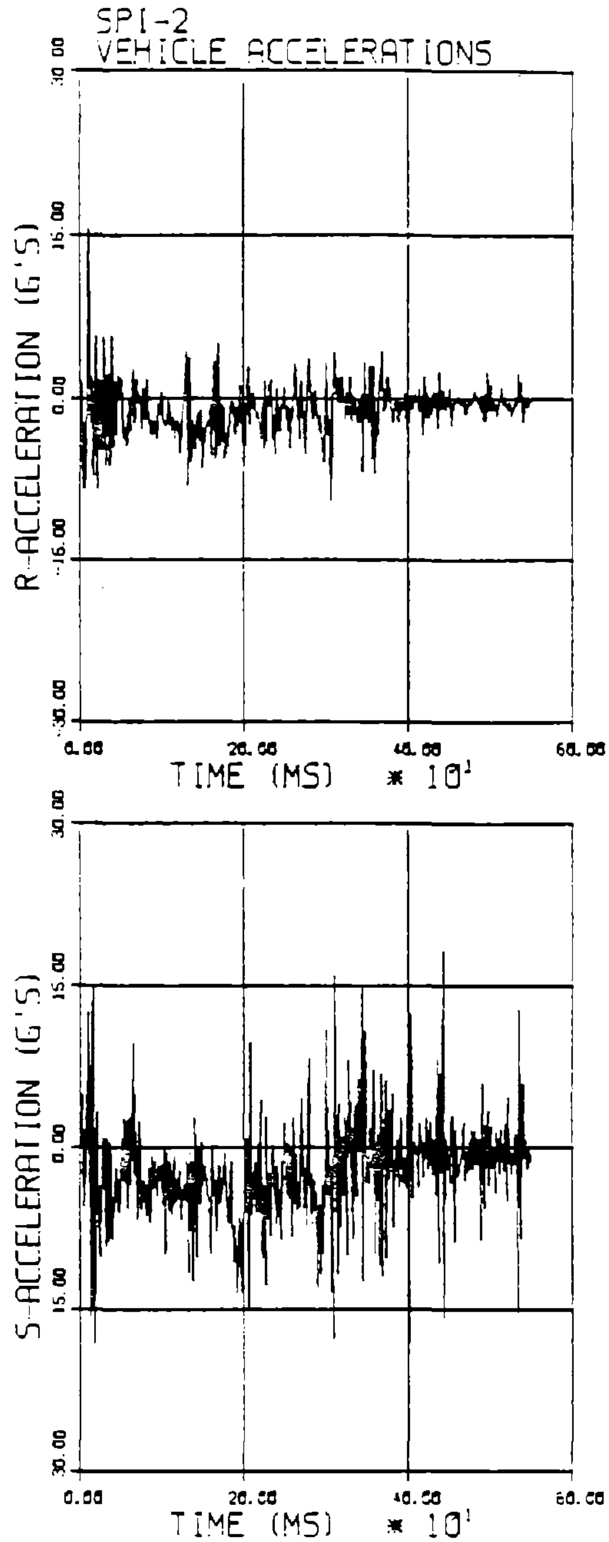


Figure 28. Vehicle accelerations, test SPI-2.

Table 17. Permanent barrier deflections, test SPI-2.

Post Number	Deflection (inches)
4	0
5	2.1
6	8.0
7	16.5
8	27.3
9	33.0
10	26.0
11	14.3
12	6.3
13	1.0
14	0

Table 18. Film analysis data, test SPI-2.

SOIL POST INTERACTION TEST SPI-2 7-12-85
OCCUPANT RISK SUMMARY -- FROM FILM ANALYSIS
NOTE: AVG. ACCEL. FOR PRIOR 0.010 SEC. CALCULATED
FROM VEHICLE VELOCITY CHANGE
RELATIVE VALUES-(OCCUPANT W.R.T. VEHICLE)

	(------- VEHICLE	--------)(		------------ OCCUPANT	------------)		
TIME	ACCEL. (G'S)		ANG. VEL	VEL. (FPS)		DISP. (F)	
(S)	LONG.	LAT.	(RAD/S)	LONG.	LAT.	LONG.	LAT.
0.000	-.16	-.51	.41	0.00	0.00	0.00	0.00
.010	-.26	-.63	.41	.05	.16	.00	.00
.020	-.39	-.77	.41	.10	.34	.00	.00
.030	-.55	-.94	.41	.17	.53	.00	.01
.040	-.76	-1.13	.41	.27	.75	.00	.01
.050	-.99	-1.33	.41	.40	1.00	.01	.02
.060	-1.25	-1.56	.41	.59	1.30	.01	.03
.070	-1.54	-1.81	.41	.84	1.65	.02	.05
.080	-1.83	-2.07	.40	1.17	2.09	.03	.07
.090	-2.13	-2.35	.39	1.55	2.60	.04	.09
.100	-2.42	-2.64	.39	2.03	3.21	.06	.12
.110	-2.70	-2.94	.37	2.58	3.92	.08	.16
.120	-2.95	-3.25	.36	3.20	4.76	.11	.20
.130	-3.18	-3.56	.35	3.88	5.72	.14	.26
.140	-3.37	-3.87	.33	4.61	6.82	.18	.32
.150	-3.52	-4.17	.32	5.39	8.07	.22	.40
.160	-3.63	-4.45	.30	6.18	9.46	.27	.49
.170	-3.65	-4.72	.28	6.99	10.99	.33	.60
.180	-3.69	-4.96	.26	7.77	12.66	.39	.72
.190	-3.65	-5.16	.24	8.57	14.46	.45	.87
.200	-3.56	-5.33	.21	9.31	16.37	.52	1.03
.210	-3.42	-5.44	.19	10.05	18.38	.59	1.22
.220	-3.24	-5.51	.17	10.63	20.46	.67	1.43
.230	-3.03	-5.51	.15	11.20	22.58	.74	1.66
.240	-2.79	-5.46	.13	11.70	24.74	.82	1.91
.250	-2.52	-5.35	.11	12.13	26.88	.90	2.18
.260	-2.24	-5.19	.09	12.49	29.00	.98	2.48
.270	-1.95	-4.98	.07	12.78	31.08	1.06	2.80
.280	-1.65	-4.78	.06	13.01	33.09	1.15	3.14
.290	-1.35	-4.55	.04	13.19	34.90	1.23	3.49
.300	-1.06	-3.99	.03	13.32	36.63	1.32	3.87
.310	-.77	-3.53	.02	13.40	38.23	1.41	4.26
.320	-.49	-3.13	.01	13.45	39.86	1.50	4.66
.330	-.23	-2.71	.00	13.48	40.92	1.60	5.07
.340	.01	-2.25	-.00	13.47	42.00	1.70	5.50
.350	.25	-1.80	-.01	13.44	42.90	1.81	5.93
.360	.45	-1.35	-.01	13.38*	43.62	1.93*	6.37
.370	.65	-.92	-.01	13.30	44.15	2.05	6.81

Table 18. Film analysis data, test SPI-2 (continued).

.380	.92	-.51	-.01	13.15	44.52	2.16	7.25
.390	.97	-.14	-.01	13.04	44.73	2.32	7.70
.400	1.10	.20	-.01	12.87	44.79	2.46	8.14
.410	1.20	.49	-.01	12.65	44.71	2.61	8.58
.420	1.26	.73	-.00	12.42	44.53	2.76	9.02
.430	1.32	.92	-.00	12.15	44.24	2.91	9.46
.440	1.34*	1.06	.00	11.84	43.89	3.06	9.89
.450	1.33	1.14	.01	11.51	43.48	3.20	10.32
.460	1.29	1.17	.01	11.16	43.03	3.34	10.74
.470	1.22	1.15	.01	10.79	42.58	3.48	11.16
.480	1.12	1.03	.01	10.42	42.14	3.60	11.58
.490	1.01	.97	.02	10.05	41.72	3.72	12.00
.500	.87	.32	.02	9.70	41.35	3.82	12.41

OCCUP. RISK FACTORS		TIME (S)	VELOCITY (FPS)
LONG. VEL. AFTER 2.0 FT. DISP.	--	.355	13.33
LAT. VEL. AFTER 1.0 FT. DISP.	--	.198	15.99

MAX. ACCEL. AFTER OCCUPANT IMPACT		TIME(S)	ACC.(G'S)
LONG. ACCELERATION	--	.440	1.34
LAT. ACCELERATION	--	.230	-5.51

Table 18. Film analysis data, test SPI-2 (continued).

SOIL POST INTERACTION TEST SPI-2 7-22-85

VEHICLE KINETICS SUMMARY--FROM FILM ANALYSIS

TIME (S)	VEH. ACCEL.(G'S) LONG.	LAT.	HEADING ANGLE (DEG)	VEH. VEL.(FPS) LONG.	LAT.	VEH. DISP.(F) X	Y
0.000	-.18	-.51	23.57	84.97	2.02	-18.07	-6.22
.010	-.26	-.63	23.66	84.96	1.72	-17.30	-5.86
.020	-.39	-.77	23.73	84.80	1.39	-16.53	-5.50
.030	-.55	-.94	23.76	84.65	1.06	-15.76	-5.15
.040	-.76	-1.13	23.76	84.44	.74	-14.99	-4.80
.050	-.99	-1.33	23.69	84.16	.45	-14.22	-4.46
.060	-1.25	-1.55	23.55	83.80	.18	-13.45	-4.12
.070	-1.54	-1.81	23.33	83.35	-.04	-12.68	-3.79
.080	-1.83	-2.07	23.02	82.81	-.21	-11.92	-3.46
.090	-2.12	-2.33	22.61	82.17	-.33	-11.16	-3.14
.100	-2.42	-2.64	22.10	81.45	-.40	-10.40	-2.83
.110	-2.70	-2.94	21.49	80.63	-.44	-9.65	-2.54
.120	-2.95	-3.25	20.77	79.72	-.43	-8.90	-2.25
.130	-3.18	-3.56	19.96	78.74	-.40	-8.15	-1.98
.140	-3.37	-3.87	19.05	77.69	-.36	-7.41	-1.72
.150	-3.52	-4.17	18.06	76.58	-.33	-6.68	-1.48
.160	-3.63	-4.45	17.00	75.43	-.30	-5.96	-1.25
.170	-3.69	-4.72	15.87	74.26	-.31	-5.24	-1.04
.180	-3.69	-4.95	14.70	73.06	-.36	-4.52	-.85
.190	-3.65	-5.16	13.48	71.90	-.45	-3.82	-.68
.200	-3.56	-5.33	12.25	70.73	-.60	-3.12	-.53
.210	-3.42	-5.44	11.01	69.55	-.82	-2.44	-.39
.220	-3.24	-5.51	9.77	68.39	-1.10	-1.75	-.28
.230	-3.03	-5.51	8.57	67.21	-1.44	-1.08	-.18
.240	-2.79	-5.45	7.39	66.71	-1.83	-.41	-.10
.250	-2.52	-5.35	6.27	65.89	-2.26	.25	-.05
.260	-2.24	-5.17	5.22	65.27	-2.77	.90	-.01
.270	-1.95	-4.96	4.23	64.55	-3.29	1.55	.02
.280	-1.65	-4.68	3.33	64.02	-3.83	2.20	.02
.290	-1.35	-4.35	2.52	63.60	-4.36	2.83	.02
.300	-1.06	-3.99	1.80	63.27	-4.93	3.47	-.01
.310	-.77	-3.58	1.18	63.03	-5.46	4.10	-.04
.320	-.49	-3.15	.65	62.86	-5.97	4.73	-.09
.330	-.23	-2.71	.22	62.81	-6.45	5.36	-.15
.340	.01	-2.25	-.10	62.82	-6.89	5.99	-.21
.350	.25	-1.80	-.34	62.89	-7.26	6.62	-.29
.360	.46	-1.35	-.50	63.02	-7.51	7.25	-.37
.370	.65	-.92	-.58	63.21	-7.66	7.88	-.45
.380	.82	-.51	-.59	63.45	-7.70	8.51	-.54
.390	.97	-.14	-.55	63.74	-7.65	9.14	-.62
.400	1.10	.22	-.46	64.06	-7.54	9.78	-.71
.410	1.20	.49	-.33	64.41	-7.37	10.42	-.80
.420	1.28	.73	-.18	64.79	-7.35	11.07	-.89

Table 18. Film analysis data, test SPI-2 (continued).

.430	1.32	.92	-.02	65.16	-8.27	11.72	-.97
.440	1.34	1.06	.15	65.59	-8.14	12.37	-1.05
.450	1.33	1.14	.31	65.99	-7.97	13.03	-1.13
.460	1.29	1.17	.46	66.40	-7.77	13.69	-1.21
.470	1.22	1.15	.59	66.76	-7.54	14.36	-1.28
.480	1.12	1.06	.68	67.15	-7.29	15.03	-1.34
.490	1.01	.97	.75	67.48	-7.04	15.71	-1.41
.500	.87	.82	.78	67.76	-6.79	16.38	-1.47
.510	.72	.64	.78	68.04	-6.55	17.06	-1.52
.520	.55	.43	.74	68.25	-6.33	17.74	-1.58
.530	.39	.22	.67	68.41	-6.14	18.43	-1.63
.540	.22	-.00	.57	68.51	-5.95	19.11	-1.69
.550	.07	-.21	.45	68.57	-5.88	19.80	-1.74
.560	-.07	-.40	.31	68.59	-5.81	20.49	-1.79
.570	-.19	-.56	.16	68.56	-5.79	21.17	-1.85
.580	-.26	-.67	.01	68.50	-5.81	21.86	-1.90
.590	-.35	-.73	-.14	68.41	-5.86	22.54	-1.96
.600	-.36	-.73	-.27	68.31	-5.93	23.23	-2.02
.610	-.37	-.65	-.39	68.20	-6.01	23.91	-2.09
.620	-.32	-.51	-.49	68.10	-6.08	24.59	-2.15
.630	-.24	-.29	-.57	68.01	-6.12	25.27	-2.22
.640	-.11	.00	-.63	67.90	-6.10	25.95	-2.29
.650	.04	.34	-.67	67.95	-5.99	26.63	-2.36
.660	.22	.72	-.70	68.00	-5.79	27.31	-2.43
.670	.42	1.10	-.72	68.10	-5.48	27.99	-2.49
.680	.62	1.45	-.74	68.27	-5.03	28.67	-2.55
.690	.80	1.72	-.78	68.51	-4.47	29.35	-2.61
.700	.94	1.64	-.85	68.79	-3.82	30.04	-2.66
.710	1.00	1.73	-.95	69.21	-3.11	30.72	-2.71
.720	.96	1.29	-1.10	69.44	-2.44	31.42	-2.75

HIGHEST 50-MS AVG.ACCEL.

		TIME (SEC)	
	G'S	START	END
LONG.	-3.61	.1550	.2050
LAT.	-5.50	.2050	.2550

Table 19. Transducer data, test SPI-2.

TEST ID ------- SPI-2
TEST DATE ----- 07-12-85
VEHICLE CLASS - STANDARD
IMPACT SPEED -- 54.97 FPS

VEHICLE KINETICS SUMMARY
NOTE: VALUES ARE INSTANTANEOUS AT TIME

TIME	ACCEL.(G'S)		HEAD.ANG.	VELOCITY(FPS),		DISP.(F)	
S.	LONG.	LAT.	DEG	LONG.	LAT.	X	Y
0.000	.04	.07	23.57	54.97	2.02	-18.07	-6.22
.010	11.51	12.55	23.61	54.19	2.36	-17.30	-5.86
.020	5.83	-2.90	23.72	54.81	1.15	-16.53	-5.50
.030	3.55	-1.71	23.72	54.55	.11	-15.76	-5.16
.040	.35	-6.41	23.67	54.23	-1.27	-14.99	-4.82
.050	.79	[illegible]	23.56	54.06	-2.48	-14.21	-4.50
.060	.04	2.74	23.29	53.39	-2.44	-13.43	-4.19
.070	1.75	-3.57	[illegible]	53.30	-2.00	-12.66	-3.89
.080	-1.52	-3.04	22.75	53.15	-2.59	-11.88	-3.58
.090	-7.66	-1.40	22.55	52.58	-3.39	-11.10	-3.29
.100	.56	-2.47	21.84	52.16	-3.48	-10.33	-3.01
.110	-1.72	-1.40	21.25	51.67	-4.09	-9.55	-2.75
.120	-2.54	-4.59	20.61	50.91	-4.34	-8.78	-2.50
.130	4.33	-1.34	19.35	50.50	-4.63	-8.01	-2.26
.140	-3.48	2.31	19.14	49.73	-5.20	-7.23	-2.04
.150	-6.37	-3.40	18.29	48.92	-4.30	-6.47	-1.83
.160	-5.09	-4.66	17.43	48.10	-4.03	-5.71	-1.64
.170	-3.59	-1.55	16.35	48.09	-4.94	-4.95	-1.46
.180	-4.52	-5.05	15.21	47.15	-4.42	-4.19	-1.29
.190	-3.27	-7.54	[illegible]	46.56	-4.05	-3.43	-1.14
.200	-5.05	-5.34	12.73	46.52	-5.30	-2.67	-1.02
.210	-.45	-5.15	[illegible]	46.05	-5.57	-1.92	-.92
.220	-3.17	-1.77	[illegible]	45.34	-4.70	-1.16	-.83
.230	.04	-5.07	6.24	45.40	-4.36	-.41	-.76
.240	.90	-1.77	6.02	45.03	-3.65	.35	-.70
.250	-.79	-1.34	5.52	44.76	-2.94	1.09	-.65
.260	-.99	2.51	4.34	44.20	-2.21	1.84	-.61
.270	1.65	4.54	3.44	44.25	-1.65	2.56	-.58
.280	2.29	-.21	2.50	44.10	-1.06	3.32	-.56
.290	-1.72	-12.73	2.12	43.95	-2.15	4.06	-.54
.300	3.56	11.22	1.74	43.05	-3.59	4.80	-.55
.310	4.53	15.92	1.45	42.35	-4.45	5.52	-.57
.320	1.22	.74	.93	42.75	-4.21	6.25	-.59
.330	[illegible]	[illegible]	.72	42.77	-3.93	6.98	-.62
.340	[illegible]	[illegible]	.56	42.39	-3.79	7.71	-.65
.350	-.87	[illegible]	.55	42.04	-3.16	8.43	-.68
.360	[illegible]	-10.11	.54	41.72	-3.23	9.15	-.71
.370	[illegible]	[illegible]	.54	41.73	-4.27	9.86	-.74

Table 19. Transducer data, test SPI-2 (continued).

.380	-1.61	3.10	.70	71.76	-4.63	10.58	-.77
.390	-.69	-3.46	.98	71.35	-5.42	11.30	-.81
.400	-1.61	5.92	1.08	71.10	-5.75	12.01	-.86
.410	-.36	-.21	1.17	70.99	-6.09	12.72	-.90
.420	2.08	.22	1.22	70.71	-5.24	13.43	-.95
.430	.26	-2.47	1.27	70.60	-5.27	14.14	-1.00
.440	-.79	[illegible]	1.34	70.51	-6.30	14.65	-1.04
.450	-.58	-1.91	1.52	70.55	-6.75	15.55	-1.09
.460	-.27	-1.20	1.65	70.15	-7.11	16.26	-1.14
.470	-.27	-3.04	1.75	70.05	-7.57	16.96	-1.19
.480	.47	-1.41	1.75	69.87	-8.06	17.66	-1.25
.490	-.39	5.75	2.01	69.55	-8.43	18.36	-1.31
.500	-.17	-.07	2.11	69.73	-8.56	19.06	-1.37
.510	-.68	-.73	2.23	69.53	-8.96	19.76	-1.43
.520	-.89	-3.65	2.37	69.48	-9.28	20.46	-1.49
.530	-.58	.05	2.47	69.19	-9.69	21.16	-1.55
.540	-2.23	5.90	2.55	69.22	-10.07	21.65	-1.62
.550	-.27	-.57	2.75	69.05	-10.30	22.55	-1.69

HIGHEST 50.0-MS AVG. ACCEL.

		TIME (SEC)	
	G'S	START	END
LONG.	[illegible]	[illegible]	.162
LAT.	-5.62	[illegible]	.207

Table 19. Transducer data, test SPI-2 (continued).

TEST ID ------- SPI-2
TEST DATE ----- [illegible]
VEHICLE CLASS - STANDARD
IMPACT SPEED -- 59.77 FPS

OCCUPANT RISK SUMMARY
NOTE: INSTANTANEOUS 10-MS AVERAGE ACCELERATIONS

TIME (S)	VEHICLE ACCEL. (G'S) LONG.	VEHICLE ACCEL. (G'S) LAT.	VEHICLE ANG. VEL (RAD/S)	OCCUPANT VEL. (FPS) LONG.	OCCUPANT VEL. (FPS) LAT.	OCCUPANT DISP. (F) LONG.	OCCUPANT DISP. (F) LAT.
0.000	.04	.07	.03	0.00	0.00	0.00	0.00
.010	[illegible]	-.50	.13	.90	-.23	.00	.00
.020	-1.00	-3.06	.33	.50	1.08	.01	.00
.030	-.65	-3.53	-.15	.21	1.47	.01	.01
.040	-1.14	-4.52	-.09	.39	2.90	.02	.03
.050	-.55	-2.59	-.30	.42	3.03	.02	.07
.060	-1.50	-.02	-.43	.99	4.30	.03	.11
.070	.33	-1.23	-.45	.95	4.14	.04	.15
.080	-.34	-4.22	-.50	1.12	5.17	.05	.20
.090	-2.57	-3.43	-.55	1.13	5.12	.05	.26
.100	-1.29	-3.70	-.71	1.54	5.39	.07	.32
.110	-1.97	-3.74	-1.19	1.75	6.11	.08	.40
.120	-3.21	-3.97	-1.52	2.15	7.05	.09	.48
.130	-.29	-4.41	-1.05	2.70	10.70	.11	.58
.140	-3.74	-3.71	-1.75	3.05	11.57	.13	.70
.150	-3.59	-2.29	-1.40	3.72	12.35	.15	.82
.160	-1.62	[illegible]	-1.55	4.20	14.07	.18	.96
.170	-1.64	-4.55	-1.30	5.30	15.23	.20	1.11
.180	-2.02	[illegible]	-2.27	3.95	16.13	.21	1.27
.190	-1.27	[illegible]	[illegible]	4.22	18.40	.23	1.44
.200	[illegible]	[illegible]	[illegible]	4.19	21.77	.23	1.65
.210	[illegible]	[illegible]	-2.04	3.21	22.34	.22	1.87
.220	[illegible]	-3.92	[illegible]	2.23	23.19	.20	2.11
.230	-.39	-4.57	-3.34	1.32	24.50	.17	2.36
.240	-2.23	-4.27	-2.54	2.77	27.12	.13	2.63
.250	-.79	-1.54	-2.04	2.03	28.02	.10	2.91
.260	-.45	-2.42	-1.70	3.22	29.90	.06	3.20
.270	-1.53	-2.09	-1.40	2.45	31.13	.04	3.51
.280	-.01	-2.53	-1.15	3.11	31.50	.02	3.82
.290	-1.55	-7.20	[illegible]	3.30	34.01	.02	4.15
.300	-2.34	-1.09	[illegible]	3.75	35.05	.02	4.50
.310	-.75	-4.20	-1.57	3.50	35.35	.05	4.87
.320	.20	[illegible]	-.57	4.15	37.45	.05	5.24
.330	[illegible]	[illegible]	-.33	4.05	38.09	.07	5.63
.340	[illegible]	[illegible]	.25	5.03	39.20	.10	6.01
.350	[illegible]	[illegible]	[illegible]	5.37	39.41	.15	6.40
.360	-1.23	[illegible]	.25	6.11	39.72	.20	6.78

Table 19.   Transducer data, test SPI-2 (continued).

.370	1.04	-2.25	.15	5.71	59.37	.27	7.17
.380	-.46	-.73	[illegible]	5.27	57.91	.35	7.56
.390	[illegible]	-.77	[illegible]	6.72	57.27	.44	7.90
.400	-.71	[illegible]	-.10	5.37	57.54	.53	8.35
.410	-.11	-.57	[illegible]	5.57	40.15	.61	8.77
.420	-.76	.27	.12	7.25	47.95	.69	9.17
.430	[illegible]	-.77	.25	7.45	47.55	.77	9.58
.440	-.44	[illegible]	.21	7.74	49.71	.85	9.95
.450	[illegible]	[illegible]	.31	7.71	49.00	.90	10.38
.460	-.64	-1.02	[illegible]	5.72	49.75	1.07	10.79
.470	-.55	-.47	.12	5.23	41.07	1.16	11.20
.480	[illegible]	-.49	.27	5.57	41.55	1.27	11.61
.490	-.75	[illegible]	.27	5.54	41.01	1.37	12.02
.500	.17	[illegible]	.45	9.17	42.05	1.50	12.44
.510	-.35	-.72	.55	9.31	42.15	1.62	12.85
.520	-.52	[illegible]	.75	9.75	41.90	1.74	13.27
.530	-.24	-1.41	.25	9.41	42.15	1.86	13.69
.540	-.55*	.75	[illegible]	10.17*	42.97	2.00*	14.11

OCCUP. RISK FACTORS		TIME (S)	VELOCITY (FPS)
LONG. VEL. AFTER 2.0 FT. DISP.	--	.540	10.23
LAT. VEL. AFTER 1. FT. DISP.	--	.103	14.15

MAX. ACCEL. AFTER OCCUPANT IMPACT		TIME(S)	ACC.(GS)
LONG. ACCELERATION	--	.544	-.04
LAT. ACCELERATION	--	[illegible]	-10.17

Test SPI-3

Purpose

Test SPI-3 was designed so that the soil strength would be just barely adequate to develop the full post strength. This represents the point where the two curves digress in figure 17.

Barrier Installation

The barrier was a 137.5-ft (41.9 m) long G4(1S) as shown in figure 18. Soil compaction was 90 percent standard proctor density.

Impact Conditions

Target impact conditions were 60 mph (96.5 kph) and 25 degrees as in tests SPI-1 and SPI-2.

Test Vehicle

A 1978 Dodge was ballasted to 4490 lb (2039 kg) and used as the test vehicle. No anthropometric dummies were used. The test vehicle and barrier installation are shown in figure 29.

Performance

Actual impact conditions were 59.6 mph (95.9 kph) at 23.1 degrees. The point of impact was at post 7. As shown in the sequential photographs of figure 30, the vehicle was redirected much like test SPI-1 except the vehicle rolled 32 degrees. Barrier performance was very similar to test SPI-1.

Maximum 50 msec average accelerations measured by film analysis were 4.3 g (longitudinal) and 6.4 g (lateral). Transducer data indicated 50 msec averages of 4.8 g (longitudinal) and 6.6 g (lateral). Figure 31 presents a summary of test results. Table 20 contains permanent rail deflections. Table 21 contains vehicle kinetic data as well as occupant risk data from film analysis. Analog to digital conversion from on-board transducers is tabulated in table 22. Figure 32 contains photographs of barrier and vehicle damage. Plots of transducer data are presented in figure 33.

Barrier Damage

Two sections of W-beam were deformed and posts 5 through 12 were deflected laterally as shown in table 20. The beam was detached from the post at post 9.

As shown in figure 33, the posts failed in flexure as they did in test SPI-1. No soil heaving was evident. The posts, because of the greater soil strength, developed their ultimate strength.

Vehicle Damage

The vehicle damage consisted of sheet metal deformation of the left front fender, left side, and grill. The left front and rear tires were blown out from underriding the beam. The front bumper was damaged but it remained connected to the frame horn.

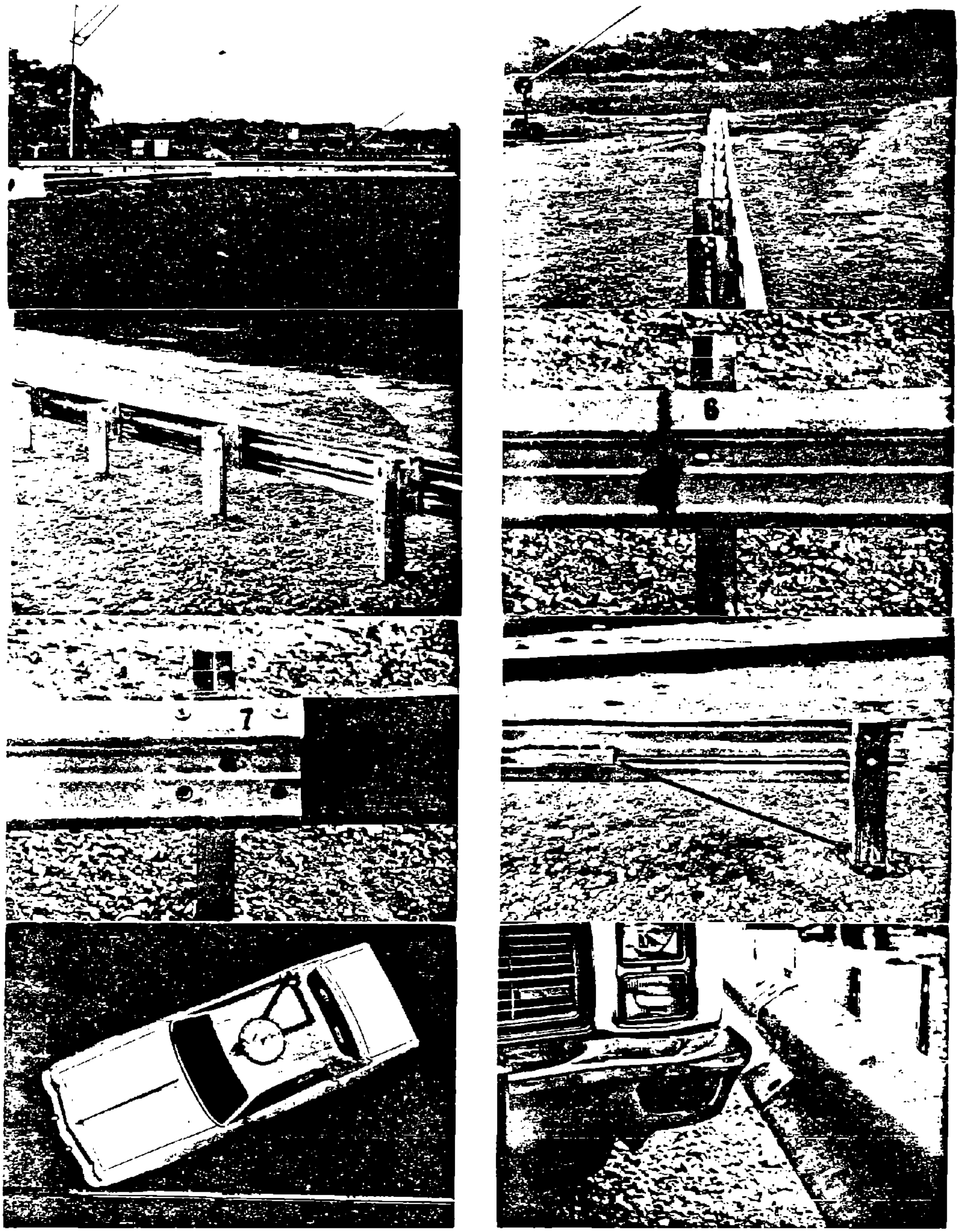


Figure 29. Pre-impact barrier and vehicle details, test SPI-3.

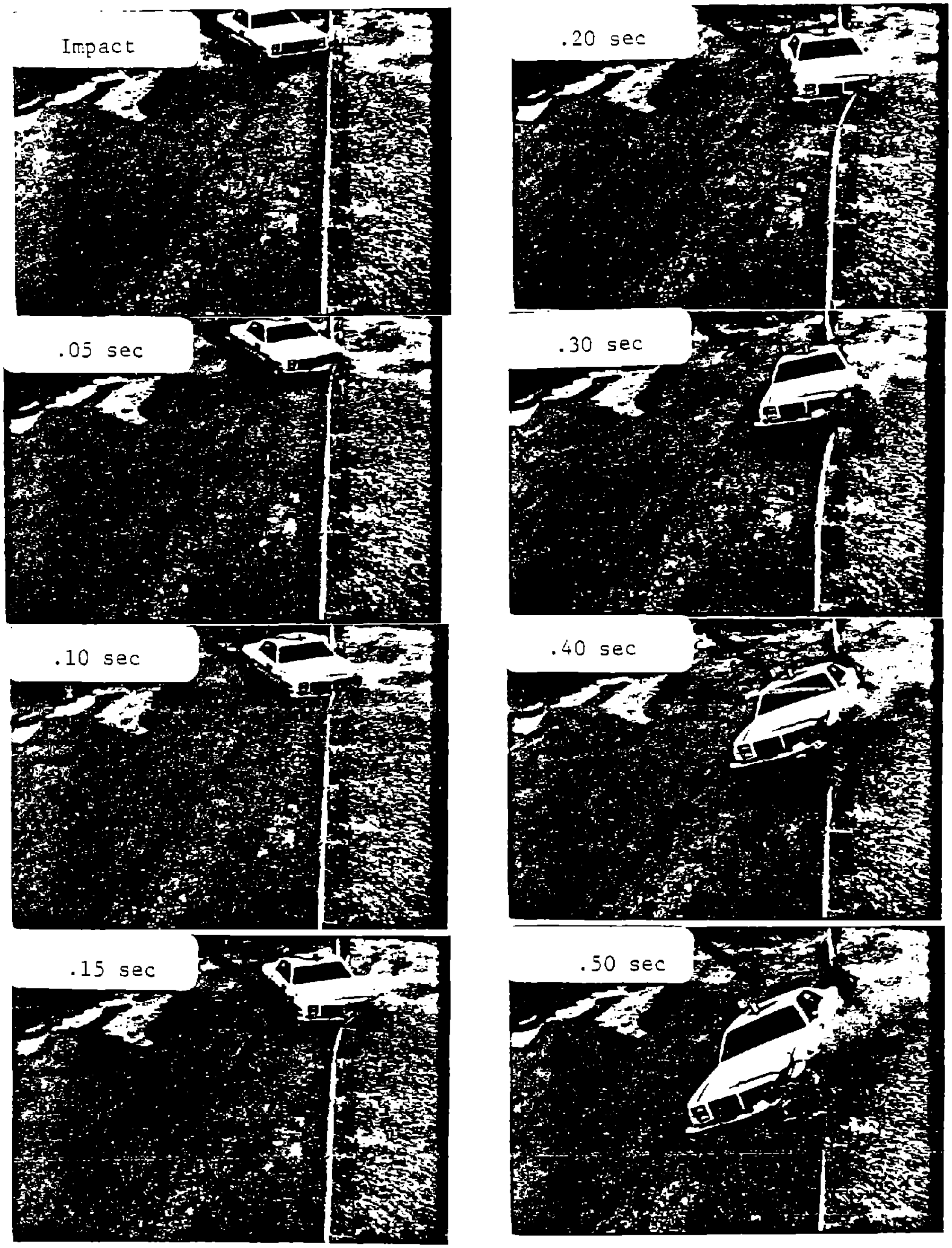
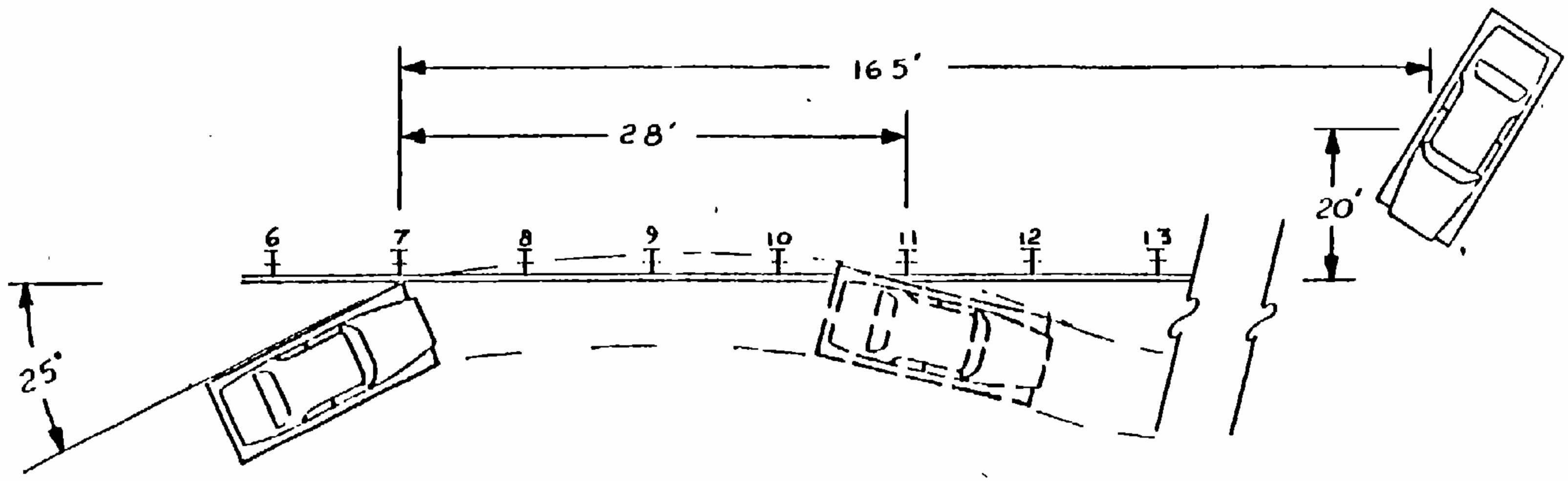


Figure 30. Sequential photographs, test SPI-3.



Test No.	SPI-3
Date	7/24/85
Installatin Length - ft (m)	137.5 (41.9)
Beam	
Member	W-beam
Length - ft (m)	12 (3.7)
Maximum Deflections - in. (cm)	
Dynamic	29.6 (75.2)
Permanent	24.5 (62.2)
Post	
Material	steel
Description	W6x8.5
Embedment -ft (m)	3.7 (1.1)
Spacing -ft (m)	6.3 (1.9)
Soil	
Soil Type	S1
Moisture Content (%)	3.5
Standard Proctor Compaction (%)	90
Vehicle	1978 Dodge

Mass - lb (kg)	4490 (2037)
Speed - mph (kph)	
Impact	59.6 (95.9)
Exit	43.0 (69.2)
Angle - deg	
Impact	23.1
Exit	10.2
Occupant Impact Velocity - fps (m/s)	
Forward (film/accel)	12.7/0.3 (3.81/0.09)
Lateral (film/accel)	15.9/18.3 (4.85/5.58)
Occupant Ridedown Accelerations -g's	
Forward (accel)	0.1/-
Lateral (accel)	6.4/8.6
Maximum 50 msec Avg Accelerations - g's	
Longitudinal (film/accel)	4.3/4.8
Lateral (film/accel)	6.4/6.6
Damage	
VDI	11FLES9

Figure 31. Summary of results, test SPI-3.

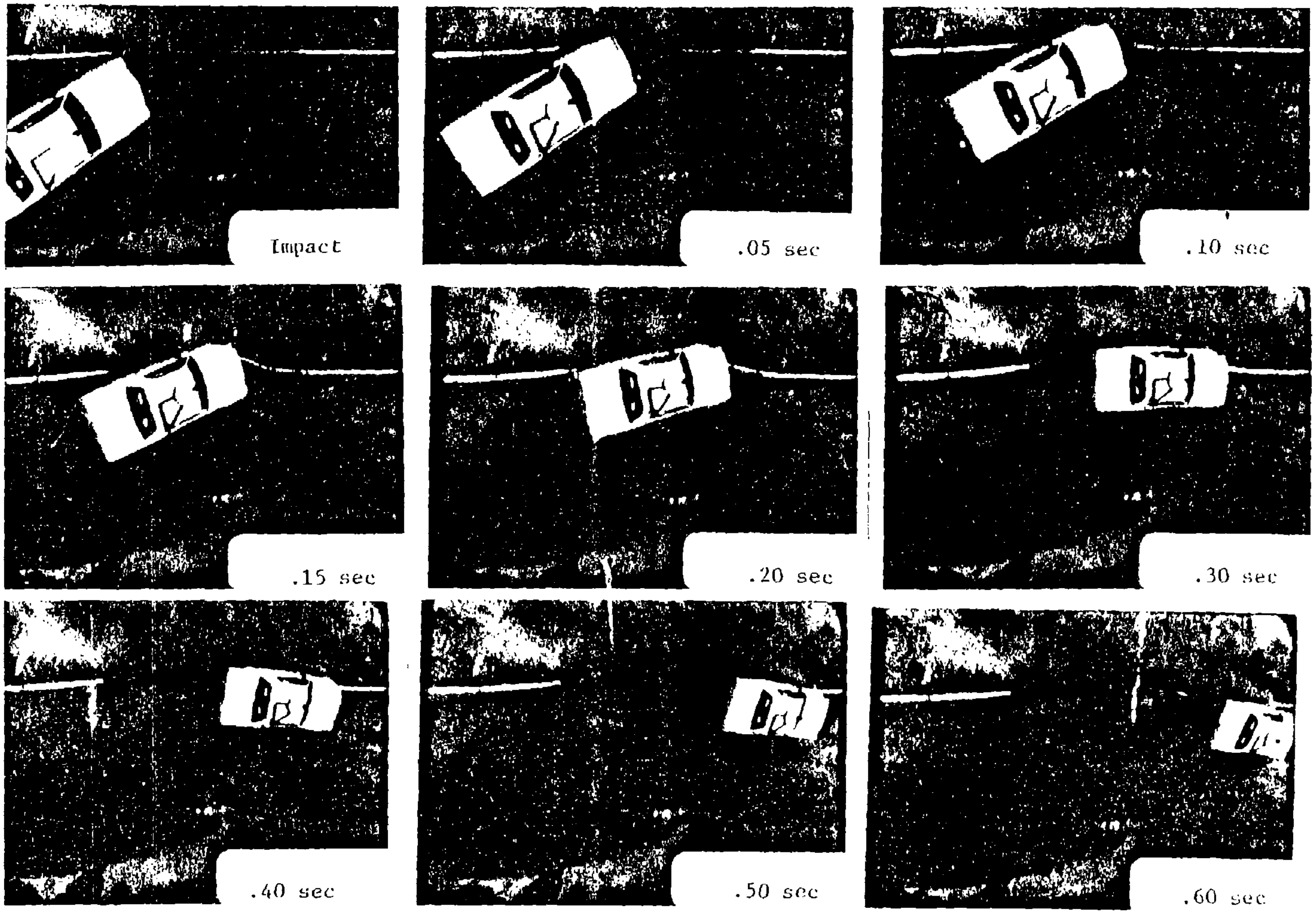


Figure 31. Summary of results, test SPI-3 (continued).

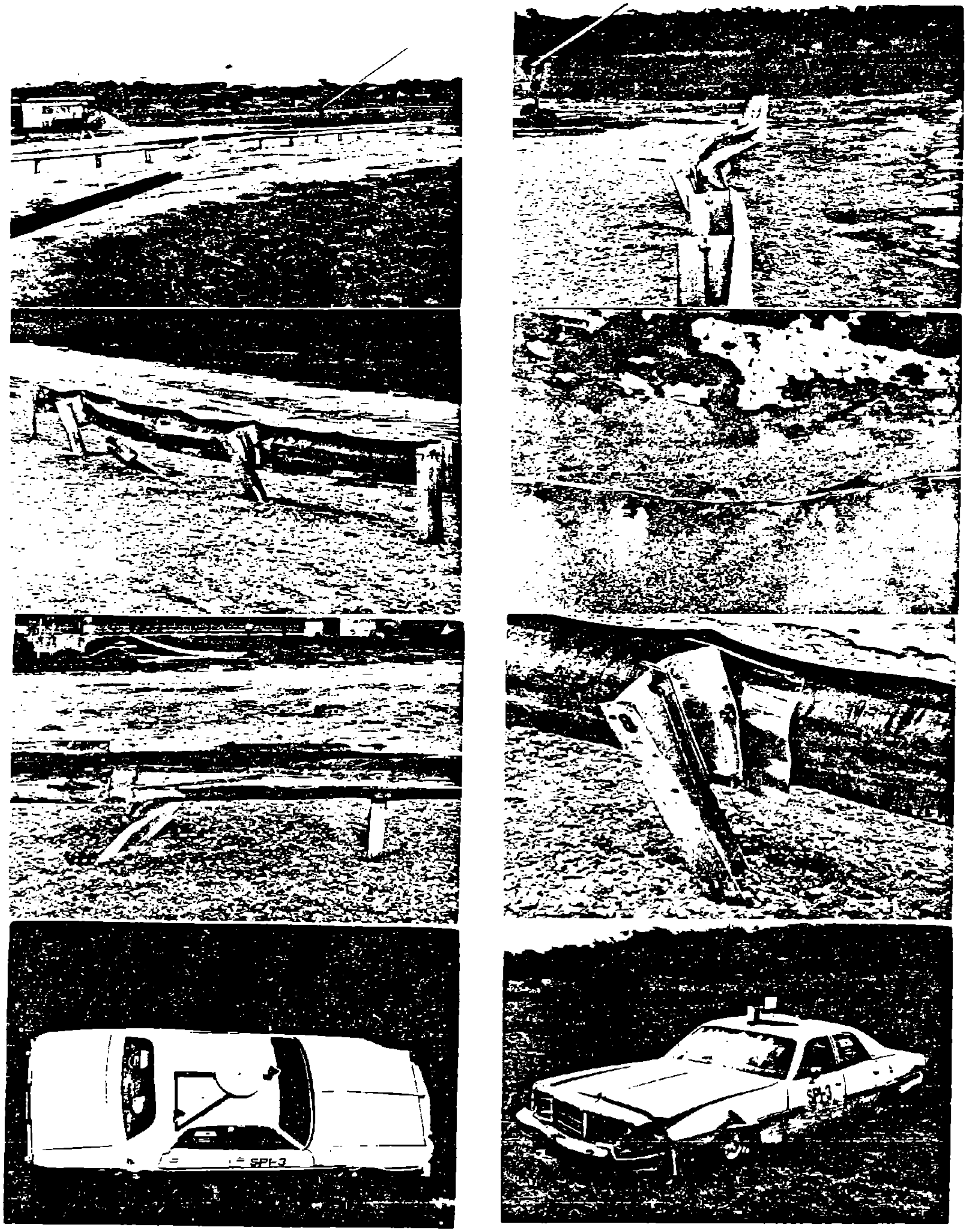


Figure 32. Barrier and vehicle damage, test SPI-3.

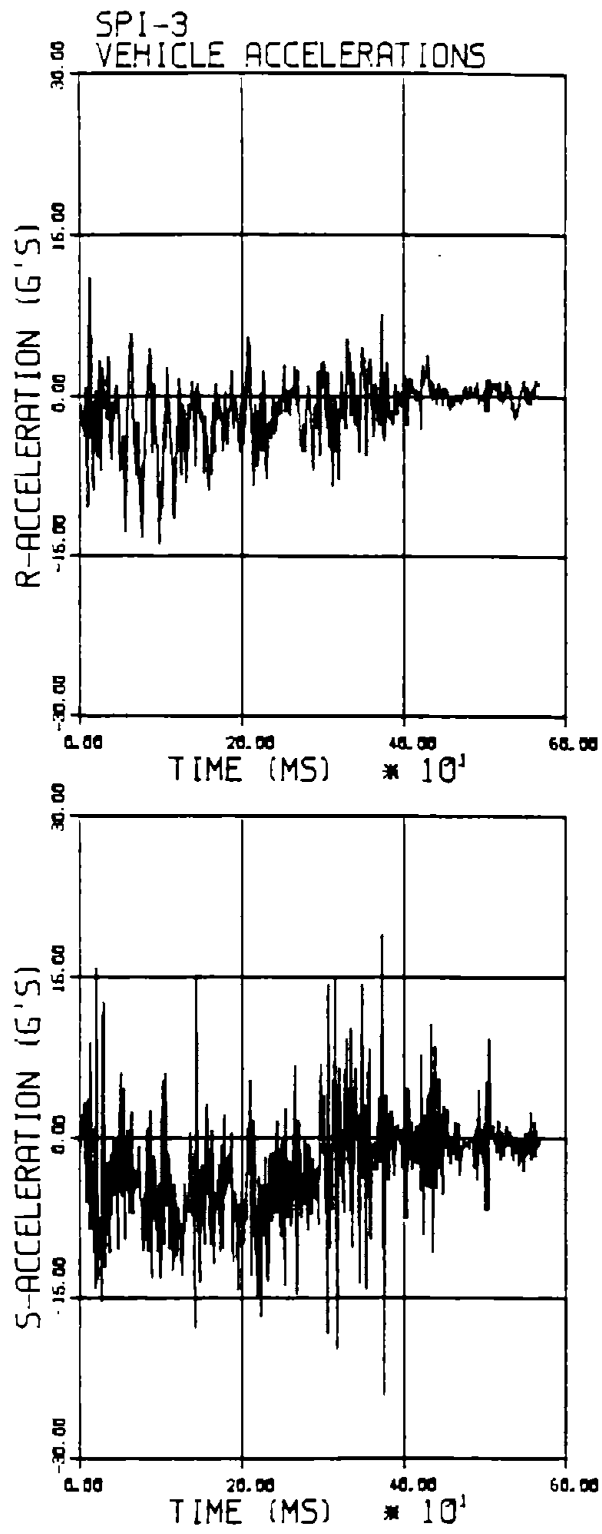


Figure 33. Vehicle accelerations, test SPI-3.

Table 20. Permanent barrier deflections, test SPI-3.

Post Number	Deflection (inches)
4	0
5	0.4
6	1.5
7	5.3
8	19.0
9	24.5
10	17.5
11	5.8
12	1.5
13	0

Table 21. Film analysis data, test SPI-3.

SOIL POST INTERACTION TEST SPI-3 7-24-85

VEHICLE KINETICS SUMMARY--FROM FILM ANALYSIS

TIME (S)	VEH. ACCEL.(G'S) LONG.	LAT.	HEADING ANGLE (DEG)	VEH. VEL.(FPS) LONG.	LAT.	VEH. DISP.(F) X	Y
0.000	-1.05	-1.54	23.12	86.27	1.96	-17.36	-5.74
.010	-1.25	-1.60	23.09	85.90	1.50	-16.57	-5.38
.020	-1.50	-1.66	23.03	85.46	1.06	-15.79	-5.04
.030	-1.78	-1.75	22.94	84.93	.65	-15.01	-4.69
.040	-2.09	-1.85	22.80	84.30	.28	-14.23	-4.36
.050	-2.41	-2.00	22.60	83.58	-.05	-13.46	-4.04
.060	-2.74	-2.19	22.33	82.75	-.34	-12.69	-3.72
.070	-3.06	-2.42	21.99	81.82	-.59	-11.93	-3.41
.080	-3.37	-2.69	21.57	80.78	-.81	-11.17	-3.12
.090	-3.65	-3.01	21.06	79.66	-1.00	-10.42	-2.84
.100	-3.90	-3.36	20.45	78.45	-1.19	-9.67	-2.57
.110	-4.10	-3.74	19.75	77.18	-1.38	-8.94	-2.31
.120	-4.25	-4.14	18.95	75.85	-1.59	-8.21	-2.07
.130	-4.34	-4.54	18.06	74.50	-1.81	-7.49	-1.85
.140	-4.37	-4.94	17.08	73.12	-2.08	-6.78	-1.64
.150	-4.33	-5.32	16.02	71.76	-2.38	-6.08	-1.46
.160	-4.23	-5.66	14.87	70.43	-2.73	-5.39	-1.29
.170	-4.06	-5.96	13.66	69.16	-3.13	-4.71	-1.15
.180	-3.84	-6.20	12.39	67.96	-3.57	-4.03	-1.03
.190	-3.57	-6.36	11.08	66.85	-4.05	-3.36	-.93
.200	-3.25	-6.44	9.74	65.86	-4.56	-2.70	-.85
.210	-2.91	-6.45	8.38	64.98	-5.09	-2.05	-.79
.220	-2.56	-6.34	7.03	64.22	-5.62	-1.40	-.76
.230	-2.20	-6.15	5.68	63.60	-6.13	-.76	-.75
.240	-1.84	-5.87	4.37	63.09	-6.61	-.13	-.76
.250	-1.51	-5.51	3.09	62.70	-7.05	.51	-.78
.260	-1.20	-5.08	1.87	62.42	-7.42	1.13	-.83
.270	-.92	-4.59	.72	62.24	-7.73	1.76	-.89
.280	-.68	-4.05	-.35	62.13	-7.95	2.38	-.97
.290	-.48	-3.48	-1.35	62.08	-8.09	3.00	-1.06
.300	-.32	-2.90	-2.25	62.08	-8.14	3.62	-1.16
.310	-.20	-2.31	-3.06	62.11	-8.11	4.24	-1.27
.320	-.11	-1.75	-3.77	62.16	-7.98	4.85	-1.39
.330	-.05	-1.21	-4.39	62.22	-7.79	5.47	-1.51
.340	-.01	-.73	-4.92	62.29	-7.52	6.08	-1.64
.350	.01	-.30	-5.37	62.34	-7.20	6.69	-1.76
.360	.01	.05	-5.74	62.39	-6.83	7.31	-1.89
.370	.01	.33	-6.05	62.43	-6.43	7.92	-2.03
.380	.01	.53	-6.30	62.47	-6.01	8.54	-2.15
.390	.01	.64	-6.52	62.49	-5.59	9.15	-2.28
.400	.00	.67	-6.70	62.51	-5.18	9.77	-2.41

Table 21. Film analysis data, test SPI-3 (continued).

.410	.01	.61	-6.86	62.52	-4.79	10.38	-2.53
.420	.01	.49	-7.02	62.54	-4.44	11.00	-2.65
.430	.02	.31	-7.19	62.56	-4.12	11.61	-2.77
.440	.03	.09	-7.37	62.58	-3.86	12.23	-2.89
.450	.04	-.15	-7.58	62.60	-3.64	12.84	-3.01
.460	.06	-.41	-7.81	62.63	-3.48	13.46	-3.13
.470	.08	-.63	-8.07	62.67	-3.36	14.07	-3.25
.480	.09	-.81	-8.36	62.72	-3.28	14.69	-3.37
.490	.11	-.91	-8.67	62.77	-3.22	15.30	-3.50
.500	.12	-.92	-8.99	62.82	-3.16	15.92	-3.62
.510	.14	-.81	-9.32	62.88	-3.09	16.54	-3.75
.520	.16	-.56	-9.63	62.95	-2.97	17.15	-3.89
.530	.21	-.13	-9.92	63.02	-2.78	17.77	-4.02
.540	.29	.35	-10.16	63.11	-2.48	18.38	-4.16

HIGHEST 50-MS AVG.ACCEL.

		TIME (SEC)	
	G'S	START	END
LONG.	-4.28	.1150	.1650
LAT.	-6.40	.1650	.2350

Table 21. Film analysis data, test SPI-3 (continued).

SOIL POST INTERACTION TEST SPI-3   7-24-85
OCCUPANT RISK SUMMARY -- FROM FILM ANALYSIS
NOTE: AVG. ACCEL. FOR PRIOR 0.010 SEC. CALCULATED
FROM VEHICLE VELOCITY CHANGE
RELATIVE VALUES-(OCCUPANT W.R.T. VEHICLE)

TIME (S)	VEHICLE ACCEL. (G'S) LONG.	VEHICLE ACCEL. (G'S) LAT.	VEHICLE ANG. VEL (RAD/S)	OCCUPANT VEL. (FPS) LONG.	OCCUPANT VEL. (FPS) LAT.	OCCUPANT DISP. (F) LONG.	OCCUPANT DISP. (F) LAT.
0.000	-1.05	-1.54	.40	0.00	0.00	0.00	0.00
.010	-1.25	-1.60	.40	.32	.46	.00	.00
.020	-1.50	-1.66	.40	.69	.91	.01	.01
.030	-1.78	-1.75	.40	1.12	1.37	.02	.02
.040	-2.09	-1.85	.40	1.63	1.84	.03	.04
.050	-2.41	-2.00	.39	2.21	2.33	.05	.06
.060	-2.74	-2.19	.39	2.87	2.87	.07	.08
.070	-3.06	-2.42	.38	3.61	3.46	.10	.12
.080	-3.37	-2.69	.38	4.42	4.13	.14	.15
.090	-3.65	-3.01	.37	5.30	4.90	.19	.20
.100	-3.90	-3.36	.36	6.24	5.80	.25	.26
.110	-4.10	-3.74	.34	7.23	6.83	.31	.32
.120	-4.25	-4.14	.33	8.24	8.02	.38	.40
.130	-4.34	-4.54	.32	9.26	9.39	.46	.50
.140	-4.37	-4.94	.30	10.26	10.93	.55	.61
.150	-4.32	-5.32	.28	11.22	12.65	.65	.73
.160	-4.22	-5.56	.26	12.12	14.54	.75	.88
.170	-4.06	-5.95	.24	12.94	16.60	.85	1.06
.180	-3.84	-6.20	.22	13.65	18.81	.96	1.25
.190	-3.57	-6.35	.19	14.24	21.13	1.07	1.48
.200	-3.25	-6.44	.17	14.70	23.55	1.17	1.73
.210	-2.91	-6.45	.15	15.02	26.03	1.28	2.00
.220	-2.56	-6.34	.12	15.20	28.53	1.38	2.31
.230	-2.20	-6.15	.10	15.24	31.02	1.47	2.64
.240	-1.84	-5.87	.08	15.16	33.45	1.56	3.00
.250	-1.51	-5.51	.05	14.98	35.78	1.64	3.38
.260	-1.20	-5.08	.03	14.71	38.00	1.71	3.78
.270	-.92	-4.59	.01	14.37	40.05	1.78	4.21
.280	-.68	-4.05	-.01	13.99	41.93	1.84	4.65
.290	-.48	-3.45	-.02	13.59	43.61	1.89	5.11
.300	-.32	-2.90	-.04	13.19	45.08	1.94	5.59
.310	-.20	-2.31	-.05	12.80	46.33	1.99	6.07
.320	-.11	-1.75	-.07	12.46	47.36	2.04	6.56
.330	-.05	-1.21	-.08	12.15	48.18	2.09	7.06
.340	-.01	-.73	-.09	11.89	48.80	2.14	7.57
.350	.01	-.30	-.09	11.67	49.24	2.19	8.08
.360	.01	.05	-.10	11.49	49.51	2.26	8.59

Table 21. Film analysis data, test SPI-3 (continued).

.370	.01	.33	-.11	11.35	49.04	2.32	9.09
.380	.01	.32	-.11	11.23	49.06	2.39	9.60
.390	.01	.04	-.11	11.12	49.59	2.47	10.11
.400	.00	.07	-.12	11.01	49.46	2.55	10.61
.410	.01	.01	-.12	10.89	49.31	2.63	11.11
.420	.01	.99	-.12	10.74	49.15	2.70	11.61
.430	.02	.31	-.13	10.57	49.03	2.77	12.11
.440	.03	.09	-.13	10.36	48.96	2.84	12.61
.450	.04	-.12	-.13	10.11	48.95	2.90	13.11
.460	.05	-.41	-.14	9.83	49.02	2.94	13.61
.470	.06	-.63	-.14	9.52	49.18	2.97	14.11
.480	.09	-.81	-.15	9.17	49.41	3.00	14.62
.490	.11	-.91	-.15	8.55	49.70	3.01	15.13
.500	.12*	-.92	-.16	8.51	50.04	3.01	15.65

OCCUP. RISK FACTORS

	TIME (S)	VELOCITY (FPS)
<LONG. VEL. AFTER 2.0 FT. DISP. --	.312	12.72
<LAT. VEL. AFTER 1.0 FT. DISP. --	.167	15.92

MAX. ACCEL. AFTER OCCUPANT IMPACT	TIME(S)	ACC.(G'S)
<LONG. ACCELERATION --	.500	.12
<LAT. ACCELERATION --	.200	-5.44

Table 22. Transducer data, test SPI-3.

TEST ID -------- SPI-3
TEST DATE ----- 07-24-85
VEHICLE CLASS - STANDARD
IMPACT SPEED -- 86.27 FPS

VEHICLE KINETICS SUMMARY
NOTE: VALUES ARE INSTANTANEOUS AT TIME

TIME	ACCEL.(G'S)		HEAD.ANG.	VELOCITY(FPS),		DISP.(F)	
S.	LONG.	LAT.	DEG	LONG.	LAT.	X	Y
0.000	.00	-.25	23.12	86.27	1.96	-17.36	-5.74
.010	-10.02	3.74	23.18	85.29	1.84	-16.58	-5.38
.020	.27	15.89	23.30	85.29	.65	-15.80	-5.03
.030	-.99	-9.76	23.33	84.91	-.41	-15.02	-4.70
.040	-2.80	-3.29	23.37	84.48	-2.65	-14.23	-4.38
.050	-6.77	4.31	23.13	83.92	-2.99	-13.44	-4.07
.060	1.27	.51	22.93	82.17	-2.98	-12.67	-3.77
.070	-5.14	-4.43	22.62	82.10	-3.76	-11.90	-3.48
.080	-4.78	-5.20	22.28	79.64	-5.15	-11.13	-3.21
.090	-.81	-2.91	21.82	79.71	-6.34	-10.37	-2.97
.100	-8.03	-9.57	21.19	77.85	-7.43	-9.61	-2.74
.110	-1.35	-10.33	20.53	76.84	-7.34	-8.87	-2.53
.120	-4.24	-10.14	19.80	74.82	-9.20	-8.12	-2.35
.130	-4.24	-6.15	18.85	74.24	-10.63	-7.39	-2.19
.140	-.27	-5.77	17.82	73.64	-10.88	-6.65	-2.07
.150	-2.26	-3.10	16.71	73.48	-11.12	-5.92	-1.95
.160	-6.05	-7.10	15.32	72.19	-10.39	-5.19	-1.85
.170	-2.08	-5.20	13.91	71.48	-10.59	-4.47	-1.78
.180	.45	-4.43	12.52	71.09	-10.40	-3.75	-1.71
.190	-2.98	-5.00	11.11	70.96	-10.09	-3.03	-1.67
.200	2.63	-4.62	9.55	70.45	-10.43	-2.32	-1.64
.210	1.72	5.45	8.06	70.94	-10.03	-1.61	-1.64
.220	-5.50	-9.19	6.68	69.97	-10.43	-.89	-1.65
.230	-6.05	-6.91	5.32	69.60	-10.96	-.19	-1.68
.240	-1.71	-5.39	4.00	68.82	-11.43	.51	-1.74
.250	.27	-5.96	2.79	68.70	-11.22	1.20	-1.81
.260	.27	-8.24	1.68	68.86	-11.64	1.89	-1.90
.270	-.81	1.46	.74	69.38	-11.48	2.59	-2.00
.280	-.27	-7.38	-.01	68.40	-11.84	3.27	-2.12
.290	-.81	-5.58	-.94	67.89	-12.14	3.96	-2.24
.300	2.63	.51	-1.77	67.93	-11.48	4.63	-2.38
.310	-.09	-5.00	-2.56	68.05	-11.50	5.31	-2.52
.320	-3.16	6.59	-3.29	67.09	-11.07	5.98	-2.66
.330	5.34	-.06	-3.91	66.95	-10.06	6.64	-2.81
.340	-2.44	6.59	-4.53	67.75	-9.45	7.31	-2.96

Table 22. Transducer data, test SPI-3 (continued).

.350	2.63	-3.67	-4.97	67.60	-8.56	7.97	-3.11
.360	2.45	-1.39	-5.33	67.90	-8.81	8.64	-3.25
.370	-2.44	1.46	-5.98	67.71	-8.30	9.30	-3.41
.380	3.17	.32	-6.67	67.80	-7.60	9.97	-3.56
.390	1.18	-.44	-7.05	67.50	-7.36	10.63	-3.71
.400	1.36	.32	-7.31	67.48	-7.02	11.29	-3.87
.410	1.72	1.46	-7.52	67.67	-7.13	11.95	-4.03
.420	.45	1.27	-7.67	67.85	-7.22	12.62	-4.19
.430	3.89	3.74	-7.89	68.36	-7.20	13.28	-4.35
.440	.63	-3.86	-8.11	68.71	-6.72	13.95	-4.52
.450	.82	2.98	-8.30	68.82	-6.82	14.62	-4.68
.460	-.09	-.06	-8.54	68.83	-6.56	15.29	-4.85
.470	-.09	-2.72	-8.74	68.80	-6.54	15.96	-5.02
.480	.09	-.25	-8.86	68.87	-6.63	16.63	-5.19
.490	.82	-.63	-9.03	69.01	-6.55	17.30	-5.36
.500	.45	1.27	-9.25	69.14	-6.35	17.98	-5.53
.510	1.00	.70	-9.43	69.29	-6.11	18.65	-5.71
.520	-.27	-1.96	-9.59	69.57	-5.89	19.32	-5.88
.530	.45	-.63	-9.75	69.68	-5.80	20.00	-6.06
.540	-1.17	-.82	-9.94	69.52	-5.83	20.68	-6.23
.550	1.54	.91	-10.08	69.54	-6.06	21.35	-6.41
.560	.54	-.82	-10.26	69.55	-5.96	22.02	-6.59

HIGHEST 50.0-MS AVG. ACCEL.

		TIME (SEC)	
	G'S	START	END
LONG.	-4.79	.068	.118
LAT.	-6.59	.093	.143

Table 22. Transducer data, test SPI-3 (continued).

TEST ID ------- SPI-3
TEST DATE ----- 07-24-85
VEHICLE CLASS - STANDARD
IMPACT SPEED -- 86.27 FPS

OCCUPANT RISK SUMMARY
NOTE: INSTANTANEOUS 10-MS AVERAGE ACCELERATIONS

	(------- VEHICLE	--------)	(	------------ OCCUPANT	------------)		
TIME (S)	ACCEL. (G'S) LONG.	LAT.	ANG. VEL (RAD/S)	VEL. (FPS) LONG.	LAT.	DISP. (F) LONG.	LAT.
0.000	.00	-.25	.10	0.00	0.00	0.00	0.00
.010	-.40	-.34	.27	1.20	.24	.00	-.00
.020	-2.44	-5.57	-.25	.55	.61	.01	.00
.030	-.74	-4.45	.36	1.69	2.38	.02	.02
.040	-1.51	-4.19	-.28	1.33	3.77	.04	.05
.050	-4.25	-.80	.09	2.34	4.93	.05	.09
.060	-.56	-2.73	-.40	3.47	4.61	.08	.14
.070	-5.69	-4.29	-.63	3.25	5.57	.11	.19
.080	-4.54	-7.27	-.63	5.68	7.46	.15	.25
.090	-.91	-4.54	-.82	5.34	9.10	.20	.33
.100	-7.82	-5.46	-1.14	6.75	10.76	.25	.43
.110	-3.20	-5.25	-1.33	7.47	11.42	.32	.55
.120	-5.19	-8.53	-1.60	9.07	14.03	.40	.68
.130	-3.37	-7.50	-1.84	9.23	16.60	.48	.84
.140	-1.04	-2.91	-1.62	9.95	18.66	.56	1.03
.150	-2.19	-6.52	-2.23	9.13	19.79	.63	1.23
.160	-5.10	-3.50	-2.47	9.83	20.84	.69	1.45
.170	-1.50	-6.12	-2.31	10.38	23.32	.76	1.69
.180	-2.54	-3.49	-2.43	10.21	25.05	.81	1.95
.190	-.63	-6.46	-2.54	9.75	26.67	.86	2.23
.200	-2.78	-7.56	-3.09	9.00	28.60	.89	2.53
.210	-.37	-2.54	-2.42	8.75	31.18	.92	2.86
.220	-3.37	-8.14	-2.62	8.36	33.33	.93	3.20
.230	-2.68	-7.21	-2.04	9.31	36.52	.94	3.57
.240	-1.88	-3.56	-2.20	9.22	38.65	.95	3.97
.250	-.19	-5.09	-1.96	9.00	40.45	.95	4.39
.260	.06	-3.79	-1.73	8.49	42.69	.95	4.82
.270	-1.24	-3.95	-1.25	8.01	44.43	.94	5.27
.280	-1.73	-4.02	-1.33	8.43	45.72	.95	5.73
.290	-2.49	-4.41	-1.78	7.80	46.73	.94	6.21
.300	.23	-1.33	-1.29	7.83	47.81	.92	6.70
.310	-2.45	.57	-1.59	6.80	48.50	.90	7.19
.320	-1.41	-2.75	-1.60	7.25	49.04	.88	7.70
.330	1.05	1.60	-.53	8.29	50.19	.87	8.20
.340	-.80	-1.24	-1.26	6.14	49.50	.85	8.71
.350	-.00	-.24	-.55	6.84	50.06	.85	9.22
.360	.23	-1.12	-.82	5.93	50.45	.85	9.72

Table 22. Transducer data, test SPI-3 (continued).

.370	.49	.05	-1.29	5.05	50.20	.79	10.24
.380	-1.12	-1.57	-.91	4.92	50.86	.72	10.75
.390	-.75	-.02	-.56	5.35	51.55	.69	11.27
.400	.13	-1.89	-.39	5.38	51.75	.70	11.79
.410	.56	.10	-.42	4.99	52.08	.70	12.31
.420	.49	-1.00	-.17	5.00	52.68	.72	12.84
.430	1.79	1.29	.08	4.64	53.25	.72	13.36
.440	.49	-1.07	-.09	3.89	52.86	.70	13.89
.450	.37	-.37	-.37	3.28	52.84	.69	14.42
.460	-.48	-.45	-.46	2.96	52.78	.66	14.95
.470	-.03	-1.12	-.36	2.95	53.13	.63	15.48
.480	.44	-.42	-.30	2.35	53.44	.63	16.02
.490	.39	-.04	-.31	2.56	53.57	.61	16.56
.500	.09	-1.40	-.40	2.13	53.53	.57	17.09
.510	.87	1.11	-.38	1.86	53.54	.53	17.63
.520	.26	-.37	-.42	1.39	53.46	.50	18.17
.530	.40	-.23	-.42	1.15	53.59	.47	18.71
.540	-1.09	-1.26	-.21	1.42	54.09	.42	19.25
.550	.56	-.72	-.15	1.34	54.58	.38	19.79
.560	.35	-.14	-.37	.91	54.43	.33	20.34

OCCUP. RISK FACTORS		TIME (S)	VELOCITY (FPS)
>LONG. VEL. AFTER 2.0 FT. DISP.	--	.570	.28
>LAT. VEL. AFTER 1.0 FT. DISP.	--	.139	18.30

MAX. ACCEL. AFTER OCCUPANT IMPACT		TIME(S)	ACC.(GS)
>LAT. ACCELERATION	--	.228	-8.57

FEDERALLY COORDINATED PROGRAM OF HIGHWAY RESEARCH AND DEVELOPMENT (FCP)

The Offices of Research and Development of the Federal Highway Administration are responsible for a broad program of research with resources including its own staff, contract programs, and a Federal-Aid program which is conducted by or through the State highway departments and which also finances the National Cooperative Highway Research Program managed by the Transportation Research Board. The Federally Coordinated Program of Highway Research and Development (FCP) is a carefully selected group of projects aimed at urgent, national problems, which concentrates these resources on these problems to obtain timely solutions. Virtually all of the available funds and staff resources are a part of the FCP, together with as much of the Federal-aid research funds of the States and the NCHRP resources as the States agree to devote these projects.*

FCP Category Descriptions

1. **Improved Highway Design and Operation for Safety**

   Safety R&D addresses problems connected with the responsibilities of the Federal Highway Administration under the Highway Safety Act and includes investigation of appropriate design standards, roadside hardware, signing, and physical and scientific data for the formulation of improved safety regulations.

2. **Reduction of Traffic Congestion and Improved Operational Efficiency**

   Traffic R&D is concerned with increasing the operational efficiency of existing highways by advancing technology, by improving designs for existing as well as new facilities, and by keeping the demand-capacity relationship in better balance through traffic management techniques such as bus and carpool preferential treatment, motorist information, and rerouting of traffic.

3. **Environmental Considerations in Highway Design, Location, Construction and Operation**

   Environmental R&D is directed toward identifying and evaluating Highway elements which affect the quality of the human environment. The ultimate goals are reduction of adverse highway and traffic impacts, and protection and enhancement of the environment.

4. **Improved Materials Utilization and Durability**

   Materials R&D is concerned with expanding the knowledge of materials properties and technology to fully utilize available naturally occurring materials, to develop extender or substitute materials for materials in short supply, and to devise procedures for converting industrial and other wastes into useful highway products. These activities are all directed toward the common goals of lowering the cost of highway construction and extending the period of maintenance-free operation.

5. **Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety**

   Structural R&D is concerned with furthering the latest technological advances in structural designs, fabrication processes, and construction techniques, to provide safe, efficient highways at reasonable cost.

6. **Prototype Development and Implementation of Research**

   This category is concerned with developing and transferring research and technology into practice, or, as it has been commonly identified, "technology transfer."

7. **Improved Technology for Highway Maintenance**

   Maintenance R&D objectives include the development and application of new technology to improve management, to augment the utilization of resources, and to increase operational efficiency and safety in the maintenance of highway facilities.

*The complete 7-volume official statment of the FCP is available from the National Technical Information Service (NTIS), Springfield, Virginia 22101 (Order No. PB 242057, price $45 postpaid). Single copies of the introductory volume are obtainable without charge from Program Analysis (HRD-2), Offices of Research and Development, Federal Highway Administration, Washington, D.C. 20590

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DEPARTMENT OF TRANSPORTATION

UNITED STATES OF AMERICA