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LABORATORY EVALUATION OF EXISTING BREAKAWAY STRUCTURES

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June 1980

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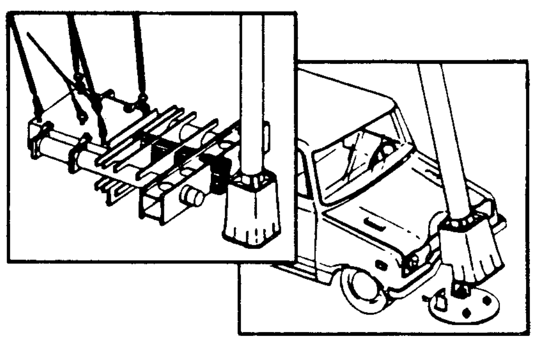

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FEDERAL HIGHWAY ADMINISTRATION

Offices of Research & Development

Structures & Applied Mechanics Division

Washington, D.C. 20590

FOREWORD

This report, one of three volumes, presents the results of a research program which evaluated a number of existing breakaway sign and luminaire supports for conformance with current AASHTO specifications. A computer simulation was used to study stresses in cast aluminum transformer bases. Design modifications were made to these bases and these revised designs meet the current AASHTO criteria.

The results of a validated bogie substitute for full-scale testing of dual-legged breakaway sign supports are presented.

Volume I (FHWA-RD-79-139) Executive Summary, and Volume II (FHWA-RD-79-140) Technical Results, are being distributed by Bulletin to FHWA field and Headquarters offices, State transportation agencies, researchers and those involved in assessing the breakaway performance of sign and luminaire supports. Volume III (FHWA-RD-79-141) Test Data, and additional copies of Volume I and Volume II may be obtained from the National Technical Information Service (NTIS), Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161. A small charge is imposed for copies provided by NTIS.

A limited number of additional copies of these reports are available (while supplies last) from the Protective Systems Group of the Structures and Applied Mechanics Division, Office of Research.

Richard E. Hay for

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Director, Office of Research
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NOTICE

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16. Abstract

A whole array of existing breakaway luminaire supports were tested using the FHWA soft-nosed pendulum test device. The pendulum nose was developed to simulate a subcompact car behavior. This nose was properly validated against full-scale test data.

Due to unacceptable impact performance, modifications were made to cast aluminum transformer bases to reduce momentum change levels. Performance was greatly improved.

The FHWA bogie test device was built and validated for use in testing dual-legged breakaway sign supports. Full-scale tests were run to provide full-scale validation data and to study off-center hit problems.

This is the second of three volumes. This volume contains the detailed results of the project. Volume I is an Executive Summary which gives a synopsis of the project. Volume III contains the backup test data for the project.

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In a contract involving the large number of commercial products that were tested in this project, cooperation of the manufacturers is essential. In this project that cooperation, as well as ideas and guidance, were given by many manufacturers. Special thanks is given to the following manufacturers of luminaire and sign supports:

Alcoa Aluminum
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Hapco Division of Kearney-National
Kaiser Aluminum
Millerbernd Manufacturing Co.
Pfaff and Kendall
Pole-Lite Industries
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Union Metal Manufacturing Co.
Valmont Industries

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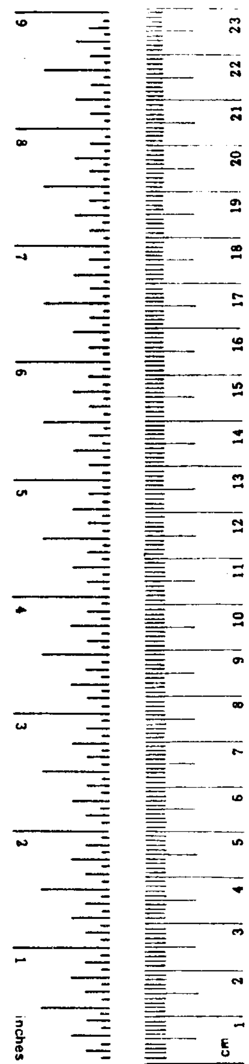
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

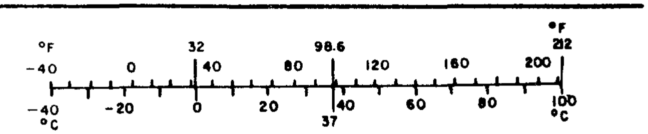
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



1. INTRODUCTION

The overall purpose of this study was to evaluate the impact performance of various types of breakaway sign and luminaire supports according to the American Association of State Highway and Transportation Officials (AASHTO) criteria [1]. The majority of these breakaway structures were never tested according to this criteria, i.e. with subcompact vehicles at 20 and 60 mph (32.2 and 96.6 km/h). If they were tested at all, the supports were tested under earlier testing criteria, usually with large automobiles at approximately 40 mph (64.4 km/h), or with a rigid pendulum. With the current trend toward lighter and smaller automobiles, the need to reevaluate these breakaway supports was of utmost importance.

At the same time the need to redesign unacceptable hardware also was a concern of this project. The cast aluminum transformer base is an example of a widely used breakaway device that in many cases did not pass the AASHTO specifications. However, during this project several types of transformer bases were turned into acceptable highway hardware with only minor modification.

To reduce the cost of testing and thereby increase the number of tests the majority of the work on this project was performed with a soft nosed pendulum or bogie vehicle simulator. It was this cost and time savings capability that allowed 132 impact tests to be performed on this contract.

One of the first tasks of this project was to develop a soft nose for the pendulum that would accurately reproduce the behavior of a subcompact car when impacting all types of breakaway supports. Earlier work by ENSCO (2) and by the Federal Highway Administration (3) was utilized in this development work. At the beginning of this contract the current soft nose design (4) was producing data that did not correlate with full-scale test data. This problem lead into a task to study the shortcomings of the existing design and to develop a replacement design that could be validated against full scale test data.

Utilizing the newly developed soft nose pendulum, a large array of breakaway luminaire supports were tested, including:

- cast aluminum transformer bases
- cast aluminum flange base supports
- progressive shear bases
- slip base supports
- breakaway couplings

The cast aluminum transformer base was found to behave erratically and in many case produced unacceptable momentum change levels. Based on these results an in-depth study of cast aluminum transformer bases was conducted. Computer simulation was employed to study the stresses in the base in order to evaluate possible modifications to improve breakaway performance. This led to the development of various types of modifications which were refined and matched to the array of transformer bases being tested.

As a result of this transformer base work, repeatable and controlled fracture mechanisms are now achievable with cast aluminum transformer bases. These T-bases are meeting the AASHTO criteria where previously they did not.

A bogie vehicle simulator was designed and constructed for use in laboratory testing of breakaway dual-legged signs as well as other breakaway hardware. This device was validated through several tests of various breakaway supports for which full scale test data were available. A means of extrapolating the test data for dual legged signs obtained at one speed to produce momentum change levels for a different speed was developed. This will allow dual legged signs to be tested at 20 mph (32.2 km/h) with a bogie and then the 60 mph (96.6 km/h) momentum change can be derived analytically.

2. BACKGROUND

2.1 INTRODUCTION

The danger of unprotected roadside structures such as luminaire and sign supports has been recognized for a long time. Design work on safer breakaway roadside support structures started in the late 1950's and has continued ever since. The Federal Highway Administration put the first official thrust toward utilization of this hardware for Federal Aid Highways in 1966 through an Instructional Memorandum [5]. This memorandum stated that breakaway structures must be used on unprotected sign and luminaire supports located adjacent to the shoulder. It also accepted the Texas Transportation Institute's (TTI) slip base sign support for immediate use, pending development of an acceptance criteria for evaluating other designs. Since that time, the Federal Highway Administration and AASHTO have established acceptance testing criteria with which to judge the effectiveness of all structural support designs.

Full-scale testing historically has been the accepted method of performance evaluation of highway support structures. This method reproduces an actual vehicle impact and as such has been considered an "indisputable" test of the breakaway performance of the structure. The June 1968 FHWA acceptance criteria based the acceptability of a design on the results of a single full-scale test [6]. It specified that the vehicle momentum change during the impact test must not exceed 1,100 lb-sec (4890 Ns). However, two crucial parameters, the vehicle weight and impact speed, were not specified in the acceptance criteria. Thus it was possible for a structure to be accepted based on a test with a heavy vehicle when it could be quite lethal for a smaller subcompact vehicle. Secondly, it is possible that a structure performs adequately at 40 mph (64.4 km/h) but is quite unsatisfactory at the lower (or higher) end of the 20-60 mph (32.2-96 km/h) speed range.

More recently, AASHTO presented specifications covering the performance of breakaway supports [1] which overcame these deficiencies. These specifications were again based on full-scale tests and set the same limit of 1,100 lb-sec (4890 Ns) change in momentum as did the FHWA criteria. However, the AASHTO criteria specified a 2,250 lb (1021 kg) test vehicle and requiring satisfactory performance over the complete speed range of 20 mph to 60 mph (32.2 km/h to 96.6 km/h). In addition, these specifications cite the desirability of a reduced limit on momentum change of 750 lb-sec (3340 Ns) in order to minimize accident severity.

Concurrently, due to the high cost of full-scale tests, simpler laboratory tests such as the rigid pendulum and drop weight tests have been investigated in recent years as alternate tools for evaluating the safety of luminaire and sign supports. In recognition of this, FHWA issued a second set of acceptance criteria in November 1970 [7] based on the use of a rigid pendulum (or drop weight) test. The specified limit of 400 lb-sec (1779 Ns) for momentum change in this test was derived from the data then available. This correlation of momentum change between full-scale and rigid pendulum test methods was based on seven full-scale tests on poles, for which rigid pendulum test data were available [8], and on three pendulum tests on poles for which full-scale test data were available [9]. A second accepted method for evaluating breakaway structures now existed. Inconsistencies were found, however, between correlation of similar full-scale and rigid pendulum tests. In addition, although pendulum testing was thought to be a more repeatable procedure, inconsistencies were found even in similar pendulum tests.

The FHWA recognized that inconsistencies existed in the rigid pendulum tests as demonstrated in the report by Chisholm and

Viner in 1973 [10]. A study was therefore initiated which had as part of its objective the evaluation of the rigid pendulum test procedure and recommendations for its improvement. This study, DOT-FH-11-8118, entitled "Safer Sign and Luminaire Support," was conducted by ENSCO, Inc. and led to a pendulum test procedure which utilized a bare-faced three-segment crushable honeycomb nose ahead of the pendulum mass [2].

While the crushable nose pendulum test showed itself to be a repeatable and meaningful acceptance test, it was not yet fully developed under DOT-FH-11-8118 because transformer bases were not tested. FHWA then conducted in-house tests to extend the test procedure for use on transformer bases [3]. This work also standardized the honeycomb module by the addition of a striker nose ahead of the honeycomb so that the interface geometry with all target structures is the same. The neoprene rubber surface of the FHWA striker nose was found to be too aggressive and resulted in tests which did not correlate with full-scale data.

As a result further research was performed in the contract reported here in order to refine the striker nose design to achieve correlation with full-scale test data.

2.2 DEVELOPMENT OF FULL-SCALE TESTING PROCEDURES AND ACCEPTANCE CRITERIA

Early full-scale tests on highway support structures were carried out according to procedures which seemed most appropriate to the testing agency in charge. As a result, impact conditions differed and the analysis of results varied. Consequently, comparison of the various test results was difficult, if not impossible, to make. In addition, the criteria against which acceptability was judged, varied just as widely as the test procedures. They varied from subjective analysis by drivers to measurement of peak accelerations at the vehicle center of gravity (c.g.).

Following the appearance of the 1966 FHWA Instructional Memorandum [5] requiring the installation of breakaway supports, it became more necessary to standardize the evaluation procedure. Two studies conducted by TTI and reported in HRR 222 [11] and NCHRP 77 [12] were necessary steps toward this goal. In the HRR 222 report, TTI reported on ten tests of six different types of breakaway luminaire poles. Nine of these tests were conducted with 3,800 lb (1724 kg) cars and one with a 2,140 lb. (971 kg) car. Impact speeds ranged from 21 to 53 mph (33.8 to 85.3 km/h). The test results indicated a drastic jump in momentum change from 1,100 lb-sec (4890 Ns), for aluminum flange base poles, to 1,840 lb-sec (8184 Ns) for steel flange base poles. An important result of this test series was the establishment of the goal of 1,100 lb-sec (4890 Ns) or less for momentum change.

In the NCHRP 77 report, TTI initially found that testing was required on several breakaway base concepts for luminaire supports. These were the slip bases, progressive shear bases (with stainless steel or carbon steel transformer housings), the cast aluminum flange bases, and the cast aluminum transformer bases. Full-scale tests on all these designs were performed to provide this needed data. All 11 tests were conducted with 1958 full-size cars weighing between 3,300 lb (1497 kg) and 3,900 (1769 kg) at speeds from 28 to 44 mph (45.1 to 70.8 km/h). Velocity changes for all tests were recorded and found to be below 9.4 mph (15.1 km/h). The designs were concluded to be acceptable for highway use due to the fact that corresponding peak decelerations were no greater than 15 g's.

NCHRP 77 suggested design criteria which based acceptability on velocity change, base fracture energy (BFE), and vehicle deceleration. An upper limit of 12 mph (19.3 km/h) change in velocity was suggested.

The June 1968 FHWA acceptance criteria were based partly on the work conducted under NCHRP 77 and also on some test data on flange base luminaires supplied by the University of Miami [13]. It appeared from both these test series that acceptable decelerations would be experienced by the vehicle occupants when vehicle momentum changes were held below 1,100 lb-sec (4890 Ns). This corresponds to a 12 mph (19.3 km/h) change in velocity for a 2,000 lb (907 kg) vehicle. For the first time, a standardized set of acceptance criteria existed. However, it fell short by not specifying vehicle weight or impact conditions.

Most testing performed under the 1968 criteria was conducted using a nominal 4,000 lb. (1814 kg) vehicle at 40 mph (64.4 km/h). Very little testing was conducted using lightweight vehicles. In addition, the critical 20 mph (32.2 km/h) and 60 mph (96.6 km/h) impact speeds virtually were overlooked.

The present AASHTO criteria carry over the 1,100 lb-sec (4890 Ns) limit on the vehicle momentum change. However, these criteria recognize the need for testing small cars and as such specifies a 2,250 lb (1021 kg) auto and impact speeds of 20 and 60 mph (32.2 and 96.6 km/h). Another advance was made when it was recognized that although 1,100 lb-sec (4890 Ns) is an acceptable momentum change, it can still result in a rather severe impact. The criteria, therefore, suggest a desirable limit of 750 lb-sec (3340 Ns). The AASHTO criteria also recognize the need to keep the peak force to cause breakaway below 20,000 lb (88960 N) in order to protect occupants from interior intrusion during side impacts.

2.3 LABORATORY TEST PROCEDURES AND ACCEPTANCE CRITERIA

Laboratory pendulum and drop weight testing has been used for many years for testing the impact resistance of structures. In

1970 the FHWA recognized that this method could be used to provide a lower cost and more consistent measure of breakaway support performance [7]. Full-scale testing methods result in a scatter due to vehicle structural variations. Supposedly a rigid pendulum test would eliminate this variable and at the same time provide a less expensive means for testing supports. Based on limited data then available, FHWA determined that a 400 lb-sec (1779 Ns) momentum change in a rigid pendulum was about equivalent to a 1,100 lb-sec (4890 Ns) change in automobile momentum. The difference was due mainly to energy dissipation in automobile body crush. The November 1970 FHWA Notice [7] established this criteria as equivalent to the full-scale acceptance criteria. It set the pendulum mass at 2,000 lbs (907 kg), the speed at 20 mph (32.2 km/h) and the striking height at 20 inches (51 cm). However, this notice did not specify a standard pendulum head geometry, a parameter which can affect the breakaway fracture mode.

The state of the art in luminaire support testing was reviewed by Chisholm and Viner [10] in 1973. The purpose of the study was to summarize available data on the comparison of full-scale and laboratory tests, so that the validity of the pendulum testing procedure could be assessed. The report assembled a wealth of existing data, and made conclusions and recommendations on laboratory pendulum testing, on improvements to existing hardware designs, and on needed research. The outstanding items of further research which were identified include:

- vehicle striking height, orientation, and stiffness, as related to impact performance;
- design guidelines to minimize Base Fracture Energy (BFE);
- guidelines for foundation design to minimize movement during impact;

- improvements into hardware designs to achieve more repeatable performance; and
- controls for impact tests, both full-scale and laboratory.

The report concluded that the scatter in the laboratory test data was probably due to hardware variations. The 400 lb-sec (1779 Ns) momentum change level for rigid faced pendulum testing seemed to be appropriate without further data.

Further research into breakaway sign and luminaire support laboratory testing was conducted by ENSCO for the Federal Highway Administration [2]. This research effort entitled, "Safer Signs and Luminaire Supports" answered many of the questions which were unresolved in 1973.

- A bare faced honeycomb aluminum nose was developed which allowed a pendulum to be used to simulate an automobile impact, taking into account vehicle crush characteristics.
- Analyzing the physics of the impact situation, ENSCO was able to identify the various phases in an impact and thereby develop relationships which allow the performance of a given support to be determined for arbitrary initial conditions. For instance, when given the momentum change at one speed, (such as 20 mph (32.2 km/h)), it would be possible to predict the momentum change at any other speed (such as 60 mph (96.6 km/h)). Furthermore, this relationship could be applied to expanding much of the data obtained at 40 mph (64.4 km/h) in past tests. Altogether, using presently available relationships, it is now also possible to predict the variation in vehicle momentum change resulting from: changing the pole dimensions or inertial properties, changing the base breakaway force, stiffening the vehicle structure, or changing the vehicle mass.
- It was found that an acceptable breakaway support will provide satisfactory impact performance

in the field when installed on a concrete foundation whose size is equal to or greater than 2 feet (.61 m) in diameter and 6 feet (1.83 m) in length. This does not necessarily provide adequate resistance to wind loads. These loads may dictate a larger size foundation and should be determined in accordance with present AASHTO specifications [1].

- It was postulated that dual-legged sign supports can also be evaluated with pendulum tests using a single support properly mass ballasted to account for the effects of the sign blank.

Southwest Research Institute (SWRI) was also doing research [14] into crushable honeycomb pendulum nose testing at the same time that the ENSCO contract was in progress. SWRI found that differences in momentum change values for a range of bolt torques on slip bases can only be seen using crushable pendulum tests (as opposed to rigid tests).

Testing under the ENSCO contract concentrated on the flange base and slip base supports only. As a result, the test procedure that was developed did not include the testing of transformer bases. Since a standardized test procedure must be applicable to all support types, it was necessary to further extend this procedure to include these bases.

FHWA conducted an in-house research program to develop a standard crushable honeycomb nose module for use with all common support types. The module recommended at the end of the ENSCO contract utilized bare-faced honeycomb and was affected by the geometry of the impacted structure to a certain extent. To remove this variable, FHWA developed a striker nose which can act as standard interface between the honeycomb and the structure. The striker nose module was also wide enough to test transformer bases. Some experimentation with a rigid sweeper plate to simulate vehicle undercarriage snagging conditions was also carried out.

At the conclusion of this work further research was required to finalize the honeycomb nose module configuration and the sweeper plate design. Most importantly perhaps, further work was required to apply the laboratory test procedure to all current hardware types and test their acceptability. The states and the pole manufacturers did not know which pieces of hardware were acceptable for highway use. Separately, they did not have the facilities or funds to perform all the needed tests. A concerted effort was required to test a broad spectrum of hardware to partially answer some of these questions. At the same time, a study was also required to investigate modifications to existing hardware when present performance was unsatisfactory. These requirements were the basis for the work carried out in the reported study.

3.0 DEVELOPMENT OF A CRUSHABLE HONEYCOMB NOSE FOR LABORATORY VEHICLE SIMULATION

3.1 INTRODUCTION

Under FHWA Contract DOT-FH-11-8118, "Safer Sign and Luminaire Supports," ENSCO developed an acceptance testing procedure for breakaway luminaire supports based on a pendulum impact test. This pendulum test procedure was an advancement over the then existing procedure since it utilized a crushable honeycomb nose attached to the pendulum to simulate the crush characteristics of the vehicle.

The previous procedure had been based on use of a rigid nose pendulum device and specified a somewhat lower limit on acceptable momentum change compared to the full-scale impact tests, in order to allow for the energy dissipated in vehicle body crush. While this approach was a positive step toward accounting for the crush energy it was not always reliable and suffered from the fact that the proportion of momentum change due to the vehicle crush was not always constant, being dependent upon such things as the type of breakaway structure being impacted, and the mass of the support. Consequently one of the objectives of the FHWA contract DOT-FH-11-8118 let in July 1973 was to develop a more conclusive and reliable pendulum test procedure based on use of a soft nosed pendulum.

The procedure that was developed under that contract called for a bare-faced honeycomb stack to be attached to the front of the pendulum, the honeycomb height being a function of pole width. It was shown that this procedure worked well for slip base and flange base poles yielding momentum changes for the impacts which closely matched full-scale data conducted under similar conditions of speed and impacting mass. However, because of the geometric configuration, it was realized that this configuration would not be able to handle transformer bases. Since these bases are a large part of the population of breakaway bases, it was known that the nose structure developed under this contract would eventually have to be modified to accommodate the transformer base.

Following the conclusion of DOT-FH-11-8118, the research staff at FHWA sought to make this pendulum test procedure more comprehensive and capable of testing breakaway bases of all geometric configurations by the addition of a striker nose. This striker nose was intended to create an impact geometry and crush characteristic that would be the same for all breakaway supports. Under an in-house FHWA testing program the striker nose was developed and its specification for use in pendulum acceptance testing were given in FHWA Notice N5040.20. The arrangement consists of three 8 in (20.3 cm) cube blocks of honeycomb, separated by ¼ in (0.61 cm) plywood spacers, and faced with a striker nose whose weight is kept below 50 lb (22.5 kg). The striker nose has a curved surface with a 3.5 in (8.9 cm) radius and is covered with 1 in (2.5 cm) of neoprene rubber.

Testing by FHWA is the fall of 1976 revealed that the pendulum test procedure using this nose set-up was not producing results which correlated with full-scale test results being concurrently obtained at the Texas Transportation Institute (TTI). In particular, steel slip base luminaires were being severely deformed by the pendulum impact and in some cases momentum changes over 1200 lb-sec (5340 Ns) were being recorded. (At the other extreme, momentum changes below 300 lb-sec (1336 Ns) were being recorded which is equally unrealistic.) Full-scale test results for a subcompact vehicle striking a slip base luminaire at 20 mph (32 km/h) tend to fall around 500 lb-sec (2226.5 Ns).

Subsequent investigations carried out by FHWA suggested that the rounded nose was overloading the slip base poles locally causing the deformation. The associated cocking of the slip base was resulting in the lock up of the base and causing the high momentum changes. This theory was strengthened by the fact that internally blocked poles which did not deform locally never exhibited high momentum change values. To solve the deformation problem the rounded nose was removed and replaced with a 2 in (5.1 cm) thick flat piece of neoprene rubber. While this configuration reduced the pole deformation, it did not eliminate it completely and still did not bring the momentum change values into line with full-scale test results.

At this juncture (October 1976) ENSCO was starting on this study. This contract called for the use of the pendulum acceptance procedure specified in the FHWA Notice N5040.20 to be used to evaluate existing breakaway structures and improve their performance where necessary. Since this procedure was not producing results that could be correlated with the full-scale data, it was necessary for ENSCO to continue the development work started by FHWA in order to produce a repeatable, reliable testing procedure which could be used to quantitatively investigate breakaway structure performance.

This chapter discusses the work carried out to refine the pendulum test procedure and improve the correlation with full-scale test data. An important ingredient of this correlation is being assured of the quality of the full-scale data. Consequently, in Section 3.3 a discussion of this test data is given. Section 3.2 lays out the philosophy for obtaining the improved pendulum crushable nose set-up, and Section 3.4 and 3.5 summarize the results of the developmental pendulum test series and the validation tests. Section 3.6 contains conclusions and recommendations for the configuration of the improved nose set-up.

3.2 TECHNICAL APPROACH FOR OBTAINING IMPROVED CORRELATIONS

The specific objective of the work reported here was to develop a pendulum nose configuration which would reproduce the full scale test results from impacts involving pre-1974 Chevrolet Vegas. This vehicle was chosen because it is a typical 2250 lb (1012.5 kg) automobile and substantial data exists on full-scale impacts of this vehicle with various breakaway supports tested according to the AASHTO specifications. In this way it was felt that credibility would be added to the pendulum acceptance testing procedure.

A key item of obtaining the improved correlation or any correlation is to make sure that the full-scale results for the momentum change are reliable. This involved reviewing the test data and understanding how the specific data was collected, what filtering was used, etc. This is discussed fully in Section 3.3. From various cross checks it was ascertained that the momentum change values obtained in the full-scale aspects of the Vega were reliable.

The next step involved the impact configuration of the pendulum and full-scale tests. Clearly, in order to correlate the results of pendulum and full-scale tests it is necessary that the impact conditions be as similar as possible. These conditions include:

- impact height;
- target support configuration;
- base bolt load (for slip bases);
- impact speed;
- force-deformation characteristics of vehicle and pendulum
- mass of vehicle and pendulum; and
- mass distribution of the crushable portion of the vehicle and pendulum.

Previous attempts at obtaining correlation between the pendulum and full-scale tests had not properly accounted for some of these factors. Consequently, special attention was paid to these items. The procedure consisted of taking the pendulum configuration recommended in FHWA notice N5040.20 and modifying it one step at a time through a series of pendulum impact tests. The various factors were adjusted until a pendulum test procedure evolved which reproduced full-scale results.

Briefly the research effort evolved as follows: early tests utilized the 2 in (5.1 cm) neoprene rubber-faced, flat nosed pendulum impacting a 35 ft (10.5 m) slip base luminaire at a 24 in (61.0 cm) impact height. The nose module consisted of the three 8 in (20.3 cm) cube blocks of honeycomb as recommended in FHWA Notice N5040.20. Results from these tests indicated very low momentum change values. Investigation revealed that the combination of the heavy weight of the nose and the relatively stiff face on the nose were producing high force peaks on the pole which were activating the slip base before any crushing of the honeycomb occurred. These force peaks are transferred to the pendulum mass but show up only as small spikes which add little to the area under the deceleration-time trace and consequently do not affect the momentum change. Analysis was then carried out to understand the contribution of the nose inertia to the impact, with the purpose of designing an appropriate nose configuration.

Tests were next conducted where the pendulum nose was removed completely. These tests resulted in high momentum changes for the pendulum. Investigation revealed that the configuration of the honeycomb experienced extensive crush before the required breakaway force level had been achieved. This crushing used up a lot of energy and high momentum changes resulted.

Tests were then conducted in which the honeycomb was configured so as to reproduce the Vega force-deflection characteristic. A temporary wooden nose was constructed to prevent uneven crushing of the honeycomb and to add appropriate nose mass to correspond to the inertia effect of the sheet metal in the actual vehicle. Several iterations were required to finally achieve the proper force-deflection characteristic. This work was done utilizing an internally blocked pole to prevent pole deformation and conserve costly poles. Eventually the pendulum impact traces converged on the deceleration-time trace for the full-scale test.

Appendix A discusses the general procedure used in designing the honeycomb nose.

3.3 FULL-SCALE TEST DATA

The full-scale test data against which the pendulum nose was designed consisted of a test conducted by Texas Transportation Institute in January 1977, designated RF3114-D15. The test utilized a 35 ft (10.5 m) Union Metal steel luminaire (40 ft (12 m) mounting height) with three bolt slip base. One inch (2.54 cm) diameter "strain-sert" bolts with 3/8 in (1.0 cm) washers were tensioned to 15,000 lb (66720 N) to hold the slip base plates together. The foundation in the tests was sunk below ground level so that the slip base plane was even with ground level. This gave an effective impact height of approximately 24 in (61.0 cm) measured to the center of the Vega bumper. The test vehicle was a 1971 Chevrolet Vega Hatchback Coupe weighing approximately 2250 lb (1012.5 kg). The luminaire in test D15 was internally blocked in the impact zone with wooden wedges to prevent deformation of the pole.

These results from the test contractor's data were as follows:

TTI TEST RF 3114-D15

Impact Speed	28.8 ft/sec (8.6 m/s)
Momentum Change (from films)	560 lb-sec (2493.7 Ns)
Impact Duration	.060 sec
Time of Breakaway	.055 sec
Time of Peak Deceleration	.053 sec
Vehicle Crush	17.5 in. (44.5 cm)
Peak Deceleration	14.9 g's
Time Average Deceleration	4.2 g's

A secondary impact occurred starting about .5 sec after impact. This secondary impact was of small magnitude and is not included in the momentum change figure.

Features of Impacting Vehicle

Two important features were found concerning the Vega test vehicle. First, the distance from the front of the bumper to the front of the engine is 17 in (43.2 cm). This indicates that the Vega force deflection characteristic will become very stiff at about 17½ in (44.5 cm), as verified by the test. Second, the Vega bumper center line is located 19 in (48.3 cm) above ground level, which indicates that in most impacts the impact height will be about 19 in (48.3 cm) (the TTI tests had the foundation for the 24 in (61.0 in) impact height that was eventually used in the pendulum impact test).

Instrumentation of Test Vehicle

Four Statham accelerometers were mounted on the test vehicle. Two 50 g's accelerometers were used to measure longitudinal accelerations and two 50 g's accelerometers were used for transverse accelerations. These are standard Statham strain gage accelerometers having a natural frequency of 1300 Hz.

The accelerometers were mounted by cutting away the sheet metal to expose left and right frame members beneath the rear seat. A 3 in (7.6 cm) square steel cube was welded directly to the frame member and the accelerometers were bolted directly to the side and rear of the cube.

The data was transmitted via an FM telemetry system, conforming to IRIG standards, to a 14 channel Hewlett Packard tape recorder and recorded at 7 ½ in/sec (19.1 cm/s). This speed was used since it gave a bandwidth of 2400 Hz which was more than sufficient for the impact phenomena of interest. The raw data from the recorder are shown in Fig. 1.

To compute the momentum change the data is filtered to SAE Class 60 specifications to remove any spurious noise, not related to the actual impact. This is done by processing the data with a digitally tuned low-pass filter set at 100 Hz. The particular filter used had a rolloff of 48 db/octave requiring the 100 Hz setting to obtain class 60 response. Plots of the data after filtering are shown in Fig. 2.

Momentum Change and Peak Deceleration

The momentum change as measured by ENSCO from the filtered and raw accelerometer data was 535 lb-sec (2379.7 Ns) and 553 lb-sec (2459.7 Ns), respectively. (The momentum change as measured by film analysis was 570 lb-sec (2535.4 Ns).) The peak deceleration for the filtered data was 10.2 g's and from the raw data was 14.9 g's based on the left longitudinal accelerometer.

Best Estimate of Momentum Change and Maximum Deceleration

In general the film estimates for the momentum change will be more reliable than the accelerometer derived momentum changes because of the noise in the data, the approximations incurred in measuring the area of the trace, the type of filtering used, etc. An estimate of the accuracy of the accelerometer derived

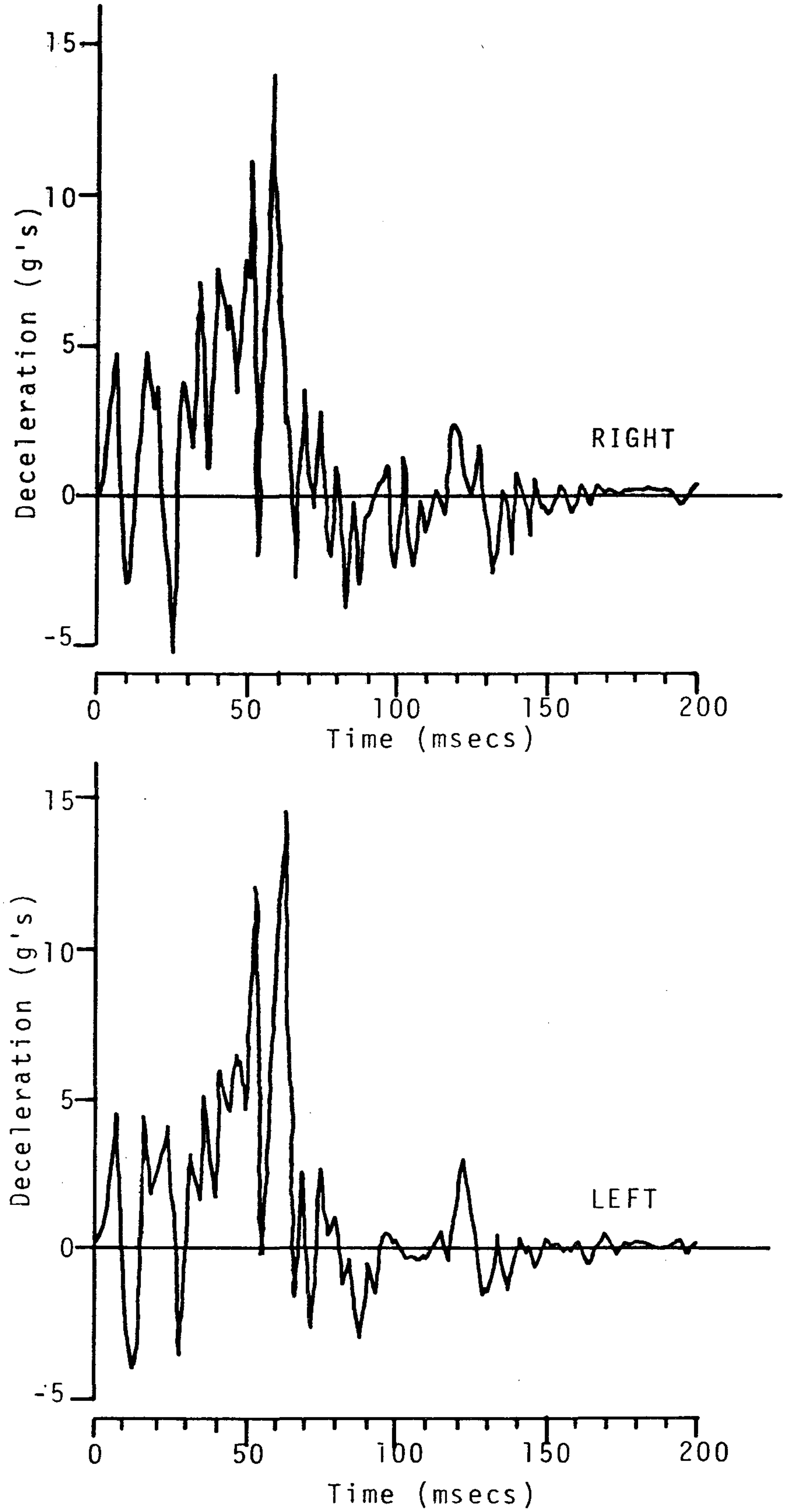
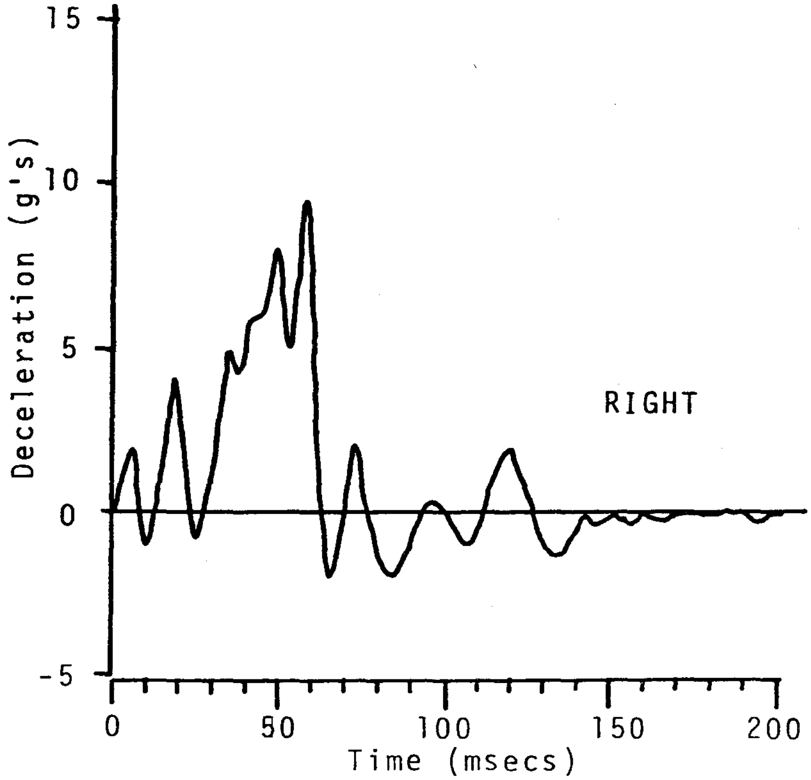


Fig. 1

Longitudinal Accelerometer Traces
for TTI Test D15 Unfiltered



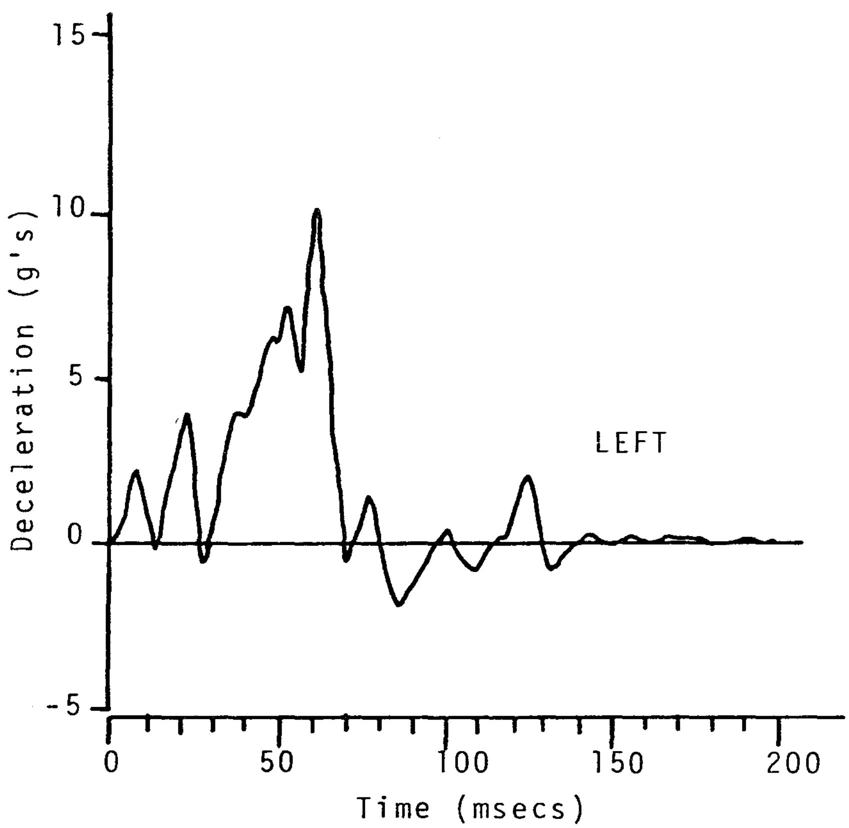


Fig. 2

Longitudinal Accelerometer Traces
for TTI Test D15 Filtered at 100 Hz

momentum change is 10% so that the results from the film analysis and accelerometer are consistent. The best estimate for the momentum change in the actual full scale impact is therefore 570 lb-sec (2535.4 Ns).

With respect to the estimate of the peak deceleration this varies from approximately 10 g's to 15 g's depending upon the type of filtering employed. Basically when trying to compare peak decelerations for full-scale and pendulum tests, it must be ensured that the same bandwidth for the data collection is being employed. In the pendulum impact test the accelerometers used have a roll off at 750 Hz and the data collection methodology of recording at high speed and playing back at a slower speed ensures that the system records frequencies well beyond 750 Hz. Consequently coverage of up to 500 Hz is easily being achieved in the pendulum impact data. For this reason, the unfiltered accelerometer data from the full scale test which showed a peak deceleration of 14.9 g's was used for comparison.

3.4 SUMMARY OF DEVELOPMENTAL PENDULUM TESTS

TEST 1147-101

Previous in-house FHWA tests had been performed with the rounded striker face recommended in FHWA Notice N5040.20. These tests had resulted in severe denting of the poles, an effect which was attributed to the aggressive nature of the rounded striker face which tends to concentrate the impact load. In order to spread the load more uniformly over a larger surface area of the pole, the use of a flat striker face was explored in this test. The face consisted of a 2 in (5.1 cm) thick piece of neoprene rubber measuring 8 in x 12 in (20.3 x 30.5 cm) attached to the front of an 8 in (20.3 cm) aluminum channel. This aluminum channel was in turn attached to two aluminum channel arms which slide in guides on each side of the pendulum mass. The entire nose assembly weighed approximately 70 lb (31.5 kg). Behind the nose were three blocks of honeycomb, the same 8 in (20.3 cm) cubes of honeycomb recommended in FHWA Notice N5040.20. The slip base bolts were tightened to 10,000 lb (44,480 N) in this test.

The results of this test showed a very low momentum change with an impact of short duration. The pole still dented approximately ½ in (1.3 cm), while the honeycomb only crushed 3¼ in (8.3 cm) in the first piece of honeycomb. The momentum change was only 227 lb-sec (1009.7 Ns).

TEST 1147-102

After reviewing the results of Test 1147-101 (see Fig. 3), it was believed that the honeycomb was too stiff to simulate the actual vehicle structure. It was therefore decided, as a next step, that the honeycomb blocks should be trimmed down in cross section to the following dimensions:

Block 1 - 75 psi	-	6"w x 6"h x 8"l (517 kPa - 15.2 x 20.3 cm)
Block 2 - 130 psi	-	7" w x 7"h x 8"l (896.4 kPa - 17.8 x 20.3 cm)
Block 3 - 230 psi	-	8"w x 8"h x 8"l (1585.8 kPa - 20.3 x 20.3 x 20.3 cm)

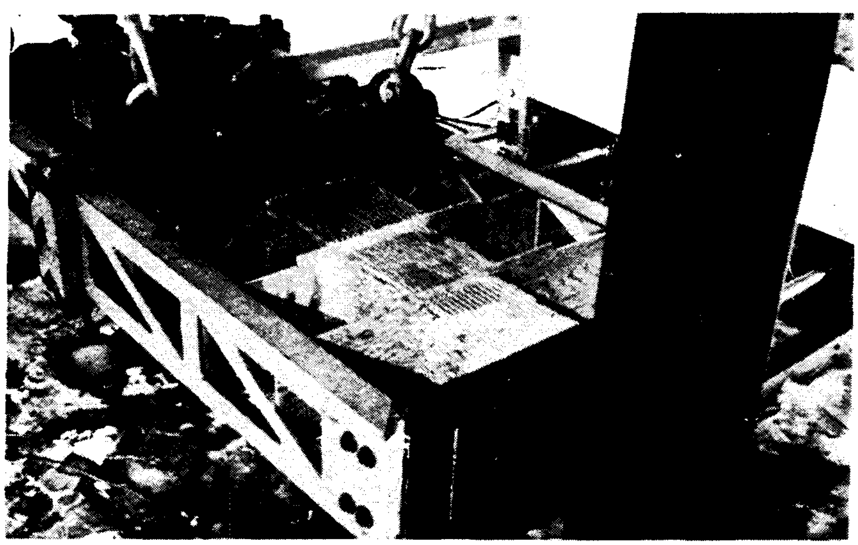


Fig. 3

Pendulum Nose Configuration as Evaluated in Test 1147-102

Other modifications were also made to widen the neoprene rubber on the front of the nose from 12 in (30.5 cm) to 20 in (50.8 cm) and to upgrade the weak corner brackets on the nose structure. These changes raised the weight of the nose to 92 lb (41.4 kg). The slip base clamping bolts were again tightened to 10,000 lb (44,480 N) in this test.

The results of this test were very similar to Test 1147-101 except that the impact duration was stretched out to 62 msecs. Honeycomb crush was increased to only 4½in (11.4 cm) and the momentum change dropped to 207 lb-sec (920.7 Ns)

TEST 1147-103

This test was a repeat of Test 1147-102 except that the slip base clamping bolts were tightened to 15,000 lb (66,720 N) each. This additional clamping force resulted in increasing the momentum change to 250 lb-sec (1112 Ns), and the amount of honeycomb crush to 6¼ in (15.9 cm). However, the impact was still quite different from the corresponding full-scale test. Fig. 4. shows the nose configuration.

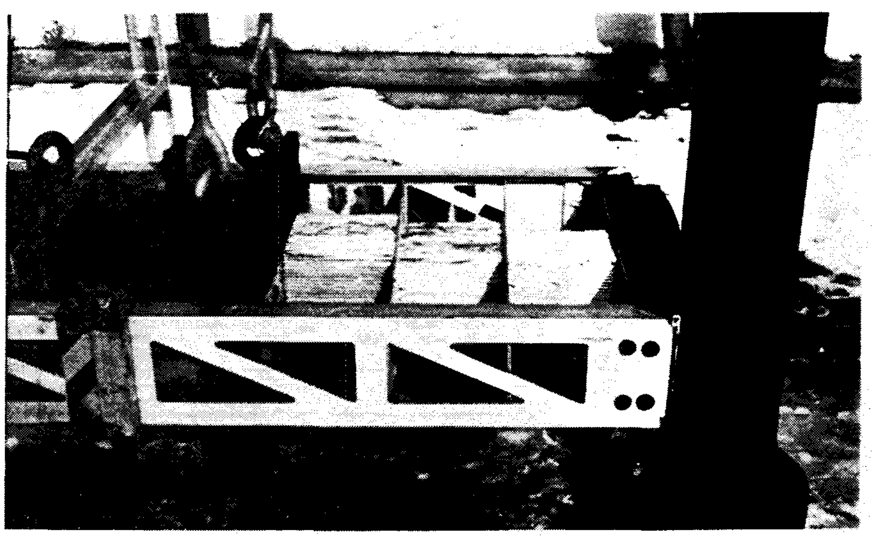


Fig. 4

Pendulum Nose Configuration as Evaluated in Test 1147-103

TEST 1147-104

After reviewing the results of the first three tests, it was recognized that the momentum change values were not being affected appreciably by either the force-defection characteristics of the honeycomb or the base clamping force. The poles were behaving very much as if they were being hit by a rigid pendulum. As a result it was believed that the inertia force of the nose alone might be high enough to be activating the slip base. A simplified analysis carried out on the dynamics of the impact further supported this belief (see Appendix B). Therefore, in this test, 100 g's accelerometers were attached to the striker nose in order to check the deceleration environment being experienced by the nose assembly.

The nose accelerometers recorded decelerations well in excess of 100 g's which for a nose assembly weight of 92 lb (41.4 kg) implies that inertia forces are acting which are easily capable of activating the slip base. This is quite unlike the action of car bumpers in typical breakaway support impacts.

In addition to the nose accelerometers, another change in this test was the configuration of the honeycomb. The honeycomb blocks were tapered (see Fig. 5) in order to attempt to create a

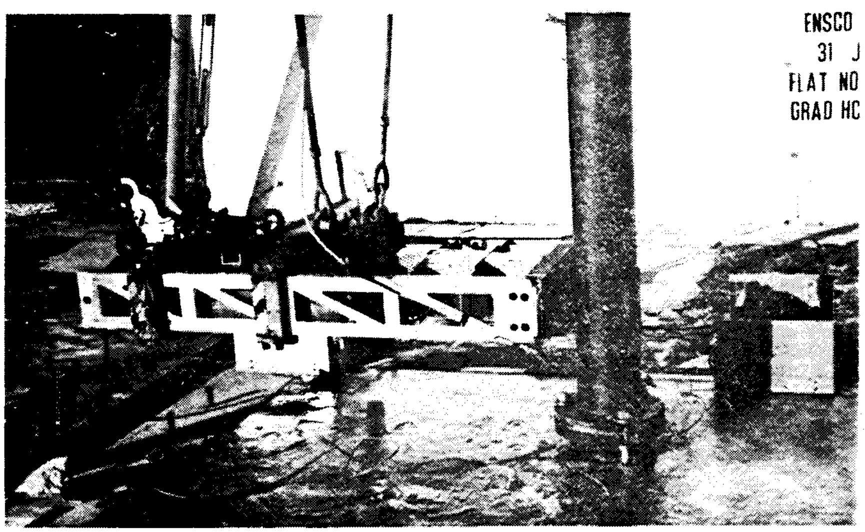


Fig. 5

Pendulum Nose Configuration as Evaluated in Test 1147-104

more realistic linearly increasing force-deflection characteristic and thereby eliminate any "stair-stepping" force-deflection behavior that seemed to be occurring.

Unfortunately, because of the inadequate strength of the plywood dividers used to separate the honeycomb blocks, the honeycomb did not crush uniformly as desired. However, the test did prove that the deceleration of the nose was a significant factor. The momentum change for this test was 262 lb-sec (1165.4 Ns).

TEST 1147-105

As a result of the findings in Test 1147-104, the 92 lb (41.4 Kg.) sliding nose was removed from the pendulum. Test 1147-104 had shown that very high inertia forces were being exerted on the pole at impact, resulting in premature activation of the base. In this test the slider rails were rigidly attached and used as guide channels for the honeycomb. The honeycomb blocks, as used in Test 1147-101, were separated by ½ in (1.3 cm) plywood spacers, and an 8 in x 8 in x 4 in (20.3 x 20.3 x 10.2 cm) thick piece of 230 psi (1585.5 kPa) honeycomb was placed on the front piece of plywood to act as a shock damper. In this test a honeycomb block fell out resulting in an unsatisfactory test.

TEST 1147-106

This test was a repeat of Test 1147-105. In this test the honeycomb nose stayed intact and resulted in a long duration, high momentum change impact. On further investigation, it was found that the standard honeycomb configuration did not duplicate the Vega force-deflection characteristic. The standard honeycomb configuration starts out at a higher force level and then rises much more slowly. As a result the pendulum uses up significantly more momentum before the needed breakaway force level has been obtained. This test resulted in a momentum change of 1205 lb-sec (5359.8 Ns) with an impact that lasted for over 100 msecs.

TEST 1147-107

After Test 1147-106 it was decided that the three block honeycomb arrangement recommended in FHWA Notice N5040.20 could not be used to correlate pendulum test results with full-scale test results because it was not adequately duplicating the actual force-deflection characteristic (see Fig. 6). The dimensions of the honeycomb were as follows:

Block 1 - 5"w x 5"h x 4"l x 75 psi
(12.7 x 12.7 x 10.2 cm x 517.1 kPa)

Block 2 - 5"w x 8"h x 4"l x 75 psi
(12.7 x 20.3 x 10.2 cm x 517.1 kPa)

Block 3 - 5"w x 8"h x 4"l x 130 psi
(12.7 x 20.3 x 10.2 cm x 896.4 kPa)

Block 4 - 5"w x 8"h x 4"l x 230 psi
(12.7 x 20.3 x 10.2 cm x 1585.5 kPa)

Block 5 - 8"w x 8"h x 4"l x 230 psi
(20.3 x 20.3 x 10.2 cm x 1585.5 kPa)

Block 6 - 12"w x 8"h x 4"l x 230 psi
(30.5 x 20.3 x 10.2 cm x 1585.5 kPa)

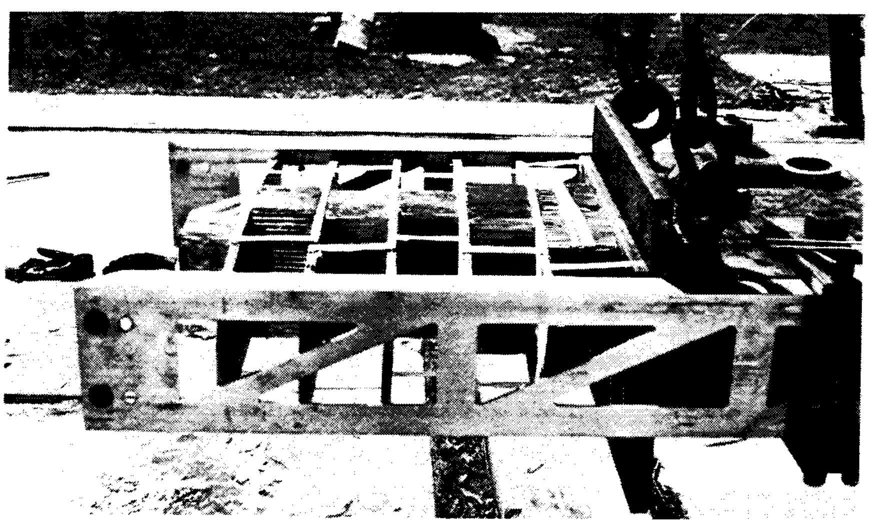


Fig. 6
Pendulum Nose Configuration as Evaluated in Test 1147-107

In this pendulum impact test it was found that the shape of the deceleration curve was more similar to TTI test D15 than in previous tests. However, it was still too long in duration, resulting in a high momentum change. The long duration was believed to be a result of uneven crushing of the last honeycomb block due to bending of the plywood spacer.

While this test again had a momentum change 1050 lb-sec (4670 Ns) the honeycomb crush depth of 19 in (48.3 cm) corresponded more closely to the full-scale test behavior where the crush is approximately 17½ in (44.5 cm).

TEST 1147-108

This test was similar to Test 1147-107 except that stronger plywood spacers were used and the last block of honeycomb was eliminated (see Fig. 7). However, sand from the recently thawed ground contaminated the pole slip base surfaces and resulted in a lock-up of the slip base. The pendulum was stopped and the pole was sheared off at the weld above the slip base.

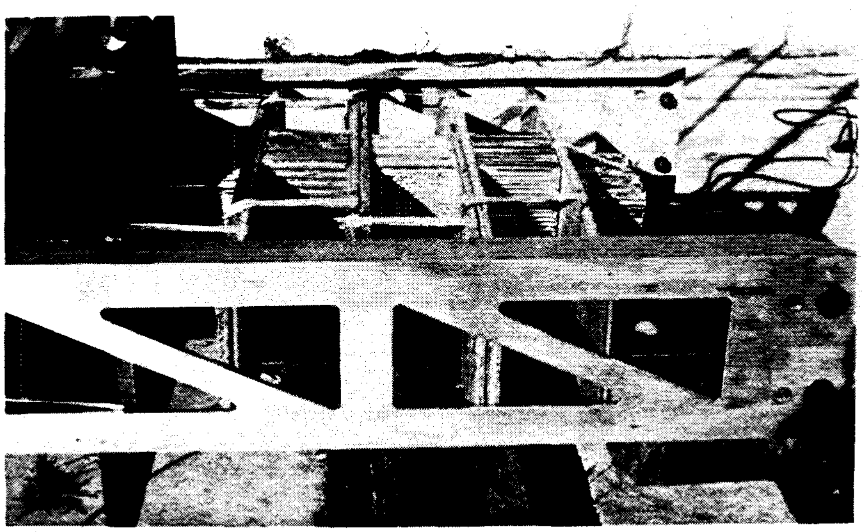


Fig. 7

Pendulum Nose Configuration as Evaluated in Test 1147-108

TEST 1147-109

In this test a 35 lb (15.7 Kg) wooden nose bumper designed to slide in the honeycomb guide channels was used to prevent uneven crush of the honeycomb (see Fig. 8). Also the results of an analysis of the slip base caused us to believe that the 24 in (61.0 cm) height of impact was too high compared to the actual full-scale impact height and should be lowered. The impact height was lowered to 18 in (45.7 cm) above ground level.* The pole was also blocked internally in this test to isolate this factor temporarily from the investigation, and also conserve poles. This test resulted in a lower momentum change, in less crushing of the honeycomb, and in a deceleration-time curve which more closely matched TTI Test D15. However, the impact duration was longer than in the full-scale test. This additional time increased the area under the deceleration-time curve thus resulting in a momentum change of 803 lb-sec (3571.7 Ns).

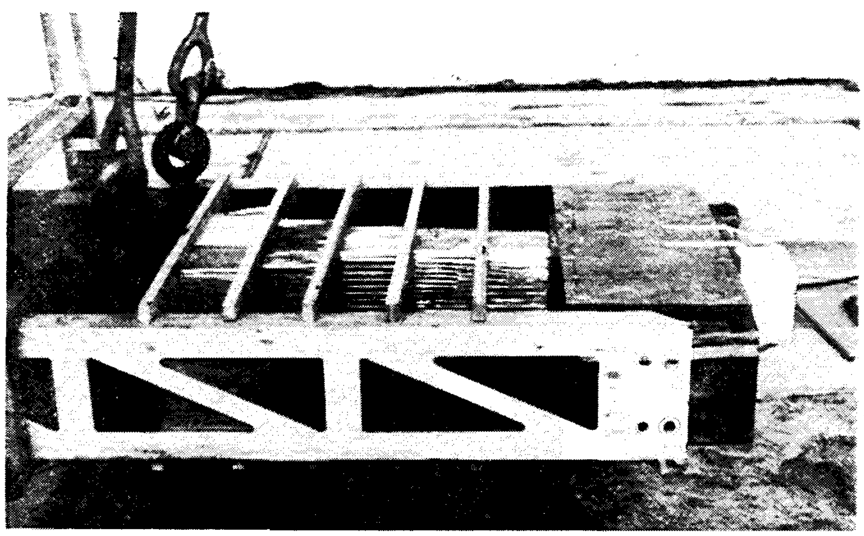


Fig. 8

Pendulum Nose Configuration as Evaluated in Test 1147-109

*It was later determined from TTI that for the full-scale test D15 the slip base had been recessed into the ground to avoid snagging on the car. As a result the effective height was probably closer to 24 in (61.0 cm) than 18 in (45.7 cm).

TEST 1147-110

This test was similar to Test 1147-109 except that the honeycomb configuration was modified to shorten the duration of impact. (See Fig. 9). The modification was successful in shortening the impact duration, however, it went too far in the other direction. Test 1147-110 had an impact duration which was less than that found in the full-scale test. The honeycomb stackup used was as follows:

Block 1 - 5"w x 5"h x 4"h x 75 psi
(12.7 x 12.7 x 10.2 cm x 517.1 kPa)

Block 2 - 5"w x 8"h x 4"l x 75 psi
(12.7 x 20.3 x 10.2 cm x 517.1 kPa)

Block 3 - 5"w x 8"h x 4"l x 230 psi
(12.7 x 20.3 x 10.2 cm x 1585.8 kPa)

Block 4 - 8"w x 8"h x 4"l x 230 psi
(210.3 x 20.3 x 10.2 cm x 1585.8 kPa)

Block 5 - 10"w x 8"h x 4"l x 230 psi
(25.4 x 20.3 x 10.2 cm x 1585.8 kPa)

Block 6 - 12"w x 8"h x 4"h x 230 Psi
(30.5 x 20.3 x 10.2 cm x 1585.8 kPa)

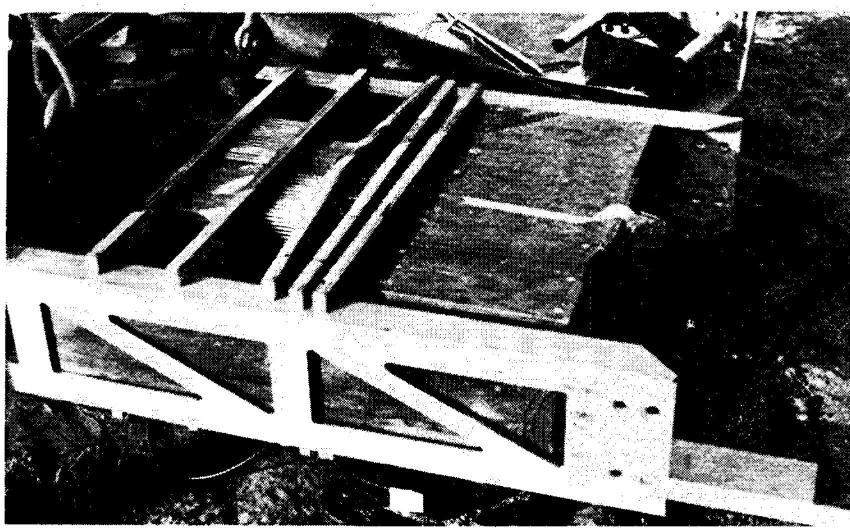


Fig. 9

Pendulum Nose Configuration as Evaluated in Test 1147-110

This test produced the closest correlation of any test so far. The momentum change of 538 lb-sec (2393.0 Ns) was very close to that found in the TTI Test D15. However, the time to peak deceleration was only .044 sec compared to .055 in the full-scale test.

TEST 1147-111

After studying the Vega force-deflection characteristic it was determined that the length of the third block of honeycomb needed to be extended in order for the honeycomb force-deflection characteristic to more closely match the Vega characteristic. This block of honeycomb which is 5 in w x 8 in h (12.7 x 20.3 cm) was lengthened from 4 in (10.2 cm) to 6 in (15.2 cm) in this test (see Fig. 10). Also the type of honeycomb in block 3 was changed from 230 psi (1585.8 kPa) to 130 psi (896.4 kPa).

This modification succeeded in matching the deceleration-time curve to the TTI D15 test curve. However, the deceleration-curve had a flat peak caused by a lengthy breakaway period which resulted in the 701 lb-sec (3118.1 Ns) momentum change.

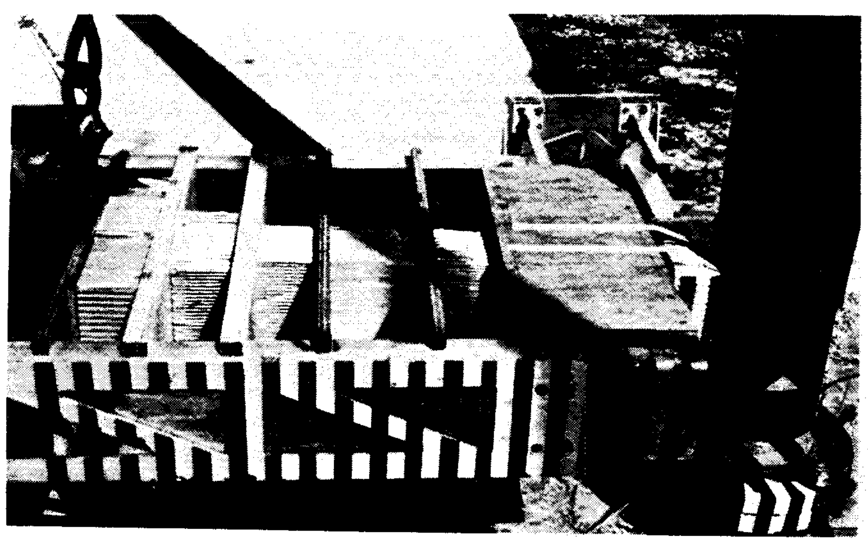


Fig. 10
Pendulum Nose Configuration as Evaluated in Test 1147-111

TEST 1147-112

In an effort to decrease the duration of the deceleration peak, the fifth block of honeycomb was increased in size in this test (see Fig. 11). Otherwise this test was similar to Test 1147--111. This modification was unsuccessful, partly due to the uneven crush of the fifth and sixth honeycomb blocks which did not provide the desired "hard point" corresponding to the engine of the actual vehicle. The momentum change was 77.7 lb-sec (3456.1 Ns).

TEST 1147-113

In both Tests 1147-111 and 1147-112 the amount of honeycomb crush was about 18½ in (50.0 cm). This crush was greater than the 17 in (34.2 cm) of crush found in the full-scale TTI Test D15. In order to reduce the crush, the length of the fifth block of honeycomb was shortened to 2 in (5.1 cm) (see Fig. 12). The size of the sixth honeycomb block was also increased in order to create a better "hard point". Otherwise this test was similar to Test 1147-112.

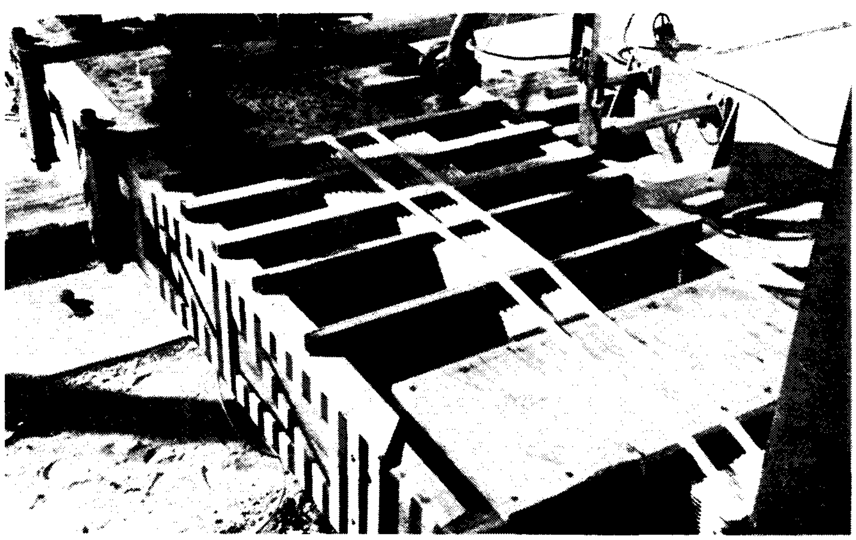


Fig. 11

Pendulum Nose Configuration as Evaluated in Test 1147-112

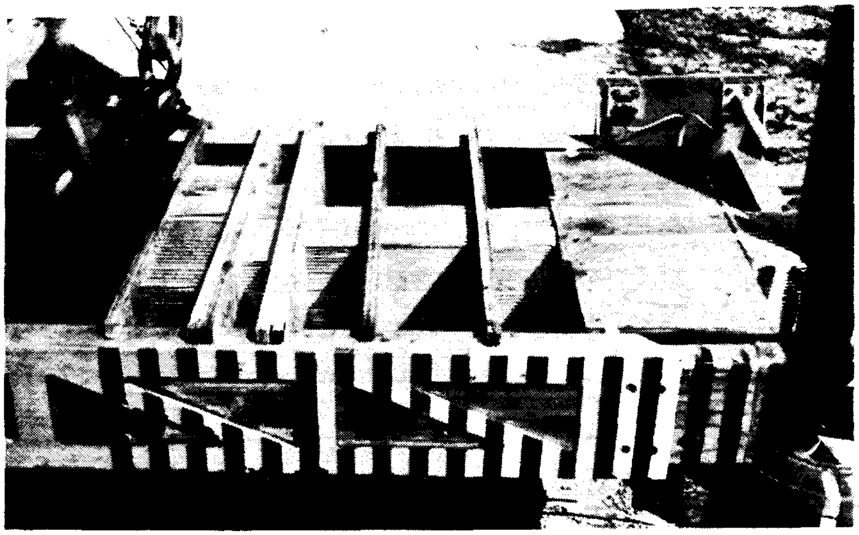


Fig. 12

Pendulum Nose Configuration as Evaluated in Test 1147-113

These modifications were successful in significantly reducing the momentum change to 635 lb-sec (1612.1 Ns) and in general, reproducing the shape of the TTI deceleration-time trace almost exactly. The momentum change was still higher than desired so further attempts were made to lower it.

TEST 1147-114

It was noticed in Test 1147-113 that the breakaway force being generated in the pendulum impact was almost identical to the force level of the fifth block of honeycomb. Since this block of honeycomb was the last to be crushed it was felt that perhaps there was some correlation between its crush force and the breakaway force level. In order to test this theory, the size of the fifth block was reduced in this test (see Fig. 13). This test resulted in a higher peak force, thereby disproving the theory. The momentum change was 659 lb-sec (2931.2 Ns).

Fig. 13

Pendulum Nose Configuration as Evaluated in Test 1147-114

TEST 1147-115

This test was designed to investigate if the high peak force in Test 1147-114 was being caused by high slip base friction. An attempt was therefore made to lower the friction coefficient by polishing all slip surfaces thereby reducing the peak force level. Unfortunately, the wooden sliding nose failed in this test resulting in uneven honeycomb crush. However, nearly the

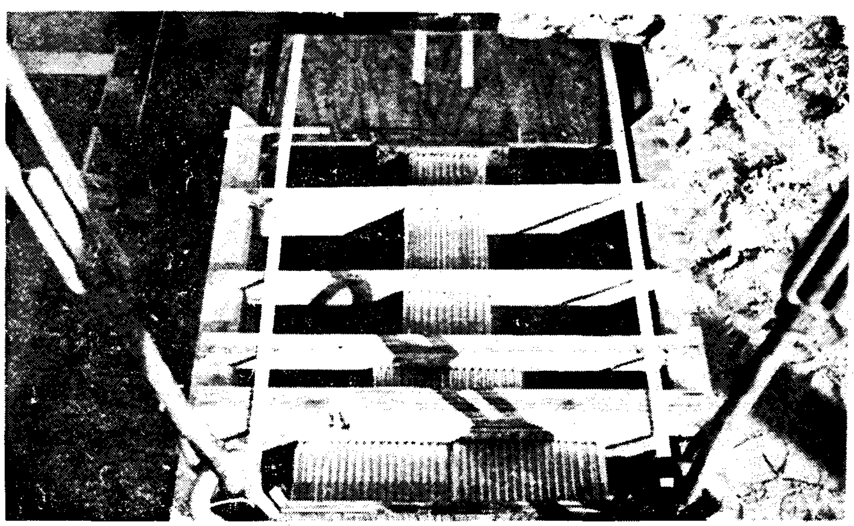


Fig. 14

Pendulum Nose Configuration as Evaluated in Test 1147-115

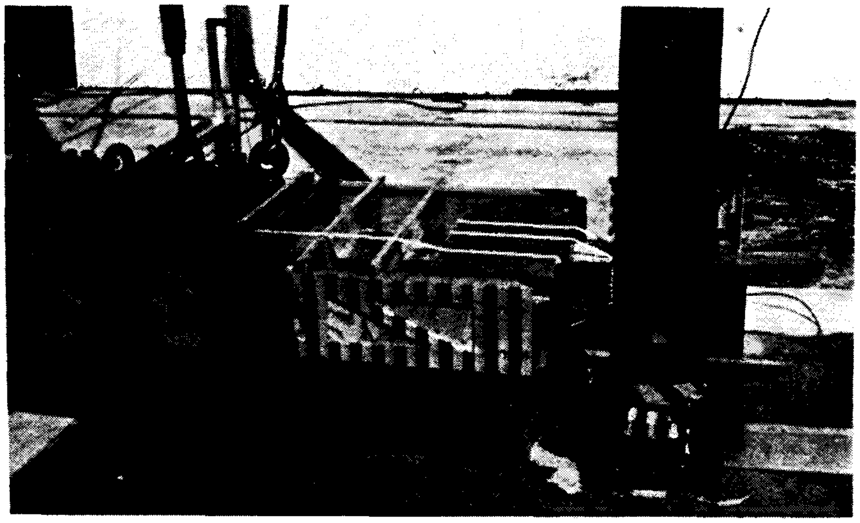


Fig. 15
Pendulum Nose Configuration as Evaluated in Test 1147-116

same high peak force was reached as in Test 1147-114, proving that polishing the slip base would not artificially lower the peak forces. The nose configuration is shown in Fig. 14.

TEST 1147-116

In this test the sixth block of honeycomb was removed in order to allow the pendulum nose to act as the hard point, representing the vehicle engine (see Fig. 15). This test gave results almost identical to those found in Test 1147-113 which was a higly successful test. This test showed that a simple five block honeycomb stackup could be used and still obtain the required force-deflection characteristic. The momentum change was 649 lb-sec (1648.5 Ns).

TEST 1147-117

Following the success in Test 1147-116, we decided to see if a four block honeycomb stackup could replace the five block version (see Fig. 16). It was felt that if a satisfactory four block configuration could be found then this would simplify the test setup. The honeycomb configuration used was:

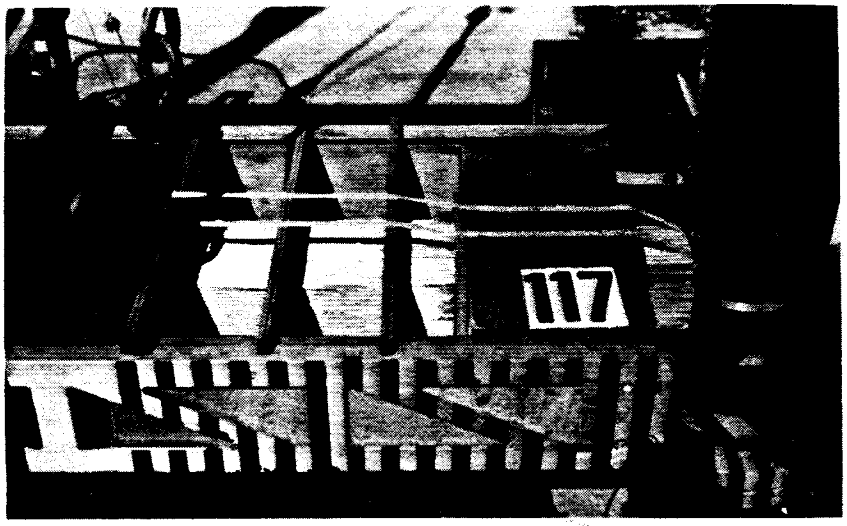


Fig. 16
Pendulum Nose Configuration as Evaluated in Test 1147-117

Block 1 - 4"l x 5"w x 5"h x 75 psi
(10.2 x 12.7 x 12.7 cm x 517.1 kPa)

Block 2 - 4"l x 5"w x 8"h x 75 psi
(10.2 x 12.7 x 20.5 cm x 517.1 kPa)

Block 3 - 6"l x 5"w x 8"h x 130 psi
(15.2 x 12.7 x 20.3 cm x 896.4 kPa)

Block 4 - 6"l x 5"w x 8"h x 230 psi
(15.2 x 12.7 x 20.3 cm x 1585.8 kPa)

The momentum change resulting from this test was lower than Test 1147-116 despite the higher peak force. However, the shape of the deceleration-time curve did not adequately match the full-scale test data. Consequently, the four block configuration was abandoned.

Fig. 17
Pendulum Nose Configuration as Evaluated in Test 1147-118

TEST 1147-118

This test set-up was the same as Test 1147-116 except that the wooden sliding nose was removed to ascertain the effect of the 35 lb (15.8 kg) nose weight (see Fig. 17). The results of the test were almost identical to the results of Test 1147-116, suggesting that the 35 lb (15.8 kg) nose weight was probably a valid simulation of the bumper of an actual vehicle.

TEST 1147-119

Since the honeycomb configuration of Tests 1147-116 and 1147-118 was considered to properly duplicate actual vehicle crush characteristics it was not time to raise the pendulum impact height back up to 24 in (61.0 cm). (The wooden sliding nose was again left off in this test.) (See Fig. 18.)

The results of this test were the best of any performed to date. The momentum change was approximately 580 lb-sec (1473.2 Ns). The time of the peak deceleration was .055 sec after impact, and the honeycomb crush was 17 in (43.2 cm). All of these results

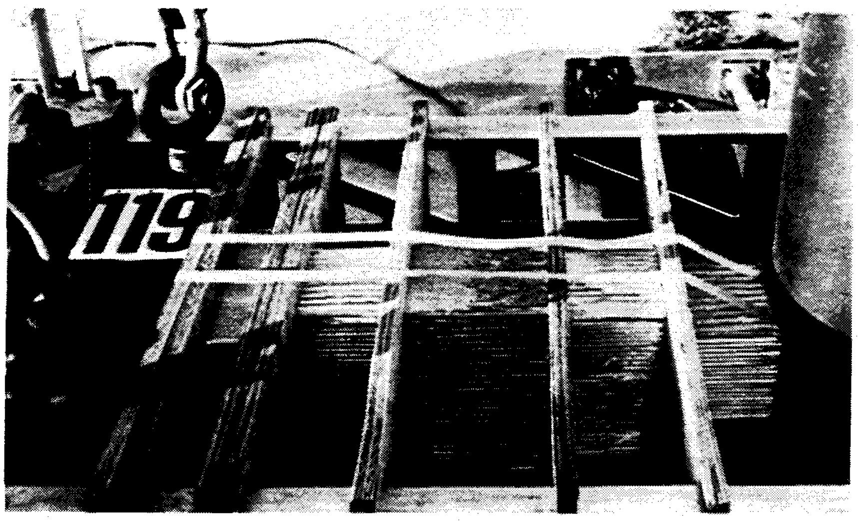


Fig. 18

Pendulum Nose Configuration as Evaluated in Test 1147-119

are very close to the full scale TTI Test D15 against which the correlation is being conducted.

TEST 1147-120

This test was identical to Test 1147-119 except that the wood sliding nose was used (see Fig. 19). A striker nose was required in the final design to provide uniform honeycomb crush regardless of the support configuration. The breakaway force level in this test was higher than in Test 1147-119 resulting in a higher momentum change of 715 lb-sec (1816.1 Ns). Other than some intrinsic variability of slip base breakaway force levels, the reasons for this slight increase in momentum change are still not apparent.

TEST 1147-121

In this test the second, third and fourth honeycomb blocks were reduced in cross section from 5 in x 8 in (12.7 x 20.3 cm) to 4 in x 8 in (10.2 x 20.3 cm). (See Fig. 20). The purpose of this was to see if the momentum change could be reduced somewhat by

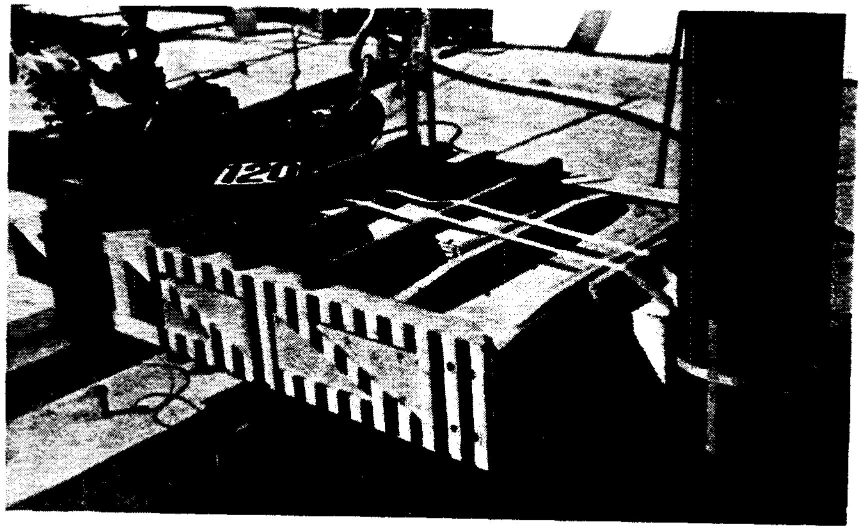


Fig. 19
Pendulum Nose Configuration as Evaluated in Test 1147-120

lowering the force levels of these particular blocks. While the results of the test did show a slight reduction in induced momentum change, it was not as large as was desired to bring the pendulum results into line with the full-scale test data. However the test did point out that the more convenient and less costly 4 in x 8 in (10.2 x 20.3 cm) honeycomb blocks could be used in place of the 5 in x 8 in (12.7 x 20.3 cm) size blocks.

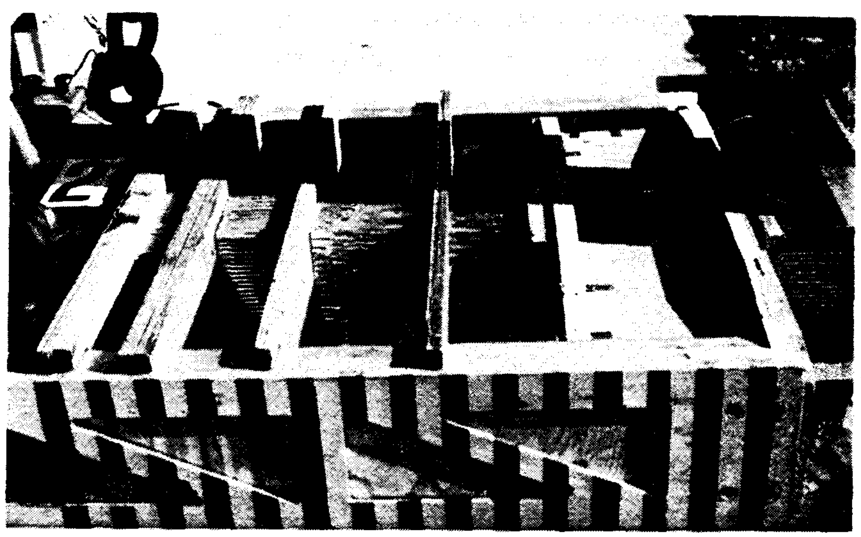


Fig. 20
Pendulum Nose Configuration as Evaluated in Test 1147-121

The results of this test very closely duplicated the full-scale data for Test D15. For convenience these are summarized below:

	Pendulum Test	Full-Scale Test
Vehicle Mass (lb)	2245	2250
Impact Speed (ft/sec)	29.7	28.8
Impact Duration (msecs)	70	60
Momentum Change (lb-sec)	644 (Accelerometer data)	560 (Film Data)
Peak Deceleration (unfiltered data)	13.5	14.9
Vehicle Crush (in)	17.0	17.5

1 ft/sec = .305 m/s
1 lb-sec = 4.448 Ns
1 in = 2.54 cm
1 lb = .454 kg

At the conclusion of this test it was felt that the pendulum nose configuration that had been evolved constituted a good basic design for reproducing full-scale test behavior of a vehicle impacting a typical breakaway support. It was realized that some refinement would still be necessary, that all of the phenomena involved were still not totally understood (e.g., effect of nose bumper mass, effect of local deformation of pole, etc.), and that several additional tests would have to be conducted to see if the configuration gave repeatable results under carefully controlled test conditions.

TEST 1147-122

This was a first cut at examining the extent of local pole deformation when using the nose configuration from Test 1147-121.

Prior to the test the internal blocking was removed from the pole. The momentum change results were only slightly higher than those obtained in Test 1147-121, 714 lb-sec (3175.9 Ns), this being due to the impact duration being drawn out by the deformation of the pole. Examination of the pole revealed that approximately an inch (2.54 cm) of deformation had occurred which is somewhat more than that observed in the full-scale test of an unblocked pole 0.7. This implies that the nose configuration was slightly too agressive in its present set-up and that the 5 in x 5 in (12.7 x 12.7 cm) cross section of the leading honeycomb block (used as a shock damper) was too small (see Fig. 20). On the other hand, the deformation could have been a result of the weakened condition of the pole which had been hit 14 times previously (13 with internal blocking).

Film analysis of the recent tests indicated that pole deformation was occurring early in the test and was increasing up to the time of breakaway. The immediate onset of the deformation indicated that the size of the impact surface was largely at fault, rather than the magnitude of the peak breakaway force as had been thought previously.

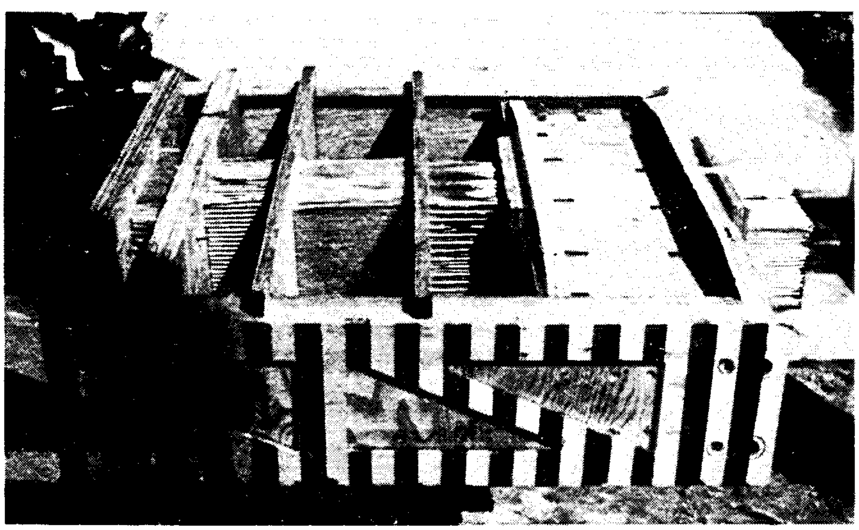


Fig. 21

Pendulum Nose Configuration as Evaluated in Test 1147-122

To test this idea, the existing wooden nose was modified to accept large (up to 16 in x 8 in (40.6 x 20.3 cm) in cross section) impact surface. This size was chosen for two reasons:

1. The films of the full-scale Vega test (TTI D15) indicated that the impact is spread over a height of approximately 18 in (45.7 cm).

2. This arrangement would accept two blocks of honeycomb, 8 in x 8 in (20.3 x 20.3 cm) in cross-section.

After the modification was made to the wooden nose, tests were begun with the idea that full blocks of honeycomb would be used initially, and if no deformation occurred, the size of the blocks would be reduced until some noticeable, but minimal, deformation took place.

TEST 1147-123

In this test the size of the 75 psi (517.1 kPa) leading honeycomb block was increased to 8 in (20.3 cm) wide by 16 in (10.6 cm) high by 4 in (10.2 cm) thick (see Fig. 22). The rest of the

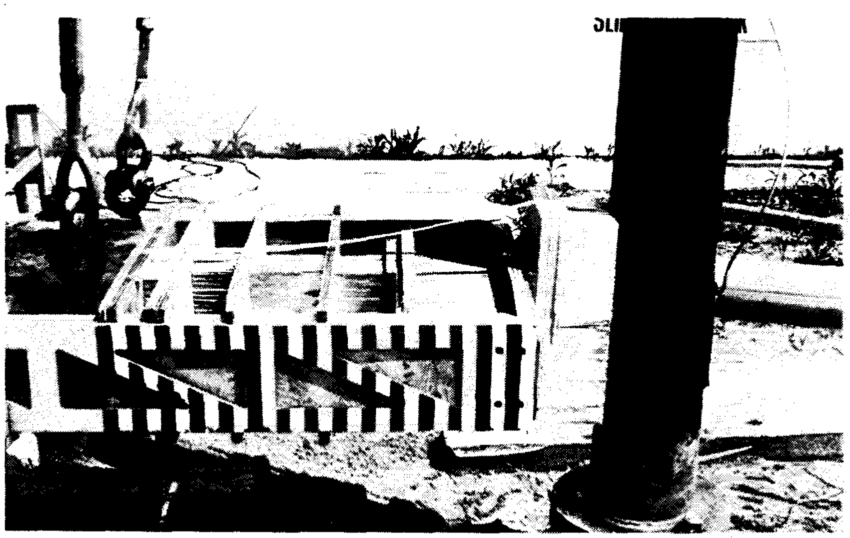


Fig. 22
Pendulum Nose Configuration as Evaluated in Test 1147-123

honeycomb was identical to that used in Test 1147-122. A new pole was used in this test. The test resulted in a momentum change, time sequence, and breakaway face level closely corresponding to TTI Test D15. The momentum change was 570 lb-sec (2535.4 Ns), peak deceleration was 7.7 g's. No pole denting occurred.

TEST 1147-124

This was was identical to Test 1147-123 except the impact surface was reduced in height by 4 in (10.2 cm) providing a surface 8 in (20.3 cm) wide, 12 in (30.5 cm) high and 4 in (10.2 cm) thick (see Fig. 23). The results of this test were virtually identical to those of Test 1147-123 with respect to momentum change and breakaway force. There was very slight denting of the pole.

At this point, in accordance with the technical approach, the series of tests ended since the slight denting of the pole in Test 1147-124 indicated that a further reduction in the size of the leading honeycomb block would only result in an unacceptable pole deformation.

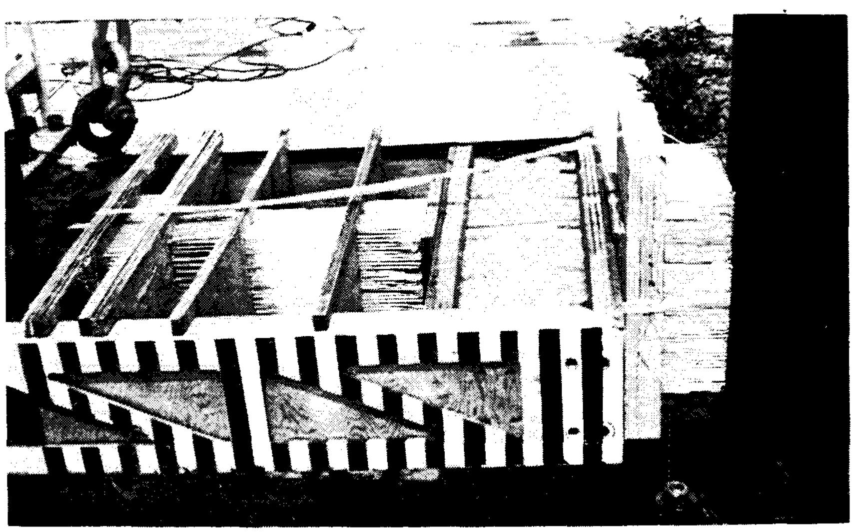


Fig. 23
Pendulum Nose Configuration as Evaluated in Test 1147-124

3.5 PENDULUM NOSE VALIDATION TESTS

Test 1147-124 was the culmination of a design effort to produce a laboratory equivalent test device for testing breakaway luminaire supports. Following this test a permanent aluminum sliding nose was constructed for the pendulum. The nose weighs approximately 60 lb (27.2 kg) and rides on a pair of 14 in (10.2 cm) O.D. tubes which are attached rigidly to the pendulum mass (see Fig. 24). The nose is designed to prevent cocking even when impacted off center. This produces a repeatable force-deflection characteristic under a variety of impact conditions.

To verify the usefulness of the pendulum vehicle simulator, several validation tests were conducted. All of these tests were reproductions of full-scale tests of subcompact car impacting luminaire supports at about 20 mph (32.2 km/h). All but one test (Test 1147-505) reproduced tests where 1971-73 Chevrolet Vegas were tested.

Fig. 24
Pendulum Nose Configuration as Evaluated in Test 1147-124

Test 1147-125

In this test a 36 ft (11 m) Union Metal three bolt slip base was assembled with a 15,000 lb (66,720 N) bolt load. The pendulum test was set up to duplicate TTI full-scale Test D15 in which a 2250 lb (1021.5 kg) Vega impacted the same type of pole at 20 mph (32.2 km/h). Results of the full-scale filtered (SAE Class 60) test data and pendulum test data are shown below in Table 1. As can be seen from this table and from Fig. 25 which is a comparison of the two time-deceleration traces, correlation was excellent.

TABLE 1. COMPARISON OF RESULTS FROM ENSCO TEST 1147-125 AND TTI TEST D15

	Test D15	Test 1147-125
Momentum Change	560	563
Peak Deceleration (g's)	10	9.3
Time at Peak Decel. (sec)	.057	.055
Impact Duration (sec)	.065	.065
Vehicle Crush (in)	17.5	17.0
Pole Deformation	None	None

1 lb-sec = 4.448 Ns, 1 in = 2.54 cm

Test 1147-202

In this test Hapco cast aluminum transformer base with a 28 ft (8.5 m) Hapco aluminum pole was impacted. This test was set up to duplicate TTI Tests D1 and D2 in which the same base and pole were impacted by 2250 lb (1021.5 kg) Vegas at 20 mph (32.2 km/h). In Test D1 the vehicle was stopped by the base which experienced some cracking near the bottom and stayed erect. Momentum change for this test was 2020 lb-sec (8985.0 Ns). In TTI Test D2 the transformer base shattered and the resulting momentum change was 1420 lb-sec (6316.2 Ns).

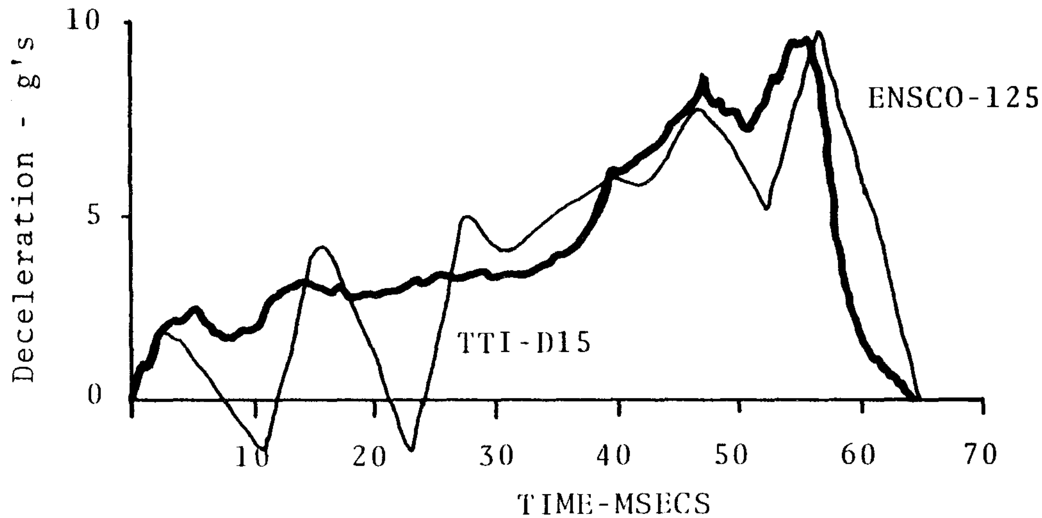


Fig. 25

Comparison of Longitudinal Accelerometer
Traces for TTI Test D15 and ENSCO Test 1147-125

Test 1147-202 resulted in a fairly low momentum change of 846 lb-sec (37,630 Ns). This test, however, was considered invalid since a sweeperplate was not used and a 12 in (30.5 cm) stub remained erect following the test. As a result this test was rerun (Test 1147-203) with a sweeperplate and better results were obtained.

Table 2 compares the test results from TTI Tests D1 and D2, and ENSCO Test 1147-202. Fig. 26 shows a comparison of the time-deceleration traces from ENSCO Test 1147-202 and TTI Test D2.

TABLE 2. COMPARISON OF TEST RESULTS FROM ENSCO TEST 1147-202 AND TTI D1 AND D2

	D1	D2	1147-202
Momentum Change (lb-sec)	2020	1420	846
Peak Deceleration (g's)	24	20	16
Time at Peak Decel. (sec)	.074	.066	.063
Impact Duration (sec)	.150	.105	.074
Vehicle Crush (in)	18.5	17.0	17.0

1 lb-sec = 4.448 Ns, 1 in = 2.54 cm

Test 1147-203

This test was a repeat of Test 1147-202 except that a rigid sweeperplate with a 6 in (15.2 cm) ground clearance was used. As can be seen from Table 3, a comparison of test results, and Fig. 27, a comparison of time-deceleration traces, correlation with TTI Test D2 was excellent.

Test 1147-208

Due to the low momentum change found in Test 1147-202 (846 lb-sec (373.0 Ns)) on a Hapco transformer base, it was felt that a third baseline test should be run on this base (Test 1147-203 was the second baseline test and showed a momentum change of 1532 lb-sec (6814.3 Ns)).

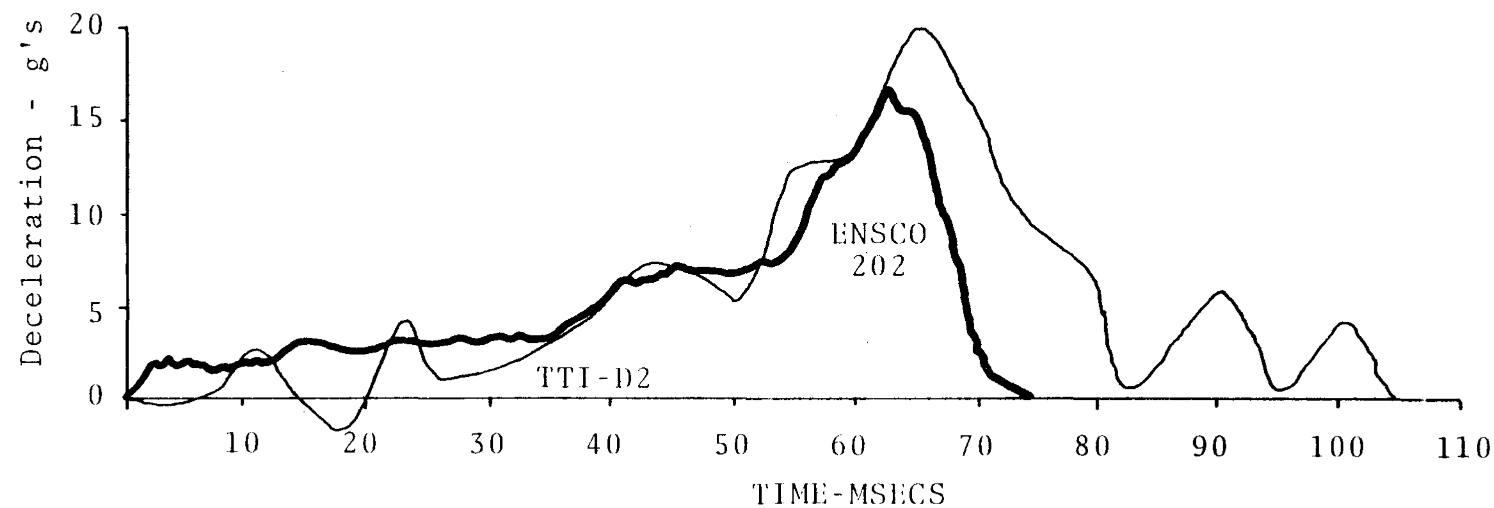


Fig. 26
Comparison of Longitudinal Accelerometer
Traces for TTI Test D2 and ENSCO Test 1147-202

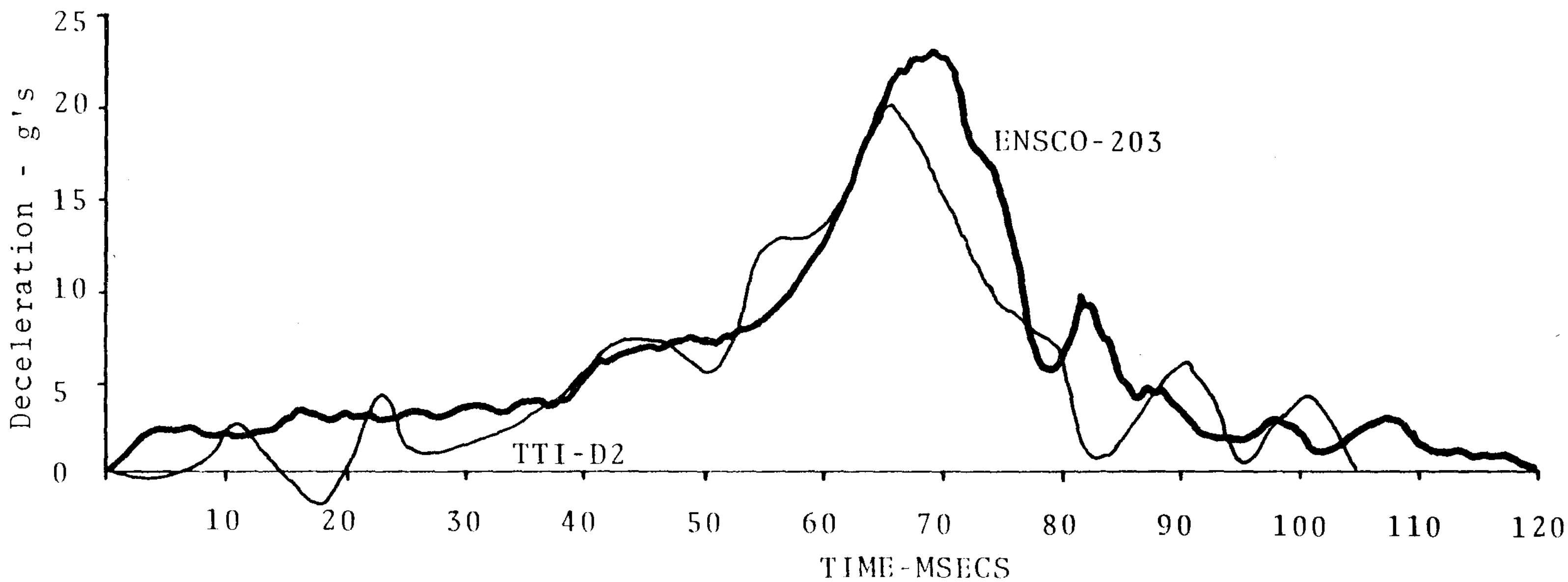


Fig. 27
Comparison of Longitudinal Accelerometer
Traces for TTI Test D2 and ENSCO Test 1147-203

TABLE 3. COMPARISON OF TEST RESULTS FROM ENSCO TEST 1147-203 AND TTI TESTS D1 AND D2

	D1	D2	1147-203
Momentum Change (lb-sec)	2020	1420	1532
Peak Deceleration (g's)	24	20	22
Time at Peak Decel. (sec)	.074	.066	.070
Impact Duration (sec)	.150	.105	.120
Vehicle Crush (in)	18.5	17.0	17.0

1 lb-sec = 4.448 Ns, 1 in = 2.54 cm

This time the base again exhibited a low momentum change similar to Test 1147-202. It is believed that these low values are due to the scatter exhibited by transformer bases, based on the excellent repeatability to the general shape of the accelerometer traces as shown in Fig. 26.

The results from Test 1147-208 are shown in Table 4. Fig. 28 compares the deceleration-time traces for accelerometer No. 1 with the filtered accelerometer data of TTI Test D2.

TABLE 4. COMPARISON OF TEST RESULTS FROM ENSCO TEST 1147-208 AND TTI TESTS D1 AND D2

	D1	D2	1147-208
Momentum Change (lb-sec)	2020	1420	901
Peak Deceleration (g's)	24	20	16
Time of Peak Decel. (sec)	.074	.066	.063
Impact Duration (sec)	.150	.105	.095
Vehicle Crush (in)	18.5	17.0	17.0

1 lb-sec = 4.448 Ns, 1 in = 2.54 cm

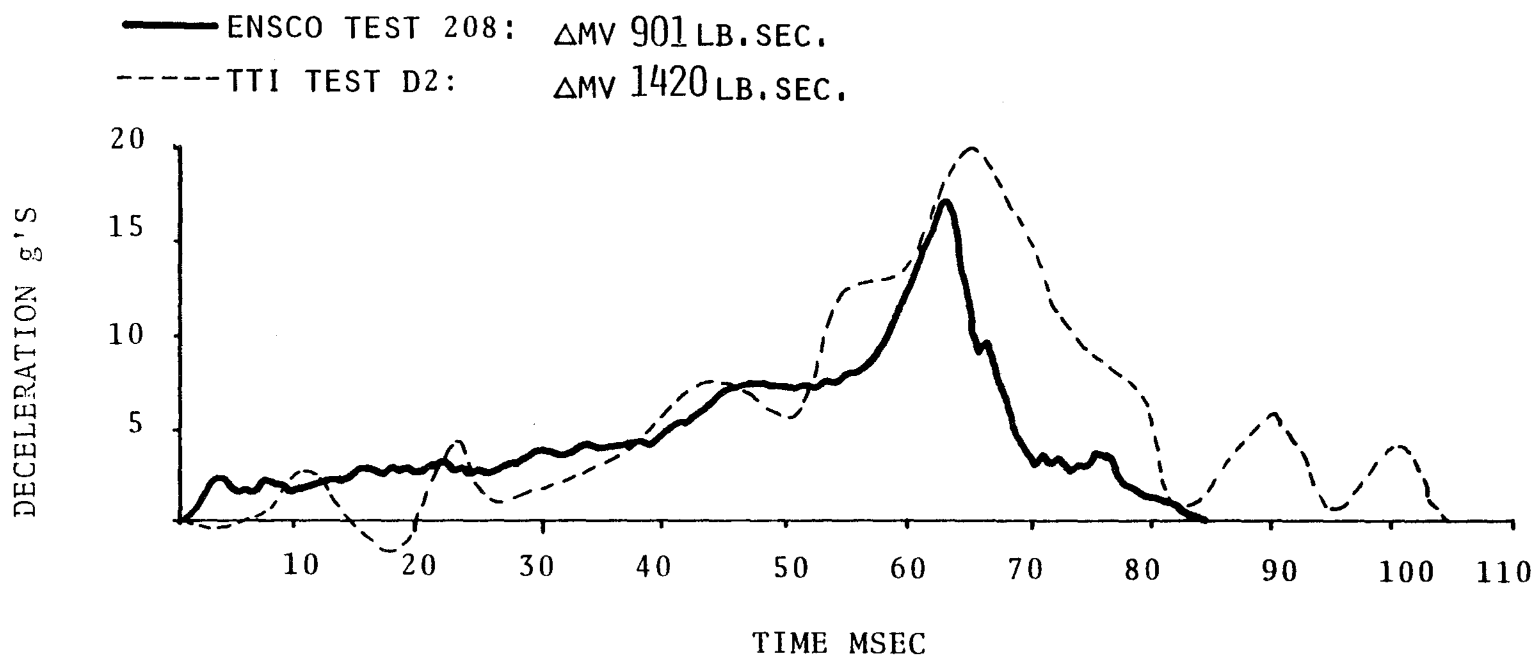


Fig. 28
Comparison of Longitudinal Accelerometer
Traces for TTI Test D2 and ENSCO Test 208

Test 1147-505

Test 1147-505 was set up to duplicate a test which had been run in California using a California type 31 slip-base pole impacted by a 1971 Ford Pinto at 17.5 mph (28.2 km/h) [15].

Table 5 shows a comparison of test conditions for Test 1147-505 and California Test 311.

TABLE 5. TEST CONDITIONS: ENSCO 1147-505 AND CALIFORNIA 311

	1147-505	311
Initial Velocity of Impact (mph)	17.1	17.5
Initial Bolt Torque (ft-lb)	200.0	200.0
Impact Vehicle Weight (lb)	2290.0	2265.0

1 mph = 1.61 km/h
1 ft-lb = 1.356 Nm
1 lb = .454 kg

ENSCO Test 1147-505 was set up for a direct impact where California 311 was set up for a 30-degree impact. They used this angle because of evidence that it is the most severe impact angle for three bolt slip bases. Since the directional dependence of these slip bases is minimal, the difference in impact angle is not considered to be significant.

The comparison of test results shown in Table 6 further illustrates the similarity of the two tests.

Although no accelerometer traces were available from California 311 for comparison, the indications are that the two tests were very close to being equivalent.

TABLE 6. COMPARISON OF TEST RESULTS

	1147-505	311
Final Velocity (mph)	11.5	10.8
Δ velocity (mph)	5.6	6.7
Momentum Change (lb-sec)	621.0	689.0
Deformation/honeycomb crush (in)	16.5	17.0
Time to Base Separation (sec)	.060	.055
Time in Pole Contact (sec)	.174	.181

1 mph = 1.61 km/h
1 lb-sec = 4.448 Ns
1 in = 2.54 cm
1 lb = .454 kg

Test 1147-601

This was a test of the Alcoa Breakaway Couplings with a 50 ft (15.3 m) MH spun aluminum pole on top. The test was a duplication of a similar full-scale test conducted at TTI numbered 3290-3. The couplings behaved as designed in that they split longitudinally during the impact. No denting of the pole occurred as had been the case in an earlier test (FHWA (FHWA Staff Study [3]) utilizing the neoprene rubber faced pendulum nose. Results of the test were very similar to those seen in the full-scale test as shown in Table 7.

TABLE 7. COMPARISON OF RESULTS FROM ENSCO TEST 1147-601 AND TTI TEST 3290-3

	1147-601	3290-3
Momentum Change (lb-sec)	606	590
Peak Deceleration (g's)	8.0	8.3
Time at Peak Decel. (sec)	.061	.044
Impact Duration (sec)	.075	.075

1 lb-sec = 4.448 Ns, 1 lb = .454 kg

Fig. 29 shows a comparison of the accelerometer traces for the pendulum and full-scale tests.

3.6 CONCLUSIONS AND RECOMMENDATIONS

From this series of 25 pendulum impact tests the design of a crushable nose has been evolved which when used with a 2250 lb (1021.5 kg) pendulum mass will closely duplicate the impact of a subcompact vehicle striking a typical breakaway support. The design is shown in Fig. 30.

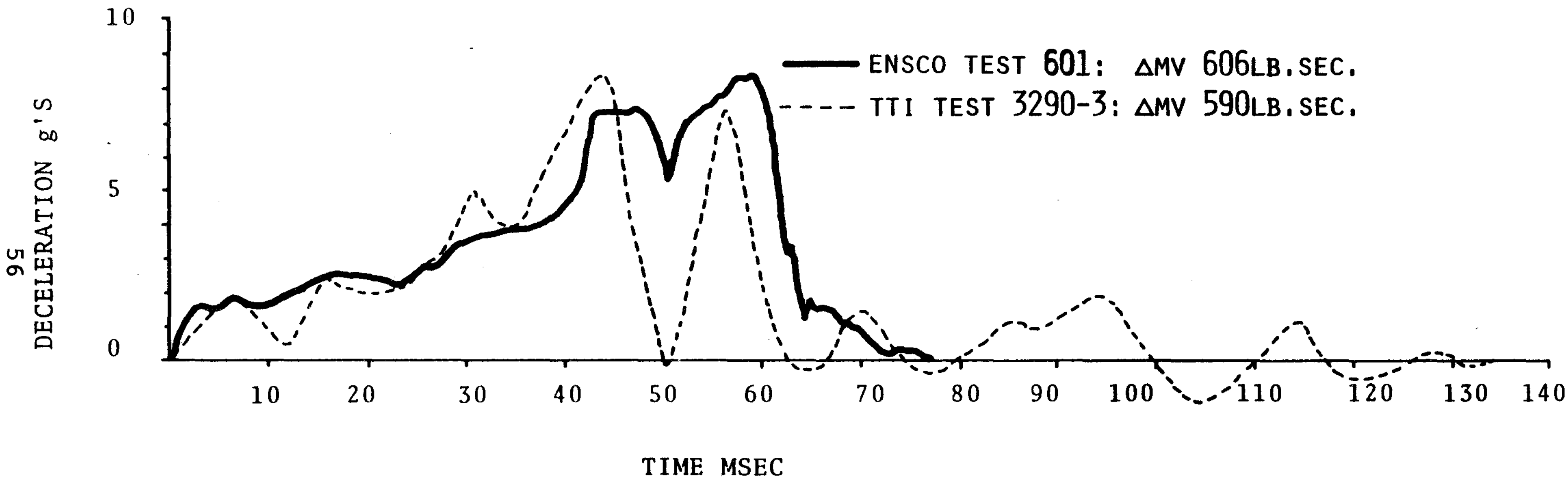
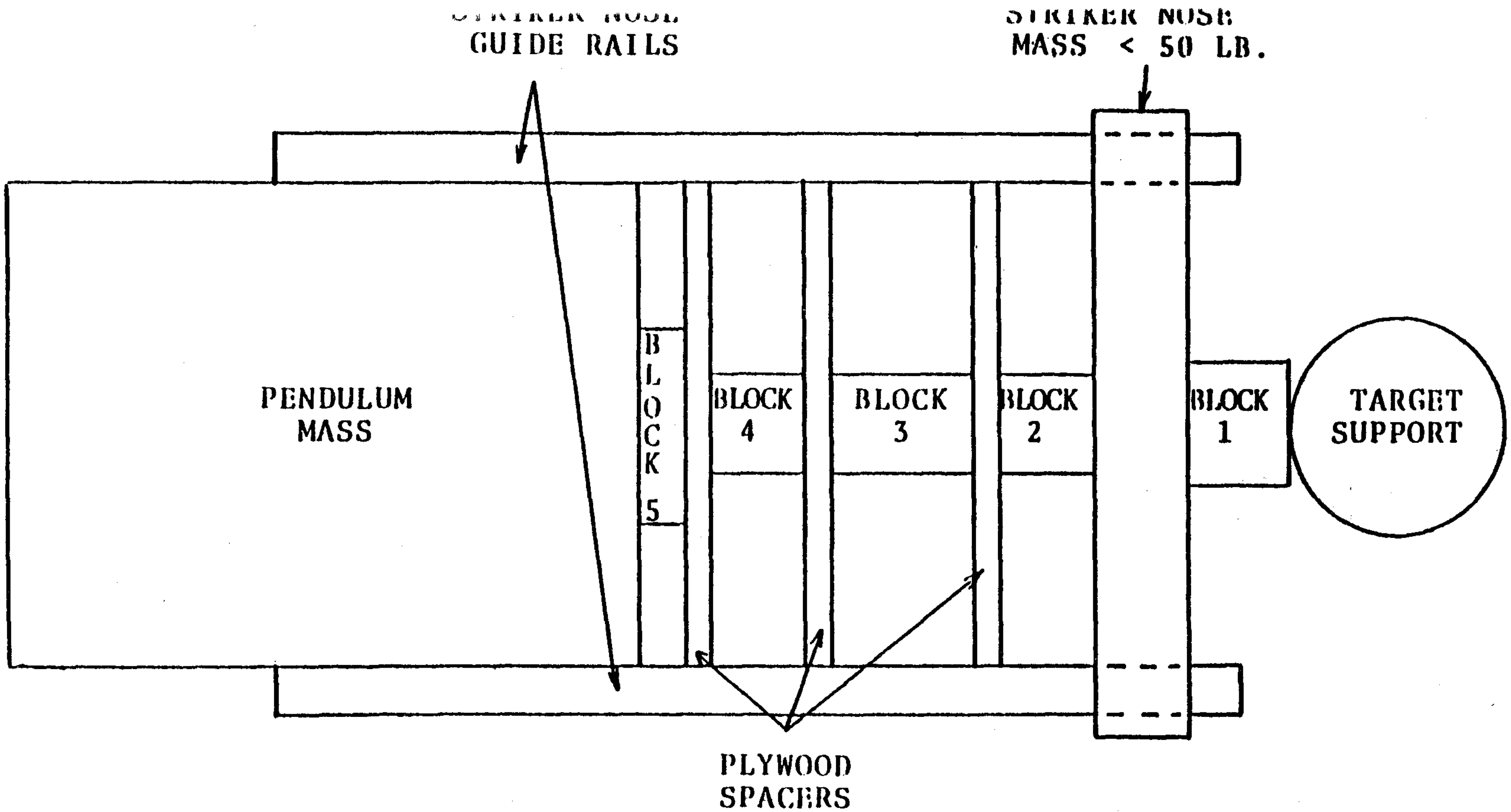


Fig. 29

Comparison of Longitudinal Accelerometer
Traces for TTI Test 3290-3 and ENSCO Test 1147-601



HONEYCOMB (Precrush 1/4"):

Block 1 -12"h x 8"w x 4"ℓ x 75 psi
Block 2 - 8"h x 4"w x 4"ℓ x 75 psi
Block 3 - 8"h x 4"w x 6"ℓ x 130 psi
Block 4 - 8"h x 4"w x 4"ℓ x 230 psi
Block 5 - 8"h x 8"w x 2"ℓ x 230 psi

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1 in = 2.5 cm, 1 lb = .45 kg, 1 psi = 6.89 kPa

Fig. 30

Basic Design for Pendulum Nose Configuration

4. BREAKAWAY LUMINAIRE SUPPORT TESTING

4.1 INTRODUCTION

The FHWA pendulum impact facility was used to test a variety of breakaway luminaire support types. All tests were conducted at approximately 20 mph (32 km/h) with a pendulum mass of 2290 lb (1039 kg). The pendulum incorporated the 5 block honeycomb nose developed under this contract and discussed in Chapter 3. Except for two tests (tests 1147-501 and 1147-506) no mast arm or luminaire was used. The mast arms were used in these tests as a comparison to check the validity of testing without mast arms. For convenience, the luminaire support tests were categorized into test series according to the type of breakaway device. These series were classified as follows:

Series	Support Type
1147-200	Cast Aluminum Transformer Bases
1147-300	Aluminum Flange Base Poles
1147-400	Steel Progressive Shear Bases
1147-500	Steel Slip Base Poles
1147-600	Breakaway Couplings
1147-700	Fiberglass Poles

The 1147-300 to 1147-700 series tests will be discussed in this chapter. Series 1147-200 tests are covered separately in Chapter 5.

4.2 ALUMINUM FLANGE BASE POLE TESTS

Three tests were conducted on aluminum flange base poles. The following is a brief summary of these tests:

Test	Manufacturer and Type
1147-301	Kaiser AT-50
1147-302	Hapco 8 in (.21 m) dia.
1147-303	Hapco 7 in (.18 m) dia.

TEST 1147-301

Test 1147-301 was conducted with a Kaiser 50 ft (15 m) MH AT-50 breakaway base pole. This pole had been full-scale tested by the Texas Transportation Institute (TTI) with a resulting momentum change of 590 - 730 lb-sec (2624-3247 Ns) depending on the method of data collection.

The AT-50 pole consists of a support shaft 44 ft-8 in (13.5 m) long, 13½ in (.34 m) base diameter and 6½ in (.16 m) top diameter, mounted on an integral breakaway flange base. The flange base is made of 356-T6 aluminum alloy and extends 17 in (.43 m) into the base of the support shaft. The shaft and flange base are joined together with epoxy.

Film analysis of Test 1147-301 shows that the initial breakaway of the support occurred at the base of the support shaft. Approximately 140 msecs after initial contact with the support shaft, the sweeper plate came into contact with the remaining section of the shoe base and broke it off.

The initial breakaway of the support shaft caused a momentum change of approximately 970 lb-sec (4315 Ns). The impact of the sweeper plate with the shoe base caused an additional momentum change of about 600 lb-sec (2669 Ns). Based on the "duration of event" criteria given in TRC 191, only the 970 lb-sec (4315 Ns) momentum change was used.

The support shaft after impact is shown in Fig. 31. It is noted that the cast aluminum riser was shattered inside the shaft and sheared off at the connection to the remainder of the shoe base.

Fig. 31 also shows the portion of the shoe base which stayed on the mounting base and the pieces of the shoe base scattered around the test site. It should be noted that although the lugs

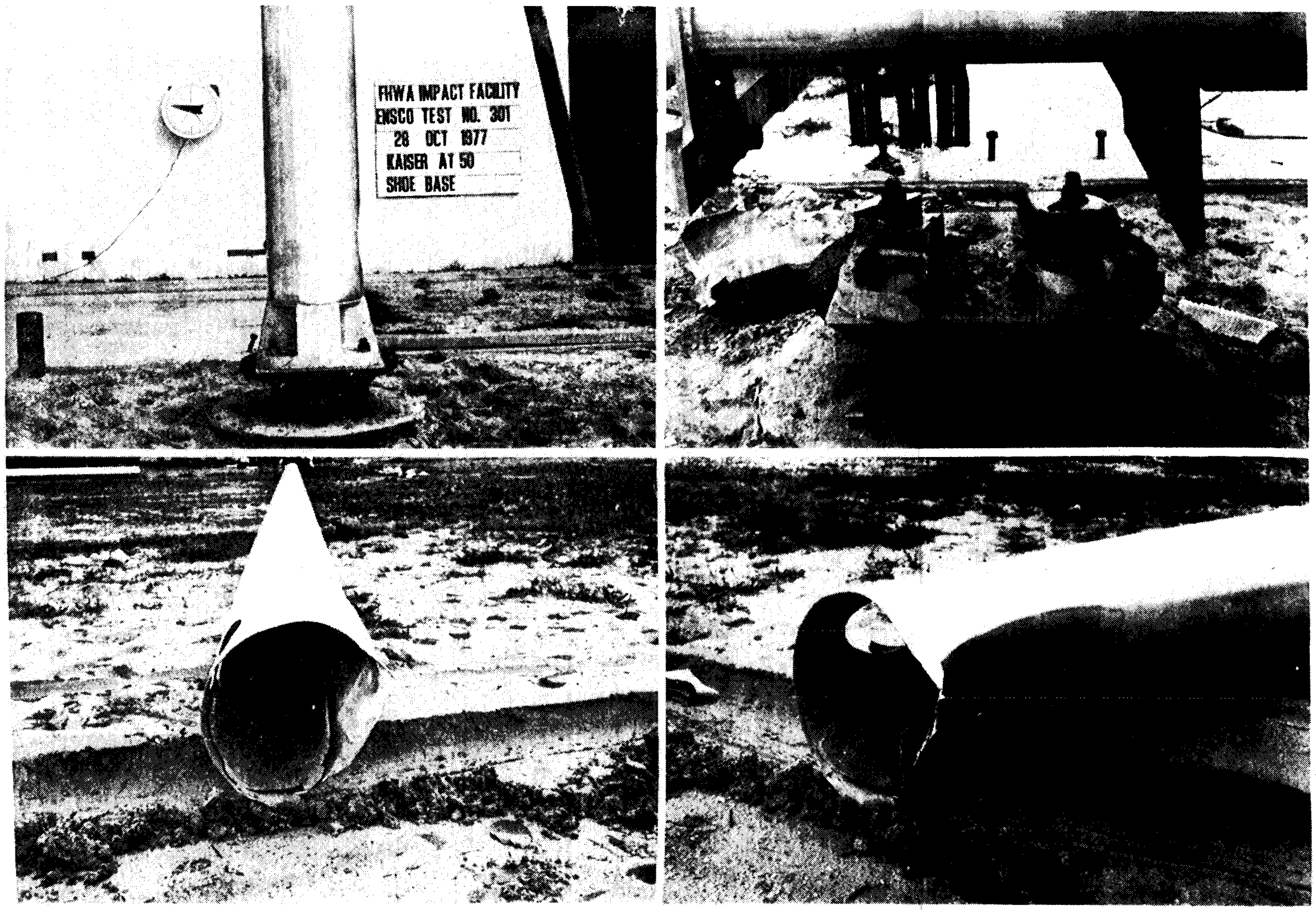


Fig. 31
Representative Photographs of Test 1147-301

still remain on the mounting base as intended, the other portion of the shoe base which should have broken away with the support shaft for a low momentum change were instead broken away by the sweeper plate.

A summary of test results for Test 1147-301 is shown in Table 8.

TABLE 8. TEST RESULTS OF TEST 1147-301

Momentum Change	970 lb-sec
Peak Deceleration	
Support Shaft Impact	16 g's
Flange Base Impact	23+ g's
Time of Peak Deceleration	
Support Shaft Impact	.056 sec.
Flange Base Impact	.139 sec.
Impact Duration	.254 sec

1 lb-sec = 4.448 Ns, 1 in = 2.54 cm

TEST 1147-302

Test 1147-302 was conducted on a Hapco 30 ft (9.1 m) MH, 8 in (.21 m) base diameter, spun aluminum flange base pole. The pole has a cast aluminum flange base welded to the tube circumferentially at the top and bottom of the casting. The bolt circle is 11 in (.28 m) to 12 in (.30 m).

During the impact the .188 in (.47 cm) wall tube sheared off just above the flange casting. Fig. 32 shows the test set-up and the post-test conditions. A summary of test results is shown in Table 9.

TEST 1147-303

In this test a Hapco 25 ft (7.6 m) MH, 7 in (.18 m) base diameter, spun aluminum flange base pole was impacted. The pole was similar in design to the Test 1147-302 pole but had a

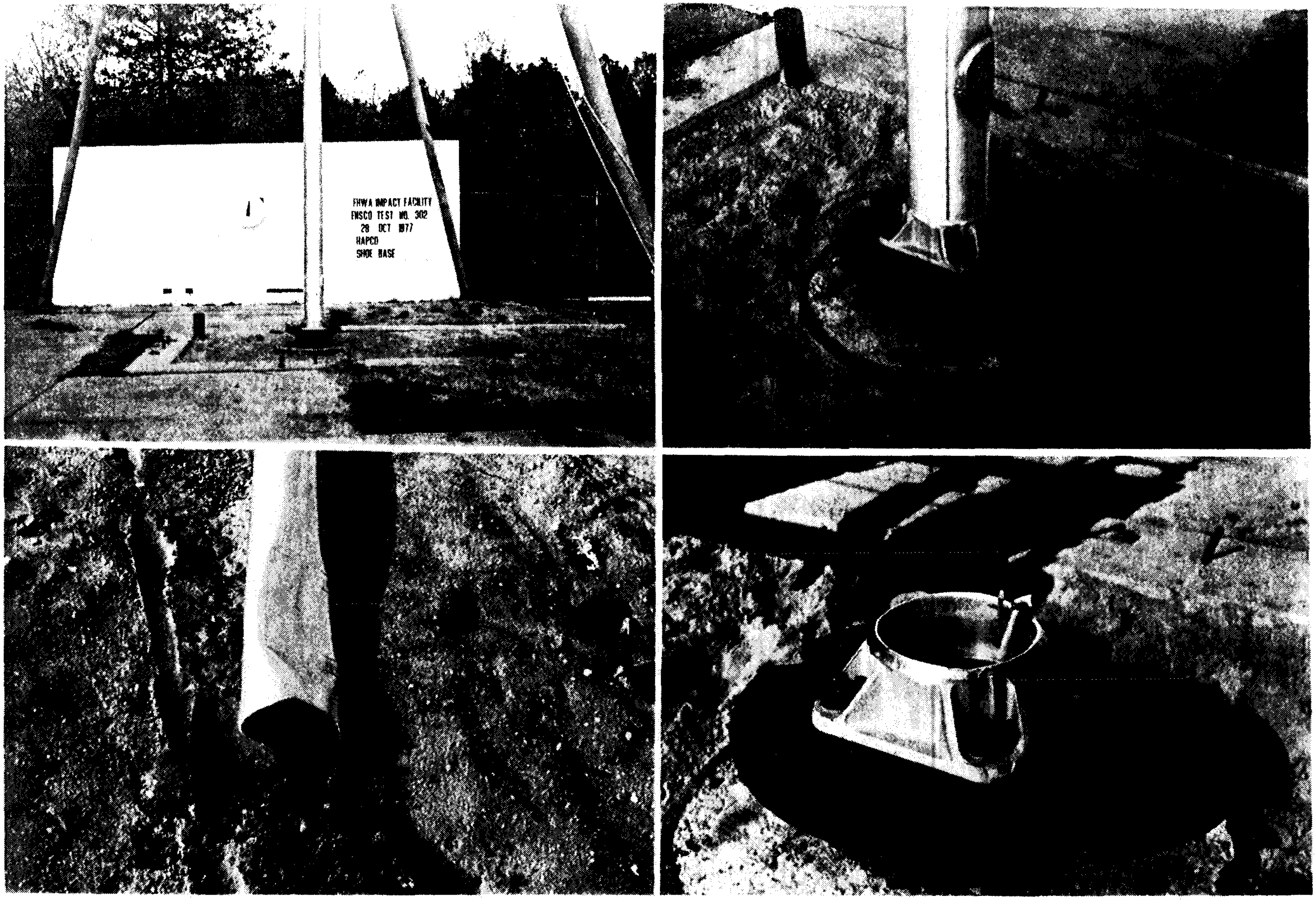


Fig. 32
Representative Photographs of Test 1147-302

TABLE 9. RESULTS OF TEST 1147-302

Momentum Change	763 lb-sec
Peak Deceleration	8.1 g's
Time at Peak Decel.	.055 sec.
Impact Duration	.112 sec
Honeycomb Crush	17.5 in

1 lb-sec = 4.448 Ns, 1 in = 2.54 cm

smaller tube and base casting. The pole had a 10 in (.25 m) to 11 in (.28 m) bolt circle and a .188 (.47 cm) wall tube.

The base failure was at the base flange weld. The weld completely sheared leaving the base intact. There was severe deformation of the pole around the impact area. The impacted pole is seen in Fig. 33. Table 10 gives the results of the test.

TABLE 10. TEST 1147-303 RESULTS

Momentum Change	774 lb-sec
Peak Deceleration	12.1 g's
Time at Peak Decel.	.064 sec.
Impact Duration	.082 sec
Honeycomb Crush	17.5 in

1 lb-sec = 4.448 Ns, 1 in = 2.54 cm

4.3 STEEL PROGRESSIVE SHEAR BASE TESTS

Seven tests were conducted on steel progressive shear luminaire support bases. These bases were all manufactured by Millerbernd Mfg. Co. The supports break away by shearing rivets which connect the base skirt to a mounting flange. The rivets shear in a progressive manner to reduce the peak load during impact. The progressive shear is provided by the deformation of the base. A summary of these tests is shown on page 65.

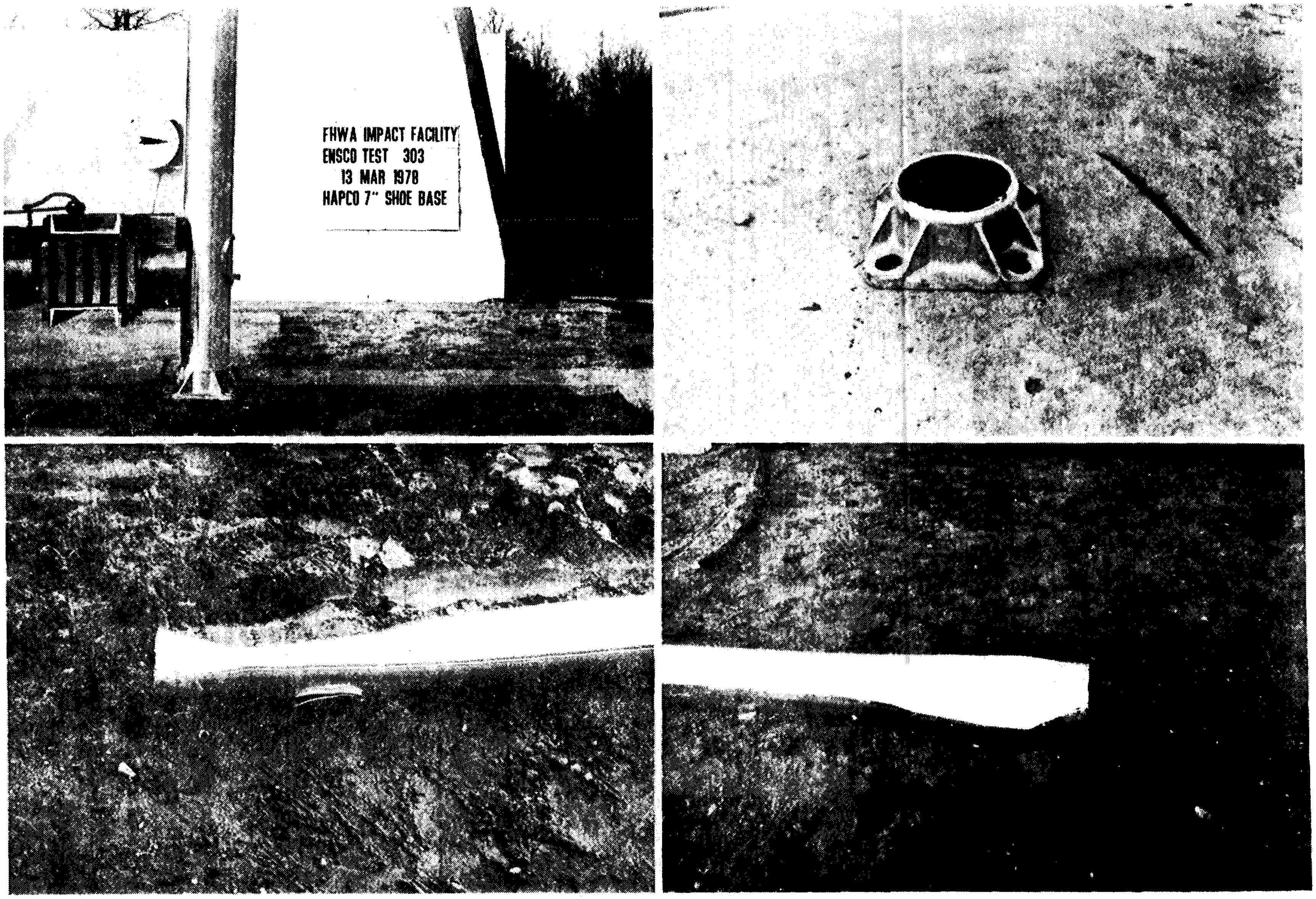


Fig. 33
Representative Photographs of Test 1147-303

Test	Manufacturer and Type
1147-401	Millerbernd 40 ft Stainless Davit
1147-402	Millerbernd 40 ft Stainless Davit
1147-403	Millerbernd 50 ft Stainless Davit
1147-404	Millerbernd Large T-Base
1147-405	Millerbernd Large T-Base
1147-406	Millerbernd Small T-Base
1147-407	Millerbernd Small T-Base

TESTS 1147-401 AND 1147-402

Tests 1147-401 and -402 were baseline tests of the Millerbernd progressive shear base with 40 ft MH davit style poles. Test 1147-401 was a degree side on impact while Test 1147-402 was a 45 degreee impact.

The stainless steel Millerbernd integral base shown in Fig. 34a is attached to a rigid bottom plate (d) by six rivets on each side. During an impact the base crushes and allows the rivets to shear in a progressive manner, whereas during wind loading the rivets act together as a unit for better strength.

The Millerbernd base behaved well in both tests. Crush of the impact side occurred and all rivets sheared off smoothly. Fig. 34b shows after impact photos of Test 1147-401 while Fig. 34c shows Test 1147-402.

Results of Tests 1147-401 and -402 are shown in Table 11.

TEST 1147-403

In view of the earlier success which had been experienced with the integral stainless progressive shear base (Tests 1147-401 and -402) it was decided to run a test with a larger base of the

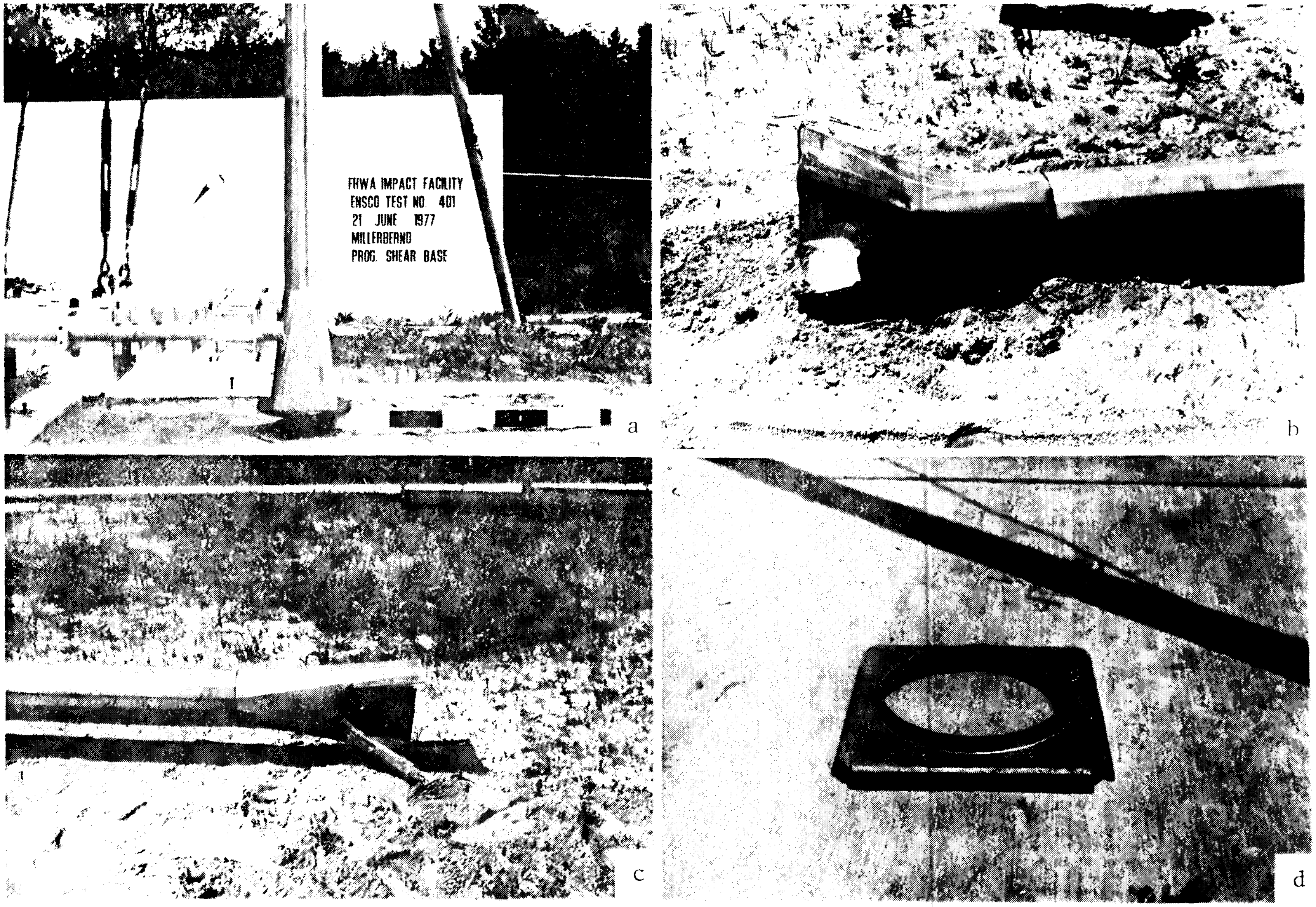


Fig. 34

Representative Photographs of Tests 1147-401 and -402

TABLE 11. RESULTS OF TESTS 1147-401 AND 1147-402

	Test 1147-401	Test 1147-402
Momentum Change (lb-sec)	580	612
Peak Deceleration (g's)	6.5	7.5
Time at Peak Decel. (sec)	.052	.057
Impact Duration (sec)	.075)	.095
Honeycomb Crush (in)	17	17

1 lb-sec = 4.448 Ns, 1 in = 2.54 cm

same type. In addition to the generally larger size of this base (Fig. 35), there are eight rivets at each of the corners versus six in the smaller base. The base was run with the lower 35 ft (10.7 m) portion of a two piece 50 ft (15 m) MH base/pole combination.

This impact once again produced a low momentum change and failure of the base in the expected mode. A summary of the test data is shown in Table 12.

TABLE 12. RESULTS OF TEST 1147-403

Momentum Change	726 lb-sec
Peak Deceleration	7.7 g's
Time at Peak Decel.	.064 sec
Impact Duration	.095 sec.
Honeycomb Crush	15 in

1 lb-sec = 4.448 Ns, 1 in = 2.54 cm

TESTS 1147-404 AND 1147-405

In these tests 115-lb (51 kg) prototype progressive shear transformer bases were tested. The bases were made of weathering

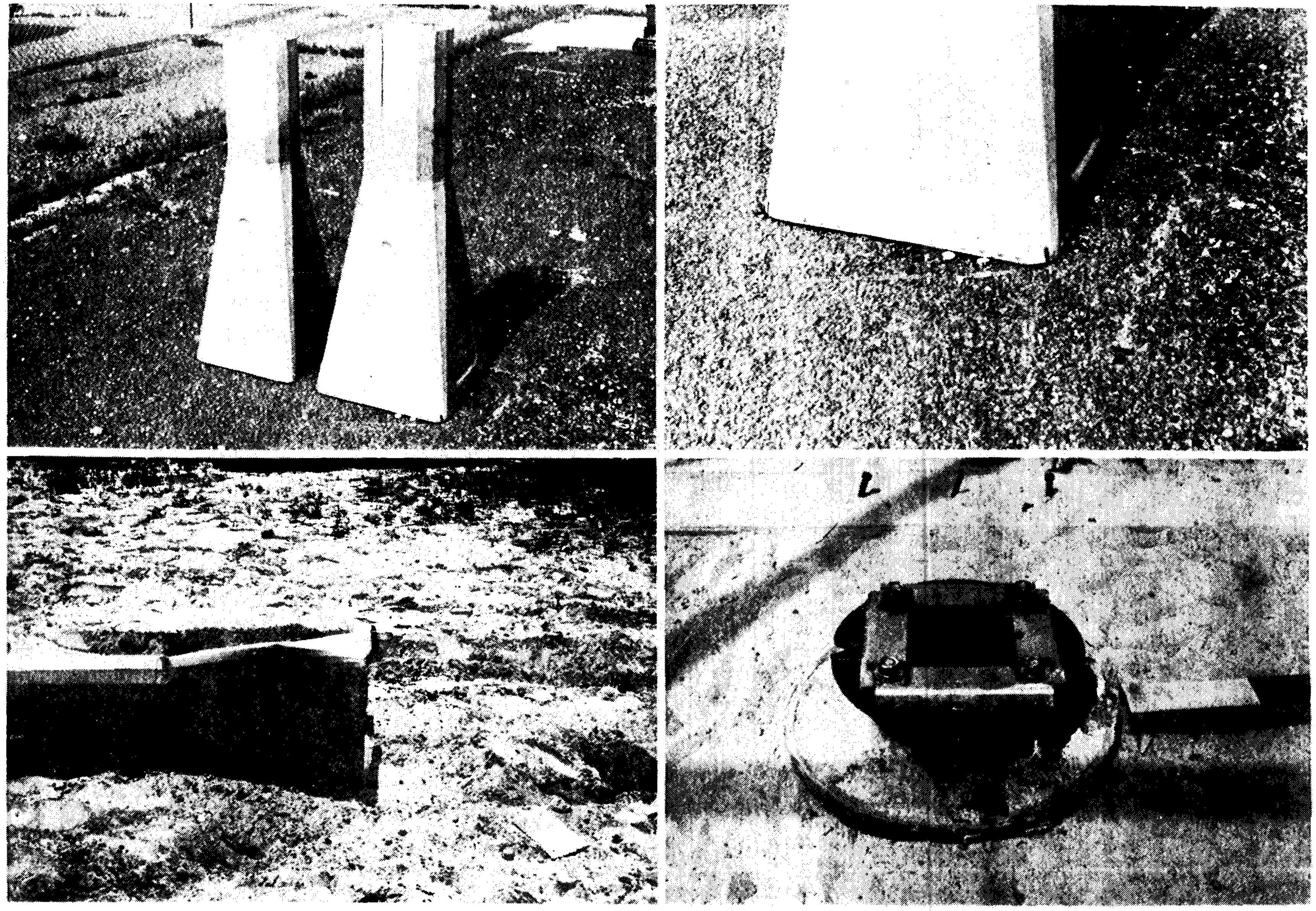


Fig. 35

Representative Photographs of Test 1147-403

(Core 10 type) steel and had ten rivets per side holding the sheet steel walls to the heavy steel base plate. The base had an 18 in (.46 m) bolt circle on the bottom and was mounted to a 50 ft (15 m) MH steel octagonal pole with a 15 in (.38 m) bolt circle weighing 384 ft (175 kg). Fig. 36a and 36b show a photo of the bases and pole prior to the test.

Despite the large number of rivets and the weight of the structure, the base in Test 1147-404 performed well. A momentum change of 984 lb-sec (4377 Ns) was recorded. The only damage sustained by the base, other than the shearing of the rivets, was the bending up of the bottom edge of the base on the impact side. This can be seen in Fig. 36c.

The momentum change in Test 1147-405 was 972 lb-sec (4323 Ns). As can be seen in the photo in Fig. 36d, the damage to the base in test 1147-405 was almost identical to that found in Test 1147 -404. Table 13. summarizes the results obtained in the test.

TABLE 13. RESULTS OF TEST 1147-404 AND 1147-405

	Test 1147-404	Test 1147-405
Momentum Change (lb-sec)	984	972
Peak Deceleration (g's)	8.9	8.9
Time at Peak Deceleration (sec)	.066	.068
Duration of Impact (sec)	.078	.082
Honeycomb Crush	17.5	17.5

1 lb-sec = 4.448 Ns, 1 in = 2.54 cm

TEST 1147-406 AND 1147-407

In these tests a smaller version of the Millerbernd progressive shear T-base were tested. The bases were made of weathering steel, had eight rivets per side and had a 15 in (.38 m) bolt circle at the bottom. A 30 ft (9.1 m) MH steel pole weighing 203 lb (92 kg) was mounted on the bases in both tests.

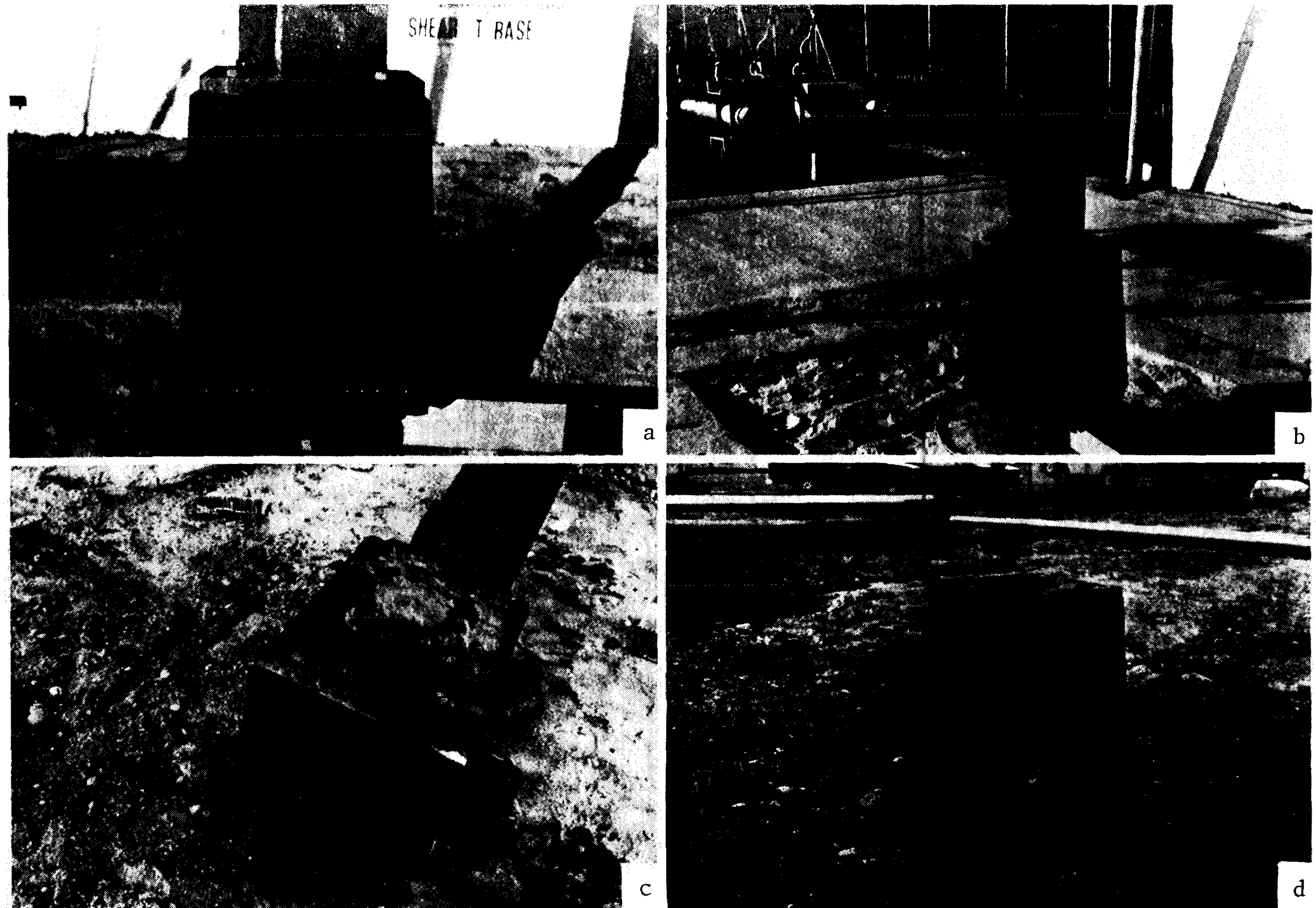


Fig. 36

Representative Photographs of Tests 1147-404 and 1147-405

As expected, the bases failed because of the shearing of the rivets that hold the mounting flange to the base skirts. As the base moved away from the mounting flange the front edge of the base skirt was bent up. Both bases failed similarly. Fig. 37c and d show the bases from tests 1147-406 and -407 respectively after impact. Because of equipment malfunction there was no accelerometer data for Test 1147-407. Test results for these two tests are in Table 14.

TABLE 14. RESULTS OF TESTS 1147-406 AND 1147-407

	Test 1147-406	Test 1147-407
Momentum Change (lb-sec)	923	812*
Peak Deceleration (g's)	14.1	N.A.
Time to Peak Decel. (sec)	.067	N.A.
Impact Duration (sec)	.085	N.A.
Honeycomb Crush (in)	17.5	17.5

*Based on film data
1 lb-sec = 4.448 Ns, 1 in = 2.54 cm

4.4 STEEL SLIP BASE LUMINAIRE SUPPORT TESTS

Seven tests were run on steel slip base luminaire supports which are in common use in the western states. The slip bases were assembled with manufacturer's supplied bolts, washers, and keeper plates. The applicable state specifications were followed for assembly and bolt torque. The following is a summary of these tests.

Test	Manufacturer and Type
1147-501	Ameron, Utah 4 bolt
1147-502	Ameron, Utah 4 bolt
1147-503	Ameron, Calif. Slip Insert
1147-504	Ameron, Calif. Type 15
1147-505	Ameron, Calif. Type 31
1147-506	Valmont, 50 ft (15 m) MH
1147-507	Valmont, 50 ft (15 m) MH

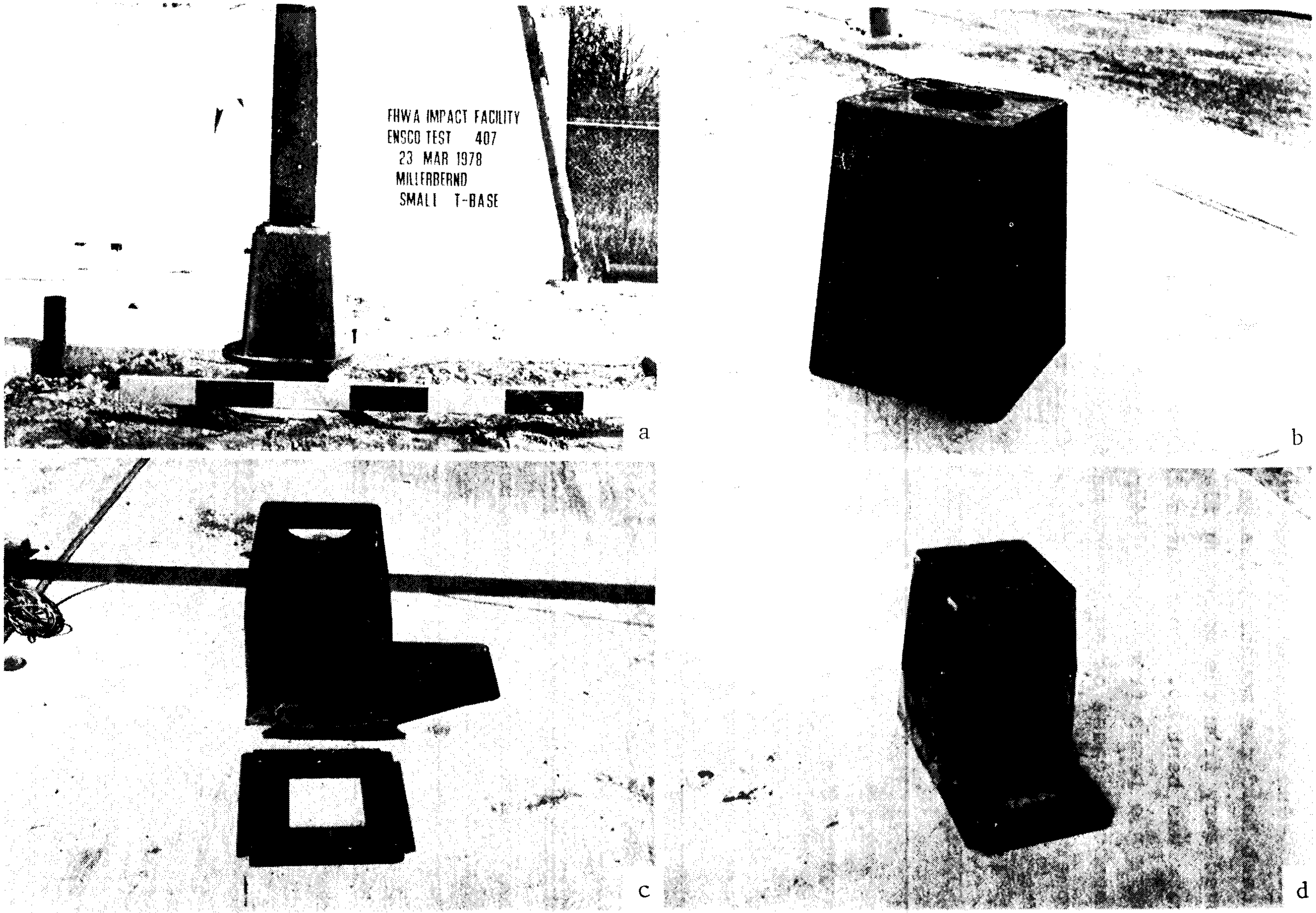


Fig. 37
Representative Photographs of Tests 1147-406 and 1147-407

TESTS 1147-501 AND 1147-502

These tests were conducted on a steel luminaire support with a Utah four bolt slip base manufactured by Ameron. The support had a 30 ft (9 m) MH and utilizes a 16 in (.41 m) foundation bolt circle. Four 1 in (2.5 cm) diameter bolts with steel rectangular washers and 18 gauge keeper plate are used to hold the slip base together. In Test 1147-501 the slip base bolts were torqued to 80 ft-lb (108 Nm) as per Utah state plans. The four bolt slip base pole is shown in Fig. 38a and b.

The impact resulted in a very low momentum change of 223 lb-sec (992 Ns). Due to the low torque value specified by Utah, a second test (test 1147-502) was run to see if overtightened bolts would adversely effect the slip base performance. The torque was, therefore, increased to 120 ft-lb (163 Nm) in this test. This 50 percent increase in bolt torque increased the momentum change to 575 lb-sec (2558 Ns), an increase of 150 percent. Fig. 38c and d show the slip base halves after an impact.

The results for tests 1147-501 and -502 are shown in Table 15.

TABLE 15. RESULTS OF TESTS 1147-501 AND 1147-502

	Test 1147-501	Test 1147-502
Momentum Change (lb-sec)	223	575
Peak Deceleration (g's)	3.4	8.5
Time at Peak Decel. (sec)	.033	.055
Impact Duration (sec)	.048	.062
Honeycomb Crush (in)	6.5	16

1 lb-sec = 4.448 Ns, 1 in = 2.54 cm

TEST 1147-503

In this test an Ameron slip base insert was tested, which is used by the California DOT to convert steel flange base type

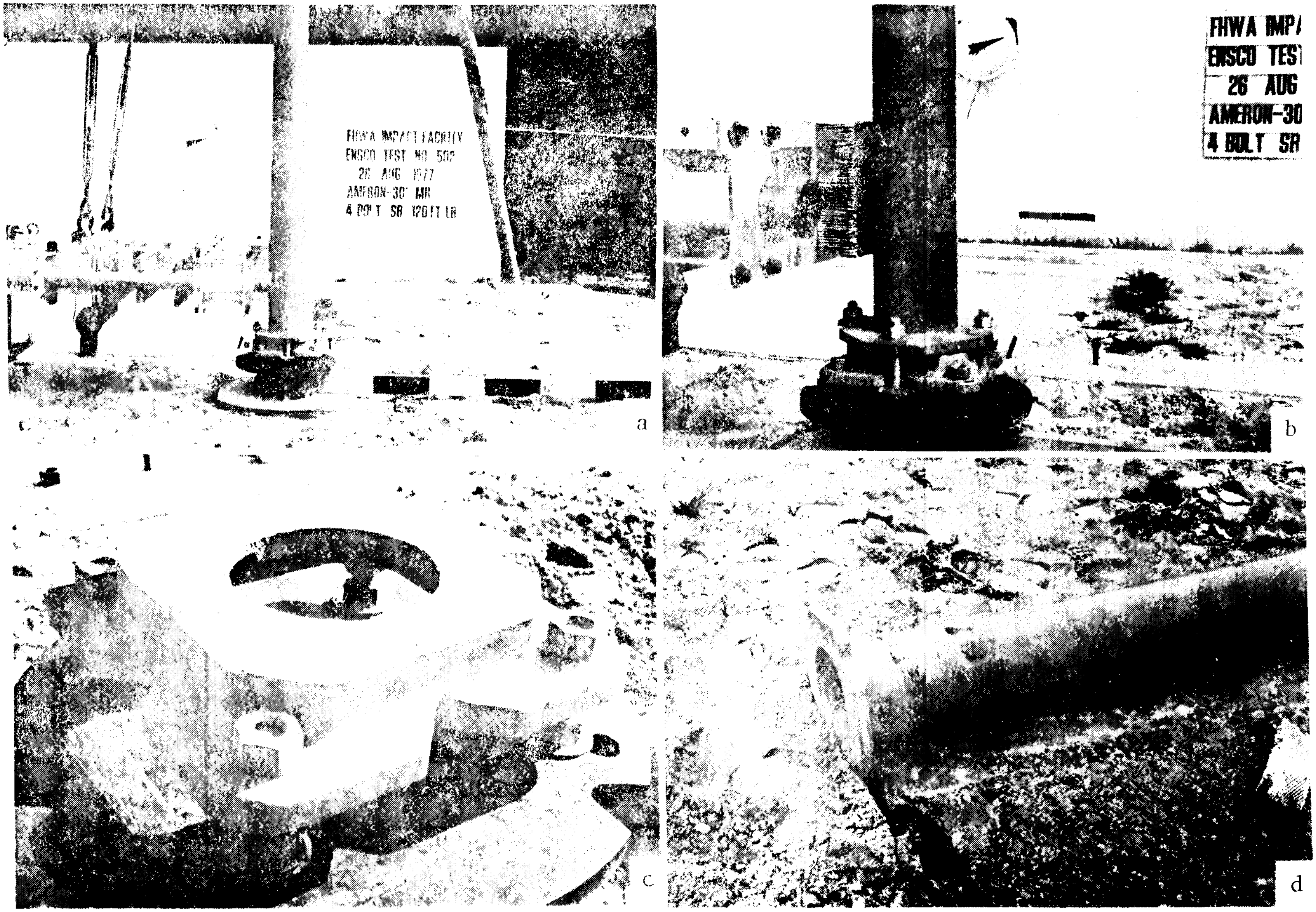


Fig.38
Representative Photographs of Tests 1147-501 and 1147-502

poles to slip bases. Fig. 39 shows the assembly procedure for the insert base. This insert consists of a lower base which is mounted to the foundation, three clamping bolts and their keeper plate, and an upper plate which is clamped to the lower base by the bolts. The pole is mounted on the studs on the upper plate resulting in a pole with a three-bolt slip base. The three 7/8 in (2.2 cm) slip base bolts are torqued to 150 ft-lb. (203 Nm).

The impact resulted in an acceptable momentum change and the slip base functioned as designed. During the impact, the pole suffered severe deformation (Fig. 39).

A summary of test results is shown in Table 16.

TABLE 16. RESULTS OF TEST 1147-503

Momentum Change	678 lb-sec
Peak Deceleration	9.3 g's
Time at Peak Decel.	.059 sec
Impact Duration	.076 sec
Honeycomb Crush	17.5 in

1 lb-sec = 4.448 Ns, 1 in = 2.54 cm

TEST 1147-504

In test 1147-504, a California type 15, 30 ft (9 m) MH steel, slip base pole manufactured by Ameron was hit in a direction parallel to a line through two bolts. The 7/8 in (2.2 cm) mounting bolts were torqued to 150 ft-lb (203 Nm) as called for in the California state standards.

This test showed the continued good breakaway characteristics of slip base type structures. No unexpected phenomena were observed during the test. Photographs of the test set-up and the

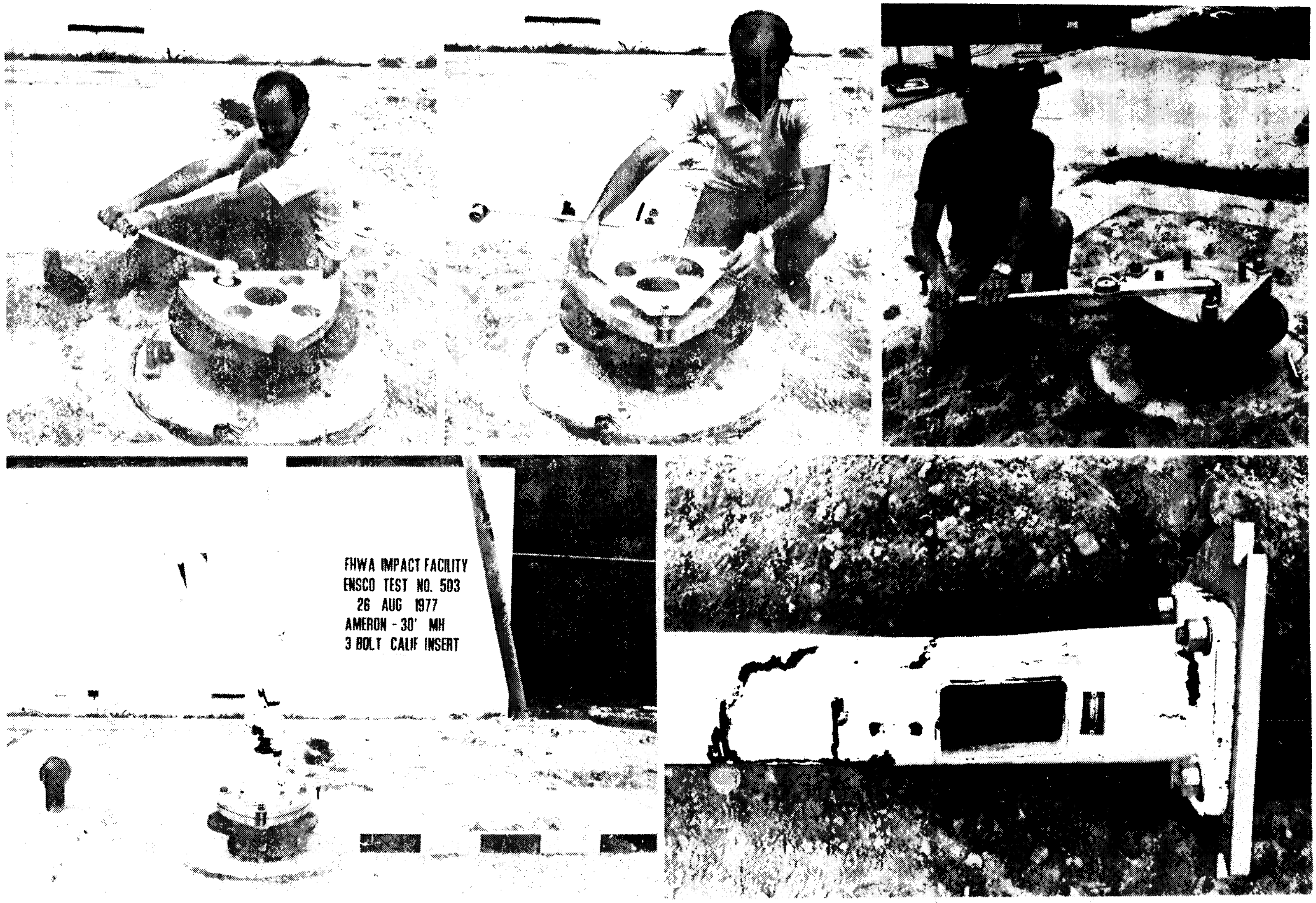


Fig. 39
Representative Photographs of Test 1147-503

pole after impact are shown in Fig. 40. A summary of the test results from test 1147-504 is shown in Table 17.

TABLE 17. RESULTS OF TEST 1147-504

Momentum Change	540 lb-sec
Peak Deceleration	8.9 g's
Time at Peak Decel.	.055 sec.
Impact Duration	.069 sec.
Honeycomb Crush	16 in

1 in = 2.54 cm, 1 lb-sec = 4.448 Ns

TEST 1147-505

Test 1147-505 was set up to duplicate a test which had been run in California using a California type 31 slip base luminaire support impacted by a 1971 Ford Pinto at 17.5 mph (78 m/s) [15]. The pole, manufactured by Ameron, is a 35 ft (10.7 m) structure weighing 650 lb (295 kg) with a 30 ft (9.1 m) mast arm weighing 280 lb (127 kg). The mast arm was installed during this test. Table 18 shows a comparison of test conditions for Test 1147-505 and Test 1147-311.

TABLE 18. TEST CONDITIONS: ENSCO 1147-505 AND CALIFORNIA 311

	Test 1147-505	Test 311
Initial velocity of impact (mph)	17.1	17.1
Initial bolt torque (lb-ft)	200	200
Impact vehicle weight (lbs)	2290	2265
Impact Angle	90° to mast arm	30° to mast arm
Vehicle	Pendulum	Pinto

1 mi/hr = 1.61 km/h = 4.47 m/s
1 lb = .454 kg
1 lb-ft = 1.4 Nm

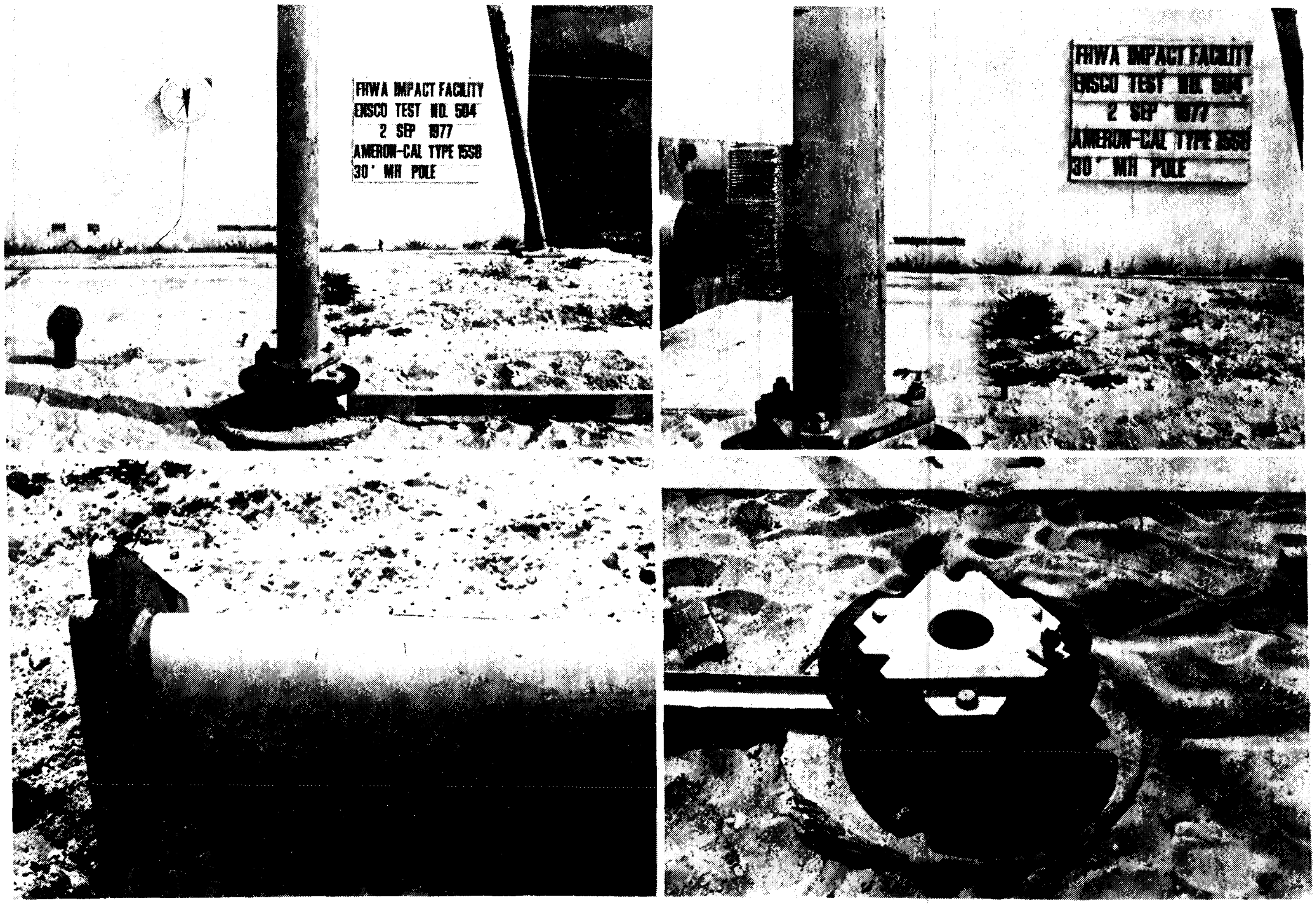


Fig. 40

Representative Photographs of Test 1147-504

ENSCO Test 1147-505 was set up for a direct impact where California 311 was set up for a 30-degree impact. They used this angle because of evidence that it is the severest impact angle for three bolt slip bases. Since the directional dependence of these slip bases is minimal, the difference in impact angle is not considered to be significant. The comparison of test results, shown in Table 19, further illustrates the similarity of the two tests.

TABLE 19. COMPARISON OF TEST RESULTS

	Test 1147-505	Test 311
Final velocity (mph)	11.5	10.8
Δ velocity (mph)	5.6	6.7
Momentum Change (lb-sec)	621.0	689.0
Deformation/honeycomb Crush (in)	16.5	17.0
Time to Base Separation (sec)	.060	.055
Time in Pole Contact (sec)	.174	.181

1 lb-sec = 4.448 Ns, 1 in = 2.54 cm
1 mph = 1.6 km/h = 4.47 m/s

Although no accelerometer traces were available from California Test 311 for comparison, the indications are that the two tests were very close to being equivalent. Photographs of the test, showing the test set-up and the pole after impact are shown in Fig. 41. Table 20 shows the result of Test 1147-505.

TABLE 20. RESULTS OF TEST 1147-505

Momentum Change	621 lb-sec
Peak Deceleration	8.4 g's
Time at Peak Decel.	.060 sec
Impact Duration	.076 sec
Honeycomb Crush	16.5 in

1 lb-sec = 4.448 Ns, 1 in = 2.54 cm

TESTS 1147-506 AND 1147-507

These tests were run on a Valmont DS70, large 50 ft (15 m) MH galvanized steel slip base pole. The pole has a base diameter of 10.5 in (.27 m), top diameter of 3.92 in (.10 m) actual height of 47 ft (14 m) and the wall thickness is 11 gauge. The poles set on a three-bolt slip base (California type) with a 14 in (.136 m) bolt circle. The slip base connecting bolts were 7/8in (.64 m) diameter and used rectangular washers. The bolts were torqued to 110 ft-lb (149 Nm) using a bees wax based lubricant on the threads according to Alabama state specifications.

In Test 1147-506 the pole was equipped with its standard mast arm (DS70) and simulated luminaire. The mast arm had a 3 ft (.91 m) rise and 20 ft (6 m) reach. The luminaire was simulated with a 1 in (2.5 cm) thick steel plate which weighed 68 lb (31 kg). In test 1147-507 the pole was tested without a mast arm or luminaire. The test conditions and test results are shown in Table 21.

TABLE 21. TEST CONDITIONS AND RESULTS FOR TESTS 1147-506 AND 1147-507

	Test 1147-506	Test 1147-507
Bolt Torque (lb-ft)	110	110
Impact Speed (ft/sec)	28.2	28.2
Momentum Change (lb-sec)	295	309
Peak Deceleration (g's)	4.3	3.8
Time to Peak Decel. (sec)*	.036	.032
Duration of Impact (sec)*	.054	.046
Peak Decel. of Sweeper-Plate (g's)	6.6	8.3
Time of Sweeperplate Impact (sec)	.097	.097

*during initial impact (does not include sweeperplate)
1 lb-sec = 4.448 Ns, 1 in = 2.54 cm, 1 lb-ft = 1.356 Nm

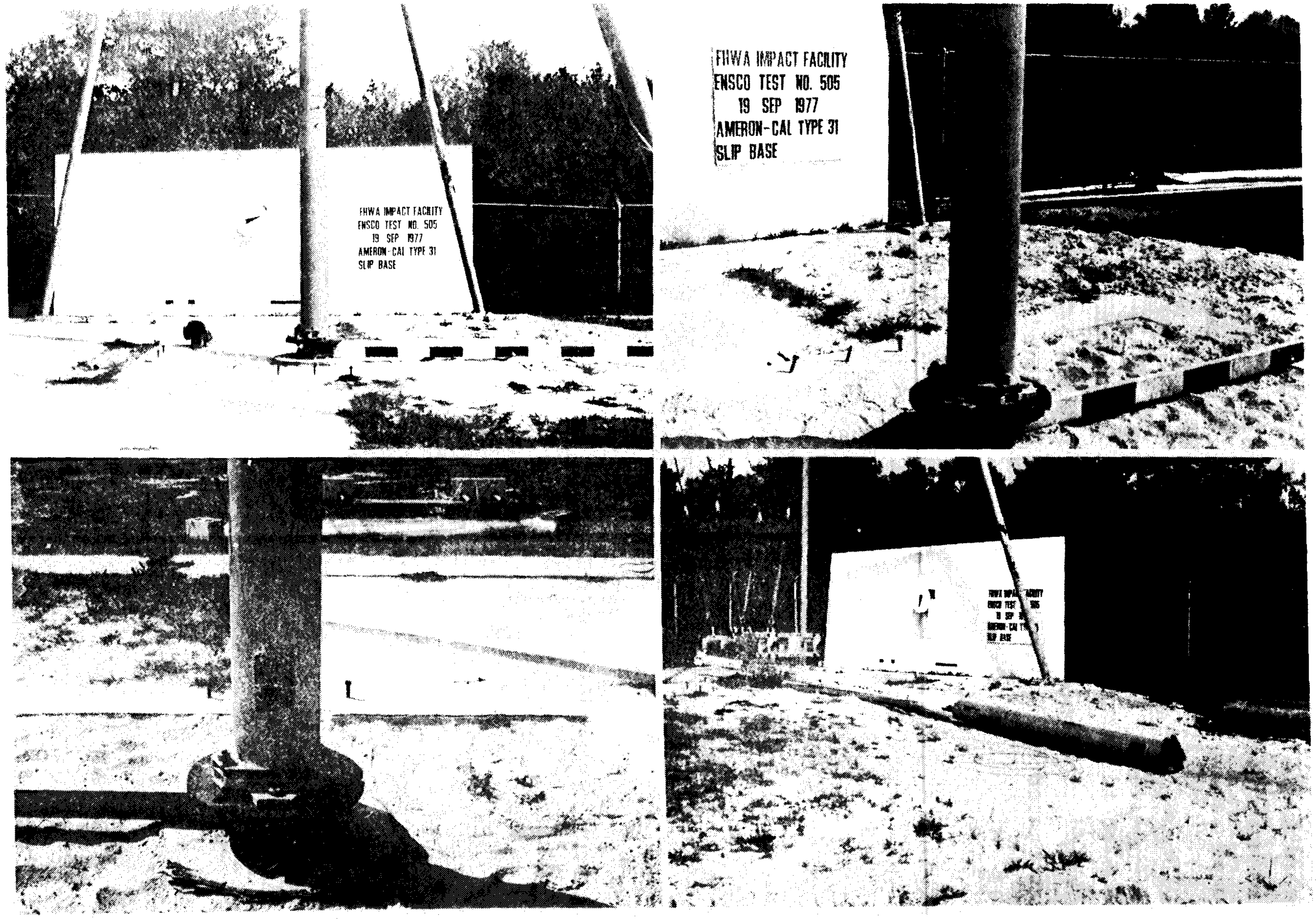


Fig. 41
Representative Photographs of Test 1147-505

These results indicate that the use of a mast arm and luminaire had no measurable effect. It should be emphasized that the mast arm used was very large and heavy (220 lb (100 kg) with luminaire).

In each of these tests the sweeperplate impacted one of the slip base bolts causing the pendulum to further decelerate. This bolt impact accounted for approximately 20 percent of the momentum change.

Photographs showing the pole, mast arm, and simulated luminaire used in the tests are found in Fig. 42.

4.5 BREAKAWAY COUPLING TESTS

Breakaway couplings are devices which are installed between the foundation and luminaire support that are designed to break away when the support is impacted. To function properly the couplings should be strong in tension and weak in shear. In this series of tests, four different types of couplings were tested under various types of supports. A summary of the tests is given below:

Test	Manufacturer and Type
1147-601	Alcoa, 100-1
1147-602	Hapco
1147-603	Hapco
1147-604	Transpo-Safety, Pole Safe 101
1147-605	Transpo-Safety, Pole Safe 101
1147-606	Transpo-Safety, Pole Safe 101
1147-607	Break-Away Bolt Co, Notched Bolt
1147-608	Break-Away Bolt Co, Notched Bolt

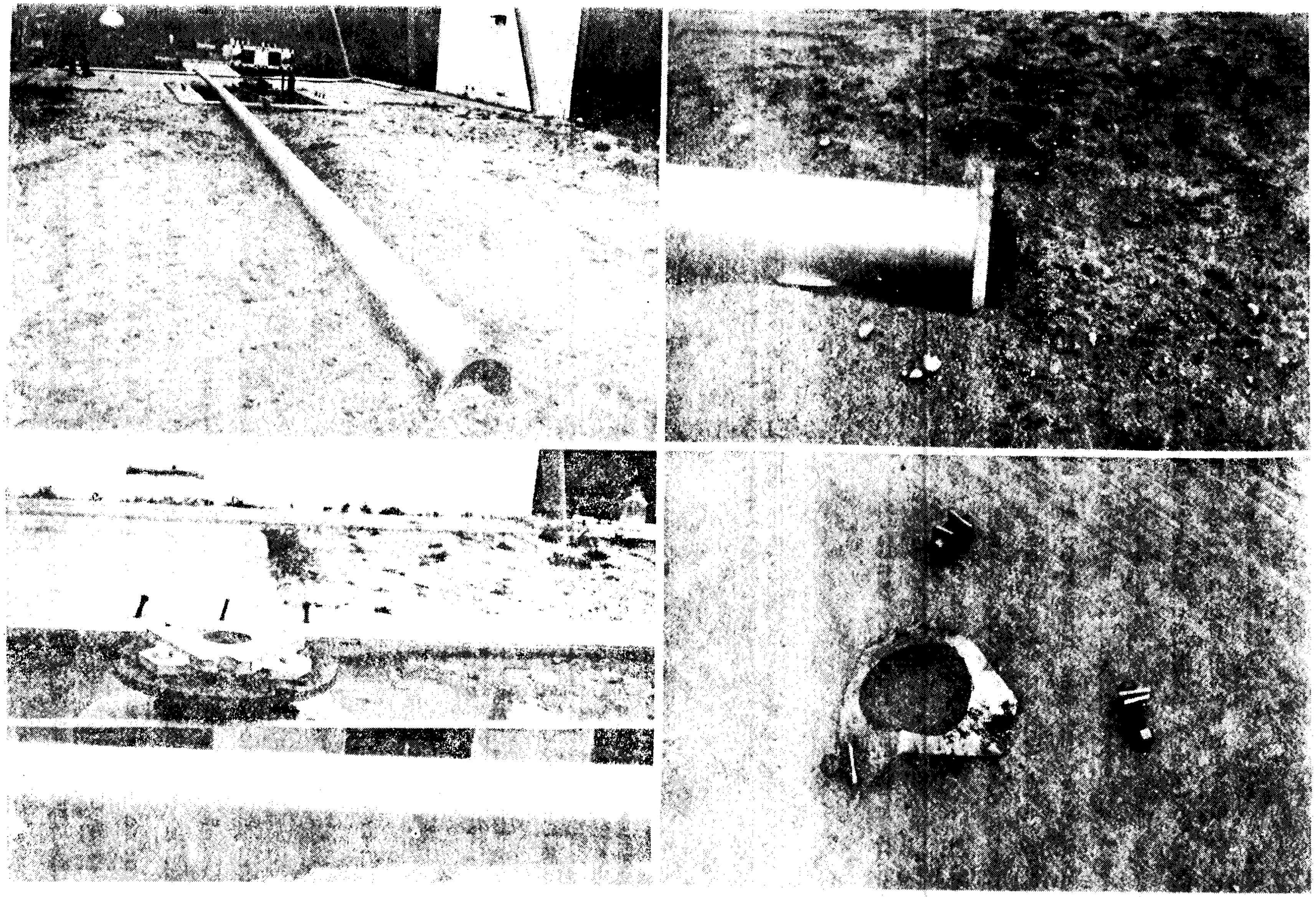


Fig. 42

Representative Photographs of Tests 1147-506 and 1147-507

TEST 1147-601

This is a test of the Alcoa Breakaway Couplings 100-1 with a Hapco 50 ft (15 m) MH spun aluminum pole on top. The test was a duplication of a similar full-scale test conducted at TTI numbered 3290-3 [18]. The couplings behaved as designed in that they split longitudinally during the impact. No denting of the pole occurred as had happened in an earlier test [3] utilizing the neoprene rubber faced pendulum nose. Results of the test were very similar to those seen in the full-scale test as shown in Table 22. Photographs of this test are shown in Fig. 43. Fig. 44 shows a comparison of accelerometer traces for the pendulum and full-scale tests.

TABLE 22. COMPARISON OF RESULTS FROM ENSCO TEST 1147-601 AND TTI TEST 3290-3

	Test 601	Test 3290-3
Momentum Change (lb-sec)	606	590
Peak Deceleration (g's)	8.0	8.3
Time at Peak Decel. (sec)	.061	.044
Impact Duration (sec)	.075	.075

1 lb-sec = 4.448 Ns

TEST 1147-602

This test was run with a Hapco 30 ft (9.1 m) MH spun aluminum pole mounted on four Hapco cast aluminum (356-T6) breakaway couplings. The Hapco coupling is basically a hexagonal aluminum casting 5 in (.13 m) long. The lower end of the casting flares out in a conical base to provide a rigid lower contact surface; and there is a circumferential groove approximately 3 in (7.6 cm) from the base. Both ends of the casting are threaded internally to accept 1 in (2.5 cm) dia. bolts or threaded studs.

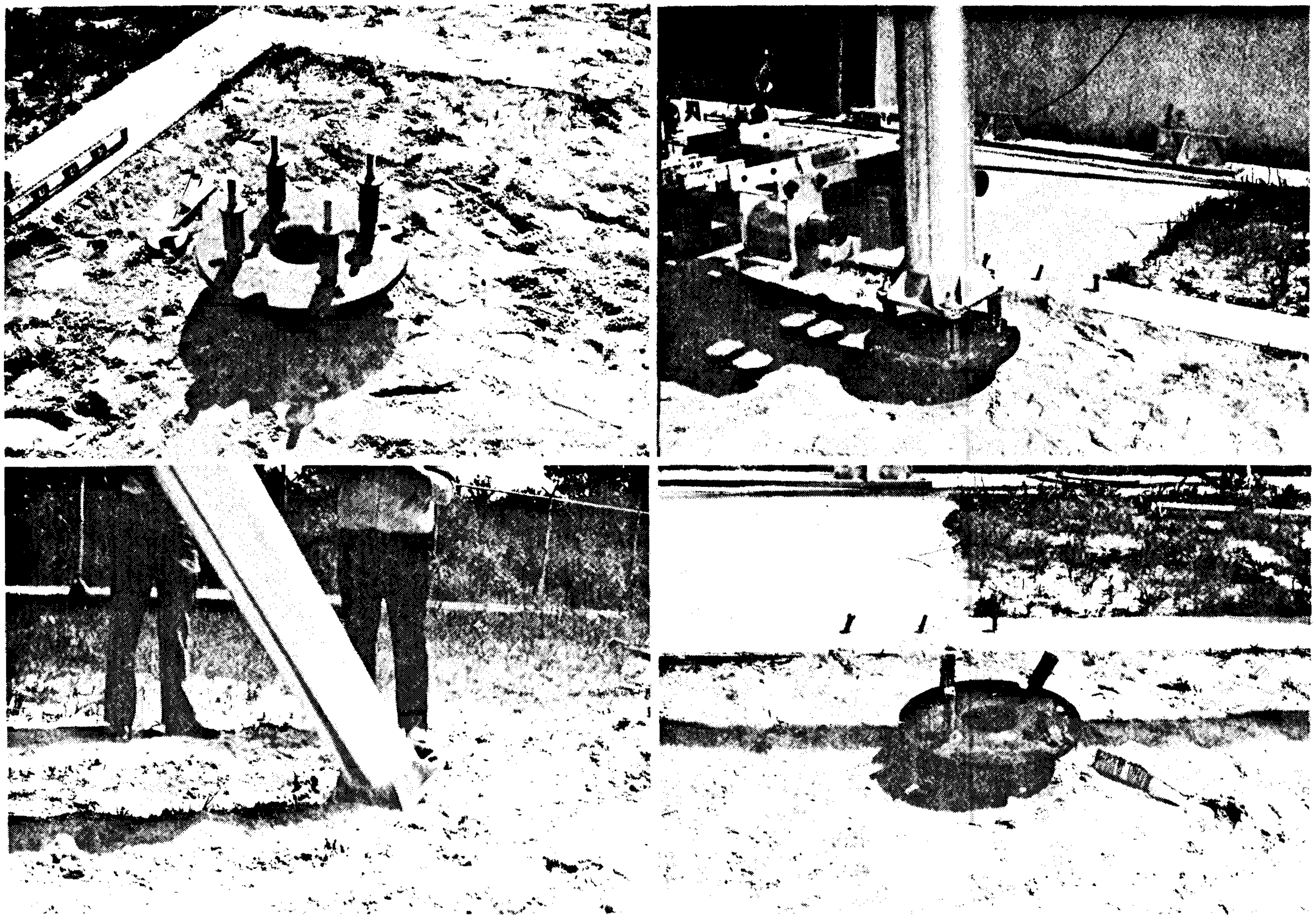


Fig. 43
Representative Photographs of Test 1147-601

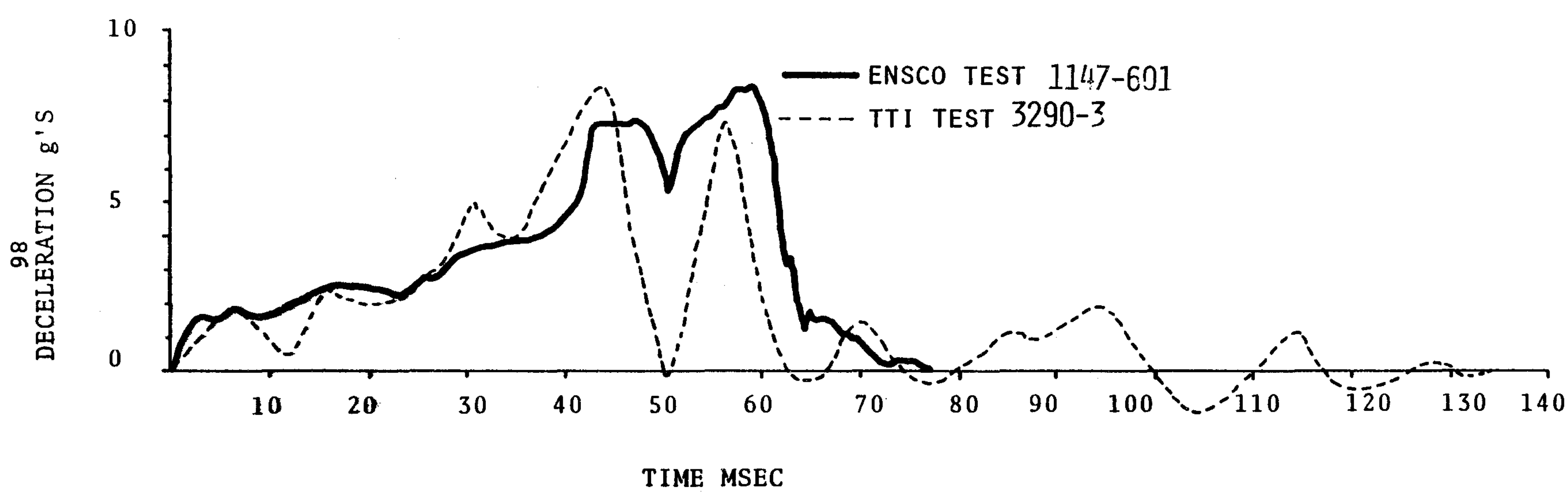


Fig. 44
Comparison of Longitudinal Accelerometer
Traces for TTI Test 3290-3 and ENSCO Test 1147-601

The Hapco specifications allow the engagement of the lower threaded stud to be from 1 in to 2-3/4 in (2.4 cm to 7.0 cm) and this test was run with 1¼ in (3.2 cm) engagement. The impact exhibited low momentum change but failure occurred at the point of maximum bolt penetration (1¼ in (3.2 cm) from the base) rather than at the circumferential groove (3 in (7.6 cm) from the base), as was intended.

A summary of test results for Test 1147-602 is shown in Table 23. Representative photographs showing the coupling and the failure mode are shown in Fig. 45.

TABLE 23. RESULTS OF TEST 1147-602

Momentum Change	595 lb-sec
Peak Deceleration	8.8 g's
Time of Peak Decel.	.058 sec.
Impact Duration	.066 sec.
Honeycomb Crush	17 in

1 lb-sec = 4.448 Ns, 1 in = 2.54 cm

TEST 1147-603

In view of the unexpected failure mode experienced in Test 1147-602 this test was run to confirm the acceptability of the coupling if it was installed with a deeper foundation bolt engagement. A Hapco 30 ft (9.1 m) MH pole was again used. For this test the foundation bolt engagement was set at the full 2-3/4 in (7.0 cm) maximum allowed by Hapco.

The impact showed the couplings did not fail with failure finally occurring at the weldment connecting the pole to its flange base. It should be pointed out that after the pole had sheared off its flange base, the sweeperplate on the pendulum came into contact with the flange base/coupling combination and still did not succeed in initiating failure.

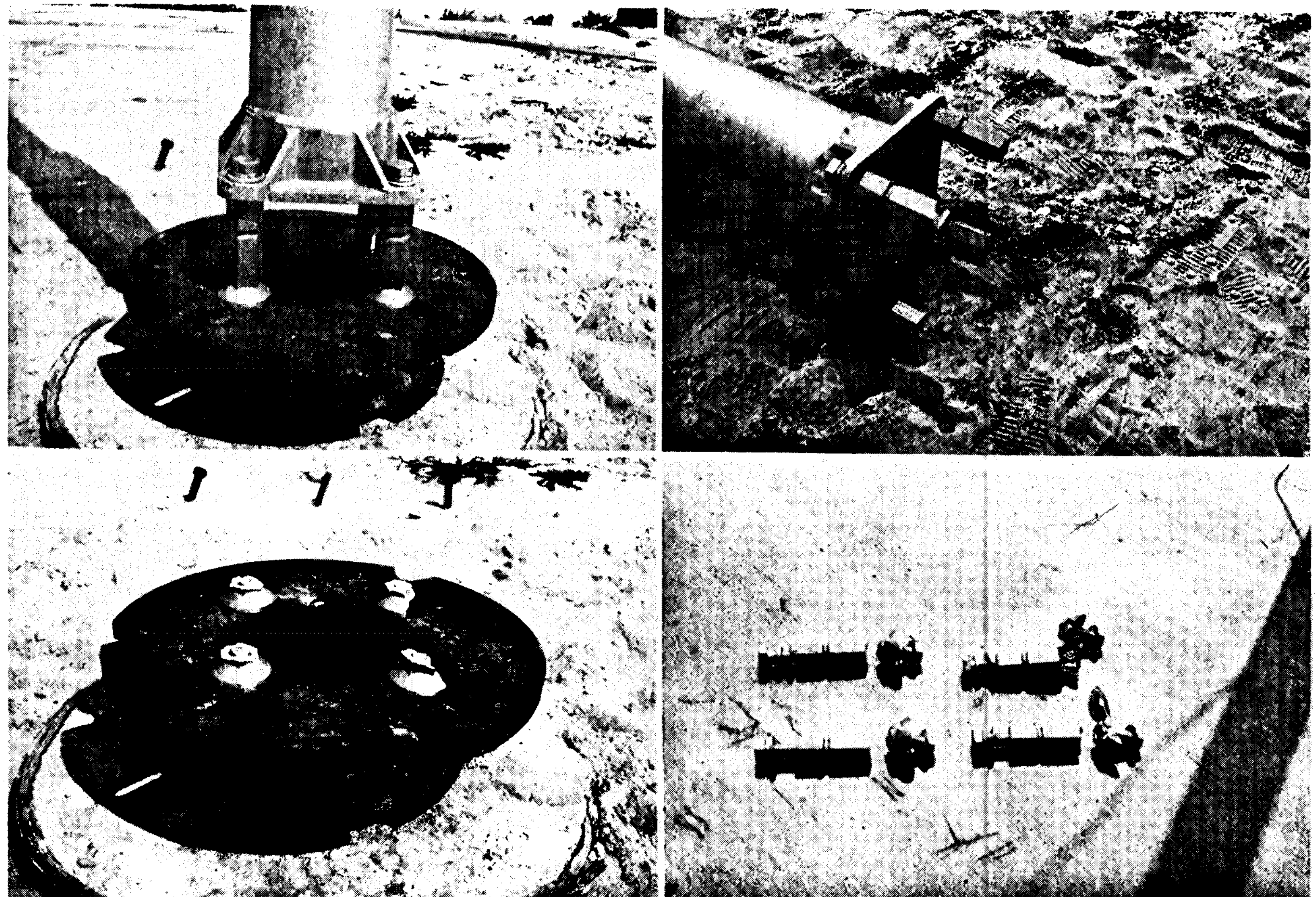


Fig. 45

Representative Photographs of Test 1147-602

A summary of test results for Test 1147-603 is given in Table 24. Representative photographs from test 1147-603 are shown in Fig. 46.

TABLE 24. RESULTS OF TEST 1147-603

Momentum Change	1822 lb-sec
Peak Deceleration	
During contact with nose	16 g's
During contact with sweeperplate	30 g's
Time Deceleration	
Contact with nose	.061 sec
Contact with sweeperplate	.133 sec
Impact Duration	.181 sec
Honeycomb Crush	17.5 in

1 lb-sec = 4.448 Ns, 1 in = 2.54 cm

TEST 1147-604

In Test 1147-604, a set of Transpo-Safety "Break-Safe" couplings was used with a 50 ft (15 m) MH Hapco spun aluminum pole mounted on them. This test was set up to duplicate Test 1147-601 which used Alcoa couplings. The main difference between the Transpo-Safety and Alcoa couplings is that the Transpo-Safety coupling is an aluminum casting while the Alcoa coupling is an extrusion.

The main purpose of this test was to detect any difference between the breakaway behavior of the casting versus the extrusion.

The results of the test show that the breakaway characteristics of both couplings are excellent. The comparison of data from the two tests is shown in Table 25.

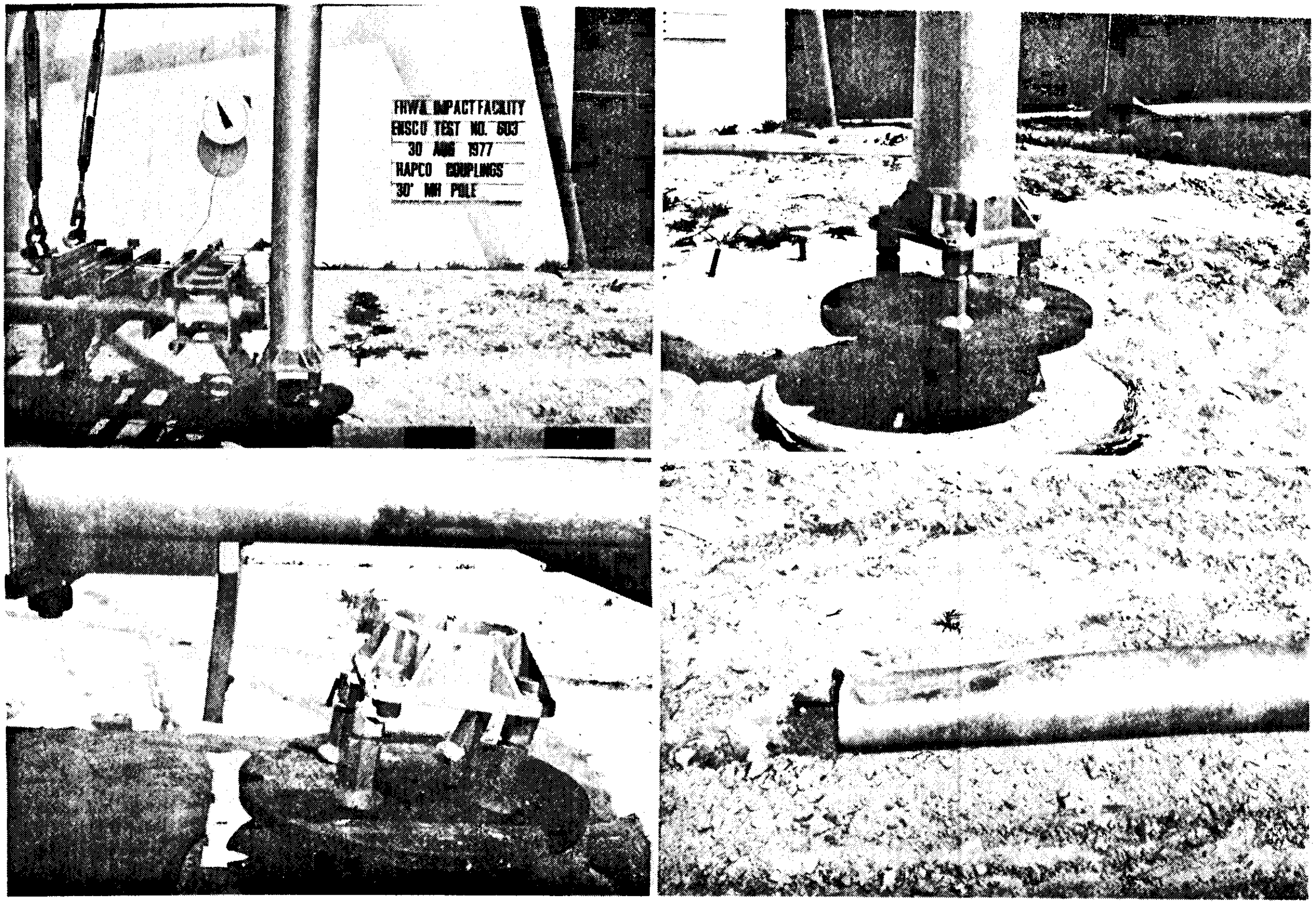


Fig. 46
Representative Photographs of Test 1147-603

TABLE 25. COMPARISON OF TEST 1147-601 AND 1147-604 RESULTS

	Test 1147-601	Test 1147-604
Momentum Change (lb-sec)	606	539
Peak Deceleration (g's)	8.0	8.3
Time at Peak Decel. (sec)	.061	.054
Impact Duration (sec)	.075	.058

1 lb-sec = 4.448 Ns

A difference was noted in the failure mode of the two types of couplings. In the Transpo-Safety coupling failure appeared to start in the longitudinal grooves at the top and then break out across the coupling at the base of the upper studs (Fig. 47). In the extruded Alcoa couplings, the failure tended to confine itself to the longitudinal grooves until one of the studs pulled out or the coupling split apart.

TEST 1147-605

In Test 1147-605, Transpo-Safety type 101 couplings were used to retrofit a New York City wrought aluminum T-base*, the couplings were attached to the bottom of the base using two 3 in (7.6 cm) O.D. x 3/8 in (.95 cm) thick washers per coupling. The washers were located above and below the bottom flange of the base as shown in Fig. 48. A 30 ft (9.1 m) MH spun aluminum pole weighing 150 lb (68 kg) was mounted to the base. The test resulted

*This is a special T-base manufactured to New York City specification by Union Metal Manufacturing in the 1960's. The base does not breakaway when impacted by an automobile.

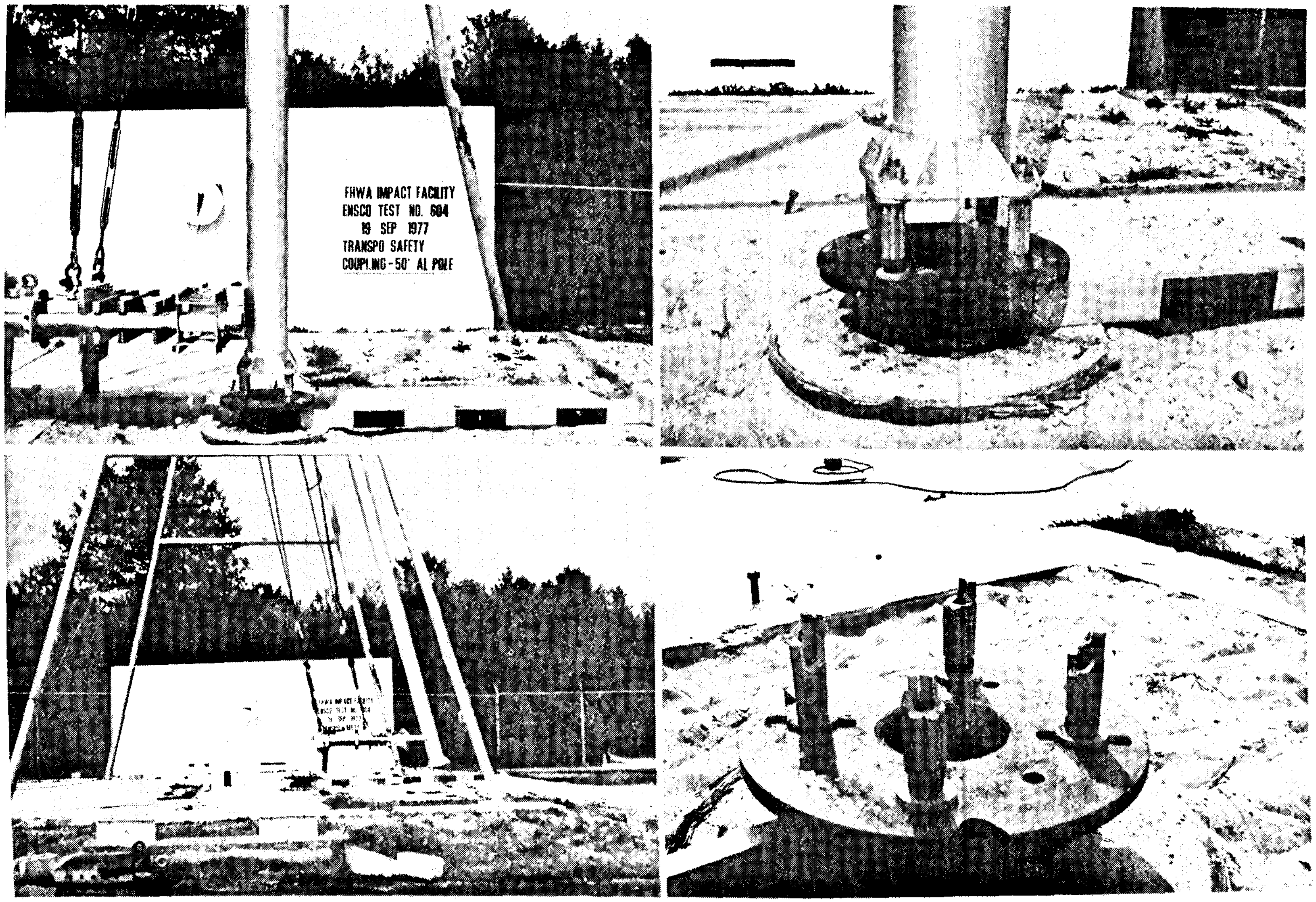


Fig. 47

Representative Photographs of Test 1147-604

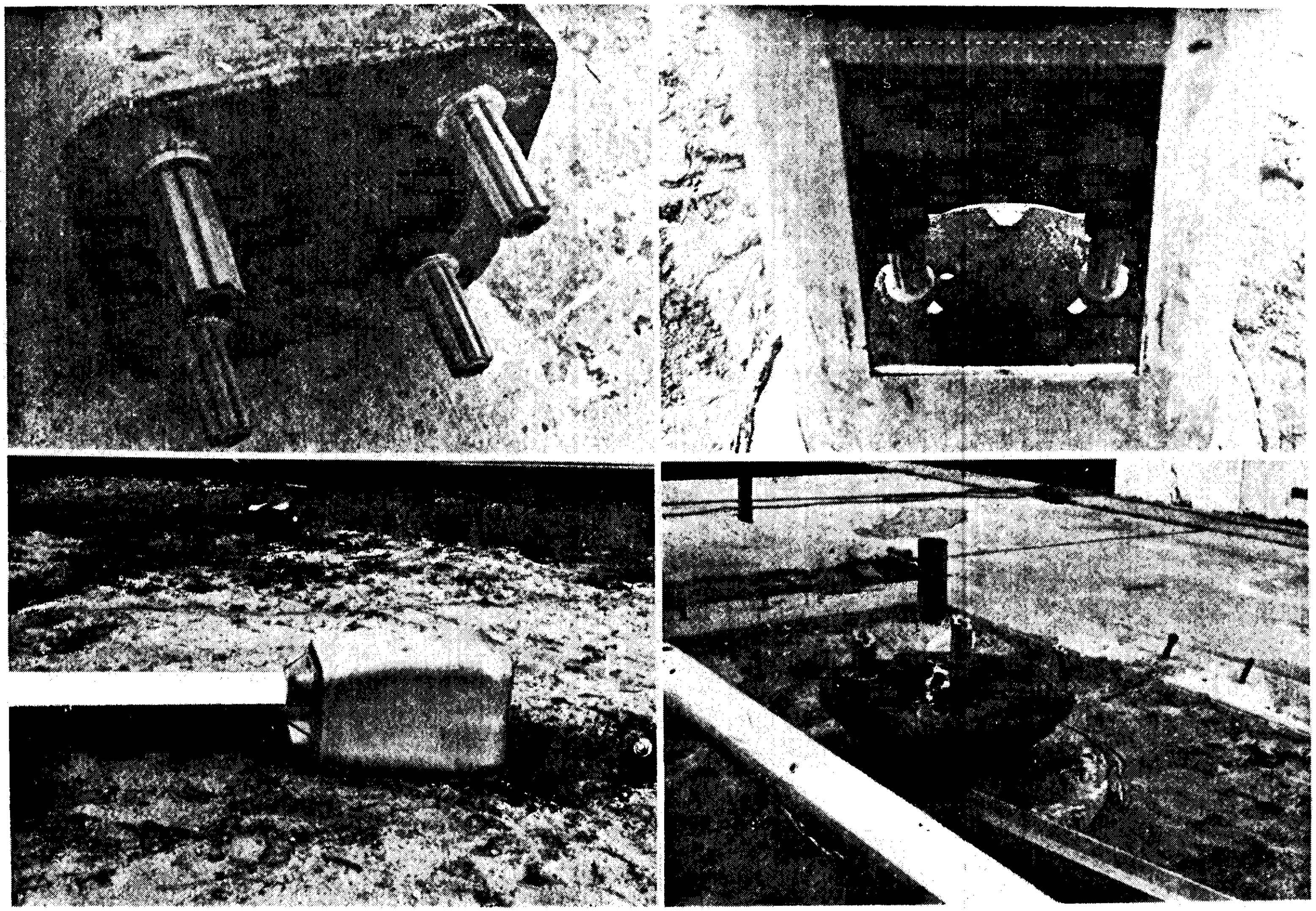


Fig. 48
Representative Photographs of Test 1147-605

in a momentum change of 828 lb-sec (3683 Ns). The base deformed about 2¼ in (5.7 cm) on the impact face which probably accounts for the difference in momentum change between this test and Test 1147-604. This deformation can also be seen in Fig. 48, as can the couplings which broke in a similar manner to those in Test 1147-604.

Table 26 summarizes the results from the test.

TABLE 26. SUMMARY OF TEST 1147-605 RESULTS

Momentum Change	828 lb-sec
Peak Deceleration	10.9 g's
Time at Peak Decel.	.073 sec
Impact Duration	.082 sec
Honeycomb Crush	17.5 in

1 lb-sec = 4.448 Ns, 1 in = 2.54 cm 1

TEST 1147-606

In test 1147-606 the concept of retrofitting transformer base installations by the addition of breakaway couplings was studied. A Pfaff and Kendall TB2A transformer base was mounted on top of four Transpo-Safety Pole Safe 101 couplings. The closed slot on the P&K base mounting flanges is ideal for accepting the couplings. Fig. 49 shows photographs of the test set-up prior to impact and after the impact. As can be seen, damage to the T-base was not extensive, consisting of break out of one impact side mounting flange,. The couplings failed as they have previously. The momentum change for this test was 667 lb-sec, which indicates that this is a desirable retrofit installation. Table 27 shows the results of Test 1147-606.

TESTS 1147-607 AND 1147-608

In these tests Break-Away Bolt Co. Couplings were tested. These couplings were used by California DOT in the early 1970's. A

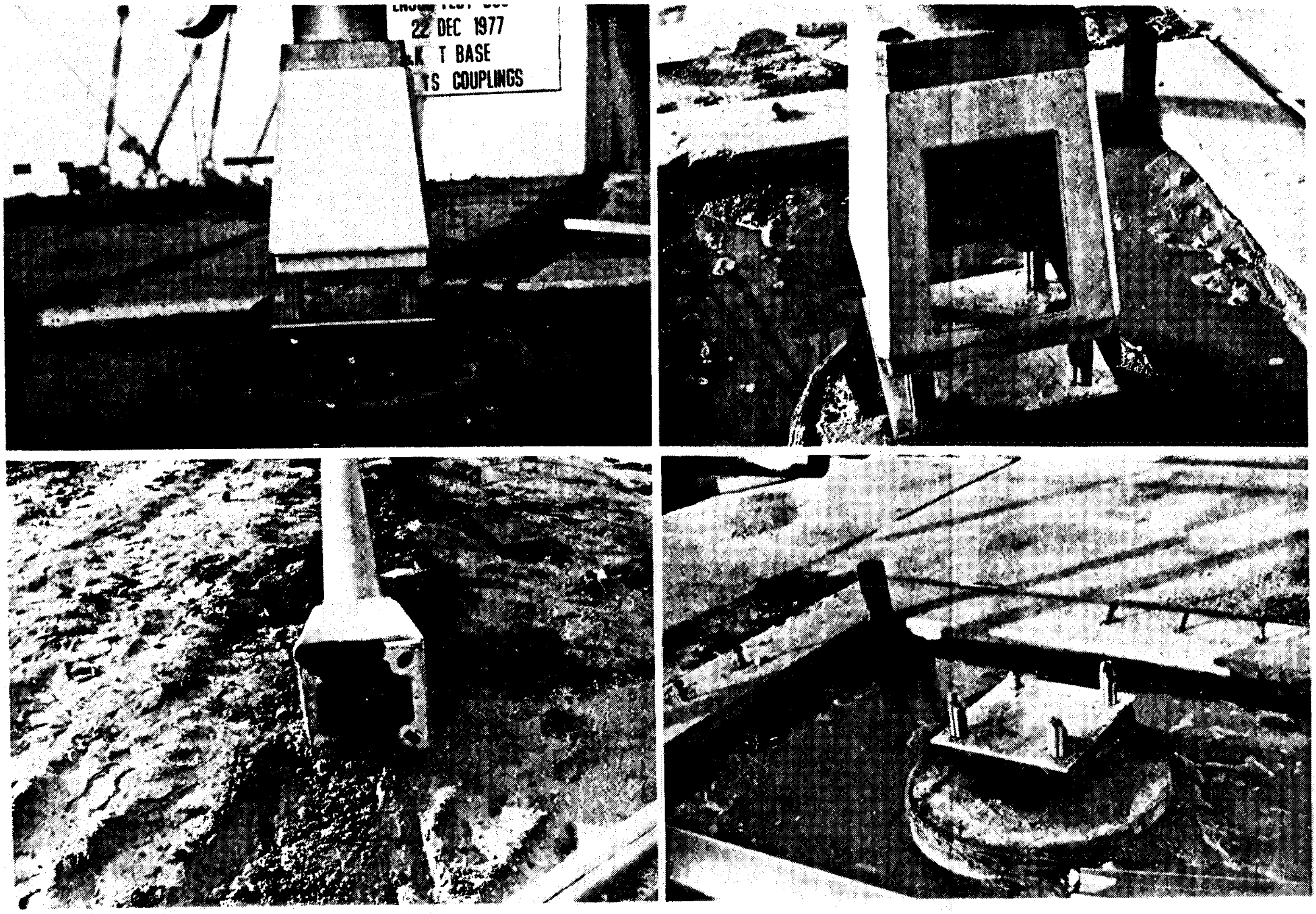


Fig. 49
Representative Photographs of Test 1147-606

TABLE 27. RESULTS OF TEST 1147-606

Momentum Change	667 lb-sec
Peak Deceleration	10.2 g's
Time at Peak Decel.	.063 sec
Impact Duration	.081 sec
Honeycomb Crush	16.5 in

1 lb-sec = 4.448 Ns
1 in = 2.54 cm

close-up view of the couplings and the installations is seen in Fig. 50. The couplings held a Hapco 10 in dia. (.25 cm), 50 ft (15 m) MH pole. The couplings are 1 in (2.5 cm) dia. stainless steel bolts and have a necked down area (.435 in (1.1 cm) dia.) where they are suppose to fail. The coupling length is 6 in (.15 m).

The Test 1147-607 results showed the couplings breaking where designed, plus breaking two of the bolts that held them onto the foundation adaptor and also breaking two lugs off on the mounting flange of the pole. Besides destroying the pole the couplings caused a high momentum change. Figs. 51a and b show the impact results.

Test 1147-608 was a retest of the couplings, since the first test resulted in a momentum change between 750 and 1,100 lb-sec (3360 and 4930 Ns). The couplings held a Millerbernd steel pole which had a mounting height of 50 ft (15 m) (actual height 43 ft (13.1 m)) and weighted 384 lbs (174.3 kg).

The test resulted in coupling breakage in the necked down area plus breaking two of the bolts that held them to the foundation adaptor. Failure of these bolts is analogous to the J-bolts in the foundation breaking. The pole was severely dented around the impact area. This can be seen in Figs. 51c and d. Table 28 presents the results for Tests 1147-607 and -608.

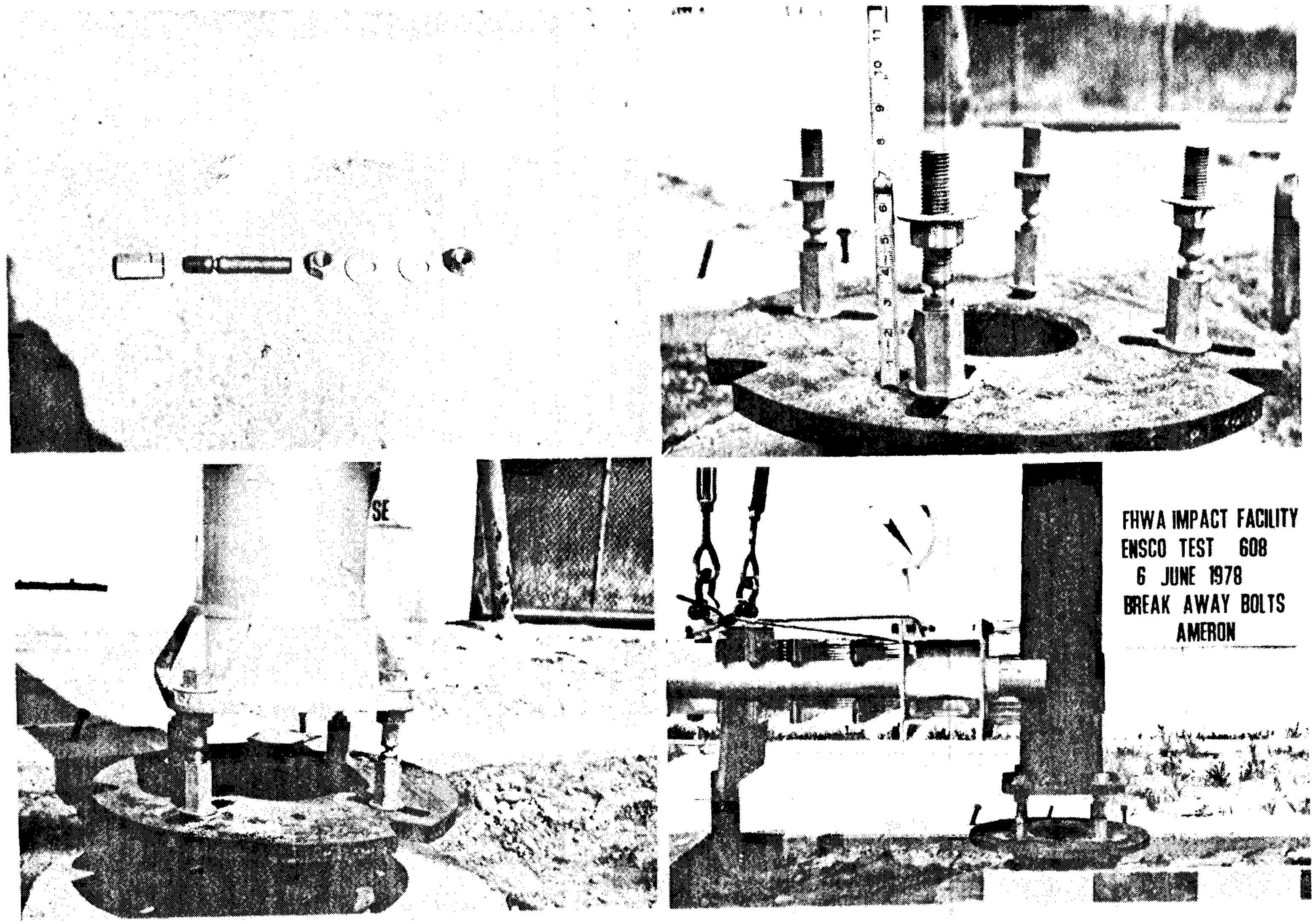


Fig. 50
Pre-Test Photographs of Tests 1147-607 and 1147-608

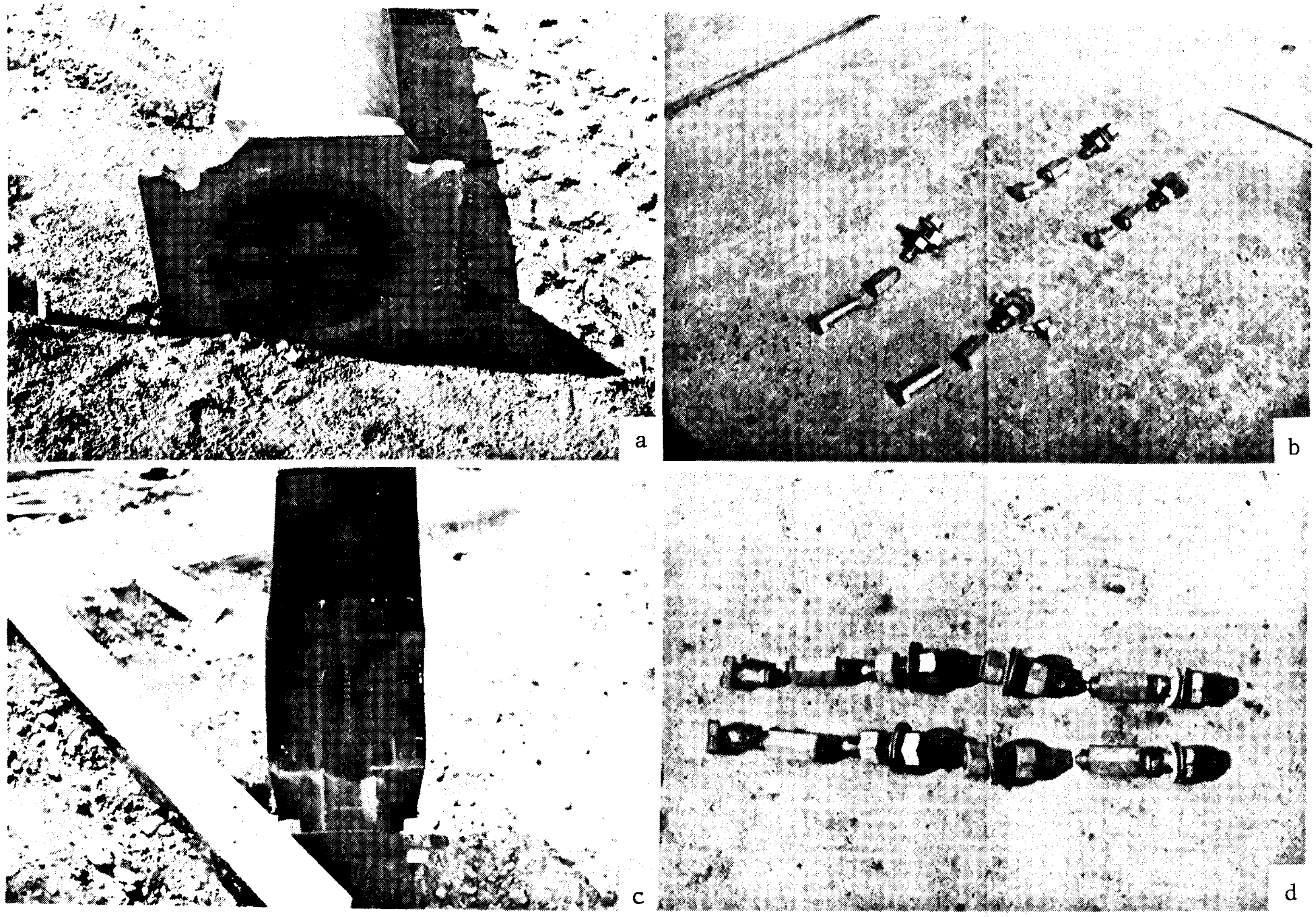


Fig. 51
Post-Test Photographs of Tests 1147-607 and 1147-608

TABLE 28. RESULTS FOR TESTS 1147-607 AND -608

	1147-607	1147-608
Momentum Change (lb-sec)	1037	1512
Peak Deceleration (g's)	20.0	12.6
Time to Peak Decel. (sec)	.062	.067
Impact Duration (sec)	.077	.112
Honeycomb Crush (in)	17.5	17.5

1 lb-sec = 4.448 Ns, 1 in = 2.54 cm

4.6 FIBERGLASS POLE TESTS

Although fiberglass poles are used extensively for smaller luminaire supports in cities, their use as a highway lighting support has not evolved. A prototype fiberglass highway luminaire support was tested under this contract. This is the only fiberglass pole tested under this project.

TEST 1147-701

This is an impact test on a 35 ft (10.7 m) MH Shakespeare model 920-35 spunwrap fiberglass pole with a cast aluminum base. The pole was epoxied to a tall integral base. The pole and test set-up are seen in Fig. 52.

The support failed when the pole pulled out of the aluminum casting. However, when the sweeperplate hit the base casting, the pendulum stopped. About 1/3 of the momentum change occurred before sweeperplate impact while the sweeperplate impact itself accounted for the remaining 2/3. If the pole was redesigned with a shorter base casting, better results would possibly be obtained. The results of Test 1147-701 are given in Table 29.

4.7 LUMINAIRE SUPPORT STATIC LOAD AND FATIGUE TESTS

The principal function of a luminaire support is, of course, to hold up a highway luminaire fixture. Breakaway ability is

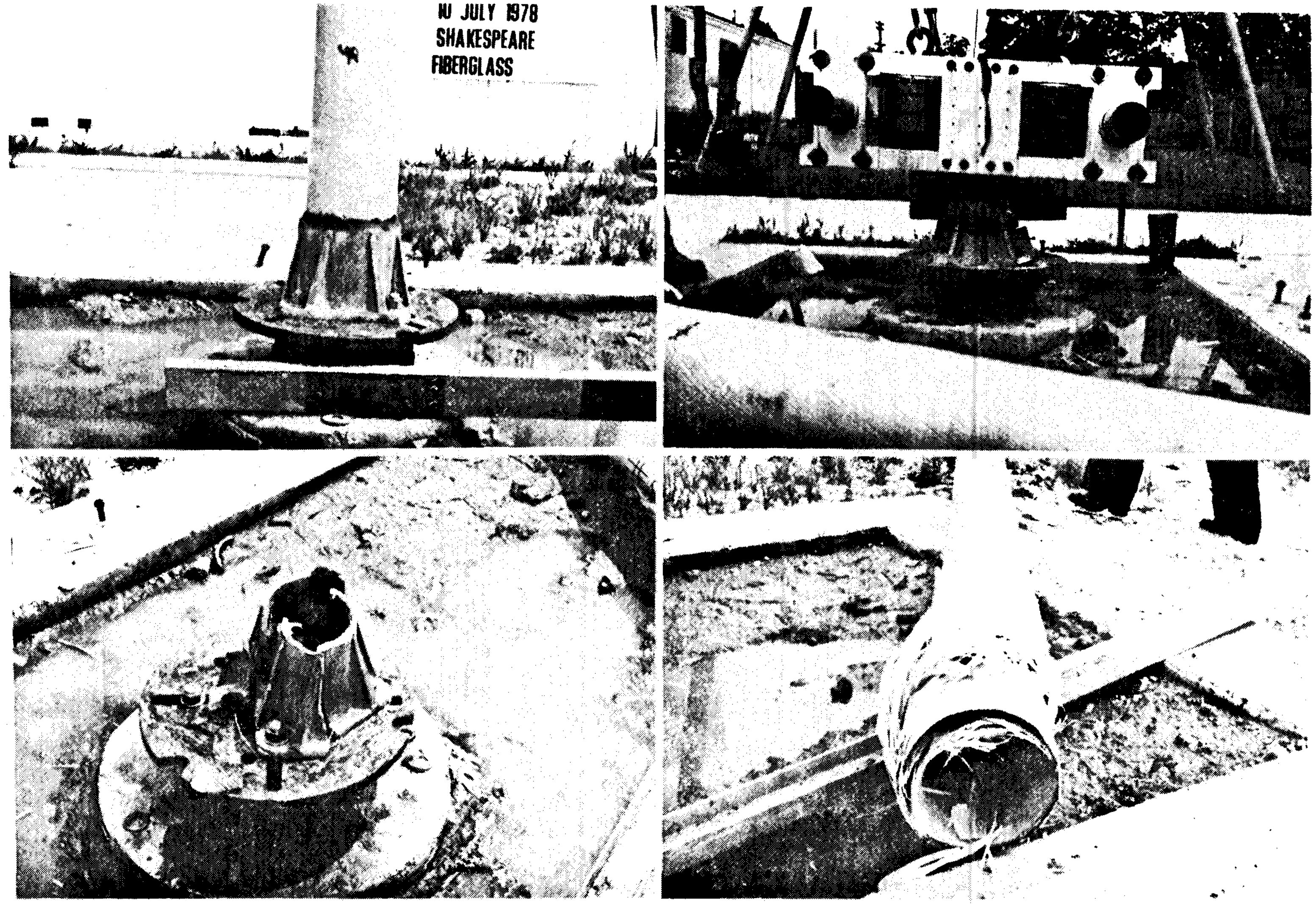


Fig. 52
Representative Photographs of Test 1147-701

TABLE 29. RESULTS OF TEST 1147-701

Momentum Change	2073 lb-lb
Main Peak Deceleration	7.6 g's
Time to Peak Decel.	.048 secs
Main Impact Duration	.112 secs
Honeycomb Crush	17.5 in
Peak Sweeperplate Decel.	43 g's
Time to Peak Sweeperplate Deceleration	.117 secs
Total Test Duration	.170 secs

1 lb-sec = 4.448 Ns, 1 in = 2.54 cm

secondary to the requirement for adequate support of the lighting fixture. Therefore, in this study of luminaire supports, the structural adequacy of the device was considered to be an important concern. In cases where modifications were made to the support, the need to evaluate the strength was of primary concern. Also, certain designs which were not widely accepted were tested to evaluate their structural properties.

Two types of tests were performed in this study. The first was a static load to failure test. In this test the luminaire support (pole and base) is anchored in the normal anchoring configuration to a rigid support with the pole in a horizontal position. The pole is then pulled upward at a point approximately 20 ft (6.1 m) from the bottom (see Fig. 53). The load is gradually increased until failure occurs and the load drops off. The load is measured using a 5 ton (4500 kg) load cell. The moment on the base at failure is computed to be the load on the load cell at failure times the distance to the base minus the weight of the support times the distance from the c.g. to the base.

$$M_{failure} = \left[F_{load\ cell} \times X_F\right] - \left[F_{support\ weight} \times X_{CG}\right] .$$

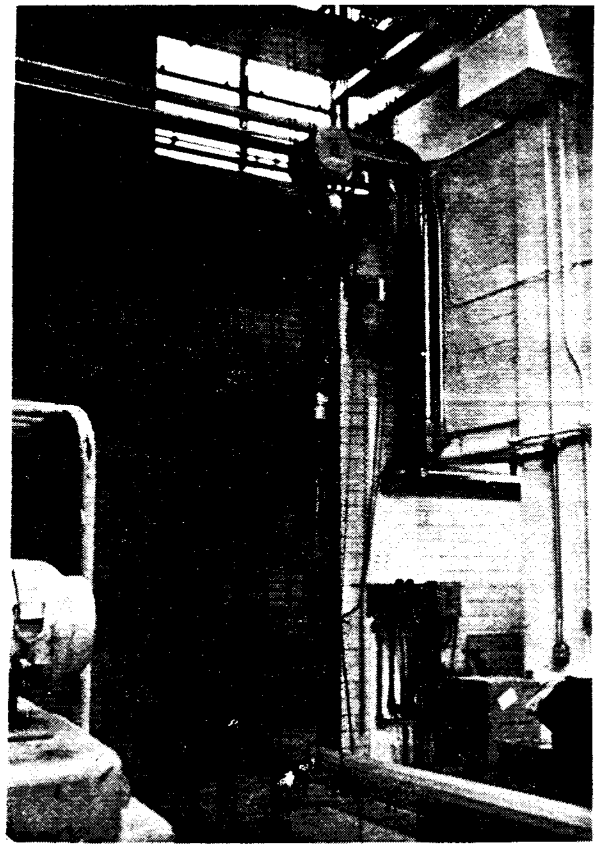


Fig. 53

Luminaire Support with Static Load Device Installed

The second type of test that was run was an accelerated fatigue life test. In this test the luminaire support is attached to the same rigid foundation in a horizontal manner as before. An eccentric vibrator is clamped to the pole at the point of maximum excursion for a second mode vibration (see Fig. 54). The vibrator is positioned so that the load is being applied in the vertical direction. The eccentric vibrator consists of a 1 lb (.45 kg) weight rotating at a 4 in (10.2 cm) radius. The vibrator has a variable speed motor which enables the frequency of vibration to be adjusted to match the second mode resonance frequency of the support.

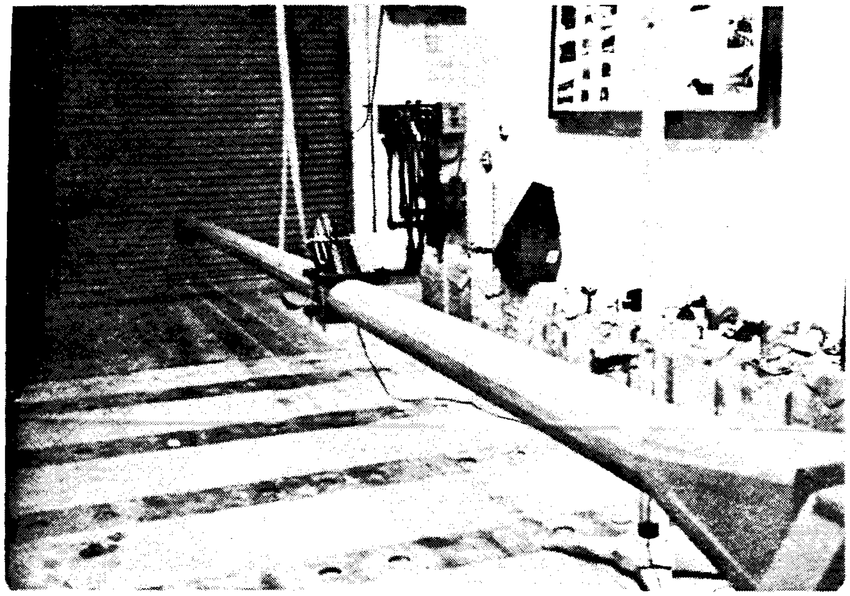


Fig. 54
Luminaire Support with Fatigue Test Vibrator Installed

The fatigue life test is thus run by vibrating the structure at its second mode natural frequency. It was found that for most structures tested the fatigue load was not severe enough to cause an accelerated failure. Therefore, several tests were stopped before failure. This test was not performed extensively due to the large amount of time needed to perform one test.

The list below is the static load and fatigue tests results performed for 1147-400 series luminaire supports. The 1147-200 series tests are reported in Chapter 5.

Test No.*	Related Impacted Tests	Type of Support	Cycles to Failure or Moment at Failure
F401	1147-401 & 1147-402	Millerbernd 40 ft Stainless Davit	9500 cycles (loose rivets) 13689 cycles (failure)
S402	1147-401	Millerbernd 40 ft Stainless Davit	20,300 lb
S403	1147-403	Millerbernd 50 ft Stainless Davit	27,660 lb
F404	1147-403	Millerbernd 50 ft Stainless Davit	35,161 cycles (no failure)

*F prefix denotes fatigue tests, S prefix denotes static load tests.

1 ft = .305 m, 1 lb-ft = 1.36 Nm

5. MODIFICATIONS FOR CAST ALUMINUM TRANSFORMER BASES

5.1 INTRODUCTION

A major concern of this study dealt with the effectiveness of the cast aluminum transformer base (T-base) as a breakaway device. Most of the existing designs for T-bases were either designed without breakaway in mind or were qualified using full size 4500 lb (2041 kg) cars at about 40 mph (64.4 km/h). The T-base is by far the most widely used breakaway device for luminaire supports on U.S. highways. Many state highway officials would like to continue to use T-bases, yet at the same time this project began few, if any, T-bases had passed the latest FHWA impact requirements. These requirements specify tests with a 2250 lb (1021 kg) car (or pendulum) at 20 mph (32.2 km/h) and 60 mph (96.6 km/h). The vehicle must suffer a change in momentum below 1100 lb-sec (4890 Ns).

This project therefore, looked at existing transformer base designs to ascertain if they could meet current breakaway requirements, and, if not, what modifications would be needed to make them pass. The goals of this work were as follows.

- To achieve momentum changes below 1100 lb-sec (4890 Ns), preferably below 750 lb-sec (3340 Ns) in 20 mph (32.2 km/h) impact tests with a 2250 lb (1021 kg) vehicle.
- To design modifications which can be incorporated into existing designs without costly retooling.
- To reduce the scatter and achieve a repeatable breakaway mechanism.
- To design modifications which do not degrade the structural adequacy of the support.

A total of nine different types of cast aluminum transformer bases were tested. These types cover a wide range of design variations, sizes, and manufacturers. All T-bases were first tested in the unmodified configuration. Modifications were then made to those designs not passing the 1100 lb-sec (4890 Ns) criteria.

It is strongly believed that the work performed here will have application for most cast aluminum transformer base designs.

5.2 TESTING SETUP

All of the tests (66 total) of cast aluminum transformer bases were performed using a 2290 lb (1039 kg) pendulum with a crushable nose as described in Chapter 3. The target speed for all tests was 20 mph (32.2 km/h). The transformer bases were bolted to a steel adaptor plate utilizing the largest design bolt circle where multiple bolt circles are allowed. Base washers as provided by the manufacturer were utilized unless otherwise noted. Impacts were made on the base side opposite the access cover unless otherwise noted. The pendulum height was 18 in (.45 m) from the center of the honeycomb to the surface of the adaptor plate. A rigid sweeperplate with a 4 in (10 cm) clearance above the adaptor plate was utilized to investigate snagging. Various size poles were tested with the bases as supplied by the respective manufacture.

5.3 FINITE ELEMENT COMPUTER MODELING OF TRANSFORMER BASES

Before any attempt was made to modify a transformer base, design ideas were sorted out utilizing a computer model. A finite element model for a Hapco 45964 transformer base was developed and used to investigate design modifications for improving breakaway characteristics. The finite element model is a two-dimensional* model of one side of a transformer base.

*Thickness variations are input into the model for stress calculations.

A two-dimentional model allowed the study of the stress contours existing in the sides of the base adjacent to the impact side. Therefore, the effects of modifications were examined to see if they would cause stress concentrations, stress pattern shifts, or load capacity changes. The MARC program [19] was used with the appropriate input data. This model allows the base to be loaded in both a wind load and impact load configuration. The program loads up the base in a simulated real-life manner and finds the stresses at points in each element. It then scales up the load until yield is reached at some point in the base. The stresses are then displayed graphically on a Von Mises stress contour plot which shows lines of equal stress. It is possible, therefore, to determine both the relative load capacity of the base and the point at which yielding will first take place. With this information available, design modifications can be fine-tuned to give good wind load capabilities coupled with more repeatable impact fracture tendencies.

Fig. 55 shows a Von Mises stress contour plot for an unmodified transformer base loaded in a wind loading configuration. The input wind loading was scaled by a factor of 9.48 to reach yield in the upper left hand corner of the base (the area where the 10's are). A design modification was modeled and its stress contour for wind loading is shown in Fig. 56. The modification consists of two diagonal slots on each side of the base. The slots start at the bottom, about 5 in (13 cm) in from each corner and slant diagonally outward to a height of about 4 in (10 cm) above the bottom. The stress contour plot for this configuration shows a high stress concentration at the root of the slots during wind loading. It must also be noted that the load to cause this failure is only 43 percent of the load needed to fail the base in its unmodified form.

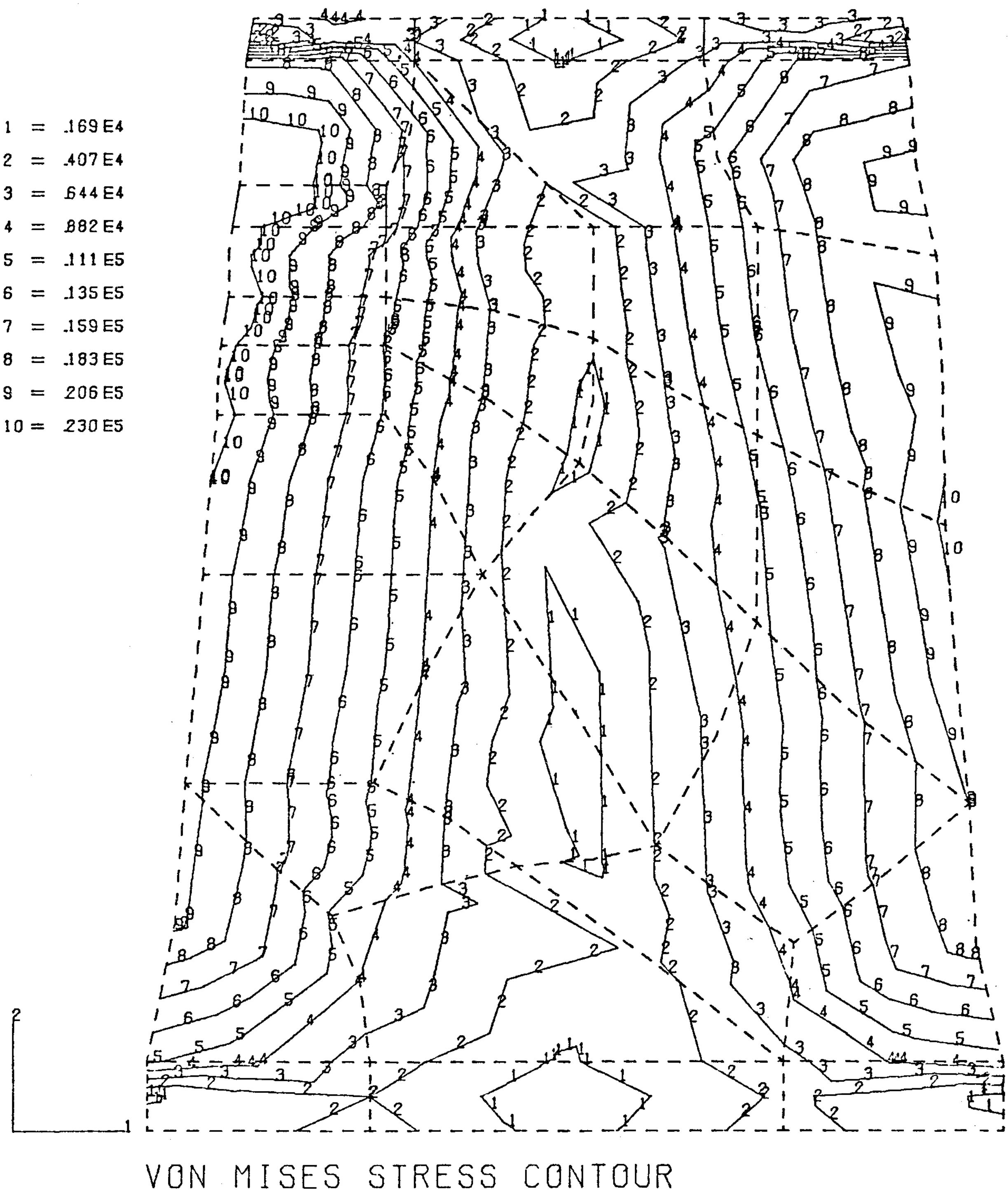


Fig. 55
Stress Contour for Unmodified T-Base, Wind Loading

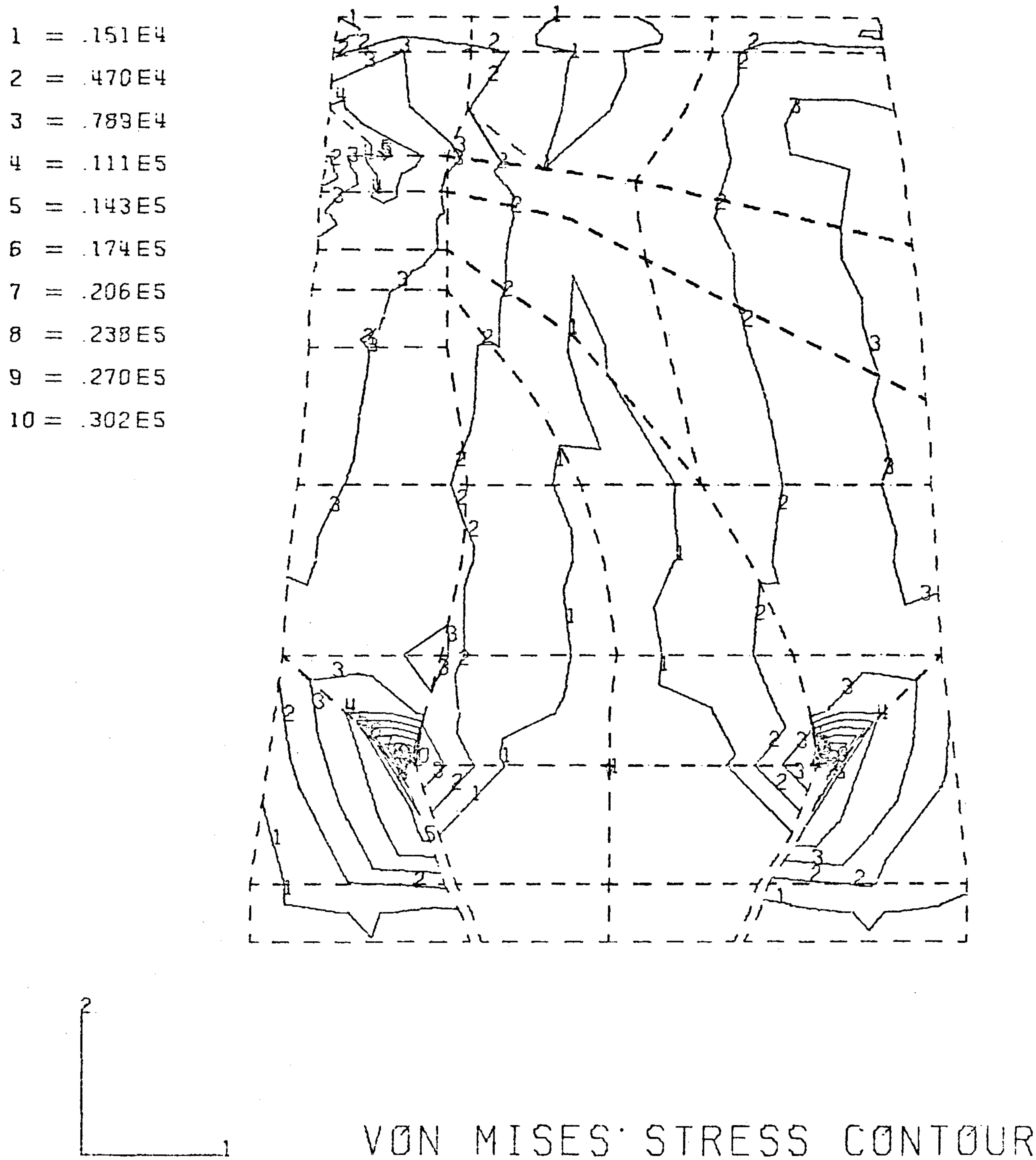


Fig. 56

Stress Contour for Diagonally Modified T-Base
Wind Loading

Fig. 57 shows the stress contours for the unmodified base under impact load conditions. As can be seen, the highest stresses are in the upper left hand corner of the base in the area adjacent to the loading. High stresses do not occur anywhere else. Fig. 58 shows a similar loading for the diagonally slotted base. Stress concentrations occur at the root of the slot as is desirable.

The diagonally slotted base modification shows tendencies to fail under impact loading by cracking from the root of the slot. However, the same tendency is shown (but to a more severe degree) under wind loading conditions. Therefore, this modification was not considered desirable from an environmental view point. To counter these undesirable effects, a second modification was tried. This time the slots were made almost vertically, actually following the theoretical lines of stress for wind loading instead of cutting across them. Fig. 59 shows the Von Mises stress contour plot for this configuration during wind loading. As can be seen, high stresses do not occur at the root of the slot in this configuration. In addition, yield stress is first reached in the upper left hand corner as in the unmodified base and is 72% of that found in the unmodified base.

Fig. 60 shows the stress contours for the second modification under impact loading. A stress concentration similar to that in the diagonally slotted base can be seen at the root of the slot indicating that failure will occur at this point as is desired.

This vertically slotted modification exhibits the desirable features of good wind loading ability with stress concentrations under impact loading at the root of the slot in the direction of desired failure.

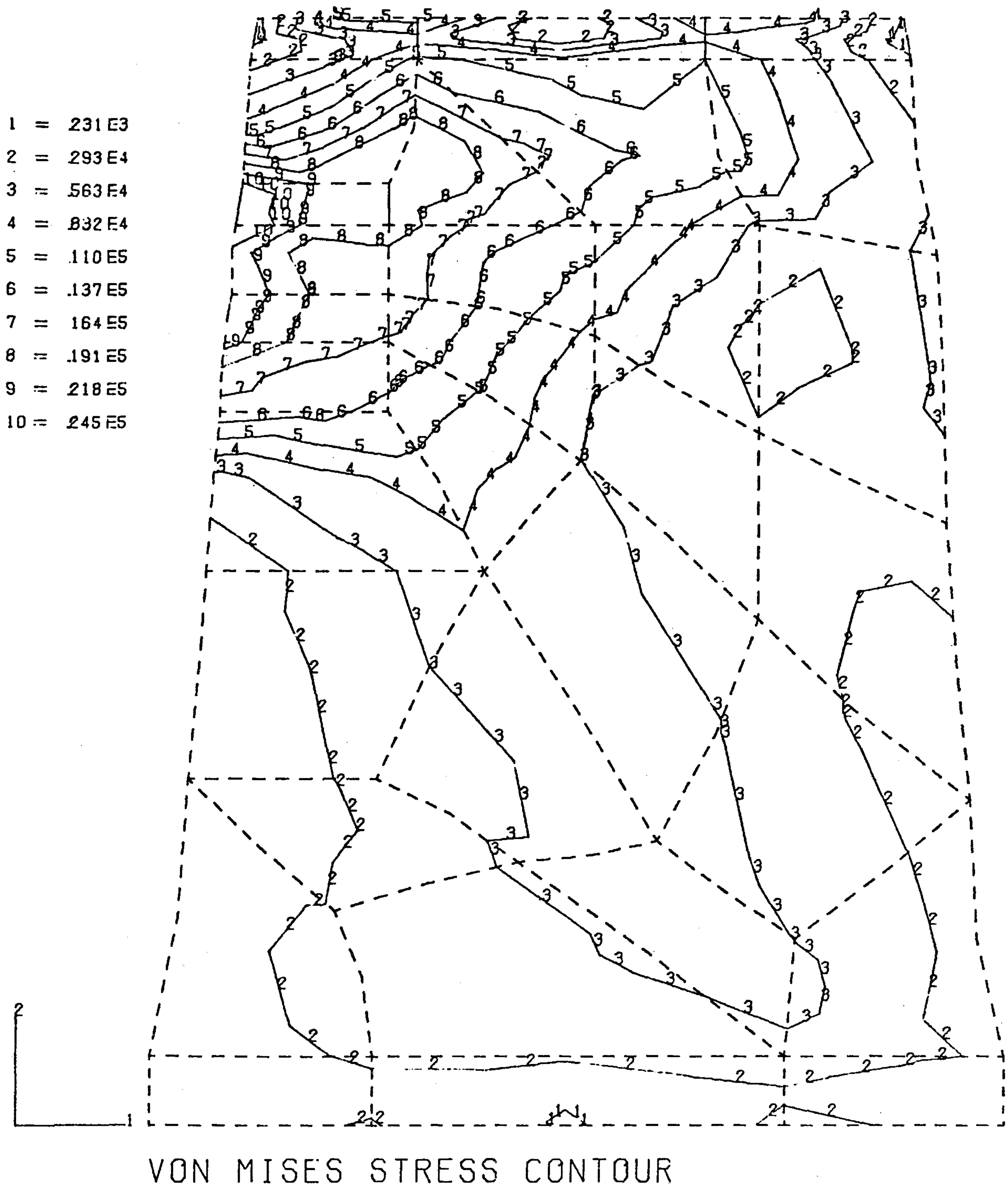


Fig. 57
Stress Contour for Unmodified T-Base, Impact Loading

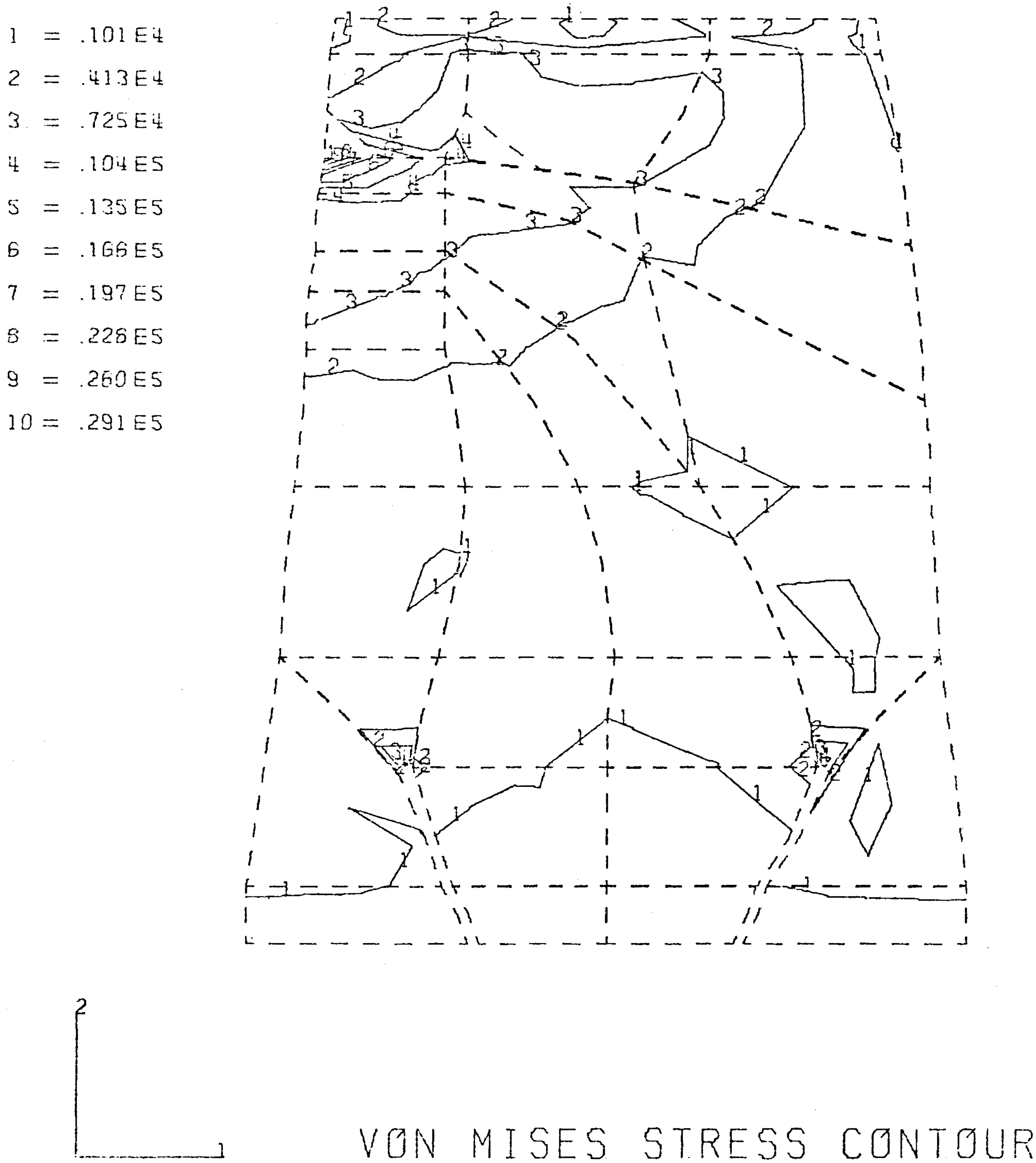


Fig. 58

Stress Contour for Diagonally Modified T-Base, Wind Loading

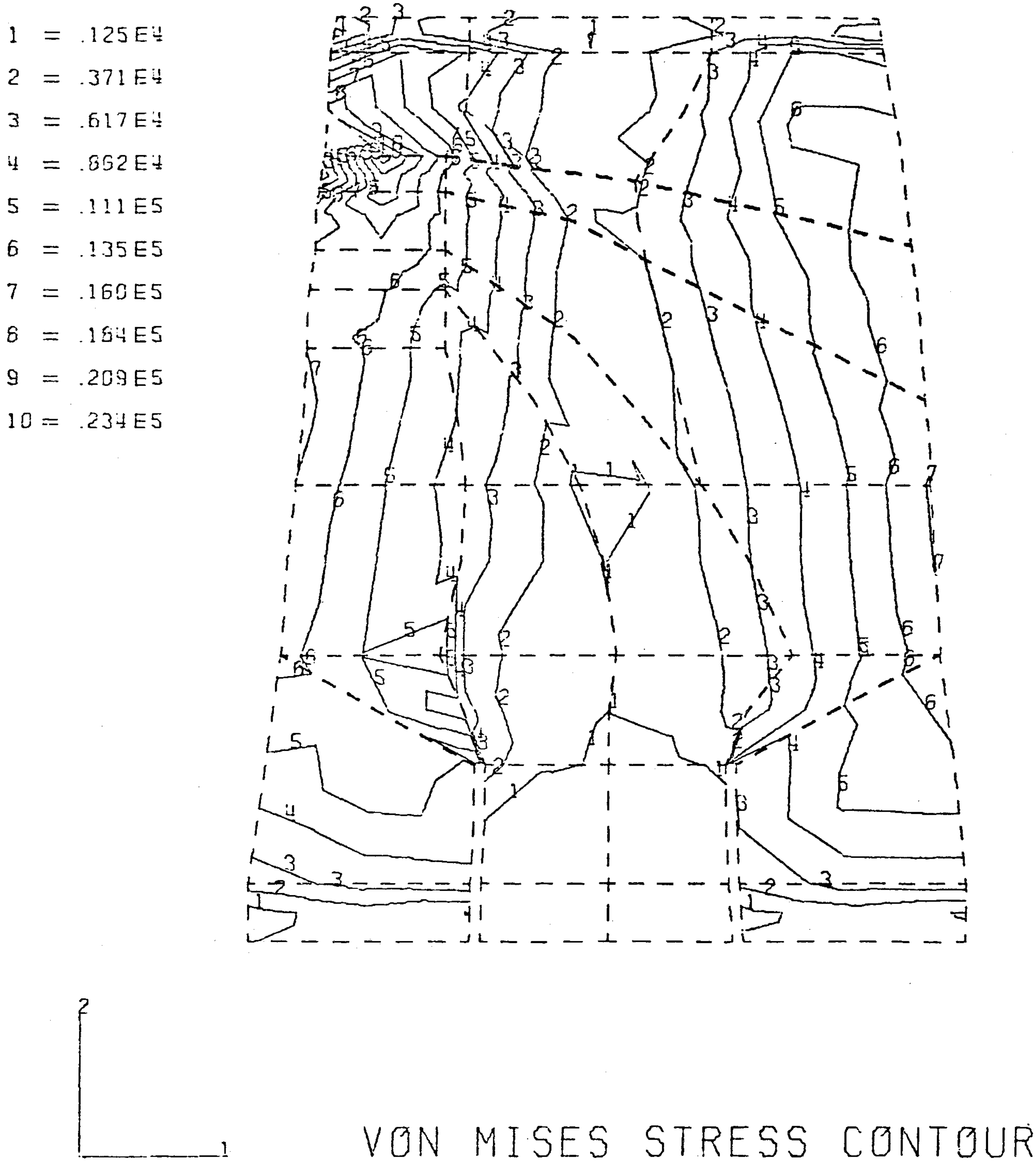


Fig. 59

Stress Contour for Vertically Modified T-Base, Wind Loading

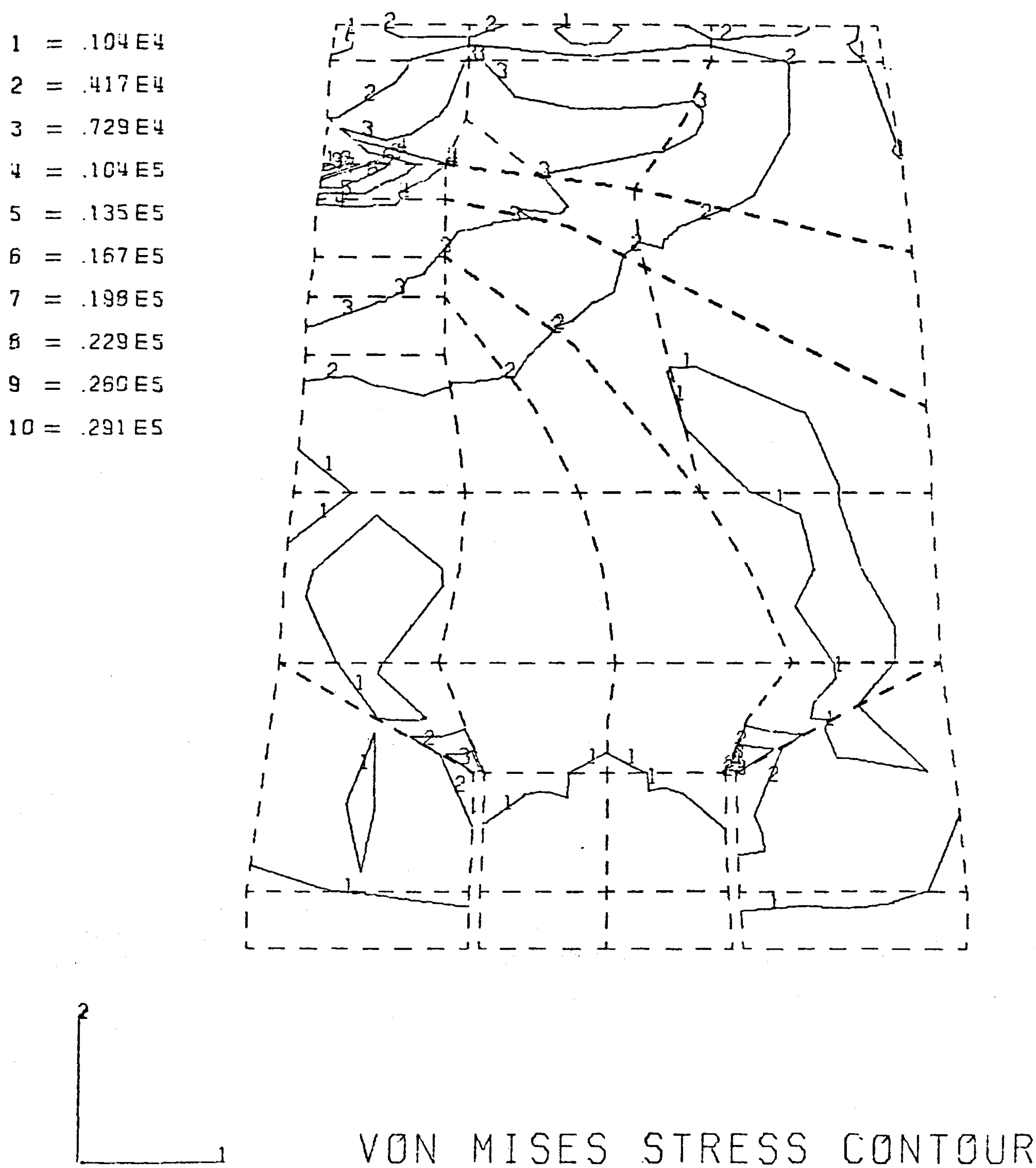


Fig. 60
Stress Contour for Vertically Modified T-Base, Impact Loading

This second modification was tested in pendulum impact test 1147-215, discussed later in this report.

A model of the door side of a Hapco transformer base was also developed. This model was developed to study the effects on wind load strength of modifications to the door side. The previous work had been concerned only with the other three sides of the base because it was felt that the door side was probably weak enough during an impact without modification. As reported later in this chapter, in Test 1147-219, where the base was impacted 90° to the door, it was found that the door side offered more resistance than the other modified sides. Therefore, an attempt to weaken the door side to impact was initiated.

The door side of a Hapco 45964 transformer base was modeled as a two-dimensional plate as was done previously. A simulated wind loading was applied to the plate which was held rigidly at the anchor bolt locations. The results of this loading can be seen in the Von Mises stress contour map of Fig. 61. This map shows that the area below the door opening is a region of low stress during wind loading. It was felt, therefore, that this area could be modified with little effect on the wind load characteristics of the base.

The model was then modified by the addition of a 1½ in (3.8 cm) high vertical slot in the center of the side below the door. It was believed that during impact the slot would crack up into the door opening and allow the impact side corner to be torn free. The simulation indicated that the slot had little effect on the wind load capability of the base. The load needed to reach yield in the modified side was identical to that needed in the unmodified side.

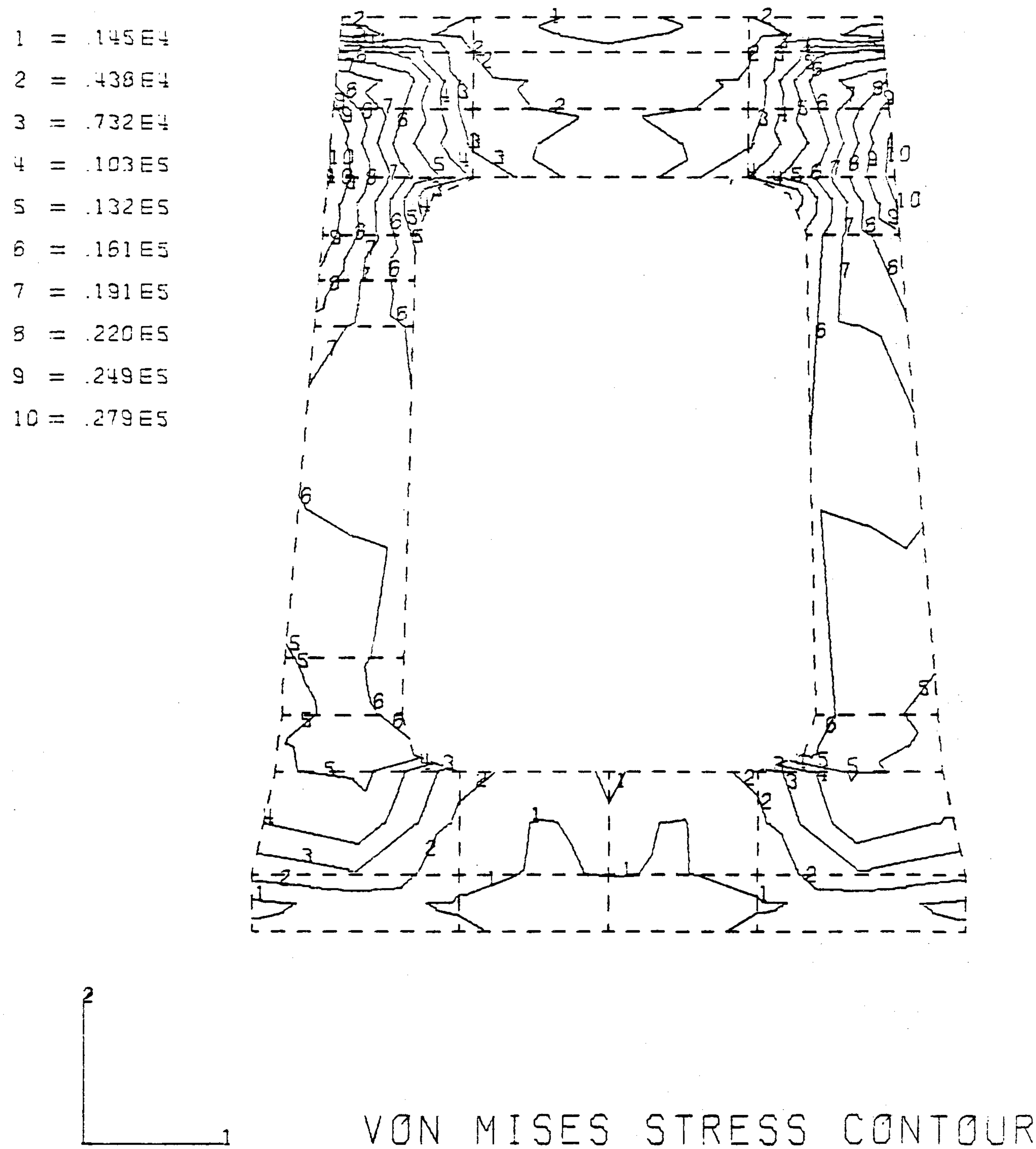


Fig. 61
Stress Contours of T-Base Door Side Under Wind Loading

In the impact test of this modification, Test 1147-220, the slot had no effect on the breakaway behavior of the base. It is now felt that for a better modification, this side should be modified with two slots, one below each lower corner of the door opening. Just as it was necessary to go to two slots on each of the other sides, the door side would need the same type of modification. Since such a modification would make the area below the door susceptible to damage during transport, it is felt that no modification to the door side on this base should be performed. This compromise of no side door modification is shown acceptable by an 842 lb-sec (3745 Ns) momentum change found in Test 1147-219.

5.4 TRANSFORMER BASE IMPACT TESTS

A total of 66 transformer base tests were performed. These tests were all designated as the 1147-200 series. The order of the tests was random, depending on available hardware and related research activities. Therefore, the tests will be discussed in a logical order according to the type of base tested. For convenience, bases will be divided into the following four categories:

1. Small T-bases -- bases with a lower bolt circle in the range of 15 in to 17 in (38 cm to 43 cm).
2. Large T-bases -- bases with a lower bolt circle above 17 in (43 cm).
3. Insert T-bases -- bases with similar top and bottom bolt circles.
4. Miscellaneous bases.

In order to accommodate the large amount of data in a reasonable fashion the following procedure will be used: first, a standard table will be used to list the specifications of the base in unmodified form, then a brief description of the testing series, modifications, and results will be given, and following this, a table of results for each test of that T-base type will be given. Transformer bases will be designated by a code with the first number corresponding to the appropriate category, such as 1A. An additional number added to the end will be used to identify modifications such as 1A1.

BASE TYPE 1A - HAPCO 45964

Specifications (1A)

Manufacturer	:	Hapco
Model No.	:	45964
Configuration	:	One piece tapered skirt
Height	:	20 in (50.8 cm)
Upper Bolt Circle	:	12 in (30.5 cm)
Lower Bolt Circle	:	15 in (38.1 cm)
Alloy and Heat Treat	:	356-T6
Special Features	:	None

Test Series Description (1A)

This base was tested a total of 15* times. This large number of tests resulted from the fact that this base was used as a test bed to observe scatter and to refine modifications. Five tests were performed on the base in unmodified form. The following list shows the wide scatter displayed by this base. This type of scatter is not uncommon among T-base designs.

Test	Momentum Change lb-sec (Ns)
1147-201	2049 (9125)
1147-202	846 (3768)
1147-203	1532 (6945)
1147-208	901 (4012)
1147-210	2037 (9061)

*One test, 1147-252, was a retrofit modification which is covered in Section 5.5.

One base was also tested in a T51 temper which is a more brittle temper and the momentum change was 1555 lb-sec (6925 Ns).

Five different modifications were tried on this T-base design. The first (Test 1147-202) utilized vertical slots in the center of each corner. This test caused the sides to act independently and allowed the base to parallelogram thus absorbing all of the pendulum's momentum. In the second modification (Test 1147-205) the vertical cuts were moved to the upper and lower tips of each corner. Breakaway characteristics were excellent, however, static strength was low. In the third modification (Test 1147-211) a diagonal saw cut was made at the lower tip of each corner. This modification produced a desirable fracture pattern and the momentum change was 1070 lb-sec (4805 Ns). Still, a better modification was felt to be desirable. At this time the finite element work was performed and the side slot concept evolved (see Section 5.3). This concept, utilizing two 4 in (10.2 cm) high cuts at the lower edge of each skirt (none on the door side) produced excellent results as shown below for the four tests conducted.

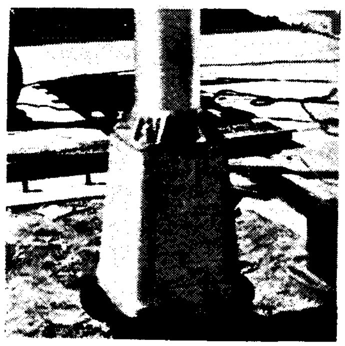
Test	Momentum Change lb-sec (Ns)	Comment
1147-215	668 (2975)	Normal impact
1147-219	842 (3750)	Impact at 90° to access hole
1147-227	714 (3180)	Larger pole
1147-259	965 (4297)	45° impact

An additional test utilizing a single 5 in (12.7 cm) high vertical side slot on each skirt was made to see if the number of slots could be reduced. The resulting momentum change was 1302 lb-sec (5798 Ns).

Test Results (1A)

Test 1147-201

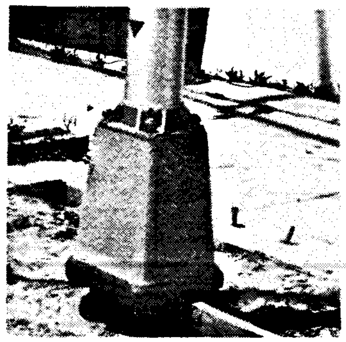
Test Description	:	Baseline
Pole Type	:	30 ft (9.2 m) aluminum
Mounting Washers	:	Al. trapezoidal
Base Failure	:	This base was completely destroyed by the impact, with the base being broken into 11 pieces. Fracture lines extended around the base at approximately 4 in (10.2 cm) up from the bottom and went diagonally up the sides
Momentum Change	:	2049 lb-sec (9114 Ns)
Peak Deceleration	:	17.7 g's
Honeycomb Crush	:	17 in (43.2 cm)
Sweeperplate Impact	:	No

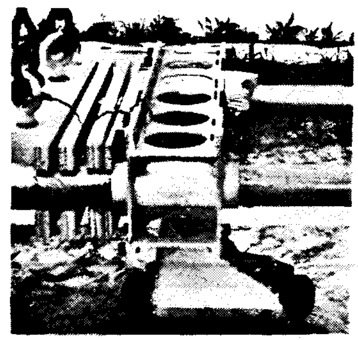


Test 1147-202

Test Description	:	Baseline
Pole Type	:	28 ft (8.5 m) aluminum
Mounting Washers	:	Al. trapezoidal
Special Test Features	:	No sweeperplate on pendulum
Base Failure	:	Fracture of this base ran across the front face at about 12 in (30 cm) high and then diagonally down toward the rear of the base. This front stub was left behind because there was no sweeper-plate on the pendulum
Momentum Change	:	846 lb-sec (3763 Ns)

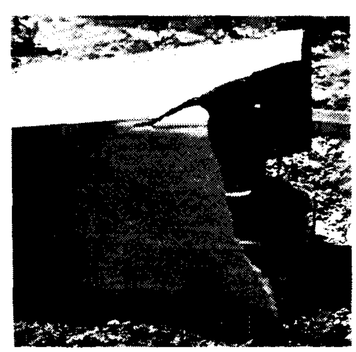
Peak Deceleration : 16 g's
Time to Peak Decel. : .063 sec
Impact Duration : .074 sec
Honeycomb Crush : 17 in (43.2 cm)
Sweeperplate Impact : No





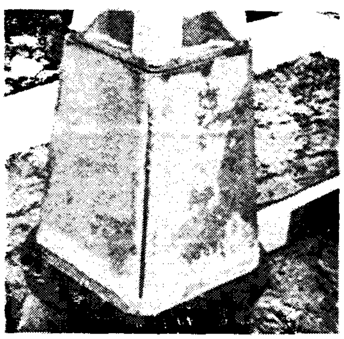
Test 1147-203

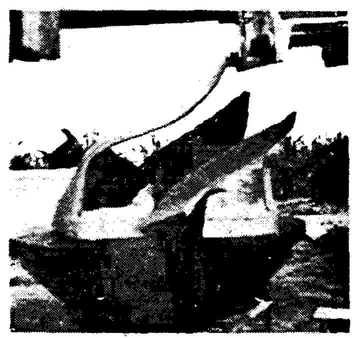
Test Description : Baseline
Pole Type : 28 ft (8.5 m) aluminum pole
Mounting Washers : Al. trapezoidal
Special Test Features : None
Base Failure : This base broke across the impact surface at about 4 in (10 cm) high. The break ran diagonally down toward the back of the base on each sie. The front lugs were left on the foundation.
Momentum Change : 1532 lb-sec (6814 (Ns)
Peak Deceleration : 22 g's
Time to Peak Decel. : .070 sec
Impact Duration : .120 sec
Honeycomb Cursh : 17 in (43.2 cm)
Sweeperplate Impact : No



Test 1147-204

Test Description	:	Modified (1A1)
Modification	:	Vertical corner slots in each corner starting 1½ in (3.8 cm) from the bottom and extending to within 2 in (5.1 cm) of the top
Pole Type	:	28 ft (8.5 m) spun aluminum
Mounting Washers	:	Al. Trapezoidal
Special Test Features	:	None
Base Failure	:	The corner slots caused each side panel to act independently thus the base tended to parallelogram over. The front panel bent over and wedged under the pendulum thus stopping it.
Momentum Change	:	2086 lb-sec (9279 Ns)
Peak Deceleration	:	21 g's
Time to Peak Decel.	:	.068 sec
Impact Duration	:	.160 sec
Honeycomb Crush	:	17.5 in (44.5 cm)
Sweeperplate Impact	:	No



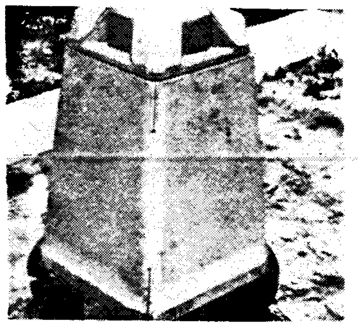


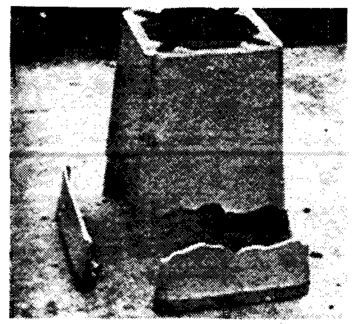
Test 1147-205

Test Description	:	Modified (1A2)
Modification	:	Eight Vertical corner cuts of which 4 extended in 5 in (12.7 cm) from the top and 4 extended up 5 in (12.7 cm) from the bottom. Each slot was terminated in a ¼ in (.6 cm) hole
Pole Type	:	Al. Trapezoidal
Special Test Features	:	None
Base Failure	:	Base fracture was very controlled with breaks running horizontally across the sides on both the impact and left hand side of the base.

Fracture initiated at the top of the lower saw cuts. Upper cuts had no effect.

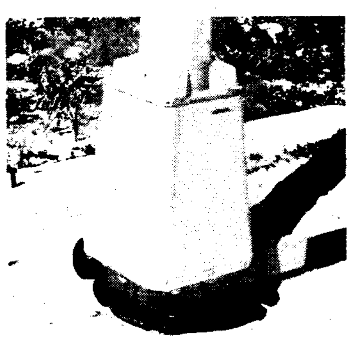
Momentum Change : 561 lb-sec (2495 Ns)
Peak Deceleration : 8 g's
Time to Peak Decel. : .058 sec
Impact Duration : .075 sec
Honeycomb Crush : 16 in (40.6 cm)
Sweeperplate Impact : No

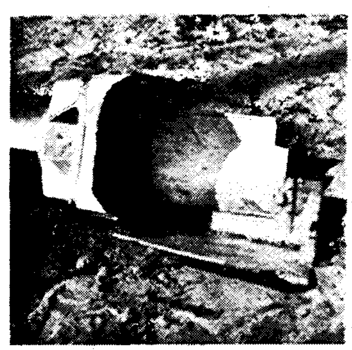




Test 1147-208

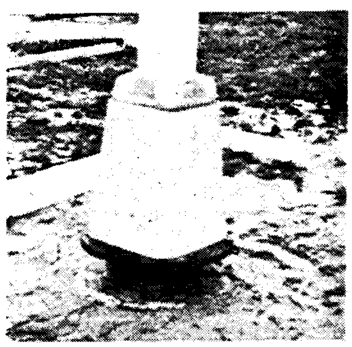
Test Description : Baseline
Pole Type : 28 Ft (8.5 m) aluminum pole
Mounting Washers : Al. trapezoidal
Special Test Features : None
Base Failure : This base failed by breaking away the front panel of about 4 in (10 cm). This break ran diagonally down to the bottom, about 5 in (12.7 cm) back along each side, thus leaving the front mounting lugs on the foundation.
Momentum Change : 901 lb-sec (4008 Ns)
Peak Deceleration : 16 g's
Time to Peak Decel. : .063 sec
Impact Duration : .095 sec
Honeycomb Crush : 17 in (43.2 cm)
Sweeperplate Impact : Yes





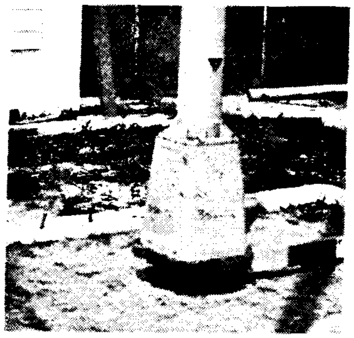
Test 1147-209

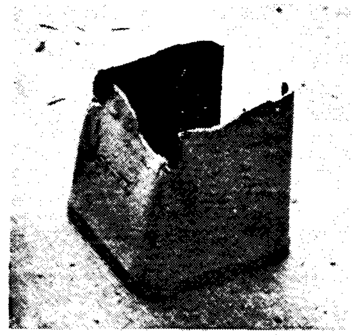
Test Description	:	Modified (temper change)
Pole Type	:	28 ft (8.5 m) aluminum
Mounting Washers	:	Al. trapezoidal
Special Test Features	:	T51 heat treat
Base Failure	:	This test had a failure very similar to Test 1147-208. The base cracked across the impact face about 5 in (12.7 cm) up from the bottom and then diagonally down each adjacent side. The remainder of the base was broken into several smaller pieces.
Momentum Change	:	1555 lb-sec (6916 Ns)
Peak Deceleration	:	21.2 g's
Time to Peak Decel.	:	.063 sec
Impact Duration	:	.111 sec
Honeycomb Crush	:	17.5 in (44.5 in)
Sweeperplate Impact	:	No



Test 1147-210

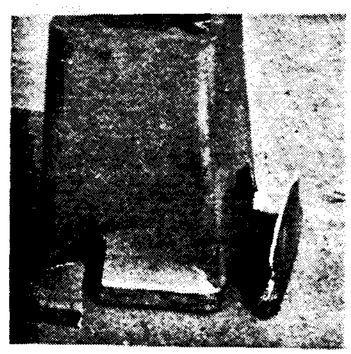
Test Descrioption	:	Baseline
Pole Type	:	28 ft (8.5 m) aluminum
Mounting Washers	:	Al. Trapezoidal
Special Test Features	:	None
Base Failure	:	The base fracture was very simple with one fracture going completely around the base at its mid-section. The bottom did not break away, thus it stopped the pendulum
Momentum Change	:	2037 lb-sec (9061 Ns)
Peak Deceleration	:	22 g's
Impact Duration	:	.063 sec
Time to Peak Decel.	:	.155 sec
Honeycomb Crush	:	18 in (45.7 cm)
Sweeperplate Impact	:	No





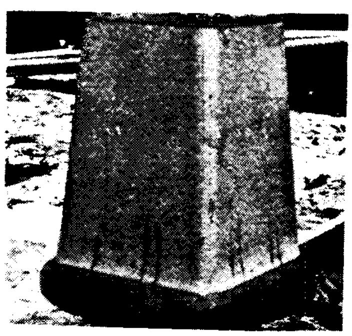
Test 1147-211

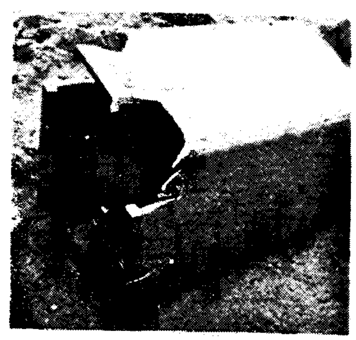
Test Description	: Modified (1A3)
Modification	: Four lower corner saw cuts running diagonally through the corner. Each slot starts at the bottom of the base where the bottom of the lug ends and runs through the corner and out at about 1¼ in (3.2 cm) up the corner.
Pole Type	: 28 ft (8.5 m) aluminum
Mounting Washers:	: Al. trapezoidal
Special Test Features	: None
Base Failure	: The base fracture was as expected with the front panel breaking through the slotted corners and across the impacted side. One side also broke free allowing the base to rotate and slide off the back bolts.
Momentum Change	: 1079 lb-sec (4799 Ns)
Peak Deceleration	: 8.6 g's
Time to Peak Decel.	: .066 sec
Impact Duration	: .146 sec
Honeycomb Crush	: 17.5 in (44.5 cm)
Sweeperplate Impact	: Yes



Test 1147-215

Test Description	:	Modified (1A4)
Modification	:	Two vertical slots on three sides (none on the door side). Each slot was 3-7/8 in high (9.8 cm), 4-7/8 in (12.4 cm) from the corner and terminated in a 3/8 in (6m) hole.
Pole Type	:	28 ft (8.5 m)
Mounting Washers	:	Al. trapezoidal
Special Test Features	:	None
Base Failure	:	The base failed when the two front mounting lugs were broken out via the modification. This allowed the remainder of the base to slide off of the foundation, thus resulting in a very controlled breakaway feature.
Momentum Change	:	668 lb-sec (2971 Ns)
Peak Deceleration	:	9.6 g's
Time to Peak Decel.	:	.058 sec
Impact Duration	:	.066 sec
Honeycomb Crush	:	16.5 in (41.9 cm)
Fatigue Life	:	6321 cycles (test F201)
Fatigue Failure	:	The aluminum pole broke at the pole-to-mounting flange weld. There was no damage to the modified base.

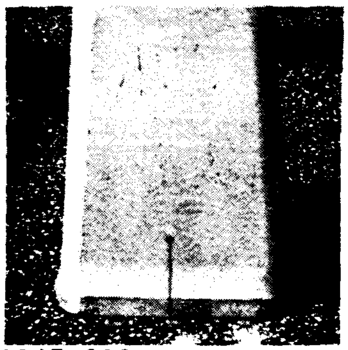




Test 1147-218

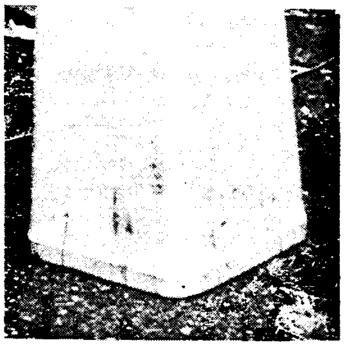
Test Description	:	Modified (1A5)
Modification	:	Three center side slots, 5 in (12.7 cm) high and terminated in a 3/8 in (1 cm) hole
Pole Type	:	28 ft (8.5 m) aluminum

Mounting Washers	:	Al. trapezoidal
Special Test Features	:	None
Base Failure	:	The front panel broke from the termination hole of the modification diagonally down and around each corner, then out the bottom just in front of the side slots. The side slots allowed the rear lugs to turn so they could slide off the foundation.
Momentum Change	:	1302 lb-sec 95791 Ns)
Peak Deceleration	:	18.5 g's
Time to Peak Decel.	:	.062 sec
Impact Duration	:	.106 sec
Honeycomb Crush	:	17.5 in (44.5 cm)
Sweeperplate Impact	:	No



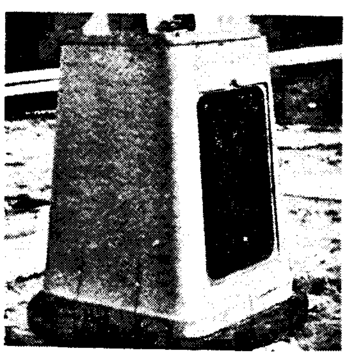
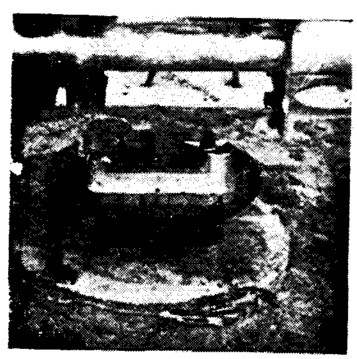
Test 1147-219

Test Description	:	Modified (1A4)
Modification	:	Same as 215
Pole Type	:	28 ft (8.5 m) aluminum
Mounting Washers	:	Al. Trapezoidal
Special Test Features	:	90° impact (door to side)
Base Failure	:	The base failed by breaking away one front lug and the complete door side via the modification. The impacted panel was broken away from the base as one large section.
Momentum Change	:	842 lb-sec (3745 Ns)
Peak Deceleration	:	12 g's
Time to Peak Decel.	:	.064 sec
Impact Duration	:	.08 sec
Honeycomb Duration	:	17.5 in (44.5 cm)
Sweeperplate Impact	:	None



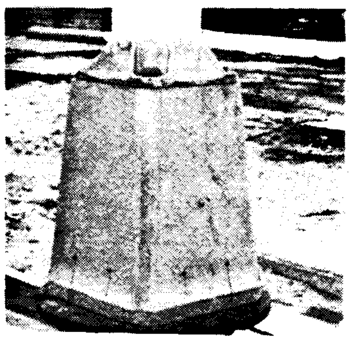

Test 1147-220

Test Description		Modified (1A4)
Modification	:	Two vertical slots on three sides, each is 4 in (10 cm) high, 5 in (12.7 cm) in from the corner and terminated in a 3/8 in (1 cm) hole. The door side also had one vertical centered slot which is 1½ in (3.8 cm) high.
Pole Type	:	28 ft (8.5 m) aluminum
Mounting Washers	:	Al. trapezoidal
Special Test Features	:	90^{o} hit
Base Failure	:	The base failure is the same as Test 219. The extra hole on the door side was not activated.
Momentum Change	:	839 lb-sec (3732 Ns)
Peak Deceleration	:	10.9 g's
Time to Peak Decel.	:	.061 sec
Impact Duration	:	.094 sec
Honeycomb Crush	:	17 in (43.2 cm)
Sweeperplate Impact	:	No

Test 1147-227

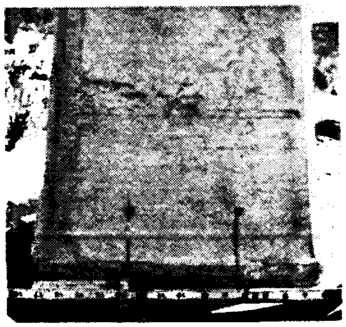
Test Description	:	Modified (1A4)
Modification	:	same as 215
Pole Type	:	42 ft-6 in (13 m) aluminum
Mounting Washers	:	Al. trapezoidal
Special Test Features	:	None
		This base failed when fracture allowed the front lugs to break free via the modification. Two of the three small panels between the side cuts were also broken away.
Momentum Change	:	714 lb-sec (3176 Ns)
Peak Deceleration	:	9.5 g's
Time to Peak Decel.	:	.068 sec
Impact Duration	:	.081 sec
Honeycomb Crush	:	16.6 in (41.9 cm)
Sweeperplate Impact	:	No



Test 1147-259

Test Description	:	Modified (1A4)
Modification	:	Same as 215
Pole Type	:	42 ft-6 in (13 m) aluminum
Mounting Washers	:	Al. trapezoidal
Special Test Features	:	45^{o} hit
Base Failure	:	The front lug broke away via the modification. The two side lugs were broken in half and completely removed. All cuts made in the modification are activated.
Momentum Change	:	965 lb-sec (4292 Ns)
Peak Deceleration	:	19.0 g's

Time to Peak Decel.	:	.060 sec
Impact Duration	:	.095 sec
Honeycomb Crush	:	17.5 in (44.5 cm)
Sweeperplate Impact	:	Yes



BASE TYPE 1B P&K TB2A

Specifications (1B)

Manufacturer	:	Pfaff & Kendall
Model	:	TB2A
Configuration	:	Two piece tapered skirt with belt line weld
Height	:	20 in (50.8 cm)
Upper Bolt Circle	:	10½ to 13½ in (26.6 to 34.3 cm)
Lower Bolt Circle	:	15 to 17½ in (38.1 to 43.8 cm)
Alloy & Heat Treat	:	356-T6
Special Features	:	None

Test Series Description (1B)

This transformer base is again in the small T-base class, however, it differs dramatically in design to the Hapco base. The base is cast in two pieces, an upper shell and a lower shell, which are welded together around the base beltline. This yields a very strong transformer base which was found to be very difficult to modify effectively. The three tests performed on unmodified bases again demonstrate the degree of data scatter found with T-base tests.

Test	Momentum Change lb-sec (Ns)
1147-206	735 (3273)
1147-212	870 (3874
1147-213	1244 (5540)

Since Test 1147-206 showed a very good momentum change, it became apparent that a momentum change from one test alone could not be used to determine the acceptance of a modification. Therefore, when reviewing test data from the TB2A tests, judgement was required to determine the repeatability of the fracture. Random fracture patterns were considered non-repeatable and the modification was, therefore, considered unacceptable for purposes of this research project. This will explain why several modifications yielded acceptable momentum change levels yet were not used.

The TB2A transformer base has closed anchor bolt slots, as opposed to the open ended slot on most base designs. Assuming that this design would prevent easy disengagement with the anchor bolts, it was decided to open the slots up. In Test 1147-207 this was done in addition to making a cut from the anchor bolt slot into the corner and extending the cut vertically up the corner 1¼ in (3.2 cm). The cut ended in a 3/8 in (9.5 cm) dia. hole. The momentum change was excellent, 644 lb-sec (2868 Ns), but the static load capability was below the needed level.

The modification in Test 1147-214 was similar to that in Test 1147-207 except that the cut in the lower mounting flange only went through half of its thickness. The fracture pattern was erratic and the momentum change was 964 lb-sec (4288 Ns) so this modification was not acceptable.

In Tests 1147-216 and 1147-217 vertical side cuts similar to those used on the Hapco base (1A), Tests 1147-215 and 1147-218 respectively, were tested. These modifications were found not to perform with this base design. In both cases, random fracture patterns occurred.

In Test 1147-226 the same modification tested in Test 1147-207 was used except that 3 in (7.6 cm) O.D. x 3/8 in (9.5 mm) thick anchor bolt washers were used. Static load tests performed by P&K showed that these washers increased the momentum capacity to above acceptable limits. Due to the greater clamping ability of the large washers, momentum change levels increased to 809 lb-sec (3598 Ns). The fracture was as desired, with the anchor bolts breaking through the corners. Manufacturing problems with this modification were found since it greatly weakened the lower casting prior to welding. Therefore, further research was performed.

Tests 1147-232 and -233 tests were performed to see if opening up the anchord bolt slots alone could produce repeatable behavior. Results for these tests were very different in nature with Test 1147-233 producing a momentum change of 1157 lb-sec (5146 Ns).

Test 1147-240 was a further refinement of the concept initiated in Test 1147-207. The anchor bolt slots were again opened up. This time the corner cuts were made only through the mounting flange, extending from the bolt slot to the corner. Breakaway occurred by breaking through the corner cuts as desired. However, the force levels were high and so was the momentum change, 1033 lb-sec (4595 Ns).

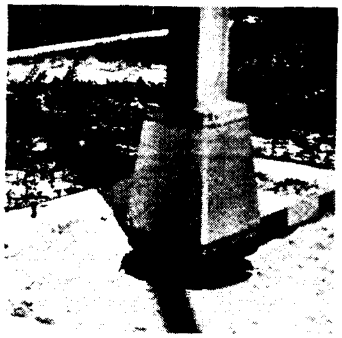
Test 1147-240 had indicated that reinforcing ribs along the lower edge of each side might be preventing flexure of the base and, consequently, raising the force levels. Therefore, in Test 1147-241, two cuts were made in each rib to essentially remove its effects. Otherwise the modification was the same as in Test 1147-240. the momentum change was 677 lb-sec (3011 Ns) and the fracture was very controlled. This became the recommended modification for this tranformer base design. Test 1147-255 was later made to see if the corner cut could be eliminated, relying only on the rib cuts and opened anchor bolt slots. This modification did not work properly and the resulting momentum change was 1078 lb-sec (4795 Ns).

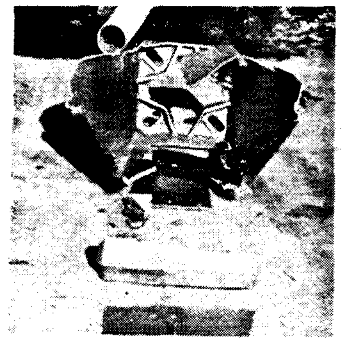
<u>Test Results (1B)</u>

Test 1147-206

Test Description	:	Baseline
Pole Type	:	36 ft (11.0 m) aluminum
Mounting Washers	:	Steel rectangular
Special Test Features	:	None
Base Failure	:	This base failed when the front panel was broken away down to the weld line. The front of the lower section including the front lugs were left on the foundation after the test. The back half of the base twisted in and each lug opened allowing the base to slide off the foundation.
Momentum Change	:	735 lb-sec (3269 Ns)
Peak Deceleration	:	9.3 g's

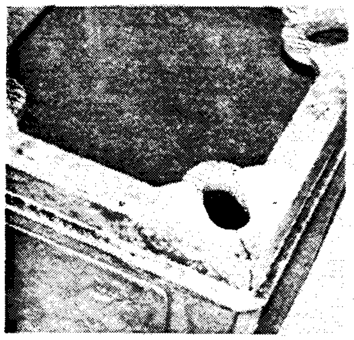
Time to Peak Decel.	:	.063 sec
Impact Duration	:	.090 sec
Honeycomb Cursh	:	17 in (43.2 cm)
Sweeperplate Impact	:	No
Static Load	:	20,7000 lb-ft (28069 Nm)
Static Failure	:	Upper base bolt lugs broke away leaving the remainder of the base intact.

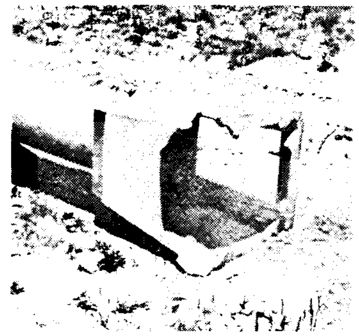




Test 1147-207

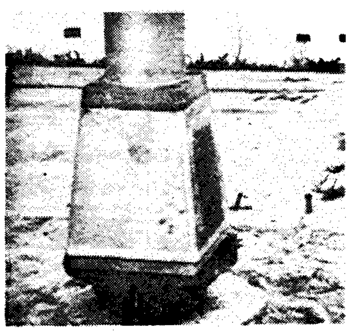
Test Description	:	Modified (1B1)
Modification	:	The closed mounting lugs were opened and vertical slots 1¼ in (3.2 cm) high were placed in each corner, terminated with 3/8 in (9.5 mm) holes.
Pole Type	:	36 ft (11m) MH aluminum
Mounting Washers	:	Rectangular steel
Special Features	:	None
Base Failure	:	Fracture ran across the front panel and down through the vertical slot in the front corners. The rear lugs opened slightly allowing the base to slide away. This seemed to be a controlled failure.
Momentum Change	:	644 lb-sec (2865 Ns)
Peak Deceleration	:	8.1 g's
Time to Peak Decel.	:	.059 sec
Impact Duration	:	.070 sec
Honeycomb Crush	:	16 in (40.6 cm)
Sweeperplate Impact	:	No

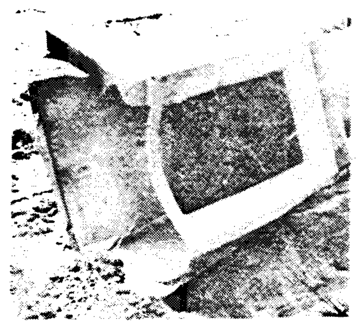




Test 1147-212

Test Description	:	Baseline
Pole Type	:	36 ft (11m) aluminum
Mounting Washers	:	2 in (5 cm) dia. steel
Special Test Features	:	None
Base Failure	:	Fractures ran along much of the weld, leaving most of the lower section on the foundation after the impact. The upper section was deformed but remained in one piece.
Momentum Change	:	870 lb-sec (3869 Ns)
Peak Deceleration	:	10.2 g's
Time to Peak Decel.	:	.062 sec
Impact Duration	:	.096 sec
Honeycomb Crush	:	17.5 in (44.5 cm)
Sweeperplate Impact	:	No

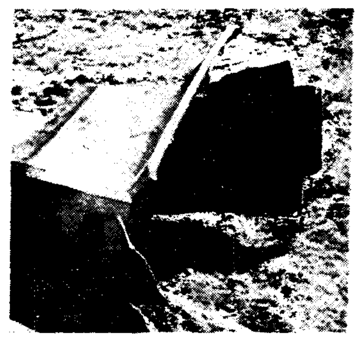




Test 1147-213

Test Description	:	Baseline
Pole Type	:	36 ft (5 cm) dia. steel
Mounting Washers	:	2 in (5 cm) dia. steel
Special Test Features	:	None

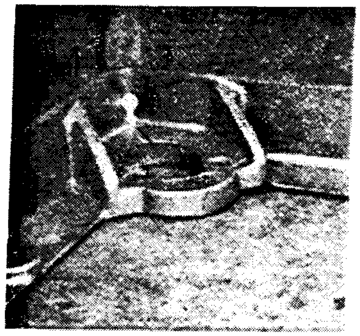
Base Failure	:	The failure was similar to other baseline tests with the lower section remaining on the foundation and fractures running along the weld line. The upper section was bent apart on the impact side but generally stayed intact.
Momentum Change	:	1244 lb-sec (5533 Ns)
Peak Deceleration	:	19.8 g's
Time to Peak Decel.	:	.070 sec
Impact Duration	:	.112 sec
Honeycomb Crush	:	17.5 in (44.5 cm)
Sweeperplate Impact	:	No

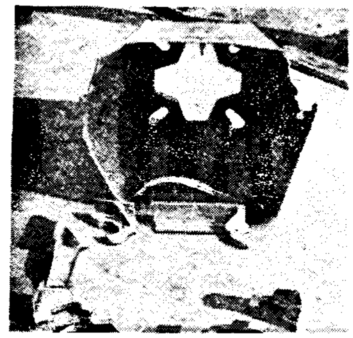


Test 1147-214

Test Description	:	Modified (1B2)
Modification	:	This modification consisted of cutting each corner starting at the weld joint and going down through approximately ½ of the thickness of the section.
Pole Type	:	36 ft (11.0m) aluminum
Mounting Washers	:	2 in (5 cm) dia. steel
Special Test Features	:	None
Base Failure	:	The base failed when the front panel broke about 6 in (15.2 cm) up and around the corners to the beltline weld. Most of the beltline weld was broken and the upper section of the base stayed intact.
Momentum Change	:	964 lb-sec (4288 Ns)
Peak Deceleration	:	15 g's
Time to Peak Decel.	:	.066 sec
Impact Duration	:	.087 sec

Honeycomb Crush	:	17.5 in (44.5 cm)
Sweeperplate Impact	:	No



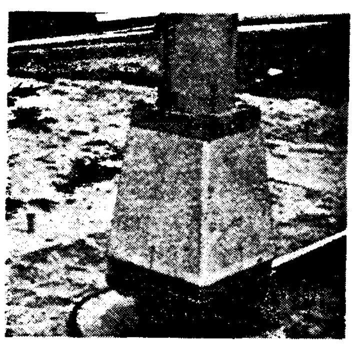
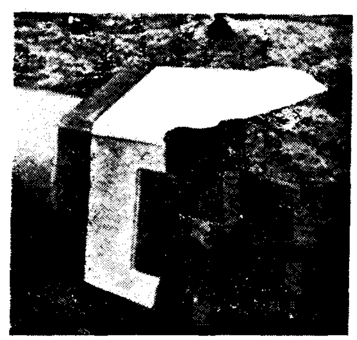


Test 1147-216

Test Description	:	Modified (1B3)
Modification	:	Eight vertical slots (2 per side) were cut in the lower section up to the beltline weld. Each cut was terminated in a 3/8 in (9.5 mm) hole and located 5 in (12.7 cm) in from the corner. A hole was also drilled into each mounting lug closure so it could break out easily.
Pole Type	:	36 ft (11.0 m)
Mounting Washers	:	3 in (5cm) dia. steel
Special Test Features	:	None
Base Failure	:	The base failed similarly to base line tests. The front panel broke out about 6 in (15.2 cm) up. This break went around each front corner to the weld line. Most of the belt line failed. The upper section stayed intact.
Momentum Change	:	946 lb-sec (4208 Ns)
Peak Deceleration	:	25 g's
Time to Peak Decel.	:	.061 sec
Impact Duration	:	.085 sec
Honeycomb Crush	:	17.5 in (44.5 cm)
Sweeperplate Impact	:	No


Test 1147-217

Test Description	:	Modified (1B4)
Modification	:	Four centered vertical side cuts, each terminated in a 3/8" hole. The door side cut stopped at the beltline weld while the 3 others were 5" high. Each hold down lug closure received 2 relief holes to facilitate lug opening.
Pole Type	:	40 ft MH aluminum
Mounting Washers	:	Rectangular steel
Special Test Features	:	None
Base Failure:	:	The upper section broke into several pieces. The lower section also broke but remained fastened to the foundation.
Momentum Change	:	892 lb-sec (film data)
Impact Duration	:	.16 sec (film data)
Honeycomb Crush	:	17.5 in (43.2 cm)

Test 1147-226

Test Description	:	Modified (1B1)
Modification	:	Same as 1147-207
Pole Type	:	36 ft (11.0 m) aluminum
Mounting Washers	:	3 in x 3/8 in (7.6 cm x .95 cm) thick round steel
Special Test Features	:	None
Base Failure	:	The base failed by breaking the front lugs away from the base. These lugs remained on the foundation after the test. The impact side of the front section was caved in, but most of the base stayed intact.
Momentum Change	:	808 lb-sec (3594 Ns)
Peak Deceleration	:	12.0 g's
Time to Peak Decel.	:	.065 sec
Impact Duration	:	.073 sec
Honeycomb Crush	:	17 in (43.2 cm)
Sweeperplate Impact	:	No

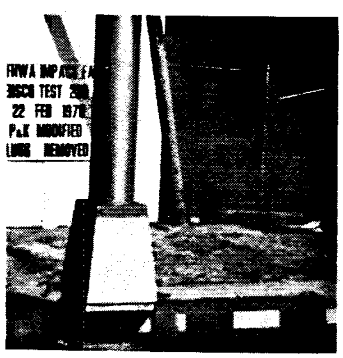

Test 1147-232

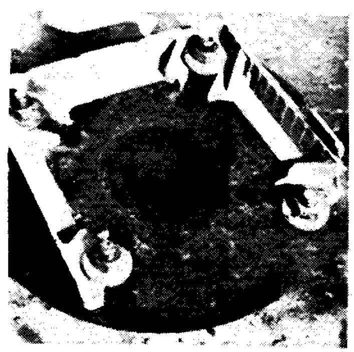
Test Description	:	Modified (1B5)
Modification	:	Closed mounting slots were opened
Pole Type	:	36 ft (11 cm) aluminum
Mounting Washers	:	3 in x 3/8 in (7.6 cm x .95 cm) thick round steel
Special Test Features	:	None
Base Failure	:	The base failed by breaking off the two front lugs and bending up the lower half of the upper section on the impact side. About 75% of the beltline weld was fractured.
Momentum Change:	:	877 lb-sec (3901 Nm)
Peak Deceleration	:	13.8 g's
Time to Peak Decel.	:	.061 sec
Impact Duration	:	.087 sec

Honeycomb Crush : 17.5 in (44.5 cm)
Time to Peak Decel. : .061 sec
Impact Duration : .087 sec
Honeycomb Crush : 17.5 in (44.5 cm)
Sweeperplate Impact : No

Test 1147-233

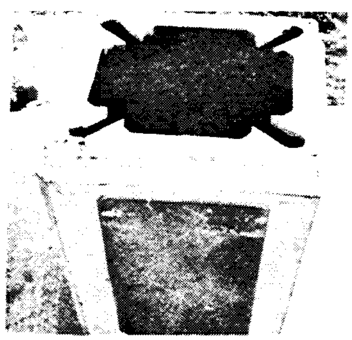
Test Description : Modified (1B5)
Modification : Same as test 1147-232
Pole Type : 36 ft (11.0 m) aluminu;m
Mounting Washers : 3 in x 3/8 in (7.6 cm x .95 cm) thick round steel
Special Test Features : None
Base Failure : The beltline weld was completely fractured leaving most of the lower section on the foundation after the impact. The upper section was broken into several large pieces running from the weld to the top of the casting.
Momentum Change : 1084 lb-sec (4882 Ns)
Peak Deceleration : 20.1 g's
Time to Peak Decel. : .064 sec
Impact Duration : .096 sec
Honeycomb Crush : 17.5 in (44.5 cm)
Sweeperplate Impact : Yes

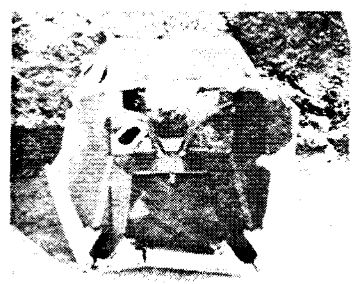




Test 1147-240

Test Description	: Modified (1B6)
Modification	: The closed mounting slots were opened and four short cuts were made starting at the bottom of the lugs and extending outward to the inside edge of the casting where they were terminated in a 3/8 in (9.5 mm) hole.
Pole Type	: 36 ft (11.0 m) aluminum
Mounting Washers	: 3 in x 3/8 in (7.6 cm x .95 cm) thick round steel
Special Test Features	: None
Base Failure	: The front lugs broke out allowing the base to slide off the rear bolts and thus off the foundation. The upper section remained intact with local deformation in the impact zone.
Momentum Change	: 1033 lb-sec (4595 Ns)
Peak Deceleration	: 19.9 g's
Time to Peak Decel.	: .065 sec
Impact Duration	: .085 sec
Honeycomb Crush	: 17.5 in (44.5 cm)
Sweeperplate Impact	: No

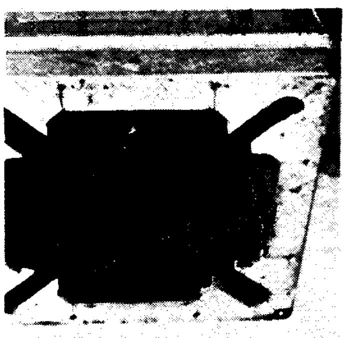




Test 1147-241

Test Description	: Modified (1B7)
Modification	: The mounting lugs were opened. Short cuts extending from the bottom of the lugs to the inside edge of the casting were made. Eight cuts were also made in the bottom flange. Each cut was 5½ in (13.9 cm) from the corner and extended into the flange to the inside edge of the casting.

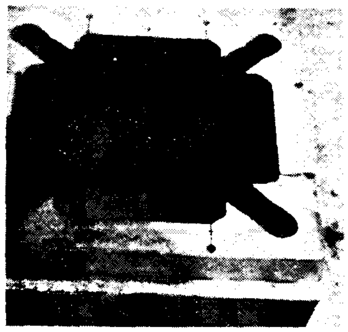
Pole Type	:	36 ft (11.0 m) aluminum
Mounting Washers	:	3 in x 3/8 in (7.6 cm x .95 cm) thick round steel
Special Test Features	:	None
Base Failure	:	Very controlled and as expected with the front panel breaking out from the two opened and cut lugs across the front. The back two lugs twisted and slid off the foundation.
Momentum Change	:	677 lb-sec (3011 Ns) (film data)
Honeycomb Crush	:	17 in (43.2 cm)
Static Load	:	24670 ft-lb (33,452 Nm) (Test 1147-S215)
Static Failure	:	Similar to base line test. The upper pole mounting lugs pulled out of the casting. The modification was not affected.

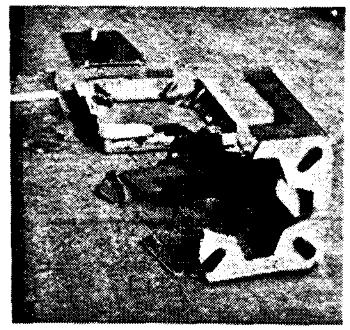


Test 1147-255

Test Description	:	Modified (1B8)
Modifcation	:	Same as in test 1147-241 except that the short corner cuts were not added.
Pole Type	:	33 ft-4 in (10.2m) aluminum
Mounting Washers	:	3 in x 3/8 in (7.6 cm x .95 cm) thick round steel
Special Test Features	:	None
Base Failure	:	The upper section completely severed from the lower section at the baseline weld. The upper section also broke into several large pieces.
Momentum Change	:	1078 lb-sec (4795 Ns)
Peak Deceleration	:	18.9 g's

Time to Peak Decel.	:	.061 sec
Impact Duration	:	.076 sec
Honeycomb Crush	:	17.5 in (44.5 cm)
Sweeperplate Impact	:	Yes





BASE TYPE 1C - UNION METAL 2851

Specifications (1C)

Manufacturer	:	Union Metal Mfg. Co.
Model No.	:	2851
Configuration	:	One piece tapered skirt
Height	:	20 in (50.8 cm)
Upper Bolt Circle	:	10 - 12½ in (25.4-31.8 cm)
Lower Bolt Circle:	:	15-17 in (38.1-43.2 cm)
Alloy & Heat Treat	:	356 T6
Special Features	:	None

Test Series Description (1C)

This transformer base is quite similar in design to the Hapco 45964 (1A). However, the anchor bolt slots are deeper because of the multiple bolt pattern arrangement. This differnece was found to be insignificant in later tests. In the baseline test, Test 1147-222, the transformer base broke into many pieces and produced a momentum change of 1196 lb-sec (5320 Ns). Due to the similarity of this base with type 1A, the first modification to be tried was two 4 in (10.2 cm) high vertical slots on each skirt as in Test 1147-215 (1A). This modification was tested in Tests 1147-223 and -224 and found to pass the 1100 lb-sec (4890 Ns) criteria. However, the fracture was not controlled as in the Hapco tests. One of the reasons for this was the deeper anchor bolt slots which prevented the base from easily sliding off of the rear under bolts. For these reasons further research was carried out to find a better modification.

In Test 1147-228 a second modification similar to that used in Test 1147-207 (1B1) was tested. This consisted of 1¼ in (3.2 cm) vertical cuts through each corner. The T-base breakaway performance was good, with the corners splitting open allowing the base to disengage from the anchor bolts. Although this modification worked, the momentum change of 855 lb-sec (3803 Ns) was above the desired level of 750 lb-sec (3340 Ns). Therefore, further research was conducted to find a better modification. A second objective was to find a modification that could be incorporated into a mold change.

Tests 1147-229 and -235 investigated a new approach to T-base modifications. In these tests the lower mounting lugs were essentially removed from the casting with the exception of a small ridge adjacent to the inner wall. Special steel clamps

(Fig. 62) were used to hold the base to the foundation. The four clamps were made to fit together in the bottom of the base and prevent movement once in place. A short sawcut was also made in each corner to act as a fracture starter. The T-base performed well in both tests with momentum changes of 665 lb-sec (2958 Ns) and 724 lb-sec (3220 Ns), respectively. Due to high manufacturing costs of this modfiication, additional modifications were investigated. In Test 1147-230 the corner sawcut was eliminated from the previous modification and resulted in a test that stopped the pendulum.

In Tests 1147-242 and -244 the anchor bolt slots were deepened to within ½ in (1.27 cm) of the outside corner wall. Both tests gave similar results, with momentum changes of 992 lb-sec (4412 Ns) and 921 lb-sec (4097 Ns), respectively. In both cases the base fractured by breaking out the impact side panel starting at the deepened mounting slots. The fractures were controlled and repeatable. Although the momentum changes were above the desired level, the simplicity of the modification coupled with the repeatability of the fracture brought about the conclusion that this was the best modification.

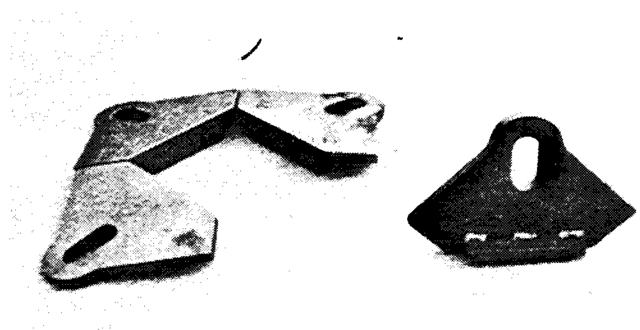
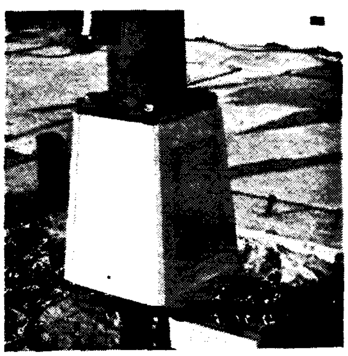


Fig. 62
Special Steel Clamps

TEST RESULTS (1C)

Test 1147-222

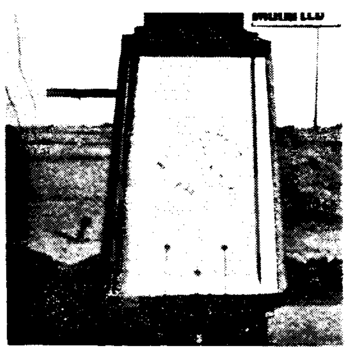
Test Description	:	Baseline
Pole Type	:	45 ft (13.7 m)
Mounting Washers	:	2 in (5.1 cm) round steel
Special TEst Features	:	None
Base Failure	:	The base failed by breaking across the front panel, down and around the front corners and along the left side at about 4 in (10.2 cm) above the bottom. The base broke into many pieces in an uncontrolled fashion.
Momentum Change	:	1196 lb-sec (5320 Ns)
Peak Deceleration	:	10.3 g's
Time to Peak Decel.	:	.063 sec
Impact Duration	:	.090 sec
Honeycomb Crush	:	17.5 in (44.5 cm)
Sweeperplate Impact	:	Yes
Static Strength	:	29,850 lb-ft (40477 Nm) (Test 1147-S203)
Static Failure	:	Base failed by breaking the lower hold down lugs which were in tension.



Test 1147-223

Test Description	:	Modified (1C1)
Modfication	:	This modification consisted of two 4 in (10.2 cm) high vertical cuts on each side (except the door side), 5½ in (14 cm) in from the corner. Each slot was terminated at the top with a 3/8 in (9.5 mm) hole.

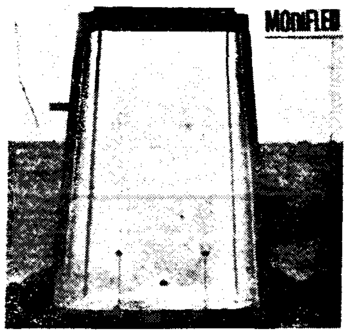
Pole Type	: 45 ft (13.7 m) steel
Mounting Washers	: 2 in (5.1 cm) round steel
Special Test Features	: None
Base Failure	: Failure occurred by fracture running diagonally upward from the top of the vertical cuts toward the corners, then across the impact panel at about 12 in (30.5 cm) high. Sweeperplate impact broke this panel away. The base slid off the rear of the foundation by breaking one rear lug, then twisting off.
Momentum Change	: 911 lb-sec (4052 Ns)
Peak Deceleration	: 20.5 g's
Time to Peak Decel.	: .064 sec
Impact Duration	: .080 sec
Honeycomb Crush	: 17.5 in (44.5 cm)
Sweeperplate Impact	: Yes

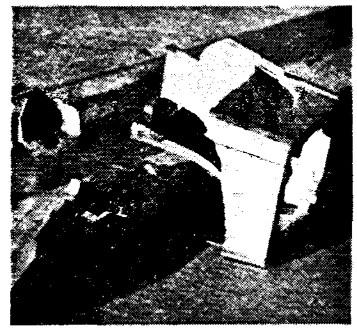


Test 1147-224

Test Description	: Modified (1C1)
Modification	: Same as Test 1147-223
Pole Type	: 45 ft (13.7 m) steel
Mounting Washers	: 2 in (5.1 cm) round steel
Special Test Features	: Repeat of Test 1147-223
Base Failure	: The fracture was similar to Test 1147-223. The base broke into several larger pieces. All cuts were activated and the front hold down lugs were left behind on the foundation.
Momentum Change	: 946 lb-sec (4208 Ns)
Peak Deceleration	: 20.5 g's
Time to Peak Decel.	: .062 sec
Impact Duration	: .095 sec

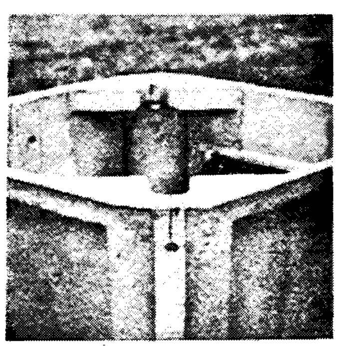
Honeycomb Crush	: 17.5 in (44.5 cm)
Sweeperplate Impact	: Yes
Comment	: Although this modification passed the 1100 lb-sec (4893 Ns) criteria, it was hoped that a better modification could be found.

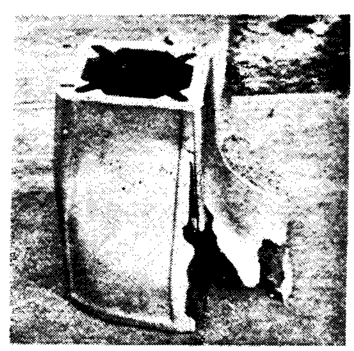




Test 1147-228

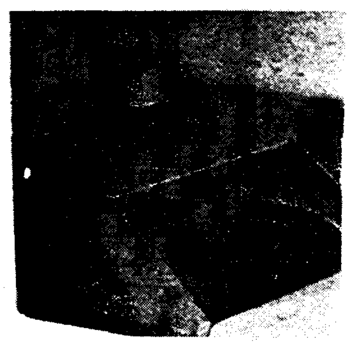
Test Description	: Modified (1C2)
Modification	: The modification consisted of cutting four vertical slots (one in each corner). Each slot was 1¼ in (3.2 cm) high and was terminated in a 3/8 in (9.5 mm) hole.
Pole Type	: 45 ft (13.7 m) steel
Mounting Washers	: 2 in (5.1 cm) round steel
Special Test Features	: None
Base Failure	: The base failed as expected by breaking out the corners via the corner cuts. The impact panel folded up and the base slid off the foundation.
Momentum Change	: 855 lb-sec (3803 Ns)
Peak Deceleration	: 10.2 g's
Time to Peak Decel.	: .062 sec
Impact Duration	: .102 sec
Honeycomb Crush	: 17.0 in (43.2 cm)
Sweeperplate Impact	: No

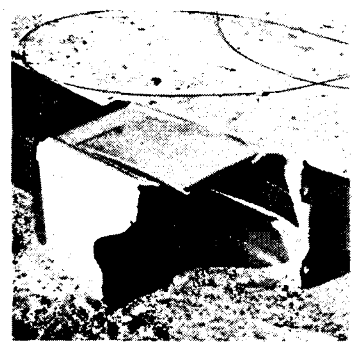




Test 1147-229

Test Description	:	Modified (1C3)
Modification	:	The mounting lugs were removed and saw cuts were made from the bottom of the lug to the inside edge of the casting. Special hold down clamps were fabricated to hold the base in place.
Pole Type	:	45 ft (13.7 m) steel
Mounting Washers	:	Special triangular steel clmaps
Special Test Features	:	None
Base Failure	:	Base impact resulted in a controlled failure. The front panel and one side panel broke away allowing the base to slide off the base and around the hold down clamps.
Momentum Change	:	665 lb-sec (2958 Ns)
Peak Deceleration	:	8.5 g's
Time to Peak Decel.	:	.052 sec
Impact Duration	:	.077 sec
Honeycomb Crush	:	16 in (40.6 cm)
Sweeperplate Impact	:	No

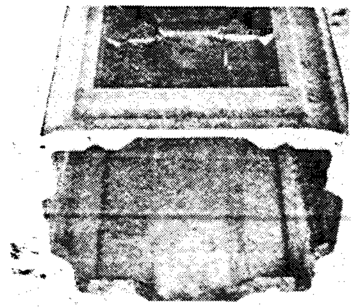


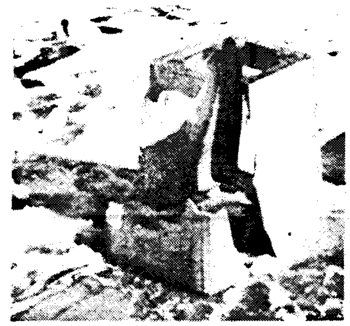


Test 1147-230

Test Description	:	Modified (1C4)
Modification	:	The mounting lugs were removed and replaced with hold down clamps. No corner cuts were made as in Tests 1147-229 and -235.
Pole Type	:	45 ft (13.7 m) steel
Mounting Washers	:	Special triangular steel clamps

Momentum Change	:	2084 lb-sec (9269 Ns)
Peak Deceleration	:	25 g's
Time to Peak Decel.	:	.077 sec
Impact Duration	:	.102 sec
Honeycomb Crush	:	17.5 in (44.5 cm)
Sweeperplate Impact	:	No



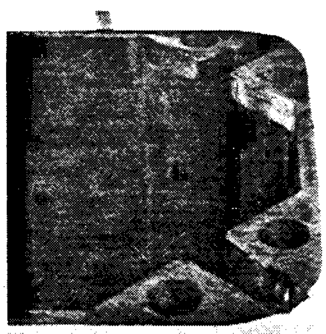


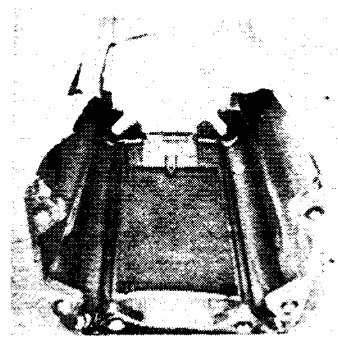
Test 1147-235

Test Description	:	Modified (1C3)
Modification	:	Same as Test 1147-229
Pole Type	:	45 ft (13.7 m) steel
Mounting Washers	:	Special triangular steel clamps
Special Test Features	:	Repeat of Test 1147-229
Base Failure	:	The base failed very similarly to Test 1147-229.
Momentum Change	:	724 lb-sec (3220 Ns)
Peak Deceleration	:	10.6 g's
Time to Peak Decel.	:	.064 sec
Impact Duration	:	.076 sec
Honeycomb Crush	:	17 in (43.2 cm)
Sweeperplate Impact	:	No

Test 1147-242

Test Description	: Modified (1C5)
Modification	: Each mounting lug was deepened to within ½ in (1.3 cm) of the outside of the casting.
Pole Type	: 45 ft (13.7 m)
Mounting Washers	: 3 in x 3/8 in (7.6 cm x .95 cm) thick round steel
Special Test Features	: None
Base Failure	: The base failed as expected by breaking out the front panel via the deepened mounting slots. This allowed the base to slide off the foundation.
Momentum Change	: 992 lb-sec (4412 Ns)
Peak Deceleration	: 20.8 g's
Time to Peak Decel.	: .063 sec
Impact Duration	: .073 sec
Honeycomb Crush	: 17.5 in (44.5 cm)
Sweeperplate Impact	: No
Static Load	: 32,870 lb-ft (44572 Nm) (Test 1147-S206)
Static Failure	: The base failed very similarly to the baseline test. The modified base was 10% stronger than the baseline and the modification was not involved in the failure.

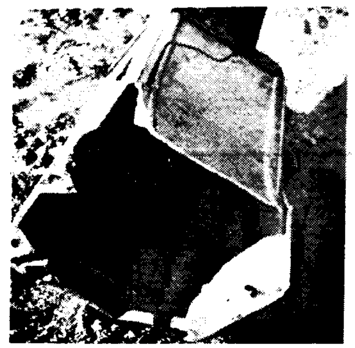




Test 1147-244

Test Description	: Modified (1C5)
Modification	: Same as Test 1147-242
Pole Type	: 45 ft (13.7 m) steel
Mounting Washers	: 3 in x 3/8 in (7.6 cm x .95 cm) thick round steel
Special Test Features	: Repeat of Test 1147-242

Base Failure	:	The base failed very similarly to Test 1147-242.
Momentum Change	:	921 lb-sec (4097 Ns)
Peak Deceleration	:	21.7 g's
Time to Peak Decel.	:	.065 sec
Impact Duration	:	.101 sec
Honeycomb Crush	:	17.5 in (44.5 cm)
Sweeperplate Impact	:	No



BASE TYPE 1D - POLE LITE TB20-8

Specifications (1D)

Manufacturer	:	Pole Lite
Model No.	:	TB20-8
Configuration	:	One piece tapered skirt
Height	:	20 in (50.8 cm)
Upper Bolt Circle	:	9½-13 in (24.1-33 cm)
Lower Bolt Circle	:	15 in (38.1 cm)
Alloy & Heat Treat	:	356-T6
Special Features	:	None

Test Series Description (1D)

This transformer base is similar in design to the Union Metal 2851. It is a one piece casting which tapers from base to top. Deep anchor bolt slots for multiple bolt circles are incorporated. Baseline tests of this base showed that the design had just adequate performance, however, it was felt that improvements could be made. Two modifications, proven on the similar base designs 1A and 1C were tested. The first modification (Test 1147-238) consisted of two 3 in (7.6 cm) high vertical sawcuts from the bottom, 5½ in (14 cm) in from each corner on all sides but access door side. The cuts terminated in 3/8 in (.95 cm) dia. holes. Although this test yielded a 787 lb-sec (3500 Ns) momentum change, the fracture was not as desired and therefore, felt to be non-repeatable. The second modification (Test 1147-243) consisted of deepening the anchor bolt slots to within 7/8 in (2.2 cm) of the outside corner edge of the base. The momentum change for this test was 649 lb-sec (2887 Ns) with the fracture pattern originating at the deepened mounting slots, running up the corner and across the impact face. Impact performance was excellent but the static momentum capability decreased substantially, from 34,610 lb-ft (4693 Nm) to 13,940 lb-ft (18903 Nm).

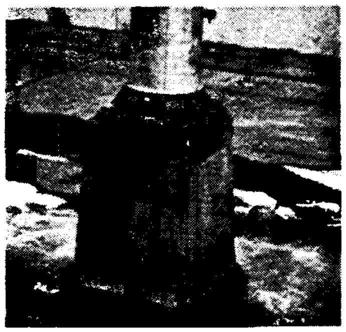
Two more substantial anchor bolt washers were substituted and tested statically, although only slight improvements could be obtained. Therefore, in Test 1147-263, variation on the deepened mounting slot idea was tried. In this case, ½ in (1.27 cm) dia. holes were drilled at a point centered ¼ in (.63 cm) outboard of the anchor bolt slots. This effectively extended the slots by ½ in (1.27 cm). This test yielded a momentum change of only 692 lb-ft (3078 Ns) while increasing the static momentum capacity to 28,270 lb-ft (38,334 Nm). The fracture was also very controlled with all deepened slots breaking through the corners.

<u>Test Results (1D)</u>

Test 1147-236

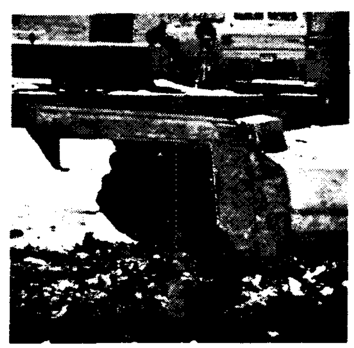
Test Description	:	Baseline
Pole Type	:	33 ft-4 in (10.1 m) aluminum
Mounting Washers	:	2 in (5.1 cm) round steel
Special Test Features	:	None
Base Failure	:	The front panel broke across and through the mounting lugs. One side panel was completely broken off. One back lug also broke away.

Momentum Change	:	1022 lb-sec (4546 Ns) (film data)
Honeycomb Crush	:	17.5 in (44.5 cm)
Static Load	:	34,610 lb-ft (46931 Nm) (Test 1147-S216)
Static Failure	:	The base failed when the lower hold down lugs pulled away from the remainder of the base.



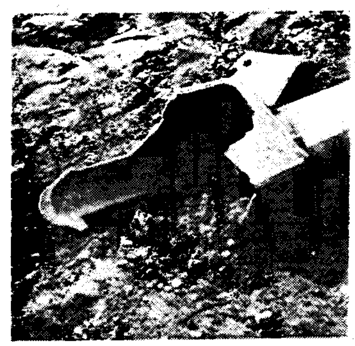
Test 1147-237

Test Description	:	Baseline
Pole Type	:	33 ft (10.1 m) aluminum
Mounting Washer	:	2 in (5.1 cm) round steel
Special Test Features	:	Repeat of test 1147-236
Base Failure	:	Very similar to Test 1147-236
Momentum Change	:	937 lb-sec (4168 Ns) (film data)
Honeycomb Crush	:	17.5 in (44.5 cm)



Test 1147-238

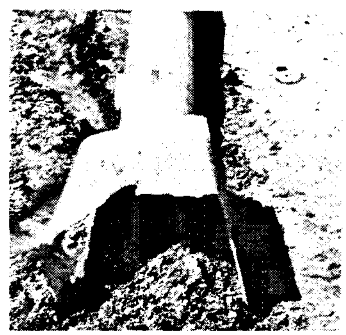
Test Description	:	Modified (1D1)
Modification	:	Two 3 in (7.6 cm) high vertical side cuts, 5½ in (14 cm) in from each corner on 3 sides with each cut terminated in a 3/8 in (9.5 mm) hole. (No cuts on the door side.)
Pole Type	:	33 ft-4 in (10.1 m) aluminum
Mounting Washers	:	2 in (5.1 cm) round steel
Special Test Features	:	None
Base Failure	:	The base failed by breaking around the front holddown lugs via the modification. One front lug was left on the foundation after the test. The base fractured around its circumference except between the side cuts. Large side sections were broken away.
Momentum Change	:	787 lb-sec (3501 Ns)
Peak Deceleration	:	7.6 g's
Time to Peak Decel.	:	.055 sec
Impact Duration	:	.086 sec
Honeycomb Crush	:	17.5 in (44.5 cm)
Sweeperplate Impact	:	Yes



Test 1147-243

Test Description	:	Modified (1D2)
Modification	:	Each anchor bolt slot was deepened to within 7/8 in (2.2 cm) of the outside edge of the casting.
Pole Type	:	33 ft-4 in (10.1m) aluminum
Mounting Washers	:	3 in x 3/8 in (7.6cm x .95 cm) thick round steel

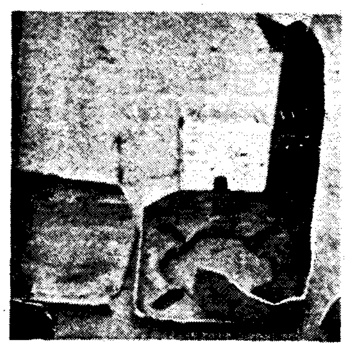
Special Test Features	:	None
Base Failure	:	The base failed by breaking out all deepened lugs. The front broke across and through each corner. The back corners broke allowing the base to slide off the foundation.
Momentum Change	:	649 lb-sec (2887 Ns)
Peak Deceleration	:	8.9 g's
Time to Peak Decel.	:	.062 sec
Impact Duration	:	.082 sec
Honeycomb Crush	:	17.5 in (44.5 cm)
Sweeperplate Impact	:	No
Static Load	:	13,940 lb-ft (18903 Nm) (Test 1147-S209)
Static Failure	:	Fracture lines ran from the deepened mounting lugs up to the lower edge of the door opening. This is much lower strength than baseline so the modification was dropped.



Test 1147-263

Test Description	:	Modified (1D3)
Modification	:	Four ½ in (.3 cm) holes were drilled so they extended the effective depth of the mounting lugs ½ in in (1.3 cm). The holes were centered ¼ in (.64 cm) in from the bottom of the lug.
Pole Type	:	42 ft-6 in (13.0 m) aluminum
Mounting Washers	:	3 in (7.6 cm) round steel
Special Test Features	:	None

Base Failure	:	The base failed by breaking through the deepened mounting lugs, allowing the base to slide off the foundation.
Momentum Change	:	692 lb-sec (3078 Ns)
Peak Deceleration	:	15.5 g's
Time to Peak Decel.	:	.057 sec
Impact Duration	:	.070 sec
Honeycomb Crush	:	17.5 in (44.5 cm)
Sweeperplate Impact	:	Yes
Static Load	:	28,270 lb-sec (38334 Nm) (Test 1147-S217)
Static Failure	:	Base failed by breaking through the deepened mounting lugs and then diagonally up toward the bottom of the door opening.



BASE TYPE 1E - UNION METAL 2852

Specification (1E)

Manufacturer	:	Union Metal Mfg. Co.
Model No.	:	2852
Configuration	:	One piece tapered skirt
Height	:	20 in (50.8 cm)
Upper Bolt Circle	:	11-13½ in (27.9-34.3 cm)
Lowr Bolt Circle	:	17¼ in (43.8 cm)
Alloy & Heat Treat	:	356-T6
Special Features	:	Uses special cast iron trapezoidal hold down clamps

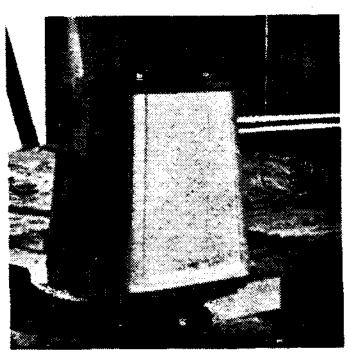
Test Series Description (1E)

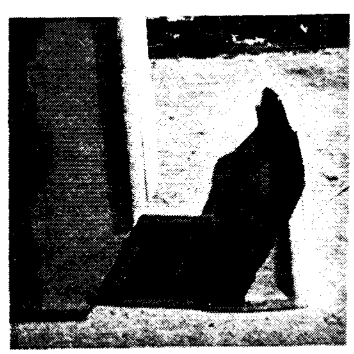
This tranformer base has a unique anchoring system which consists of four cast iron trapezoidal shaped clamps resting on small ridges at the lower inside corners of the base. This feature allows only a single lower bolt circle to be used which is an asset in achieving good breakaway characteristics for this T-base. In two tests of unmodified bases, excellent repeatable breakaway performance was achieved. Interestingly, this base is considered the more heavy duty of the two small Union Metal bases, the 2851 and 2852. Since the small ridges are confined to the corner of the base, they do not reinforce the lower edges of the skirt as found in most T-bases. This allows fracture to initiate easily, and once fracture has begun the clamps are easily disengaged allowing the base to come free of the foundation.

Test Results

Test 1147-221

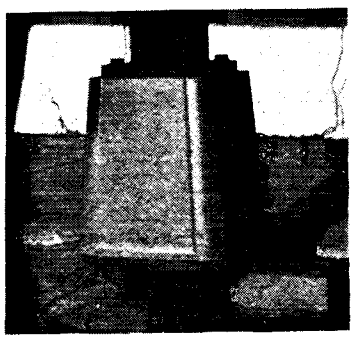
Test Description	:	Baseline
Pole Type	:	45 ft (13.7 m) steel
Mounting Washers	:	Special trapezoidal cast iron clamps
Special Test Features	:	None
Base Failure	:	The fracture started on each side about 4 in (10.2 cm) back from the front, propagated diagonally up around each front corner, then across the impact panel.
Momentum Change	:	639 lb-sec (2842 Ns)
Peak Deceleration	:	8.3 g's
Time to Peak Decel.	:	.057 sec
Impact Duration	:	.080 sec
Honeycomb Crush	:	16.5 in (41.9 cm)
Sweeperplate Impact	:	No

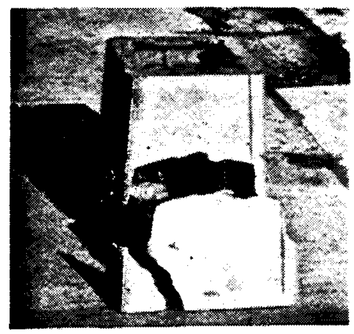




Test 1147-225

Test Description	:	Baseline
Pole Type	:	45 ft (13.7 m) steel
Mounting Washers	:	Special trapezoidal cast iron clamps
Special Test Features	:	Repeat of Test 1147-221
Base Failure	:	Similar to Test 1147-221
Momentum Change	:	672 lb-sec (2989 Ns)
Peak Deceleration	:	10.4 g's
Time to Peak Decel.	:	.059 sec
Impact Duration	:	.080 sec
Honeycomb Crush	:	17.0 in (43.2 cm)
Sweeperplate Impact	:	No





BASE TYPE 2A - HAPCO 44681

Specifications (2A)

Manufacturer	:	Hapco
Model No.	:	44681
Configuration	:	One piece tapered skirt
Height	:	24 in (61 cm)
Upper Bolt Circle	:	15 in (38.1 cm)
Lower Bolt Circle	:	22 in (55.9 cm)
Alloy & Heat Treat	:	356-T6
Special Features	:	None

Test Series Description (2A)

The transformer base is Hapco's largest with very shallow anchor bolt slots on a 22 in (56 cm) bolt circle. Tests 1147-245 and -246 are of unmodified bases.

In Test 1147-245 the fracture line was very simple. The lower edge of the impacted panel broke loose in the lower corners and folded forward. On one side the fracture went through the mounting bolt slot on the bottom, while on the other side the break started on the lower edge of the side near the corner. The momentum change for this test was 840 lb-sec (3736 Ns).

In Test 1147-246 the fracture lines were similar to Test 1147-245. The lower section of the front panel broke off about 6 in (15.2 cm) up from the base. The fracture started on each side about 2 in (5.1 cm) from the front mounting lugs, ran diagonally up and over the mounting lugs, and across the front. This section was broken by the sweeperplate at 3 in (7.6 cm) up. The momentum change for this test was 948 lb-sec (4217 Ns).

Each test had a sweeperplate impact. In Test 1147-246 it accounted for 25% of the momentum change, while in Test 1147-246 it was 7%.

Test 1147-249 was a test of a modified type 2A base. The anchor bolt slots were deepened to within approximately 1-1/8 in (2.9 cm) from the outside edge. This test was run in an attempt to improve an already acceptable base, but showed no improvement on the momentum change when compared with the base line tests. The momentum change increased as a result of a higher peak deceleration which has not been understood at this time. Fracture was as expected with the impacted side breaking through the deepened mounting lugs. The fracture ran across this side about 4 in (10.2 cm) up from the base plate. There was no sweeperplate impact in this test.

Test Results (2A)

Test 1147-245

Test Descripotion	:	Baseline
Pole Type	:	50 ft-9in (15.5 m) aluminum
Mounting Washers	:	Al. trapezoidal
Special Test Features	:	None
Base Failure	:	The base failed when the front panel broke about 6 in (15.2 cm) up, then diagonally around the corner to the bottom just around the corner. This allowed the base to slide off the foundation.
Momentum Change	:	788 lb-sec (3505 Ns)
Peak Deceleration	:	10.8 g's
Time to Peak Decel.	:	.067 sec
Impact Duration	:	.077 sec
Honeycomb Crush	:	17.5 in (44.5 cm)
Sweeperplate Impact	:	Yes

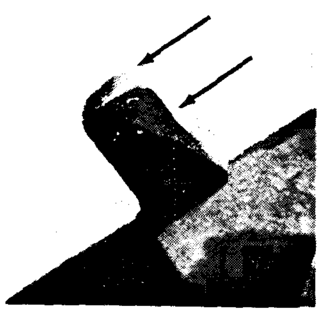
Test 1147-246

Test Description	:	Baseline
Pole Type	:	50 ft-9 in (15.5 m) aluminum
Mounting Washers	:	Al. Trapezoidal
Special Test Features	:	None
Base Failure	:	This base failed very similarly to Test 1147-245. The front panel broke away with the fracture running just around each front corner. This is a repeatable failure.

Momentum Change	: 948 lb-sec (4217 Ns)
Peak Deceleration	: 24.7 g's
Time to Peak Decel.	: .067 sec
Impact Duration	: .077 sec
Honeycomb Crush	: 17.5 in (44.5 cm)
Sweeperplate Impact	: Yes

Test 1147-249

Test Description	: Modified (2Al)
Modification	: Each mounting lug was deepened so it was within 1-1/8 in (2.9 cm) of the outside edge of the casting.
Pole Type	: 50 ft-9 in (15.5 m) aluminum
Mounting Washer	: Al. trapezoidal
Special Test Features	: None
Base Failure	: Here again as in both baseline tests, the fracture was across the front panel but in the test it ran through the deepened mounting slots instead of around them.
Momentum Change	: 1060 lb-sec (4715 Nm)
Peak Deceleration	: 22.2 g's
Time to Peak Decel.	: .067 sec
Impact Duration	: .083 sec
Honeycomb Crush	: 17.5 in (44.5 cm)
Sweeperplate Impact	: No



BASE TYPE 2B - PFAFF & KENDALL TB4

Specifications (2B)

Manufacturer	:	Pfaff & Kendall
Model Number	:	TB4
Configuration	:	Two piece casting with belt line weld
Height	:	20 in (50.8 cm)
Upper Bolt Circle	:	15-16 in (38.1-40.6 cm)
Lower Bolt Circle	:	18-20 in (45.7-50.8 cm)
Alloy & Heat Treat	:	356-T6
Special Features	:	Large version of TB2A(1B)

Test Series Description (2B)

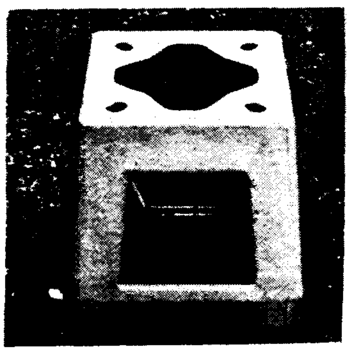
The design of this transformer base is very similar to the P&K TB2A design (1B) except that is is much larger. The baseline test of this base produced a momentum change of 1464 lb-sec (6512 Ns). Knowledge gained with the TB2A base was transferred to this one. Tests 1147-248 and -264 utilized the bottom rib cuts with the opened anchor bolt slots. The corner starter cuts were left out to check if they would be needed on this large base. In Test 1147-248 it appeared that this was true since the momentum change was reduced to 913 lb-sec (4061 Ns). However, in Test 1147-264 a momentum change of 1182 lb-sec (5258 Ns) was recorded proving that the corner starter cuts were indeed required. Therefore, tests 1147-265 and -266 were conducted with T-bases utilizing the corner starter cuts similar to modification 1B7 and the TB2A base.

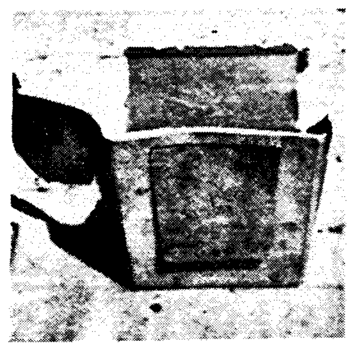
The bases failed as expected by breaking out the weakened corners on the impact side. The fractures ran through the front corners, up along the front corners and across the impact side at a height of 12 in (30.5 cm). One side of the base was broken away. The sweeperplate impacted the remaining front panel. The momentum changes were 833 lb-sec (3705 Ns) and 982 lb-sec (4368 Ns), respectively.

Test Results

Test 1147-247

Test Description	:	Baseline
Pole Type	:	50 ft-9 in (15.5 m) aluminum
Mounting Washers	:	2 in (5.1 cm) dia. steel
Special Test Features	:	None
Base Failure	:	The base was completely broken around the beltline weld, with the lower section broken into several pieces. The sides of the upper section were torn loose.
Momentum Change	:	1464 lb-sec (6512 Ns)
Peak Deceleration	:	24 g's
Time to Peak Decel.	:	.063 sec
Impact Duration	:	.103 sec
Honeycomb Crush	:	17.5 in (434.5 cm)
Sweeperplate Impact	:	No

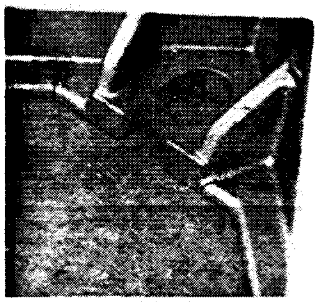


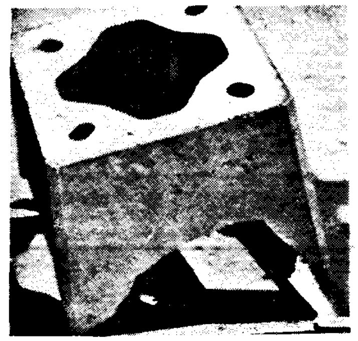


Test 1147-248

Test Description	:	Modified (2B1)
Modification	:	Opened mounting lugs and 8 bottom flange cuts which were 5½ in (14 cm) in from the corners and extended to the inside edge of the casting.
Pole Type	:	50 ft-9 in (15.5m) aluminum
Mounting Washers	:	3 in dia x 3/8 in (7.6 cm x 1.0 cm) thick round steel
Special Test Feastures	:	None
Base Failure	:	The front half of the lower section fractured via the side flange cuts. This allowed the base to slide off the foundation. The upper section stayed intact.

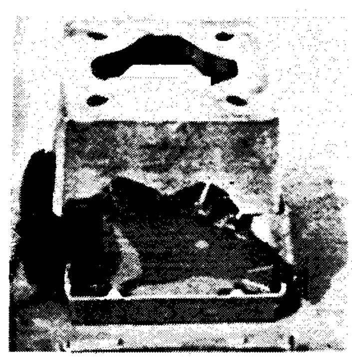
Momentum Change	:	913 lb-sec (4061 Ns)
Peak Deceleration	:	21.5 g's
Time to Peak Decel.	:	.064 sec
Impact Duration	:	.088 sec
Honeycomb Crush	:	17.5 in (44.5 cm)
Sweeperplate Impact	:	No





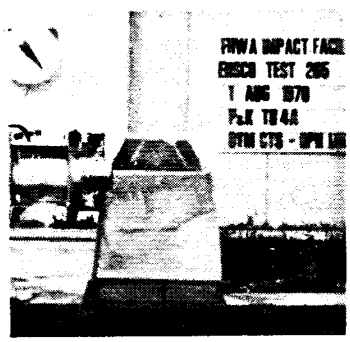
Test 1147-264

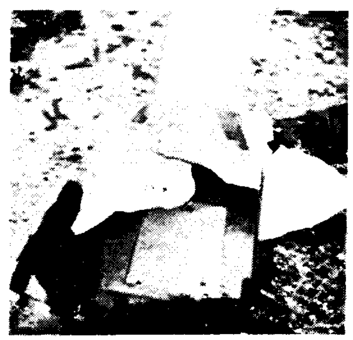
Test Description	:	Modified (2B1)
Modification	:	Same as Test 1147-248
Pole Type	:	50 ft-9 in (15.5 m) aluminum
Mounting Washers	:	3 in dia x 3/8 in (7.6 cm x .95 cm) thick steel
Special Test Features	:	Repeat of Test 1147-248
Base Failure	:	Fracture originated at side rib cuts, forward along weld to corner, up corner and across impact side at 10 in (25.4 cm) height.
Momentum Change	:	1182 lb-sec (5258 Ns)
Peak Deceleration	:	28.6 g's
Time to Peak Decel.	:	.060 sec
Impact Duration	:	.084 sec
Honeycomb Crush	:	17.5 in (44.56 cm)
Sweeperplate Impact	:	Yes



Test 1147-265

Test Description	:	Modified (2B2)
Modification	:	Mounting lugs were opened. Each mounting lug received a cut from the bottom of the lug to the inside edge of the casting. Eight flange cuts (two per side) were made 5½ in (14 cm) in from the corner.
Pole Type	:	50 ft-9 in (15.5 m) aluminum
Mounting Washers	:	3 in dia x 3/8 in (7.6 cm x .95 cm) thick steel
Special Test Features	:	None
Base Failure	:	Base failed as expected. The front lugs broke through the opened and cut lugs and around the impact side The back lugs twisted in, allowing the base to slide off the foundation.
Momentum Change	:	833 lb-sec (3705 Ns)
Peak Deceleration	:	18.9 g's
Time to Peak Decel.	:	.062 sec
Impact Duration	:	.080 sec
Honeycomb Crush	:	17.5 in (44.5 cm)
Sweeperplate Impact	:	Yes

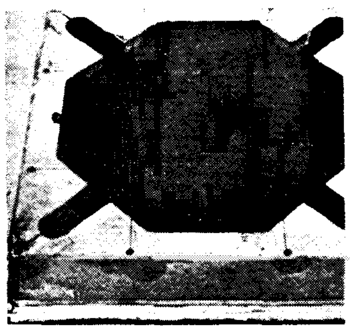


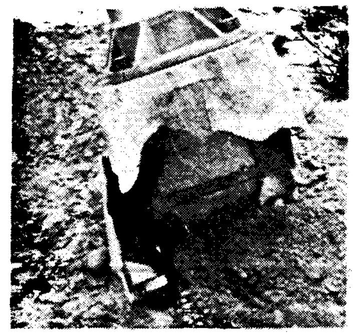


Test 1147-266

Test Description	:	Modified (2B2)
Modification	:	Same as Test 1147-265
Pole Type	:	50 ft-9 in (15.5 m) aluminum
Mounting Washers	:	3 in dia x 3/8 in (7.6 cm x .95 cm) thick steel
Special Test Features	:	None
Base Failure	:	Same as Test 1147-265
Momentum Change	:	982 lb-sec (4370 Ns)
Peak Deceleration	:	24.8 g's

Time to Peak Decel.	:	.060 sec
Impact Duration	:	.072 sec
Honeycomb Crush	:	17.5 in (44.5 cm)
Sweeperplate Impact	:	Yes





BASE TYPE 3A - UNION METAL 2850

<u>Specifications (3A)</u>

Manufacturer	:	Union Metal Mfg. Co.
Model No.	:	2850
Configuration	:	One piece tapered skirt
Height	:	20 in (50.8 cm)
Upper Bolt Circle	:	10½ in (26.7 cm)
Lower Bolt Circle	:	10½ - 12½ in (26.7-31.8 cm)
Alloy & Heat Treat	:	356 T6
Special Features	:	None

This transformer base is Union Metal's smallest base and is used mainly for retrofit in existing installations where no breakaway device was formerly installed. In the baseline test, Test 1147-231, the momentum change was 1058 lb-sec (4706 Ns). The initial impact broke away part of the base leaving a very substantial stub which was impacted by the sweeperplate. The sweeperplate impact accounted for 300 lb-sec (1334 Ns) of the total change in momentum. Due to the relatively high value of the momentum change and the dangers associated with a stub, further research was conducted to find an acceptable modification. The first modification, Test 1147-234, utilized two 4 in (10.2 cm) high sawcuts on each side, similar to the Hapco 45964 (1A4) modification. There was no improvement in impact performance as a result of this modification. The second modification (Test 1147-239) consisted of deepening the anchor bolt slot to within ½ in (1.3 cm) of the outside corner wall. This modification resulted in greatly improved performance with a 705 lb-sec (3136 Ns) momentum change. The base failed by breaking out the lower half of the impacted side as was desired. Test 1147-258 was run on the same base modification except that the angle of impact was at 45° to the side (i.e., directly into the corner). The momentum change in this test was only 580 lb-sec (2580 Ns).

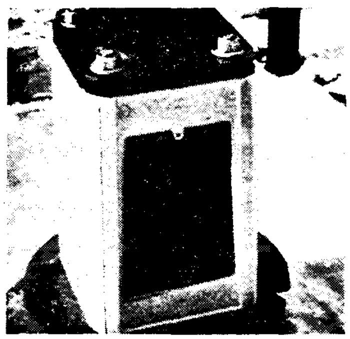
It was recognized that the deepened anchor bolt slots provided an opportunity to increase the foundation bolt circle capabilities of this (or other) base. This adds a greater versatility to the design. This idea was checked out in Tests 1147-251 and -256 where the base was tested on a 15 in (38.1 cm) bolt circle foundation set-up. To accomplish this, special washers which were 2 in (5.1 cm) dia. by 1/8 in (.32 cm) thick with the hole drilled off center by ¼ in (.64 cm) were used. The momentum changes for the two tests were 970 lb-sec (4315 Ns) and 1067 lb-sec (4746 Ns) respectively. The increase in momentum change is attributred to increased difficulty in disengaging from the anchor bolts on the side oppostie of impact.

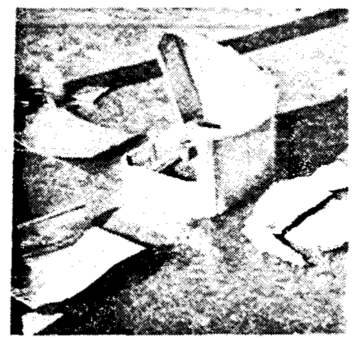
Test Results (3A)

Test 1147-231

Test Description	:	Baseline
Pole Type	:	45 ft (13.7 m) steel
Mounting Washers	:	2 in (5.1 cm) round steel
Special Test Features	:	None
Base Failure	:	During impact the base fractured diagonally across the sides and across the impact side. The front lugs were left on the foundation after the test. The base had a hard time sliding off in the back and broke rear mounting lugs. The main part of the base was broken into several pieces.
Momentum Change	:	1058 lb-sec (4706 Ns)

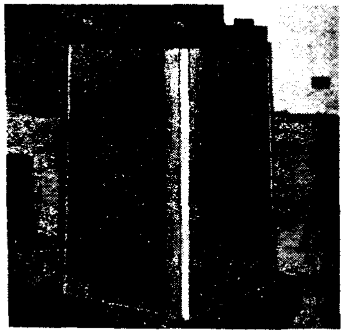
Peak Deceleration	:	12.7 g's
Time to Peak Decel.	:	.065 sec
Impact Duration	:	.111 Sec
Honeycomb Crush	:	17.5 in (44.5 cm)
Sweeperplate Impact	:	Yes
Static Load	:	34,680 lb-ft (47026 Nm) (Test 1147-S202)
Static Failure	:	The base failed when the lower mounting lugs which were in tension broke out.
Fatigue Life	:	Greater than 32,600 cycles (Test 1147-F204)
Failure	:	None. Test was stopped.





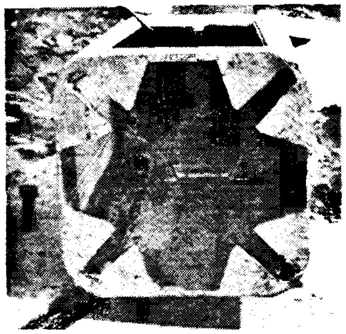
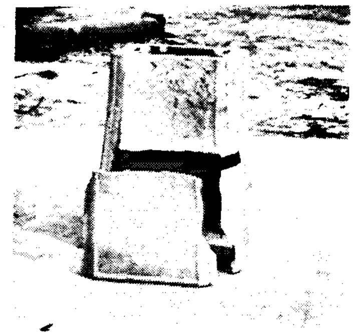
Test 1147-234

Test Description	:	Modified (3A1)
Modification	:	Six 4 in (10.2 cm) high cuts in 3 sides of the base (2 per side). Each cut was 5 in (12.7 cm) in from the corner and terminated in a 3/8 in (.95 cm) hole.
Pole Type	:	45 ft (13.7 m) steel
Mounting Washers	:	3 in dia x 3/8 in (7.6 cm x .95 cm) thick steel
Special Test Feature	:	None
Base Failure	:	This base broke into many pieces. The top half of the base was broken away from the remainder by a fracture running around the base at about 4 in (10.2 cm). The fracture did not propagate as desired, which was to run around the front corners from one sawcut to the next.
Momentum Change	:	1058 lb-sec (4706 Ns)
Peak Deceleration	:	14.9 g's
Time to Peak Decel.	:	.062 sec
Impact Duration	:	.111 sec
Honeycomb Crush	:	17.5 in (44.5 cm)
Sweeperplate Impact	:	Yes



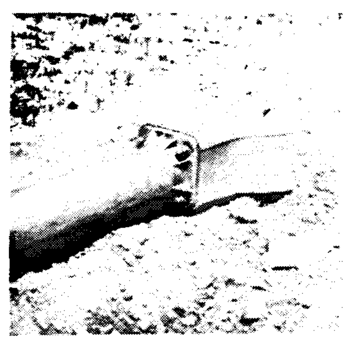
Test 1147-239

Test Description	: Modified (3A2)
Modification	: Each anchor bolt slot was deepened to within ½ in (1.3 cm) of the outside edge of the casting.
Pole Type	: 45 ft (13.7 m) steel
Mounting Washers	: 2 in dia. (5.1 cm) steel
Special Test Features	: None
Base Failure	: The base failed as expected by breaking out the front panel through the corners via the deepened mounting lugs. The back of the base broke out one lug then twisted and slid off the foundation. This was a very controlled failure.
Momentum Change	: 705 lb-sec (3136 Ns)
Peak Deceleration	: 10 g's
Time to Peak Decel.	: .060 sec
Impact Duration	: .087 sec
Honeycomb Crush	: 17.5 in (44.5 cm)
Sweeperplate Impact	: No
Static Load	: 33,790 lb-ft (45819 Nm) (Test 1147-S205)
Static Failure	: The base failed by breaking out the top pole mounting lug which was in tension. The modified static load was 97% of the base line tests.
Fatigue Life	: Greater than 35,264 cycles (Test 1147-F207)
Fatigue Failure	: There was no failure at 35,264 cycles.

Test 1147-251

Test Description	: Modified (3A2)
Modification	: Same as Test 1147-239
Pole Type	: 33 ft-4in (10.1 m) aluminum
Mounting Washers	: Special "off-center hole" round steel
Special Test Features	: Base mounted on a 15 in (38.1 cm) bolt circle instead of the nominal maximum design of 12½ in (31.8 cm)
Base Failure	: The front panel broke through the deepened mounting lugs, up the corners and across the panel. Placing the bolts deep into the slots made it hard for the base to slip out.
Momentum Change	: 970 lb-sec (4315 Ns)
Peak Deceleration	: 19.6 g's
Time to Peak Decel.	: .061 sec
Impact Duration	: .087 sec
Honeycomb Crush	: 17.5 in (44.5 cm)
Sweeperplate Impact	: No

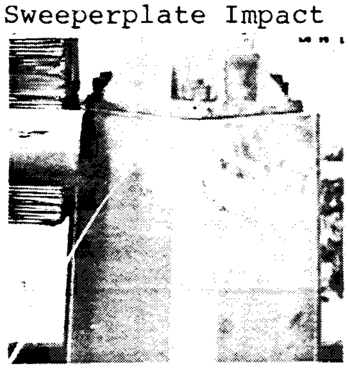
Test 1147-256

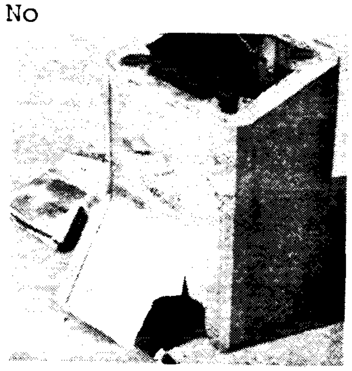
Test Description	: Modified (3A2)
Modification	: Same as Test 1147-239
Pole Type	: 42 ft-6 in (13 m) aluminum
Mounting Washers	: Special "off center hole" round steel

Special Test Features	:	Repeat of Test 1147-251
Base Failure	:	Failure was not as expected since the front lugs did not split open through the deepened lugs. One back lug split open while both broke off the base. The base was generally deformed.
Momentum Change	:	1067 lb-sec (4746 Ns) (film data)
Honeycomb Crush	:	17.5 in (44.5 cm)
Sweeperplate Impact	:	Yes

Test 1147-258

Test Description	:	Modified (3A2)
Modification	:	Same as Test 1147-239
Pole Type	:	42 ft-6 in (13 m) aluminum
Mounting Washers	:	2 in (5.1 cm) round steel
Special Test Features	:	45° hit
Base Failure	:	The base failed as expected with the front lug splitting up the corner. The half of the two side lugs which resisted impact broke away. This was a very controlled impact.
Momentum Change	:	580 lb-sec (2579 Ns)
Peak Deceleration	:	11.4 g's
Time to Peak Decel.	:	.058 sec
Impact Duration	:	.069 sec
Honeycomb Crush	:	17.5 in (44.5 cm)
Sweeperplate Impact	:	No





BASE TYPE 4A - VALMONT BREAK AWAY BASE

Specifications (4A)

Manufacturer	:	Valmont Industries
Model No.	:	Break Away Base
Configuration	:	Four Cast Vertical corners with 12 gauge aluminum sides
Height	:	20 in (50.8 cm)
Upper Bolt Circle	:	10-15 in (25.4-38.1 cm)
Lower Bolt Circle	:	12-17 in (30.5-43.2 cm)
Alloy & Heat Treat	:	356-T6 corners
Special Features	:	Prototype Design

Test Series Description (4A)

This transformer base was a prototype fabricated from a one piece cast aluminum T-base. The center portions of each side of the original base were cut out leaving four corner sections which included upper and lower mounting lugs connected by a corner section. These four corner sections were in turn connected by 12 gauge aluminum panels by six screws per side. The Valmont theory of operation was that during impact the sheet metal sides would easily tear off allowing the four corners to bend over and break off. The bolt circle could also be changed by simply attaching different size side panels.

In Test 1147-261 the impact resulted in all four corners breaking off about 2 in (5.1 cm) from the bottom of the base plus three of the four corners also breaking just below the top. The momentum change was 1113 lb-sec (4951 Ns). In Test 1147-262 the failure was similar with a momentum change of 1617 lb-sec (7192 Ns).

The poor performance was a result of the ductility of the base which could literally "bend over" without fracturing, thus absorbing more energy than the typical brittle T-base. The failure was similar in character to the first modified Hapco 45964 (1A1), Test 1147-204.

Test Results (4A)

Test 1147-261

Test Description	:	Protype Baseline
Pole Type	:	47 ft (14.3 m) galvanized steel
Mounting Washers	:	2 in x 3 in x ¼ in (5.1 x 7.6 x .63 cm) rectangular steel
Special Test Features	:	None
Base Failure	:	Four corners broke about 2 in (5.1 cm) above the bottom and three broke just below the top. Base parallelogrammed during impact.
Momentum Change	:	1113 lb-sec (4951 Ns)
Peak Deceleration	:	14.1 g's
Time to Peak Decel.	:	.063 sec
Impact Duration	:	.088 sec
Honeycomb Crush	:	17.5 in (44.5 cm)
Sweeperplate Impact	:	No

Test 1147-262

Test Description	:	Prototype Baseline
Pole Type	:	47 ft (14.3 m) galvanized steel
Mounting Washers	:	2 in x 3 in x ¼ in (5.1 x 7.6 x .63 cm) rectangular steel
Special Test Features	:	None
Base Failure	:	Similar to 1147-261
Momentum Change	:	1619 lb-sec (7201 Ns)
Peak Deceleration	:	20.6 g's
Time to Peak Decel.	:	.064 sec
Impact Duration	:	.174 sec
Honeycomb Crush	:	17.5 in (44.5 cm)
Sweeperplate Impact	:	No

5.5 TRANSFORMER BASE RETROFIT CONCEPTS

The transformer base modifications discussed in Section 5.4 were mostly designed for new installations since they involve machining of the base while it is off of the foundation. There are, however, millions of cast aluminum T-bases already on the highway which would be safer if modified. To replace each base, or remove and modify it, would be very costly from a labor standpoint. What is greatly needed is a modification which can be made in the field on the installed T-base.

A possible field retrofit concept is the vertical side cut concept which was successful on the Hapco 45964 T-base (1A4) test 1147-215. This concept could possibly be implemented by drilling a hole such as ½ in (1.3 cm) diameter and cutting vertically down from that hole with a reciprocating saw to the bottom. The only problem which is foreseen is in sawing through the bottom where the base touches the foundation. For proper functioning of this modification, the cut must go through the bottom. Stopping before the bottom could prevent proper activation of the failure mechanism. In all tests of this modification on various types of bases, acceptable performance was found. Since this modification is a difficult and possibly time consuming one, other simpler retrofit modifications were tested.

The first concept to be tested (Test 1147-250) was a variation of the vertical side cut modification. In essence, the cuts were not continued through to the bottom of the base. To modify the base, two 3/8 in (.95 cm) dia. holes were made approximately 5 in (9.7 cm) in from each edge. One hole was at a height of 4 in (10.2 cm), the other at a height of 1 in (2.5 cm) from the bottom. Then the holes were connected with a saw cut made using a reciprocating saw. This modification was made on a Union Metal 2850 base (type 3A). (See Fig. 63.)

The results of Test 1147-250 were encouraging, however, further testing is required. A momentum change of 932 lb-sec (4146 Ns) was recorded which is lower than that found on the same modification made all the way through the bottom, 1058 lb-sec (4706 Ns). This leaves open the question of what the data scatter would be. The encouraging part was that the failure mechanism worked as intended, with the crack originating at a side cut and continuing around the impact face to the other side cut.

The same modification was also tested on a Hapco 45964 T-base (see Fig. 64). Since this is the base that worked so well when the cuts extended through the bottom, it was believed that this retrofit modification would also work. The results were not as expected. The fracture was basically uncontrolled. Although the front lower corners did break out and were left on the foundation, the rest of the base was shattered into many pieces. It is believed that a very high force was required to initiate the corner tear out which caused the extensive damage. The high force level can be verified by the 23.8 g's peak deceleration level. The momentum change in Test 1147-252, was 1258 lb-sec (5596 Ns). The reason for the high force level in this test as compared to Test 1147-258 is believed to be due to the much thicker section at the bottom of the base on the Hapco design. If the cuts had been made 1½ in (3.9 cm) closer to the center, the thinner section may have provided easier fracture.

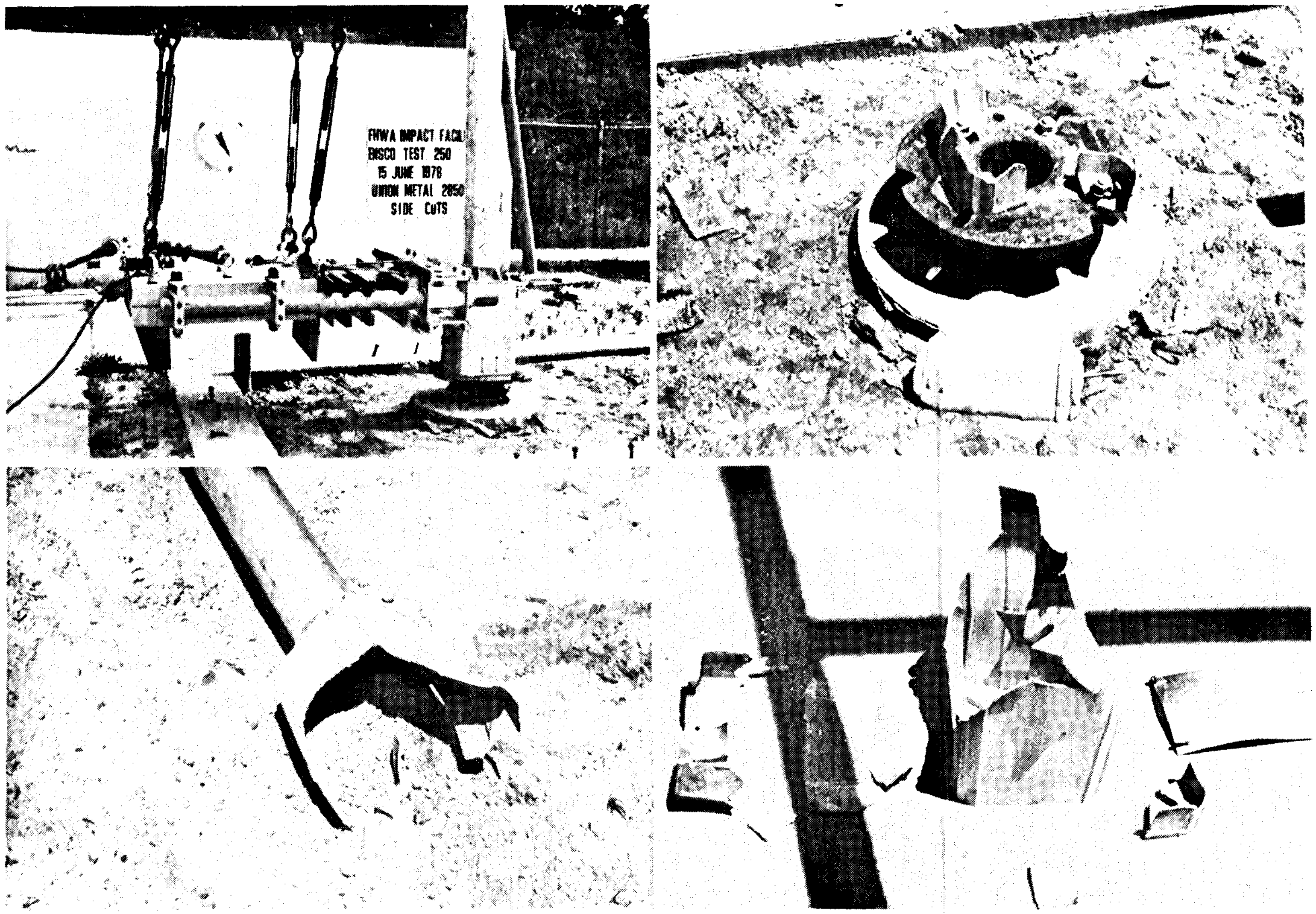


Fig. 63
Representative Photographs of Test 1147-250

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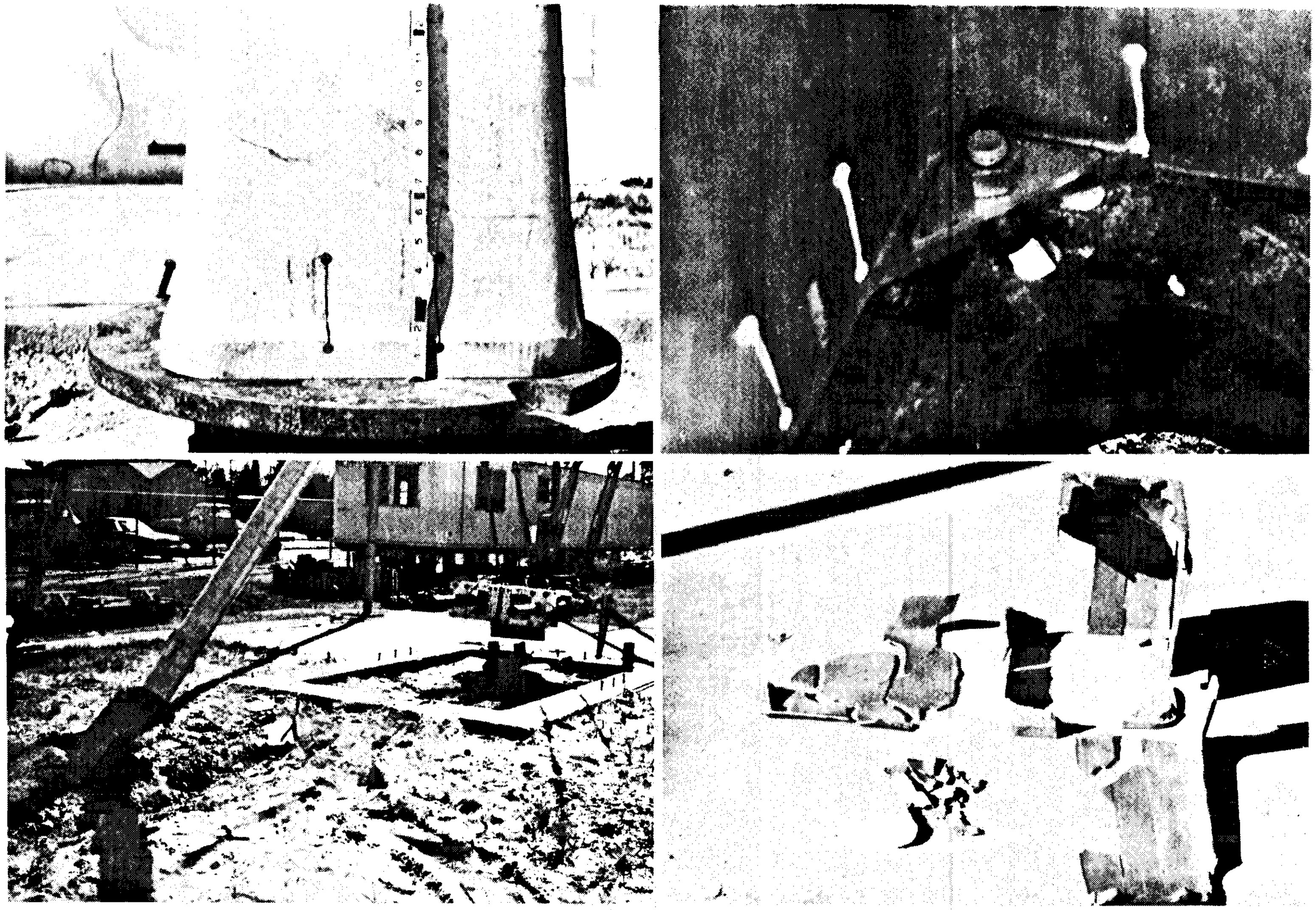

Fig. 64
Representative Photographs of Test 1147-252

A second retrofit modification was designed to eliminate the need for a reciprocating saw. A network of 17-3/8 in (.98 cm) dia. holes were drilled in a pattern as shown in Fig. 65. The intention was that during impact the lower corners would be broken out from the T-base. This modification was not successful since the fracture did not follow the holes as intended. The momentum change for Test 1147-253 was 1410 lb-sec (6272 Ns). The retrofit was a Union Metal 2850 base.

The third retrofit concept, tested in Test 1147-254 on a Union Metal 2850 base consisted of horizontal saw cuts centered on three sides (not on the door side). The cuts were made at a height of 3½ in (8.9 cm) and were 9-3/4 in (25 cm) long. The saw cut was terminated with a 3/8 in (.98 cm) dia. hole on each end. This modification is shown in Fig. 66. From a breakaway standpoint this modification was excellent. The fracture ran completely around the base at the saw cut height. The momentum change was 591 lb-sec (2629 Ns) with a peak deceleration of 8.2 g's. However, the static strength of the base was reduced to 16,090 lb-ft (21818 Nm) which is 46% of the original strength.

In Test 1147-257 a compromise modification was tested based on the results of Test 1147-254. A Union Metal 2850 base was again modified with horizontal saw cuts as in the previous modification. However, the sawcut length was reduced to 6 in (15.3 cm). This modification can be seen in Fig. 67. The fracture line in this test ran around the base at the sawcut level in all but one corner. One lower rear corner (opposite impact side) did not break free which prevented a clean fracture line. The base disengaged from the anchor bolt at this point, but only after some bending of the base. The momentum change was 994 lb-sec (4421 Ns) in this test which is an acceptable level. This modification produced a static

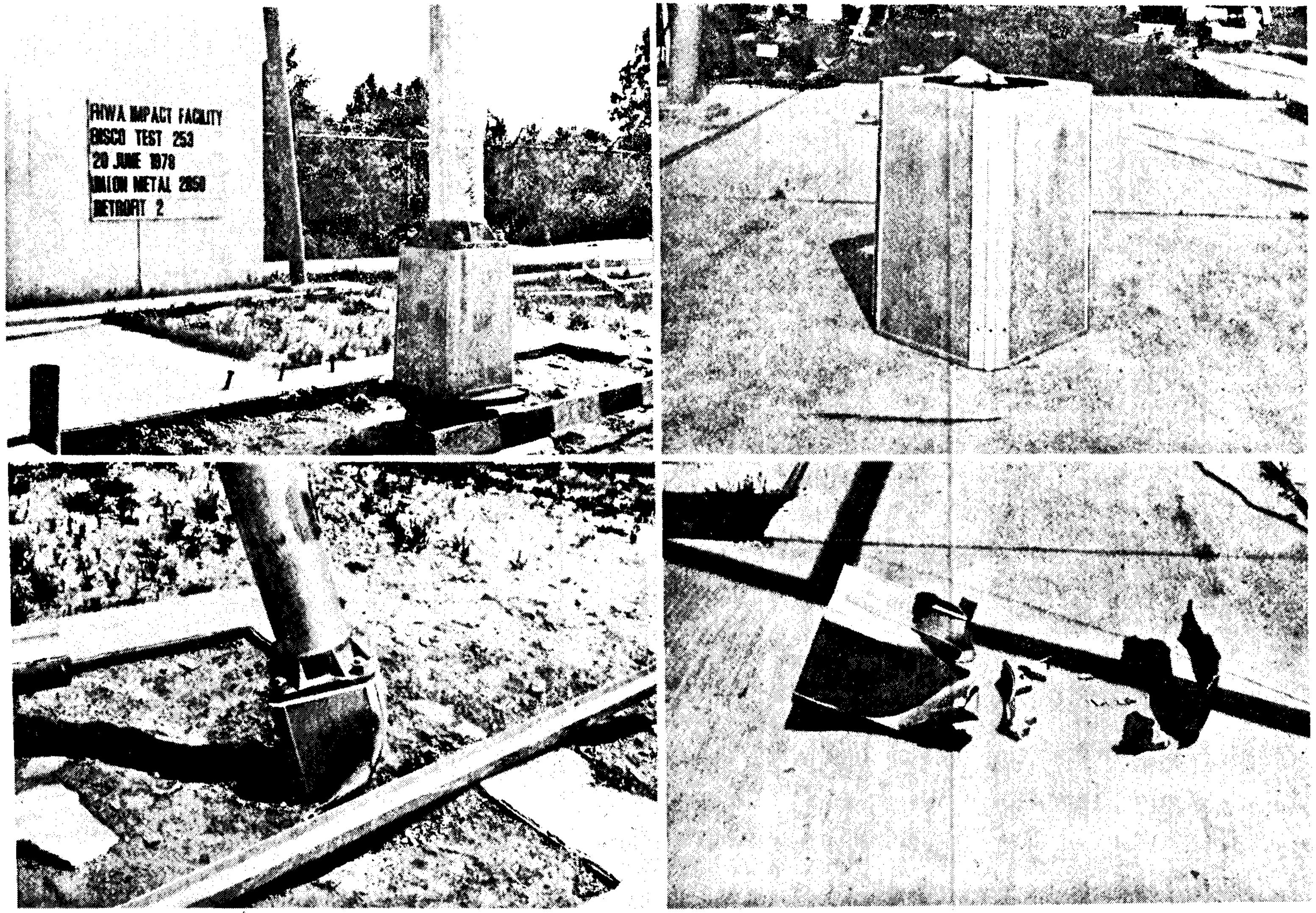

Fig. 65
Representative Photographs of Test 1147-253

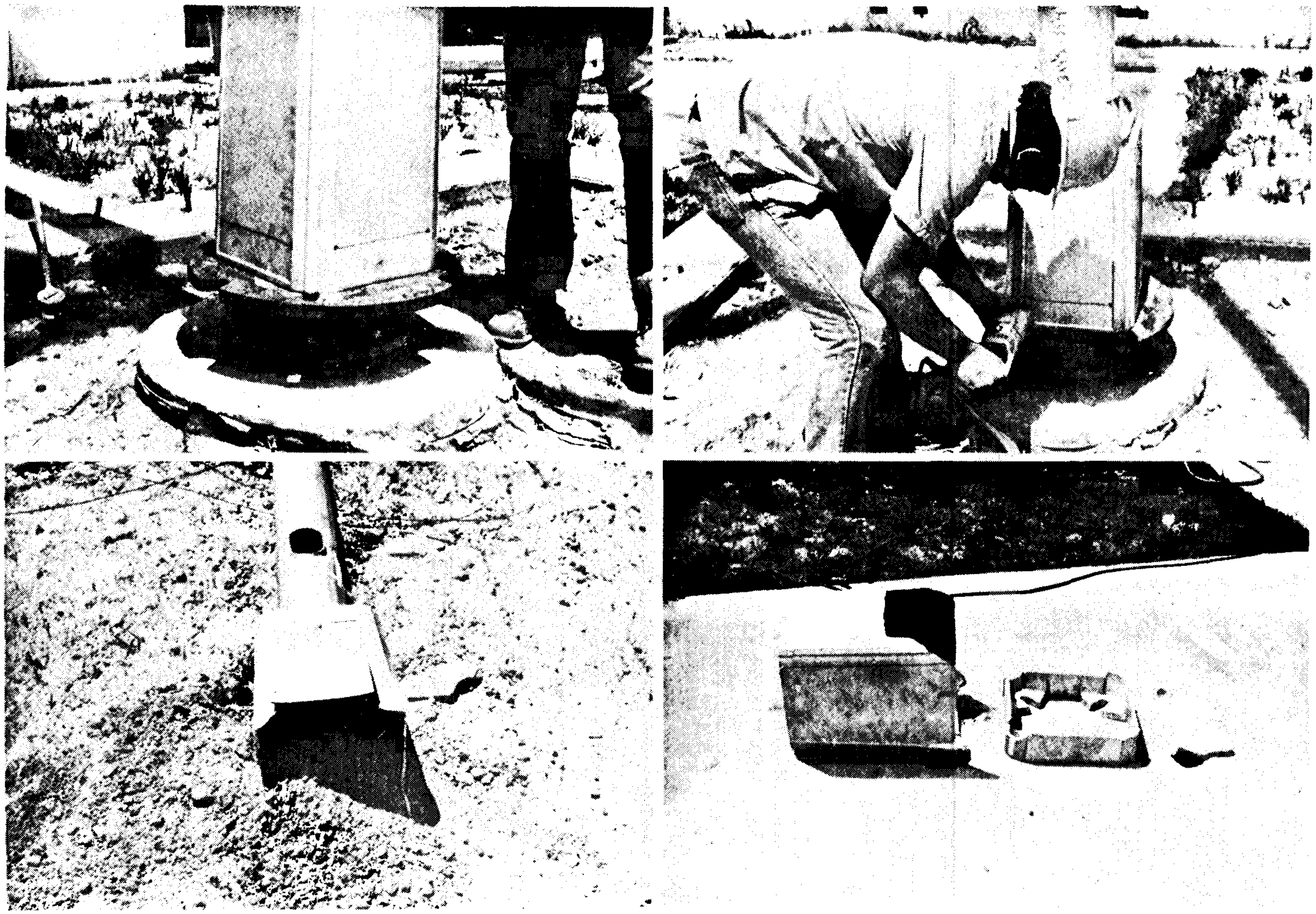

Fig. 66

Representative Photographs of Test 1147-254

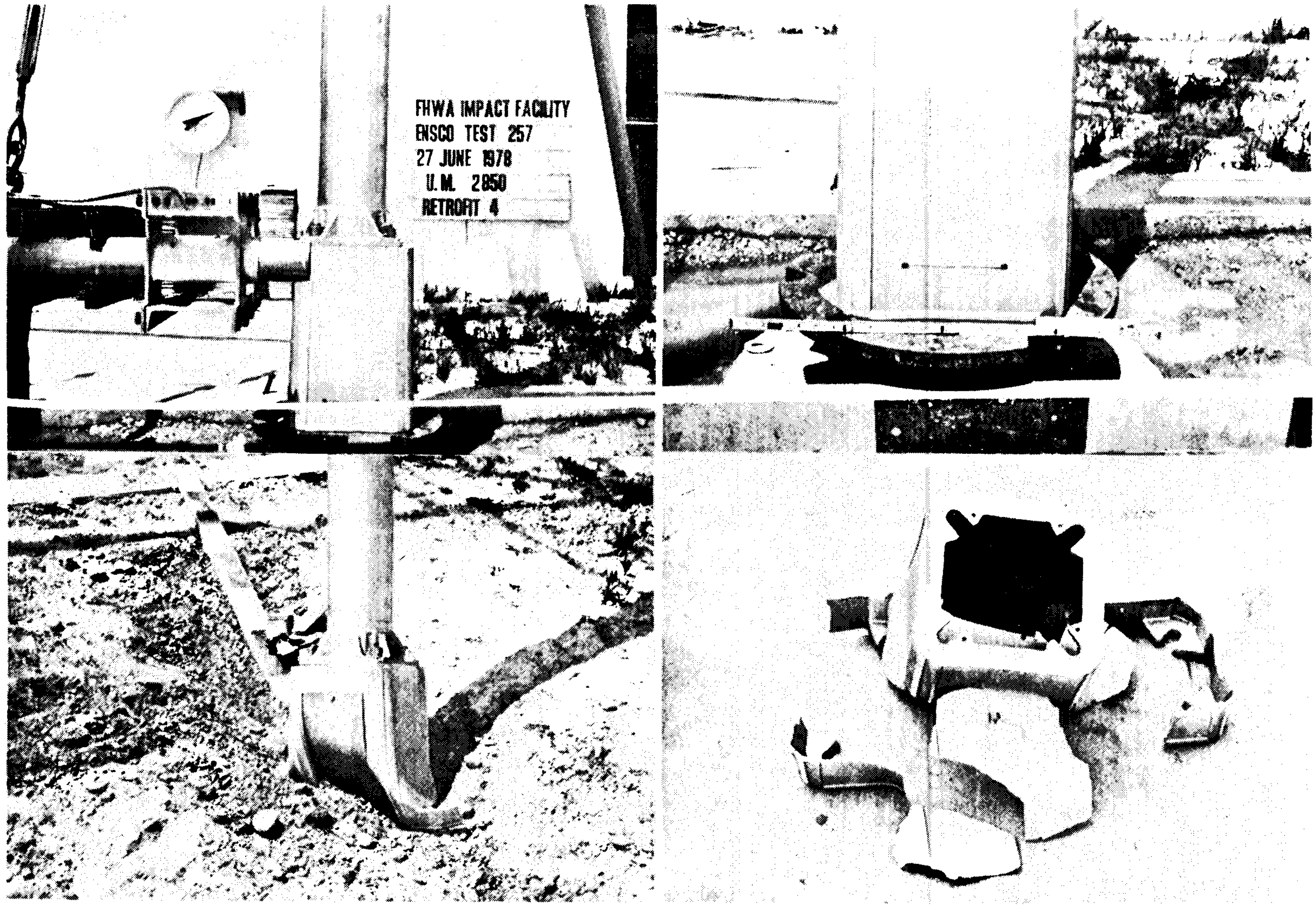

Fig. 67
Representative Photographs of Test 1147-257

strength of 26,800 lb-ft (36340 Nm) which is 77% of the unmodified strength. The failure at that load was in the anchor bolt lugs and was not involved with the modification.

The fifth retrofit modification was again made to a Union Metal 2850 T-base (Test 1147-260). Two 2¼ in (5.8 cm) dia. holes were drilled in each side of the base except for the door side. The holes were centered at a height of 3½ in (8.9 cm) from the bottom and 1-3/4 in (4.5 cm) in from the corner ridge. This modification is shown in Fig. 68. Fracture was partly as expected with features connecting the holes on the sides adjacent to the impact side.

The impact side was broken off from the base and left standing on the foundation to be impacted by the sweeper plate. The rear anchor bolt lugs remained attached to the base and had difficulty engaging from the anchor bolts due to the deep slot. The momentum change for this test was 931 lb-sec (4141 Ns). It is difficult to assess the potential of this modification from one test. Perhaps a variation on the hole positions would produce better results.

T-BASE RETROFIT MODIFICATION TESTS
SUMMARY OF RESULTS

Test 1147-	Base	Retrofit	Change in Momentum lb-sec(Ns)	Peak Deceleration g's	Percent of Baseline Static Strength
250	2850*	(1) Vert Cut	932 (4146)	11.7	N.A.
252	45964**	(1) Vert Cut	1258 (5596)	23.8	N.A
253	2850*	(2) Hole Network	1410 (6272)	24.7	N.A.
254	2850*	(3) Long Horiz Cuts	591 (2629)	8.2	46
257	2850*	(4) Short Horiz Cuts	994 (4421)	20.3	60
260	2850*	(5) Large Holes	931 (4141)	12.0	121

* Union Metal
**Hapco

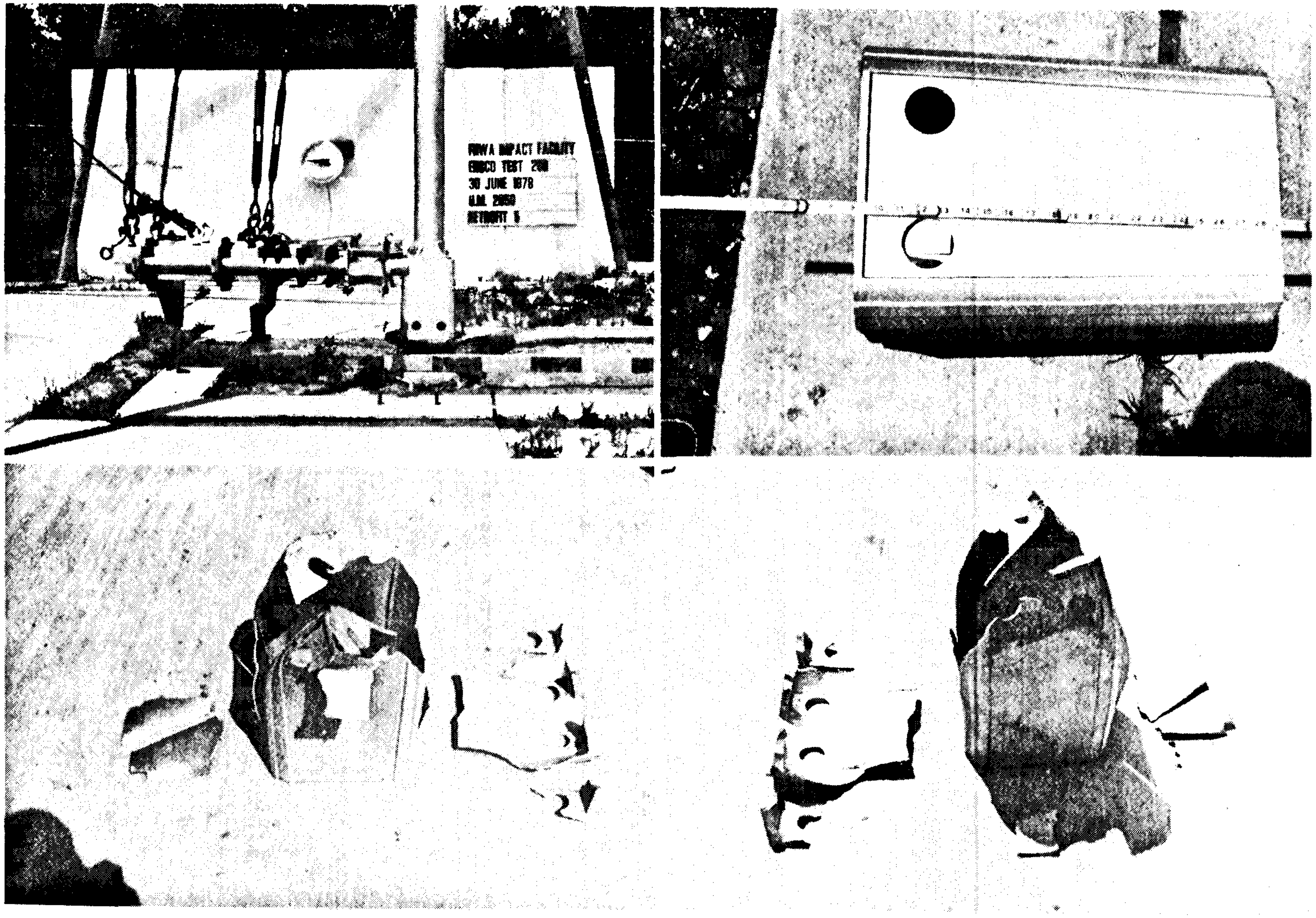

Fig. 68
Representative Photographs of Test 1147-260

5.6 STATIC LOAD AND FATIGUE TESTS

Static load and fatigue tests were performed on some transformer bases. Only selected tests were run where questions arose because not all T-bases could be tested due to project limitations. These tests were conducted in accordance with the procedure outlined in Section 4. The following is a summarization of the test results:

TRANSFORMER BASE STATIC LOAD AND
AND FATIGUE TEST RESULTS

Test No. 1147-	Base Type (Modification)	Related Impact Test 1147-	Static Load at Failure or Cycles to Failure
F201[1]	1A (4)	215	6321 cycles[2]
S202	3A (None)	231	34680 lb-ft (47026 Nm)
S205	3A (2)	239	33790 lb-ft (45819 Nm)
F204	3A (None)	231	32600 cycles[3]
F207	3A (2)	239	35264 cycles[3]
S203	1C (None)	222	29850 lb-ft (40476 Nm)
S206	1C (5)	242	32870 lb-ft (44511 Nm)
S208[4]	1D (2)	243	13940 lb-ft (18903 Nm)
S209[4]	1D (2)	243	13940 lb-ft (18903 Nm)
S210[4]	1D (2)	243	15340 lb-ft (20801 Nm)
S216	1D (None)	236	34610 lb-ft (46931 Nm)
S217	1D (3)	263	28270 lb-ft (38334 Nm)
S211	Retrofit 3	254	16090 lb-ft (21818 Nm)
S212	Retrofit 4	207	20740 lb-ft (36340 Nm)
S218	Retrofit 5	260	41880 lb-ft (56789 Nm)
S213	1B (None)	206	20740 lb-ft (28123 Nm)
S214[5]	1B (7)	241	15620 lb-ft (21181 Nm)
S215[5]	1B (7)	241	24670 lb-ft (33453 Nm)

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[1]F prefix denotes fatigue test, S prefix denotes static load test.

[2]Aluminum pole failed at flange base circumferential weld.

[3]Tests were stopped at these levels with no failure due to low apparent stress levels.

[4]Tests S208, S209 and S210 differed in the type of hold down washers used. Test 208 used 2 in (.95 cm) dia. x 3/16 in (.48 cm) thick steel washers, Test S209 used 3 in (7.6 cm) x 3/8 in (.95 cm) thick steel washers, Test S210 used trapezoidal aluminum washers measuring 2.5 in (6.3 cm) wide x .25 in (.63 cm) thick x 2 in (5.1 cm) - 7 in (17.8 cm) long. The S208 configuration was impact tested in Test 1147-243.

[5]Tests S214 and S215 differed in the type of hold down washers used. Test 214 used 2 in (5.1 cm) x 3/16 in (.48 cm) thick steel washers, Test S215 used 3 in (2.6 cm) dia. x 3/8 in (.95 cm) thick steel washers. The S215 configuration was impact tested in Test 1147-241.

1 in = 2.54 cm

6. UPGRADING OF THE IMPACT TEST FACILITY

The luminaire support impact tests reported in chapters 3, 4, and 5 were performed at the FHWA Impact Test Facility (ITF). This facility incorporated a pendulum which swung from a 36 ft (11 m) high tower. The pendulum was capable of carrying a mass up to 5000 lb (2270 kg) and attaining a speed of 25 mph (40.3 km/h) on impact. This facility was built under a previous FHWA contract DOT-FH-11-8118 [2].

Due to the problems associated with testing large signs using a pendulum, the ITF was reconfigured into a bogie vehicle facility. The bogie facility is capable of impact speeds up to 25 mph (40.3 km/h). The facility has been found to be reliable and repeatable and can be used for luminaire support as well as large and small sign testing.

6.1 BOGIE VEHICLE

The bogie vehicle uses a 24 in wide x 36 in long x 4 in high (61.0 cm x 91.4 cm x 10.2 cm) steel plate as its basic mass. Weights of 100 lb (49.4 kg) can be added to the bogie as required to bring the weight from 1750 lb (79.4 kg) to 2450 lb (1112.3 kg). A chassis is fabricated from a steel channel with rigidly affixed rear axle spindles from a Volkswagon Dasher. Dasher wheels, hubs and brakes are also used. The brakes are powered by a small nitrogen charged bladder accumulator which pressurizes the hydraulic system when a solenoid valve is released. A 1 in (2.5 cm) thick steel plate is attached to the front of the mass and extends below the bogie to act as a sweeperplate. A 2 in (5.1 cm) diameter steel pipe is used as a roofline simulator. This pipe is 5 ft (1.5 m) long and is located at a height of 3.5 ft (1.06 m) above the runway.

The honeycomb nose as described in chapter 3 is attached to the front of the bogie. The bogie rides on a 8 ft (2.4 m) wide x 70 ft (21 m) level concrete runway. A line drawing of the bogie is found in Fig. 69.

The bogie is guided by an elevated 2 in x 2 in (5.1 x 5.1 cm) steel angle iron rail located outboard of the wheels on the left side of the bogie. Arms extend from the left front and rear spindles over to the rail. Two cam followers on each arm guide the bogie. The arms are tied together on their ends by an angle iron bar for greater strength.

6.2 BOGIE TOW SYSTEM

The bogie is powered by a reverse tow system, with a drop weight pulling the reverse tow line. The drop weight consists of steel plates bolted together weighing about 4000 lb (1816 kg). The drop weight is suspended from a four cable sling which is attached to a large eyebolt connected to a tackle block. The drop weight is lifted by pulling back on the bogie through the two systems with a winch. The drop weight is guided by a vertical cable running from the top of the tower to the ground. Release is accomplished with a solenoid release hook.

The tow cable is attached to the top of the 36 ft (11 m) high pendulum tower. It runs down and through the tackle block on the top of the drop weight and then back up around a sheave at the top of the tower. This gives 2 to 1 mechanical advantage. From the tower sheave the cable runs over a series of sheaves until it gets to the bogie. A slot in the bogie sweeperplate is used for towing. The end of the tow cable slips through a rod and then passes through the sweeperplate slot. As the tow cable passes through the reversing sheave located in front of the impact area, it is pulled down and out of the slot, releasing the bogie. All sheaves are equipped with grease fittings to

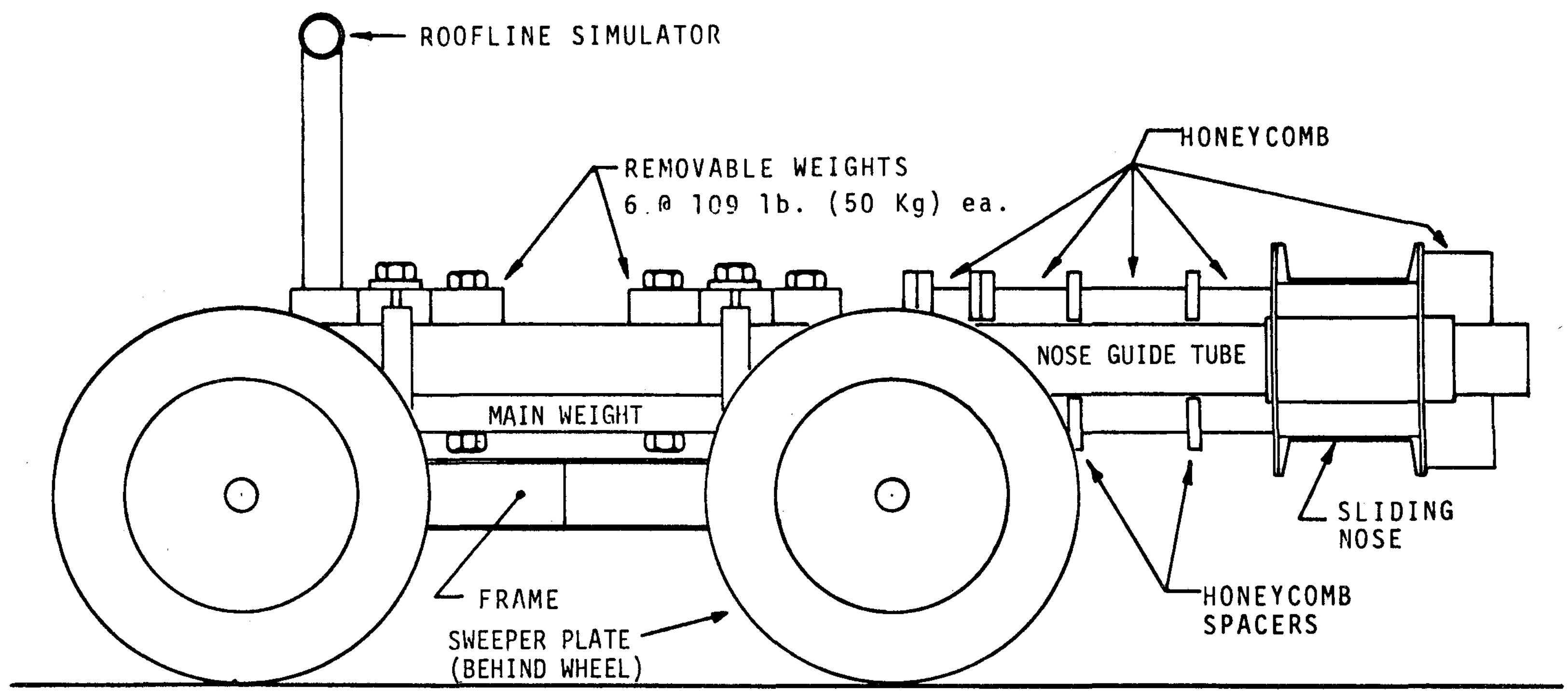

Fig. 69
Rubber Wheeled Soft-Nosed Impact Bogie Vehicle

allow for lubrication, hence, even and repeatable operation. A wooden impact surface made from railroad ties is located on the ground to absorb the drop weight impact energy.

6.3 JIB CRANE AND FOUNDATIONS

A jib crane was built for the purpose of erecting the signs. The jib crane consists of a 38 ft (11.6 m) high 12 in (30.6 cm) diameter steel circular support mounted on a concrete foundation with a 12 ft (3.7 m) long rotating boom mounted at a height of 32 ft (9.8 m). A tension member runs from the boom to the top of the support. A trolley supporting a 1 ton (908 kg) chain hoist rides on the boom.

Dual-legged signs and luminaires are mounted on concrete foundations located 42 ft (12.8 m) past the start of the runway. One of the foundations located in the center of the runway is used for mounting luminaire supports and the impact leg of dual-legged sign systems. Two sets of foundations located on a radius of 10 ft and 15 ft (4.5 and 6.8 m) from the center foundations allow for dual-legged orientations of 0°, 15°, and 30°. Located beside the foundation is a large backdrop measuring 12 ft high (5.5 m) and 20 ft long (9.1 m). This white backdrop gives good film contrast to the bogie and test support. A layout of the ITF configuration for bogie testing is shown in Fig. 70.

6.4 SPEED TRAP SYSTEM

Two speed trap systems were developed in this contract. The first incorporates a laser light source and photoelectric sensors. The laser beam is segmented into four quadrants which cross the path of the pendulum. Two beams cross before the impact area to measure preimpact speed and two are located after the impact area for measurement of post test speed. The main

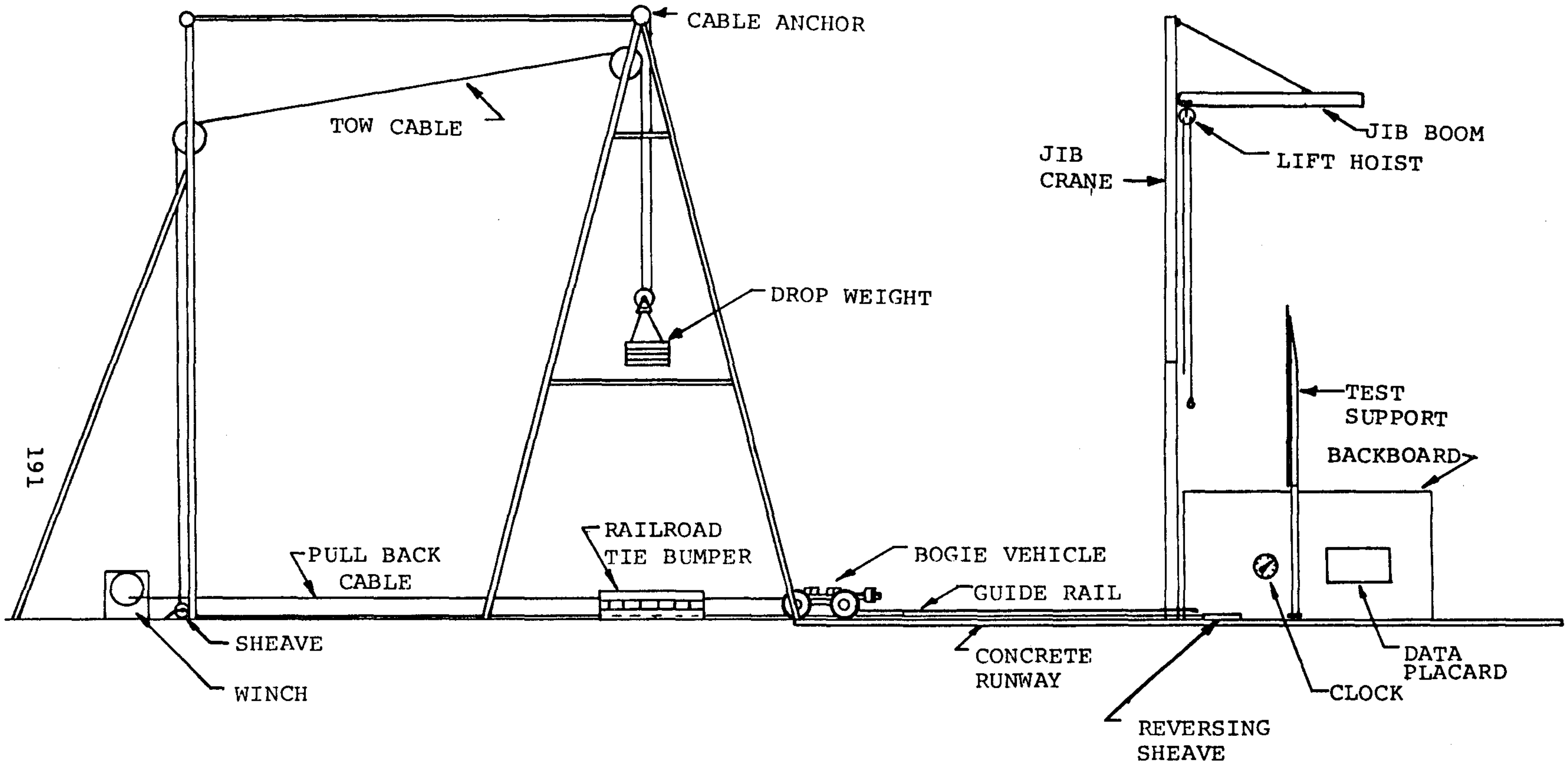

Fig. 70
Impact Test Facility

drawback of this system is the critical alignment of the light beams into the sensors. For this reason this system was not used when the bogie was built. The second system uses a micro switch FE-MLS3A photoelectric scanner mounted on the bogie. The scanner emits an invisible infrared beam. This beam is reflected by special infrared reflectors placed along the bogie path in the correct position to obtain before and after impact speeds. Each reflector generates pulses as the bogie passes by it. The reflectors are grouped in pairs. As the bogie passes the first reflector of a pair, a 50,000 Hz clock is started. The clock is stopped when the second reflector of the pair is passed. Thus an accurate time is obtained to traverse a given (1 ft (.3 m)) distance.

7. BREAKAWAY DUAL-LEGGED SIGN TESTING

7.1 INTRODUCTION

Large highway signs are most commonly made breakaway using a design developed by TTI in the 1960's [16]. This design incorporates a four bolt unidirectional slip base at the bottom of the support and a hinge joint in the support just below the sign. The hinge is held closed during non-impact conditions by a slip plate connector. Since the initial development work, very little testing has been performed. In recent years automobiles have become smaller, testing speeds have changed, and newer concepts have been developed for breakaway signs.

The development of a low-cost laboratory impact test device for breakaway dual-legged signs became necessary in order to perform the array of tests that is needed now and in the future. This chapter discusses the testing work that was necessary to develop this device, and the tests performed with it once developed.

As discussed in Chapter 6, the FHWA ITF was updated into a bogie facility. Once the construction work was complete, tests were performed to validate the ability of the facility to reproduce full-scale test results. Tests were performed on luminaire supports and signs and correlated against full-scale test data. To supplement the sparse full-scale data available for small cars impacting dual-legged signs, six full-scale tests were also performed. The validated test facility was used to test a new breakaway sign hinge concept as well as to investigate angular impacts with the standard slip base design. All these tests are reported in this chapter.

7.2 FULL-SCALE TEST OF DUAL-LEGGED SIGNS

Six full-scale tests of dual-legged breakaway signs were performed to provide data to validate the bogie vehicle facility and to investigate high speed off-center hits of small cars. Table 30 gives a overview of the test configuration.

TABLE 30. DUAL-LEGGED SIGN FULL-SCALE TEST CONFIGURATIONS

Test No. 1147-	Sign Support	Sign Blank (h x w)	Vehicle Weight (lb)	Impact Speed (mph)	Impact Location (in Off Center)
801A	8WF20	10 x 15 ft	2275	59	0
802	8WF20	10 x 15 ft	2445	23	0
1001	12WF45	12 x 24 ft	2425	19	0
1008	12WF45	12 x 24 ft	2478	58	12
1009	12WF45	12 x 24 ft	1516	61	16
1010	12WF45	12 x 24 ft	1617	21	0

1 mi/h = 1.61 km/hr 1 in = 2.54 cm
1 ft = .305 m 1 lb = .454 kg

The test vehicles were instrumented with three accelerometers mounted on a 10 in x 4 in x 2.5 in (25 cm x 10 cm x 6.4 cm) aluminum block bolted to the transmission hump at the c.g. of the vehicle. The accelerometers consisted of one 15 g and one 50 g longitudinal and one 15 g lateral. Data was transmitted back to the data acquisition van through an umbilical cable.

Photographic coverage was made with the following equipment, locations and speed:

Camera	Location	Speed
Movie, Lo Cam	Overhead, 40 ft	500 PPS
Movie, Hi Cam	Side, 70 ft	500 PPS
Movie, Lo Cam	11:00 to vehicle 80 ft	500 PPS
Movie, Arriflex	Documentary & Plan	24 PPS
35 mm, Canon	Documentary	Still

800 SERIES TESTS

In Tests 1147-801A and -802, 1973 Chevrolet Vegas were impacted into a breakaway dual-legged sign. The sign design was taken from Texas state plans and consisted of a reinforced 5/8 in (1.6 cm) thick plywood sign blank measuring 10 ft high by 15 ft wide (3 m x 4.5 m) mounted on 8WF20 breakaway supports. This sign design is shown in Fig. 71 for more details.

The bolt torque on the sign consisted of 63 lb-ft (85 Nm) on the slip base bolts and 348 lb-ft (472 Nm) on the hinge bolts. All bolts were 3/4-10 ASTM A-325 with a proof load of 28,400 lb (126,323 N) which corresponded to the 348 lb-ft (492 Nm) torque. The 63 lb-ft (85 Nm) torque represented a load of 5000 lb (22240 N) per bolt.

Test 1147-801A

In Test 1147-801A the test vehicle weighed 2275 lb (1032 kg) and impacted the sign at 59 mph (95 km/h). The sign behavior can be summarized as follows: following impact the slip base separated smoothly and the lower portion of the sign leg began rotating upward about the hinge while the sign and upper leg remained relatively still. After a small amount of rotation the hinge opened and the lower leg continued to rotate until it made about a 90° angle with the sign. Then the sign began to twist and the aluminum clips holding the upper leg to the sign broke off in a progressive fashion. This allowed the leg to rotate about the bolts at the top of the sign. This rotation continued until the upper leg made about a 90° angle to the sign blank. After this, the forward momentum of the leg twisted the sign about the opposite leg.

Table 31 summarizes the results from the test. Representative test photos are shown in Fig. 72 through 74.

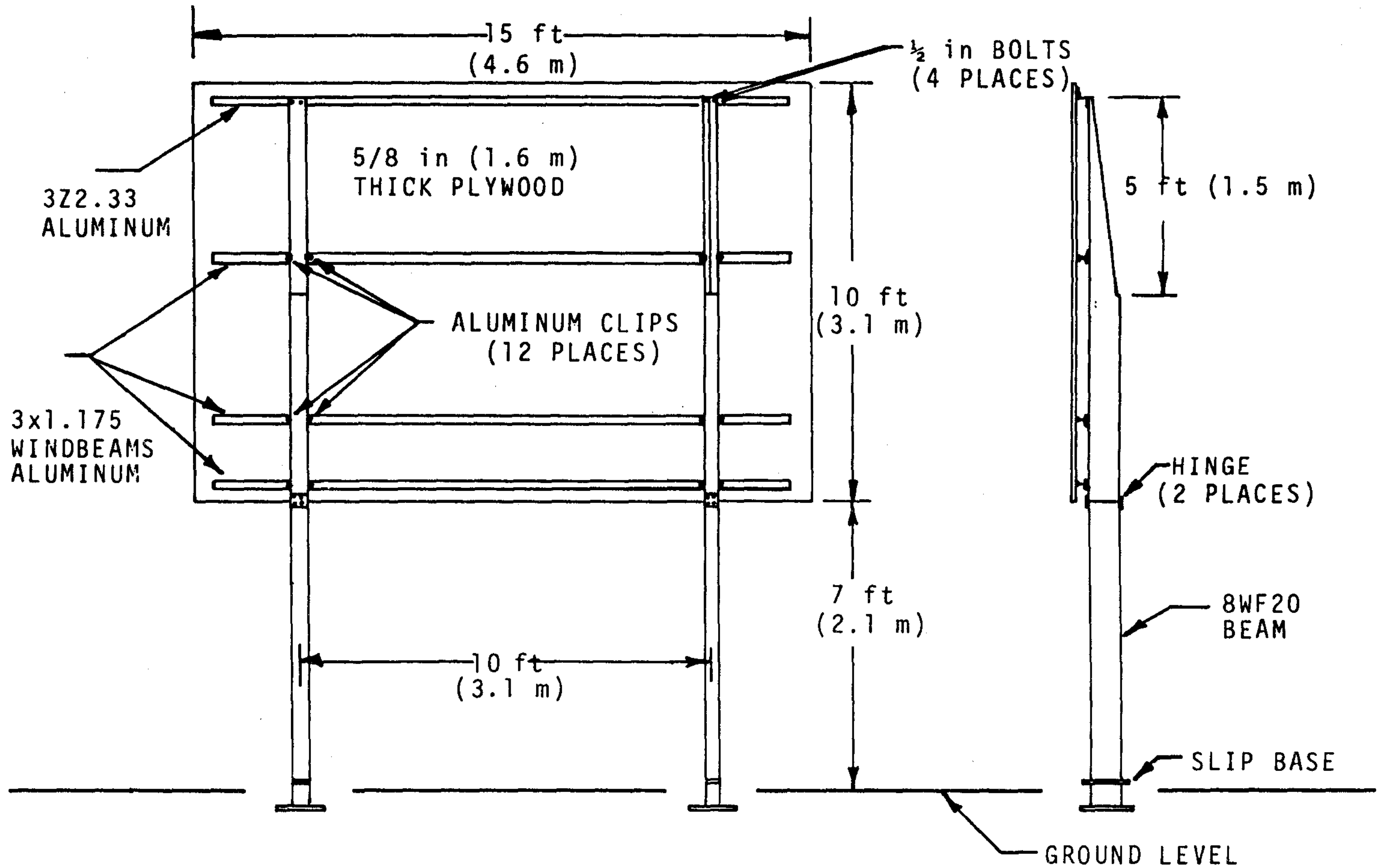

Fig. 71

Breakaway Dual-Legged Sign as Tested in the 800 Series Tests

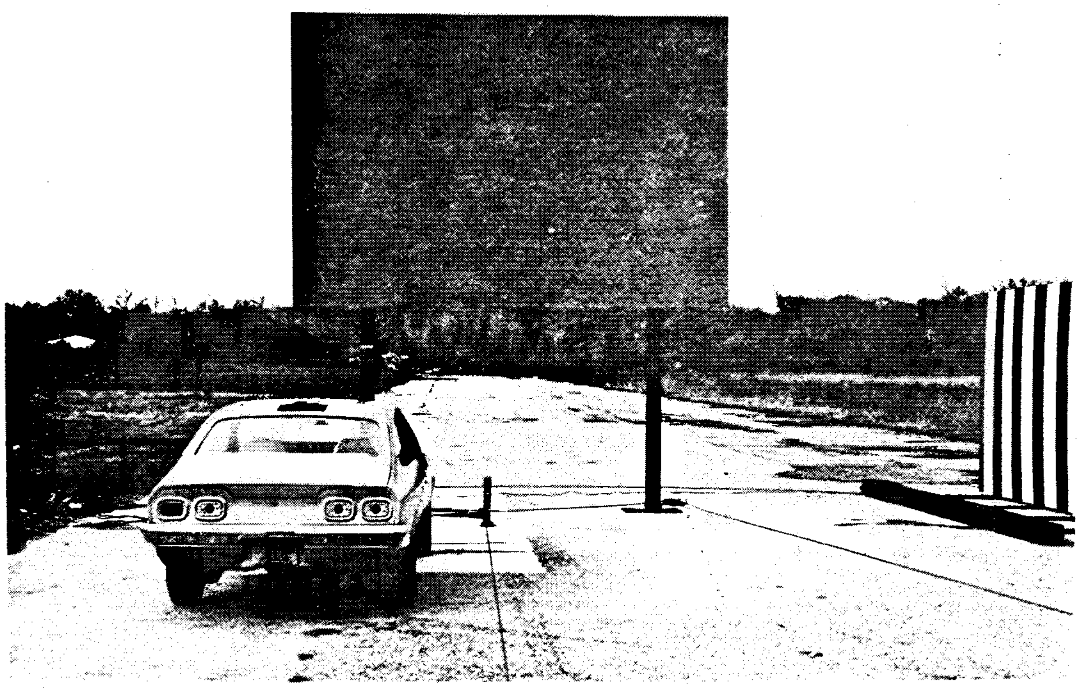

Fig. 72
Representative Pre-test Photographs of Test 1147-801A

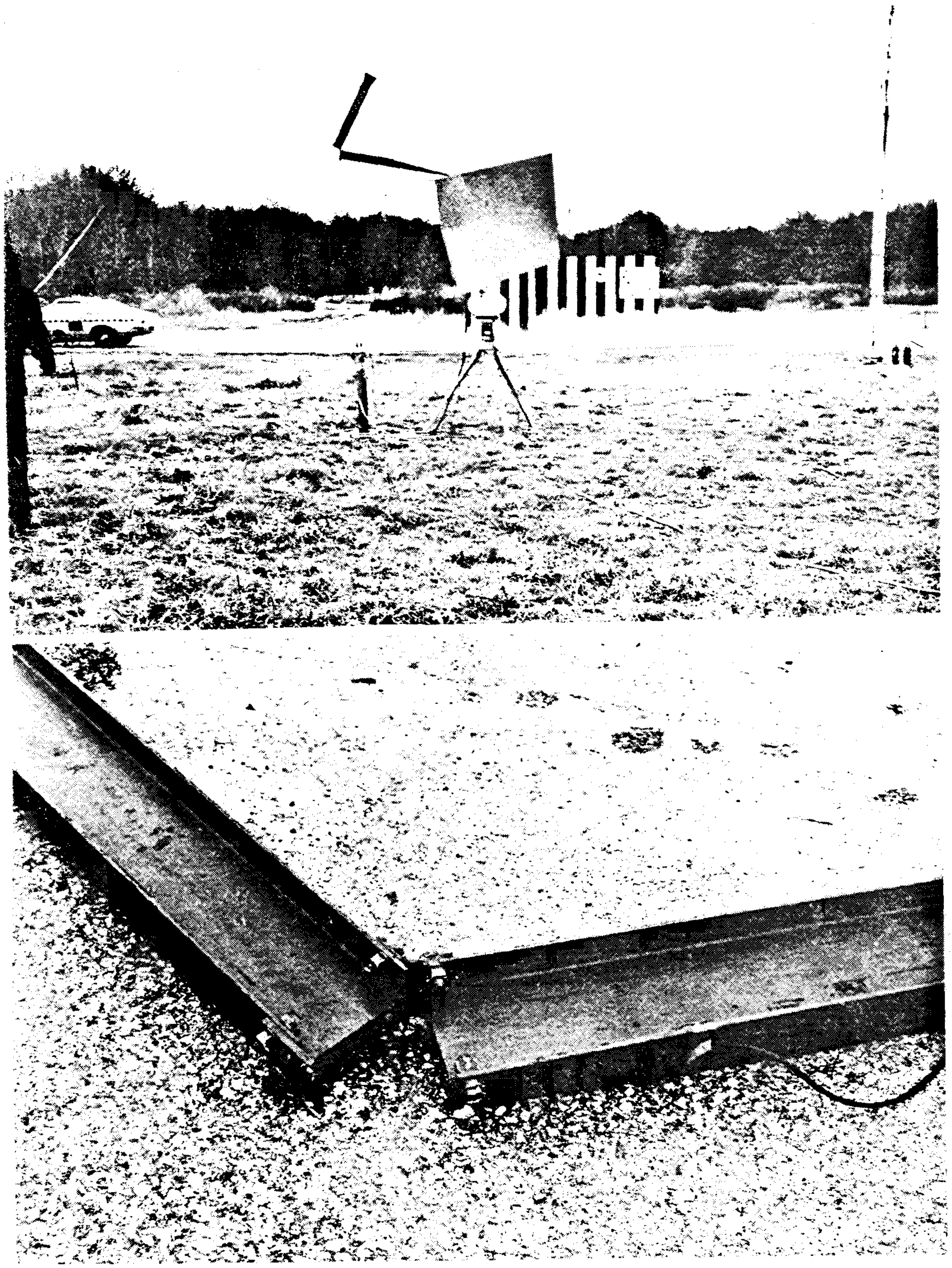

Fig. 73
Representative Post-test Photographs of Test 1147-801A

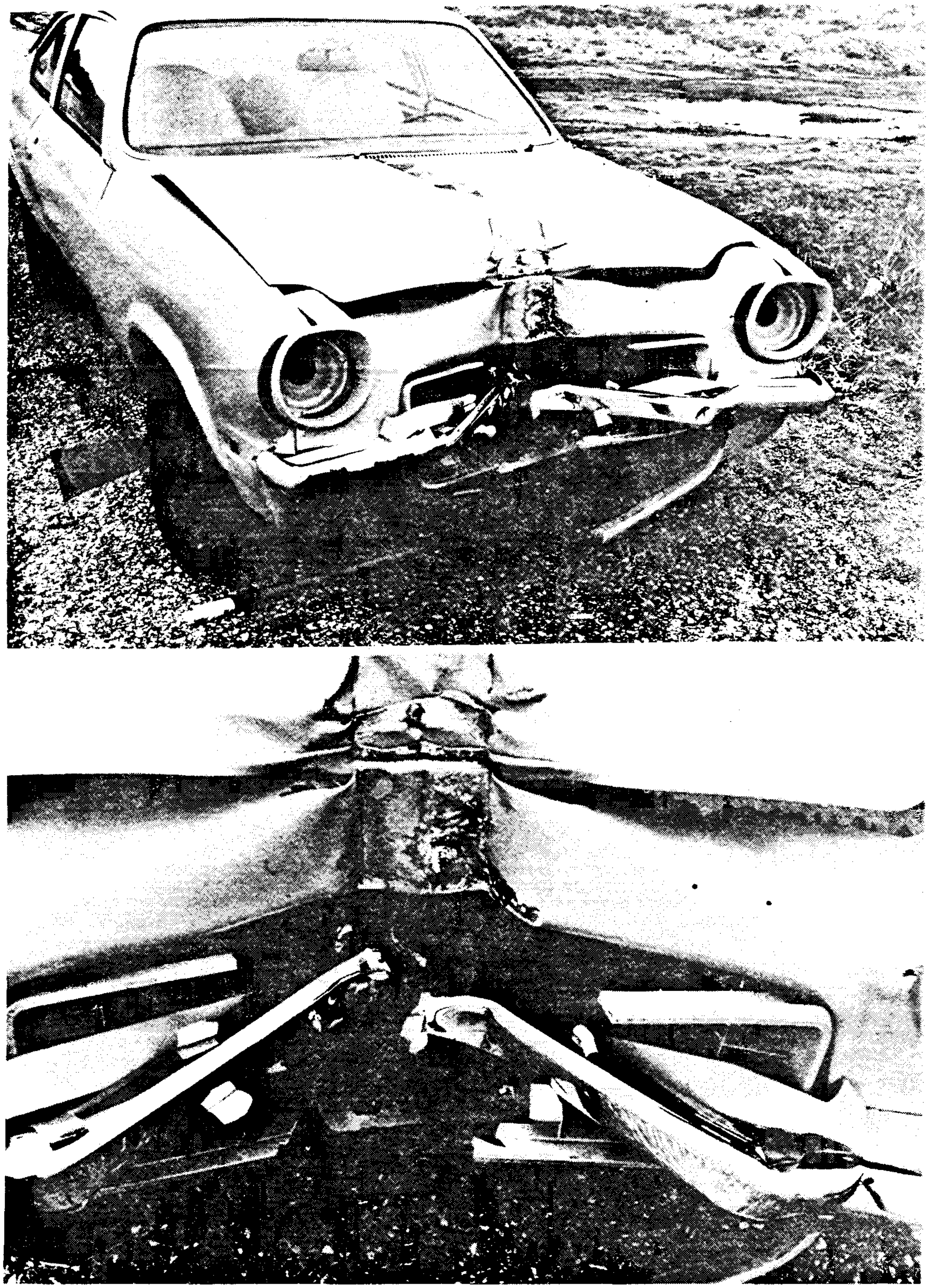

Fig. 74
Representative Post-test Photographs of Test 1147-801A

TABLE 31. TEST RESULTS FROM 800 SERIES DUAL-LEGGED SIGN TESTS

	Test 1147-801A	Test 1147-802
Vehicle Weight (lb)	2275	2445
Target Impact Speed (mph)	60	20
Slip Base Torque (lb-ft)	63	63
Hinge Torque (lb-ft)	348	348
Momentum Change (lb-sec)		
Accelerometers	569	319
Film	516	394
Average Deceleration (50 m sec avg.) (g's)		
Peak Deceleration (g's)	18.6	5.9
Time to Peak Decel. (sec)	.029	.048
Vehicle Crush (in)	16"	11½"
Damage Index		
SAE	12 FCEN2	12 FCEN2
TAD	FC-3	FC-3

1 mi/hr = 1.61 km/h
1 lb-sec = 4.448 Ns
1 ft-lb = 1.356 Nm
1 in = 2.54 cm
1 lb = .454 kg

Test 1147-802

In Test 1147-802 the test vehicle weighed 2445 lb (1109 kg) and impacted the sign at 23 mph (37 km/h). The sign behavior can be summarized as follows: following impact the slip base separated smoothly and the lower portion of the sign leg began rotating upward about the hinge while the sign and upper leg remained relatively still. After a small amount of rotation the hinge opened and the lower leg continued rotating until the bottom reached a height of about 5 feet (1.5 m). Then the sign blank began twisting about the opposite leg while simultaneously the impacted leg began coming back down. The sign twisted enough so that the leg missed hitting the car windshield by only inches on its return swing.

Although the sign behavior in this test was successful, disaster was only averted by a very slim margin. Had a stiffer sign blank been used, sign twisting would have been less and the vehicle windshield might have been penetrated.

The results of this test are also summarized in Table 31. Test photographs are shown in Fig. 75 through 77.

1000 SERIES TESTS

All tests were conducted with a sign having the following configuration. The sign blank is 12 ft (3.6 m) high by 24 ft (7.2 m) wide, made from 5/8 in plywood. The blank has 4 aluminum windbeams, the top one being 3Z2.33, and the others being special sign T-beam. The top windbeam is fastened to each leg with two ½ in (1.3 cm) diameter bolts. The T-beams are fastened to the leg with cast aluminum clips and 3/8 in (.95 cm) diameter aluminum bolts. The legs are fabricated from 12WF45 steel beam. The legs which are spaced at a 15 ft (4.5 cm) span incorporate a Texas type slip base. The 1 in (2.5 cm) diameter strain-sert slip base bolts were tightened to 5000 lb (22240 N) prior to each test. The faying surface of the slip base was located 3 in (7.6 cm) above ground line as called for in Texas state plans. The distance from ground to the bottom of the sign is 8 ft 6 in (2.6 cm). The sign is shown in Fig. 78.

In all but the last two tests the legs utilized the standard Texas slip hinge with 3/4 in (1.3 cm) diameter strain-sert bolts tightened to 28,000 lb (124,544 N).

<u>Test 1147-1001</u>

In this full scale test a 2425 lb (1100 kg) 1973 Chevrolet Vega was impacted into the sign. The test was performed at the FHWA

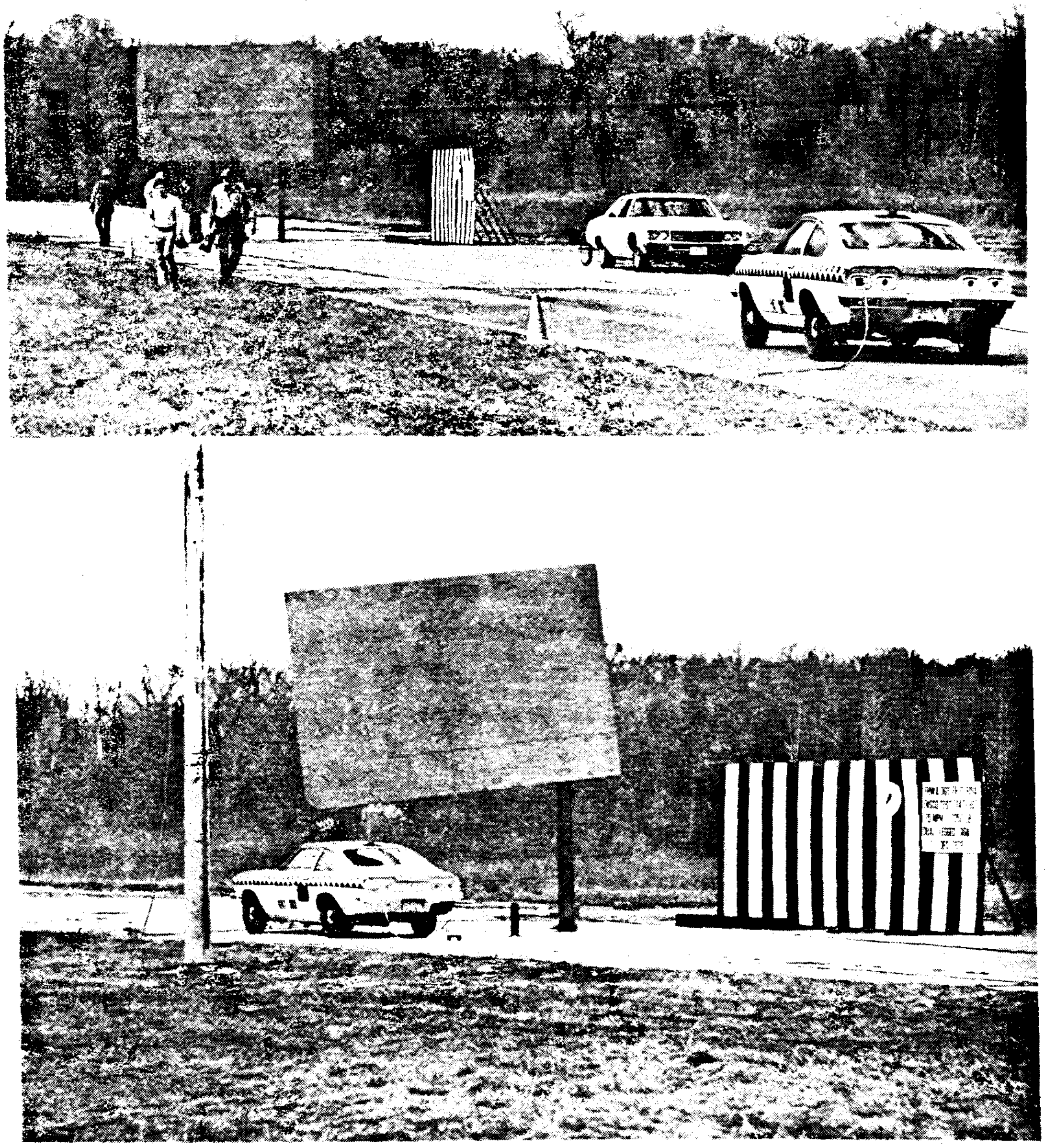

Fig. 75

Pre-test and Test Photographs from Test 1147-802

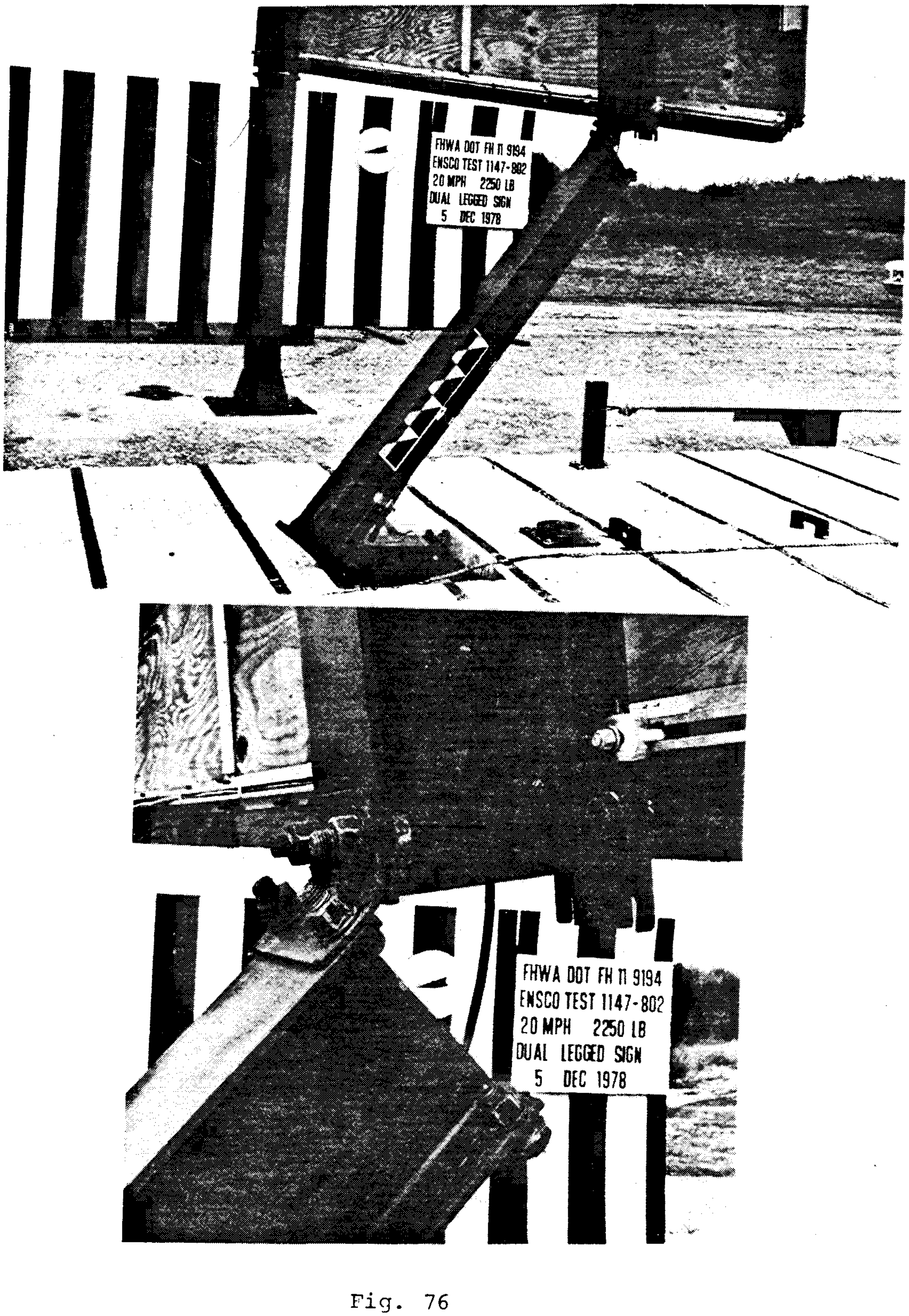

Fig. 76
Post-test Photographs of Leg of Test 1157-802

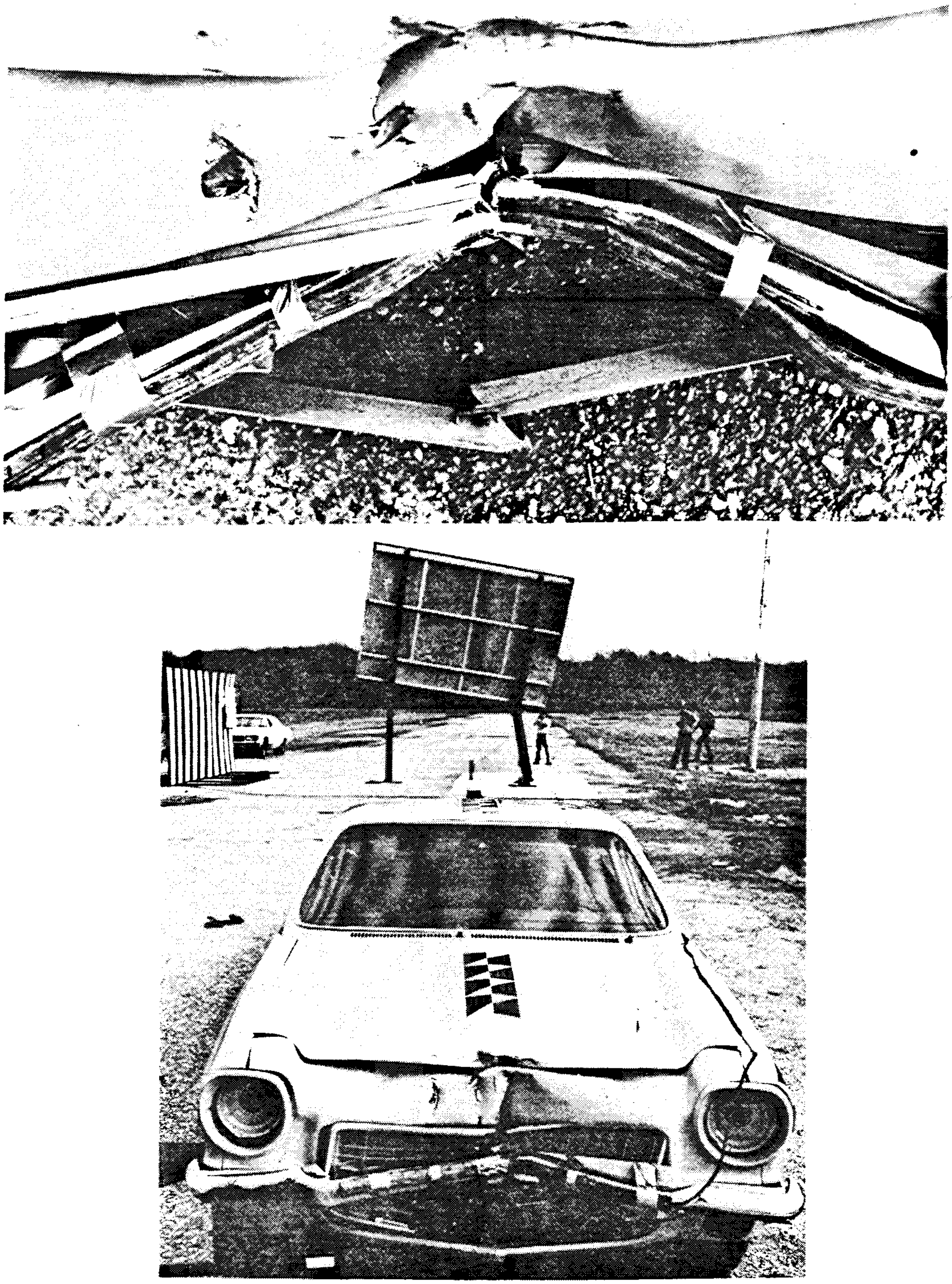

Fig. 77
Post-test Photographs of Car of Test 1147-802

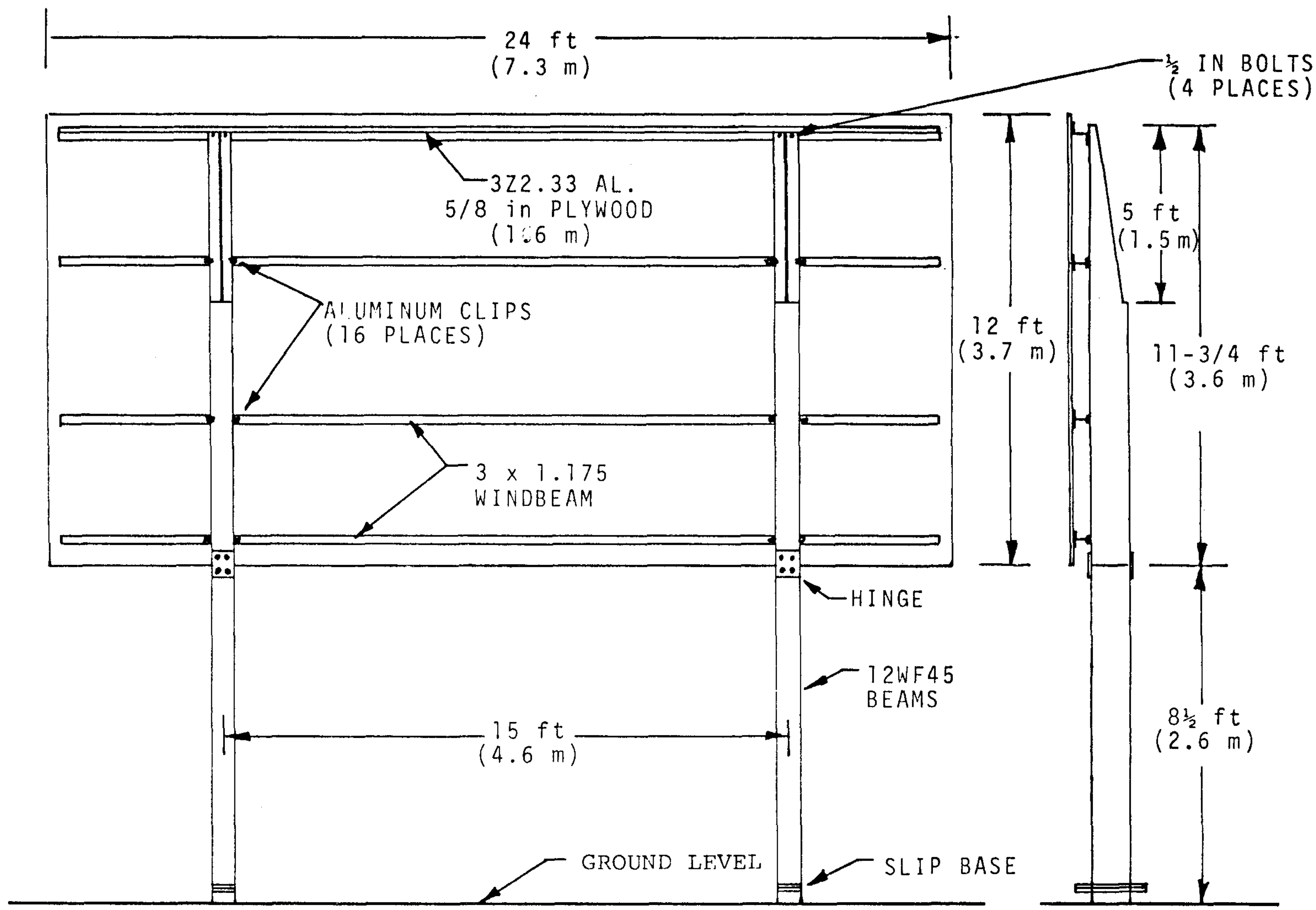

Fig. 78
Breakaway Dual-Legged Sign Tested
in 1000 Series Tests

impact facility to evaluate the ability of this facility to perform full-scale tests at low speeds.

The vehicle impacted the support at 19 mph (31 km/h). The slip base broke away smoothly. However, the hinge did not activate until after the impacted leg had broken free from the sign blank by breaking the 3/8 in (.95 cm) diameter aluminum clip bolts and hinging at the top windbeam. After this the hinge opened only slightly. The car eventually came to rest with the sign blank resting on top of the roof and the leg still connected to the top windbeam. Essentially the hinge did not function, i.e., the performance would have been the same without a hinge. The sign leg was allowed to breakaway because the aluminum bolts holding the sign blank to the leg broke.

The momentum change for this test was approximately 716 lb-sec (3185 Ns). Although the vehicle eventually came to rest, it took quite a long time until this occurred. Thus the momentum change was calculated for the "duration of the event" as defined in TRC191 [17]. The results are given in Table 32. Photographs of the test can be seen in Figs. 79 and 80.

Test 1147-1008

In this test a 1973 Chevrolet Vega was impacted into the sign at 58 mph (93 km/h). The impact point was approximately 12 in (30.5 cm) to the right of center front on the car. The car remained stable during the impact, experiencing only a slight yawing oscillation in its post-impact trajectory. The breakaway leg functioned very well with complete hinge activation at 90° upward rotation of the leg. The vehicle crush was 14-3/4 in (37.5 cm). The vehicle change in momentum was 642 lb-sec (2856 Ns). Test results can be found in Table 32.

Test photographs are shown in Figs. 81 and 82.

TABLE 32. TEST RESULTS FROM 1000 SERIES DUAL-LEGGED SIGN TESTS

	Test 1147-1001	Test 1147-1008	Test 1147-1009	Test 1147-1010
Vehicle Weight (lb)	2425	2478	1516	1617
Target Impact Speed (mph)	20	60	60	20
Slip Base Bolt Load (lb)	28000	28000	28000	28000
Hinge Bolt Load (lb)	5000	5000	5000	5000
Momentum Change (lb.sec)				
Accelerometers	710	672	369	496
Film	790	627	508	--*
Average Deceleration (50 M sec avg) (g's)	3.3	6.1	5.1	5.8
Peak Deceleration (g's)	10.0	15.6	10.3	13.6
Time to Peak Decel. (sec)	.060	.028	.036	.043
Vehicle Crush (in)	13.5	14.75	15.0	10.0
Damage Index				
SAE J224A	12FCEN2	12FREN2	12FREN2	12FCEN2
TAD	12FC2	12FR3	12FR3	12FC2

1 mi/hr = 1.61 km/hr
1 lb.sec = 4.448 Ns
* No Film Data

1 in = 2.54 cm
1 lb f = 4.448 N
1 lb m = .454 kg

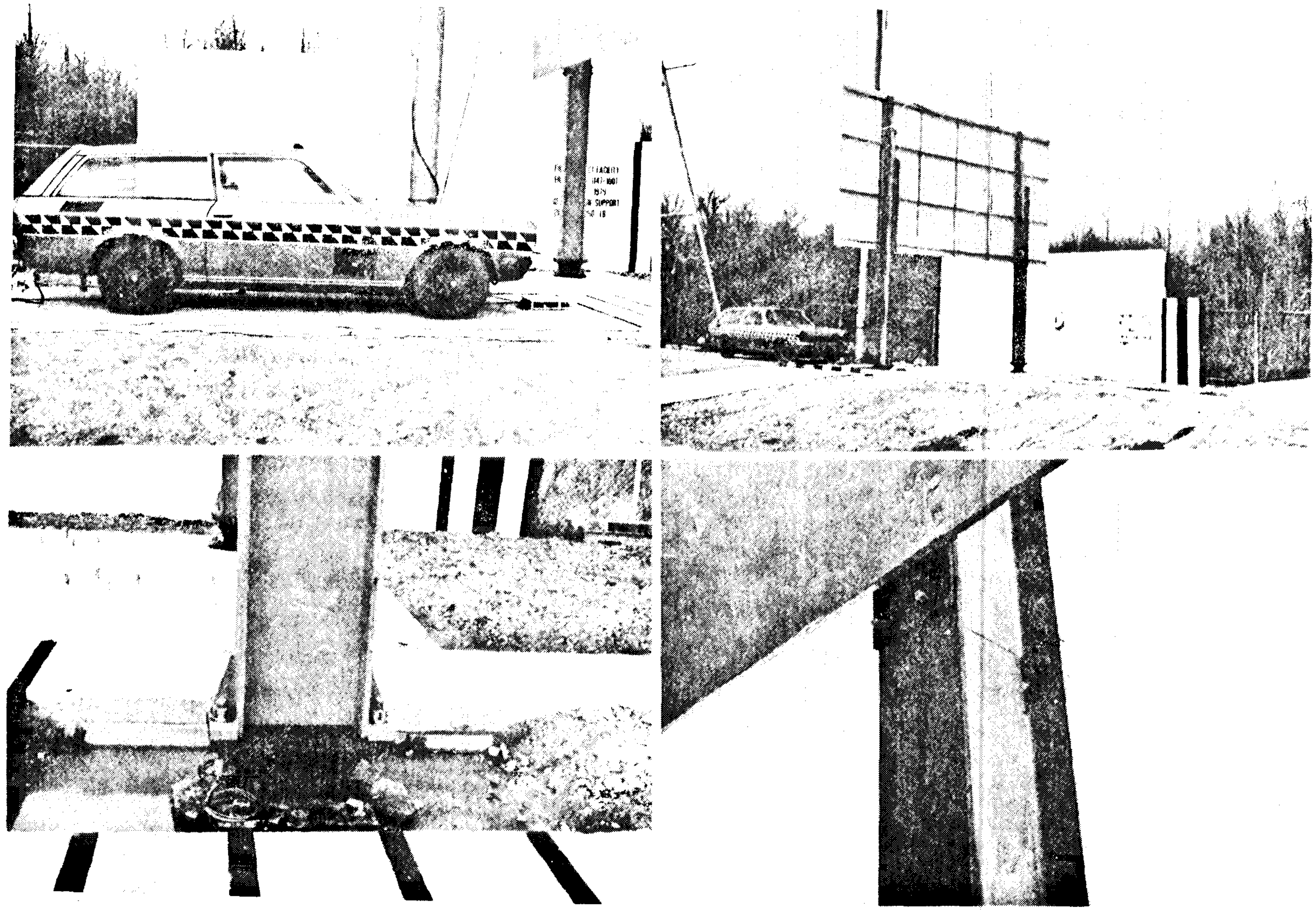

Fig. 79
Representative Pre-test Photographs of Test 1147-1001

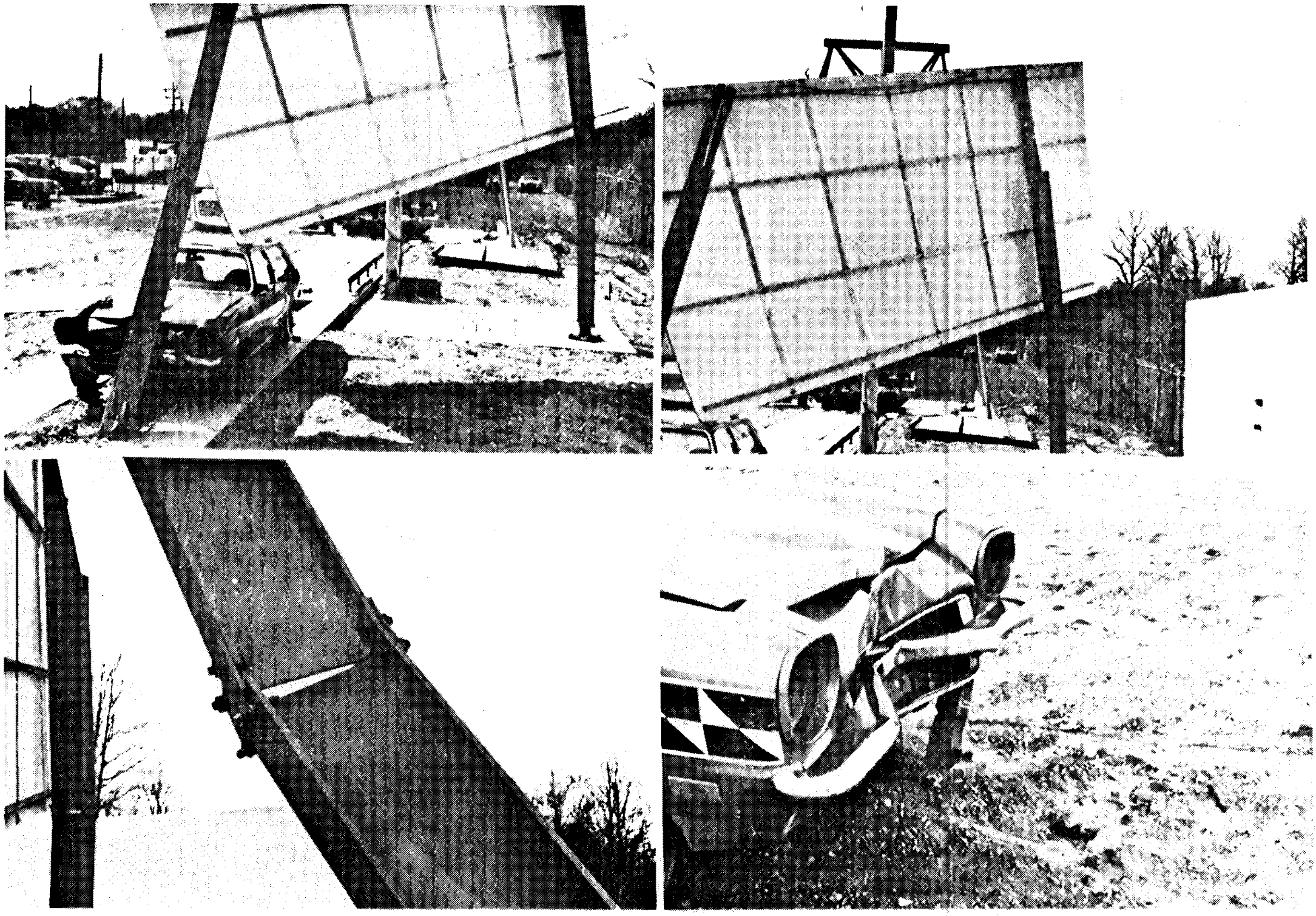

Fig. 80
Representative Post-test Photographs of Test 1147-1001

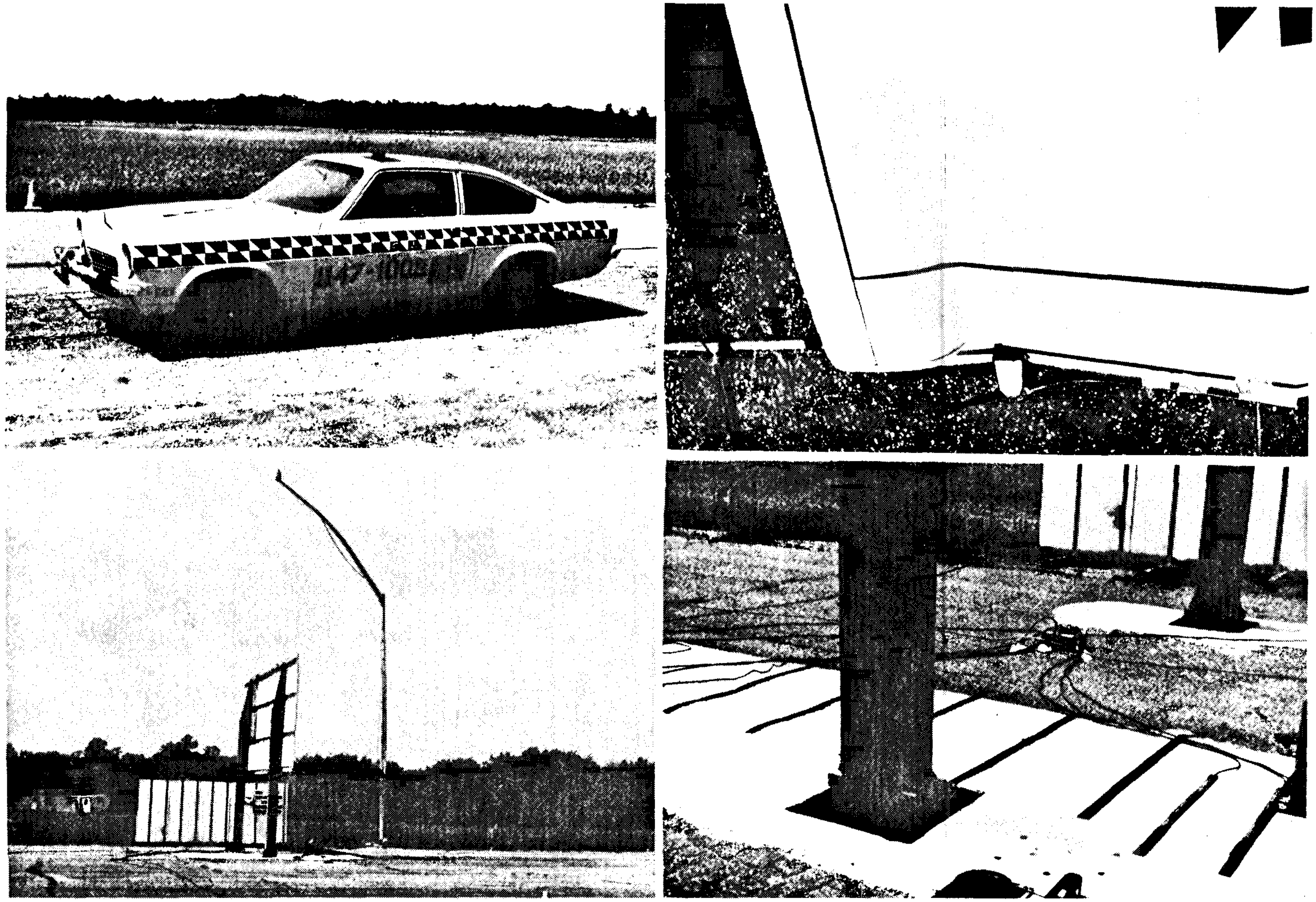

Fig. 81
Representative Pre-test Photographs of Test 1147-1008

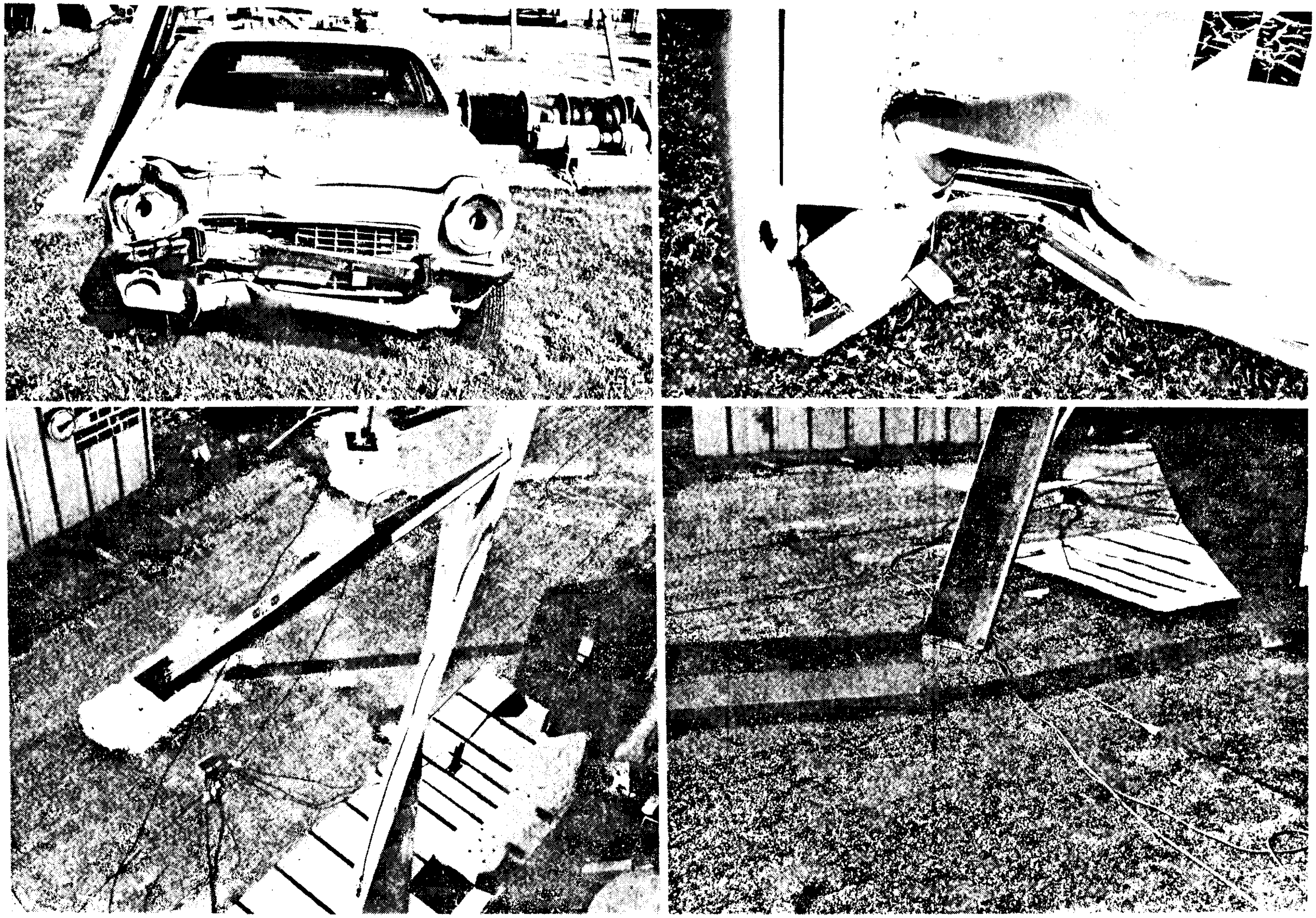

Fig. 82

Representative Post-test Photographs of Test 1147-1008

Test 1147-1009

This test was another off center hit test, this time utilizing a 1974 Honda Civic. The vehicle hit the sign support at approximately 16 in (40.6 cm) right of center at 61 mph (98 km/h). During the impact, crushing of sheet metal collapsed the right front wheel well preventing rotation of that wheel. This caused the car to rotate clockwise about the wheel and end up skidding sideways. Vehicle crush was about 15 in (38.1 cm) and change in momentum was 414 sec (91841 Ns). Table 32 shows the test results for this test.

The breakaway sign leg functioned as it did in the previous Test 1147-1008. The hinge opened more than 90° allowing the car to pass without secondary collision. Photographs of this test can be found in Figs. 83 and 84.

Test 1147-1010

In this test, conducted at the FHWA ITF, a 1974 Honda Civic Hatchback weighing 1617 lb (733 kg) impacted the sign at 20.6 mph (33 km/h). The impact point was in the front center of the car; vehicle crush was 10 in (25 cm). Although the slip base broke away as designed, the upper hinge did not activate. The sign support was torn off of the sign by breaking the attachment bolts and clips. The sign support ended up being balanced on the top of the automobile as shown in Fig. 86. The vehicle change in momentum for this test was 496 lb-sec (2206 Ns). Test results are displayed in Table 32. Representative test photographs may be found in Figs. 85 and 86.

7.3 BOGIE SYSTEM VALIDATION TESTS

A series of tests were run utilizing the bogie vehicle system for the purpose of validating the system against full-scale test data. In order to assess the range of hardware that could be

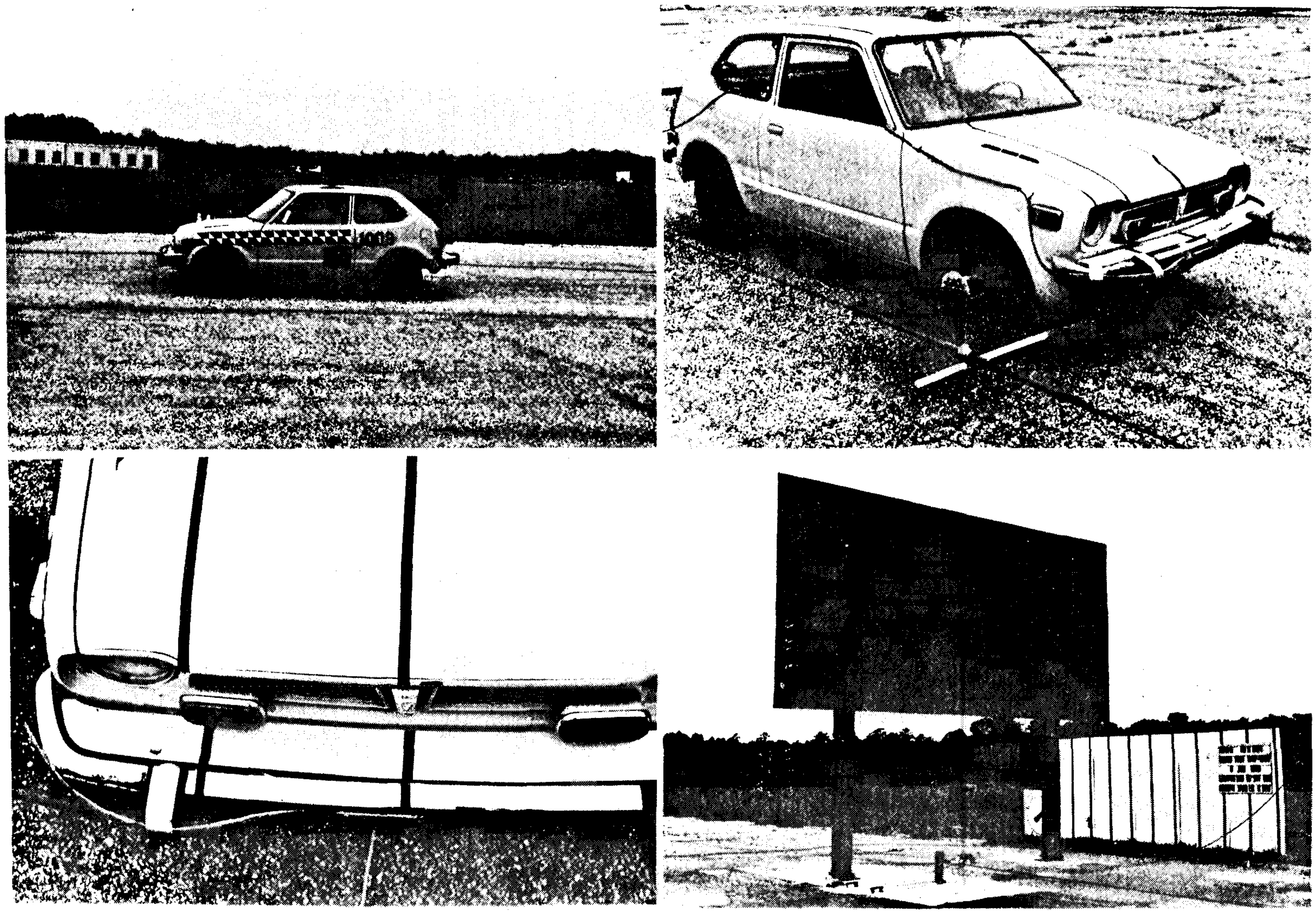

Fig. 83
Representative Pre-test Photographs of Test 1147-1009

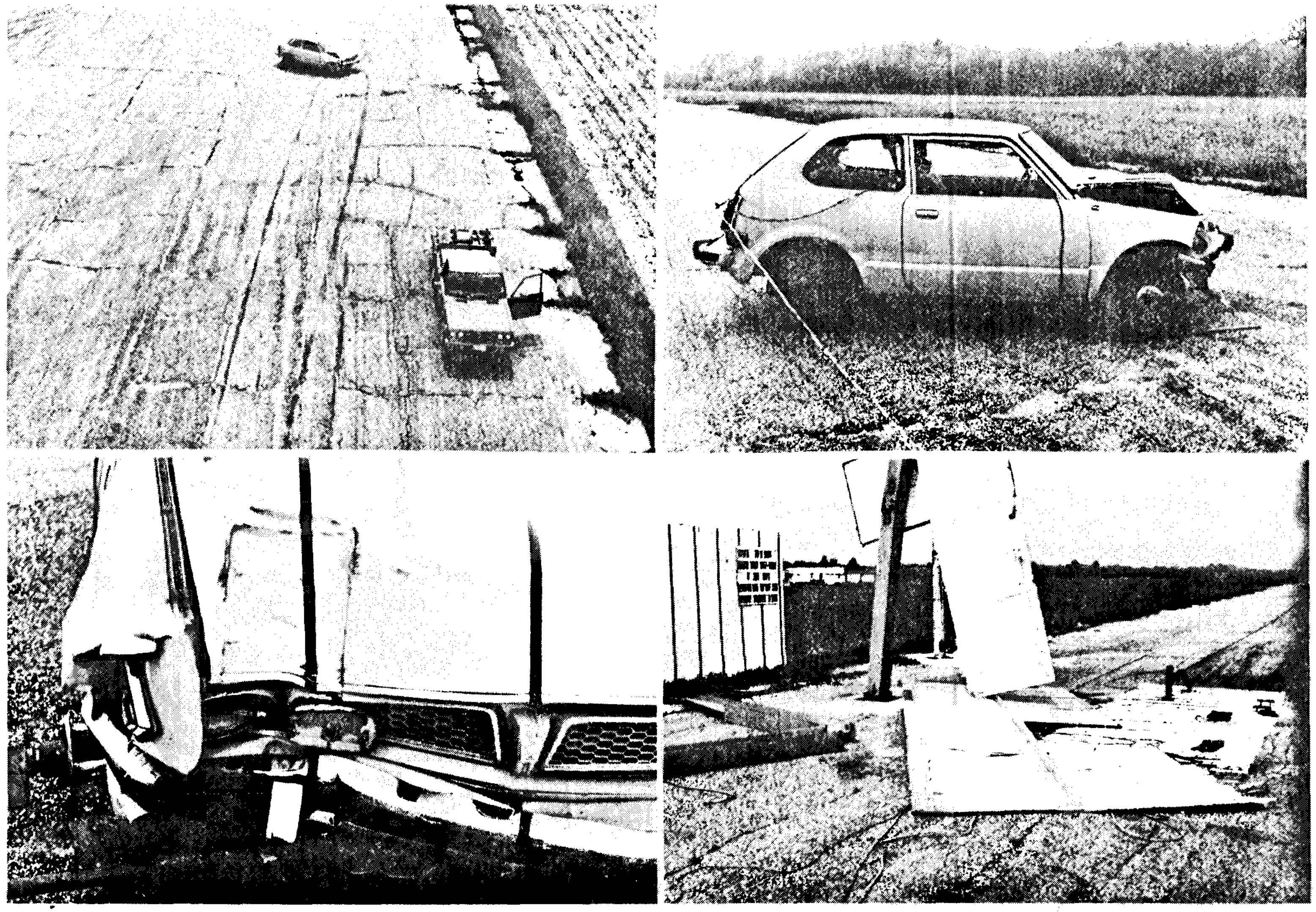

Fig. 84
Representative Post-test Photographs of Test 1147-1009

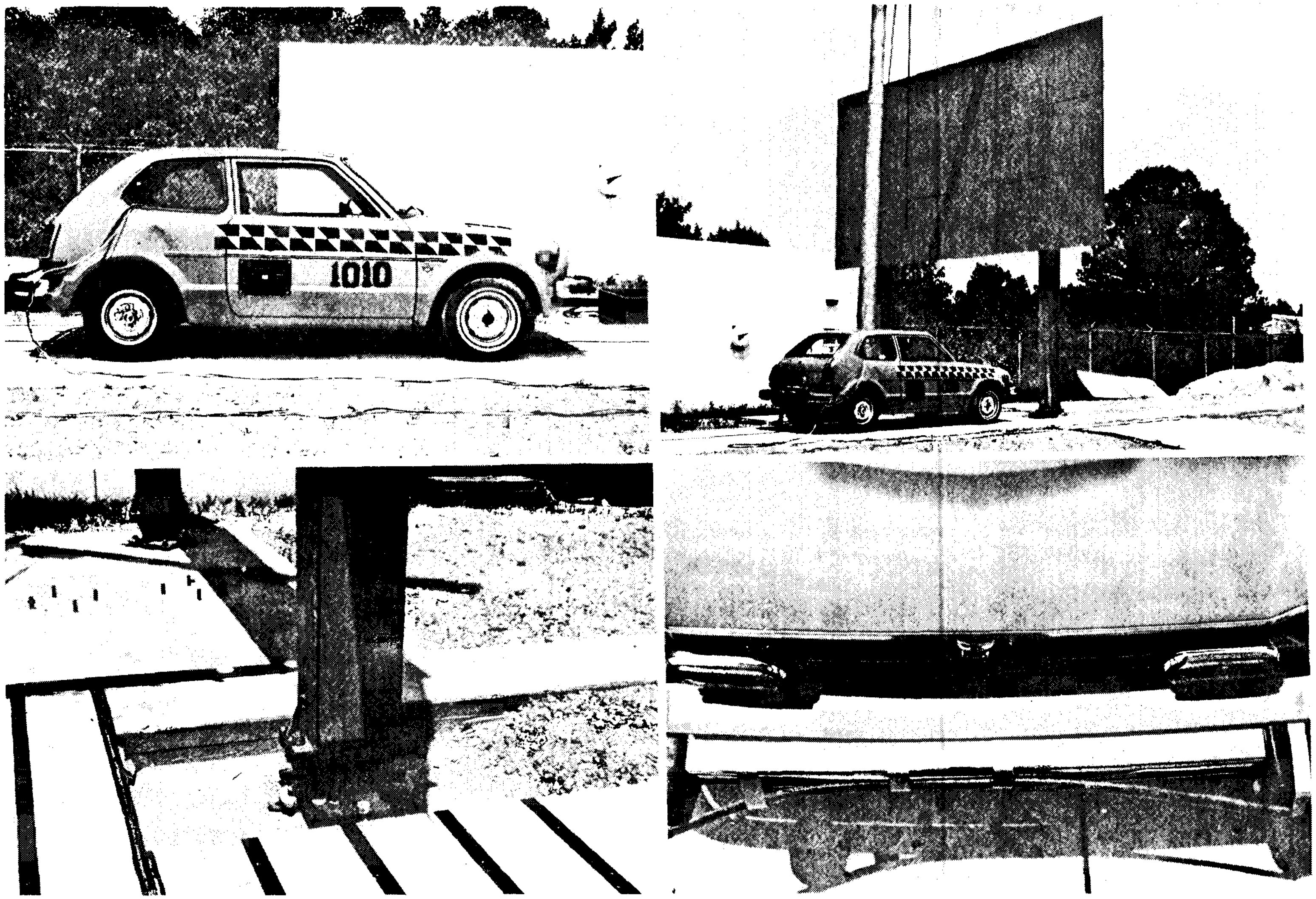

Fig. 85
Representative Pre-test Photographs of Test 1147-1010

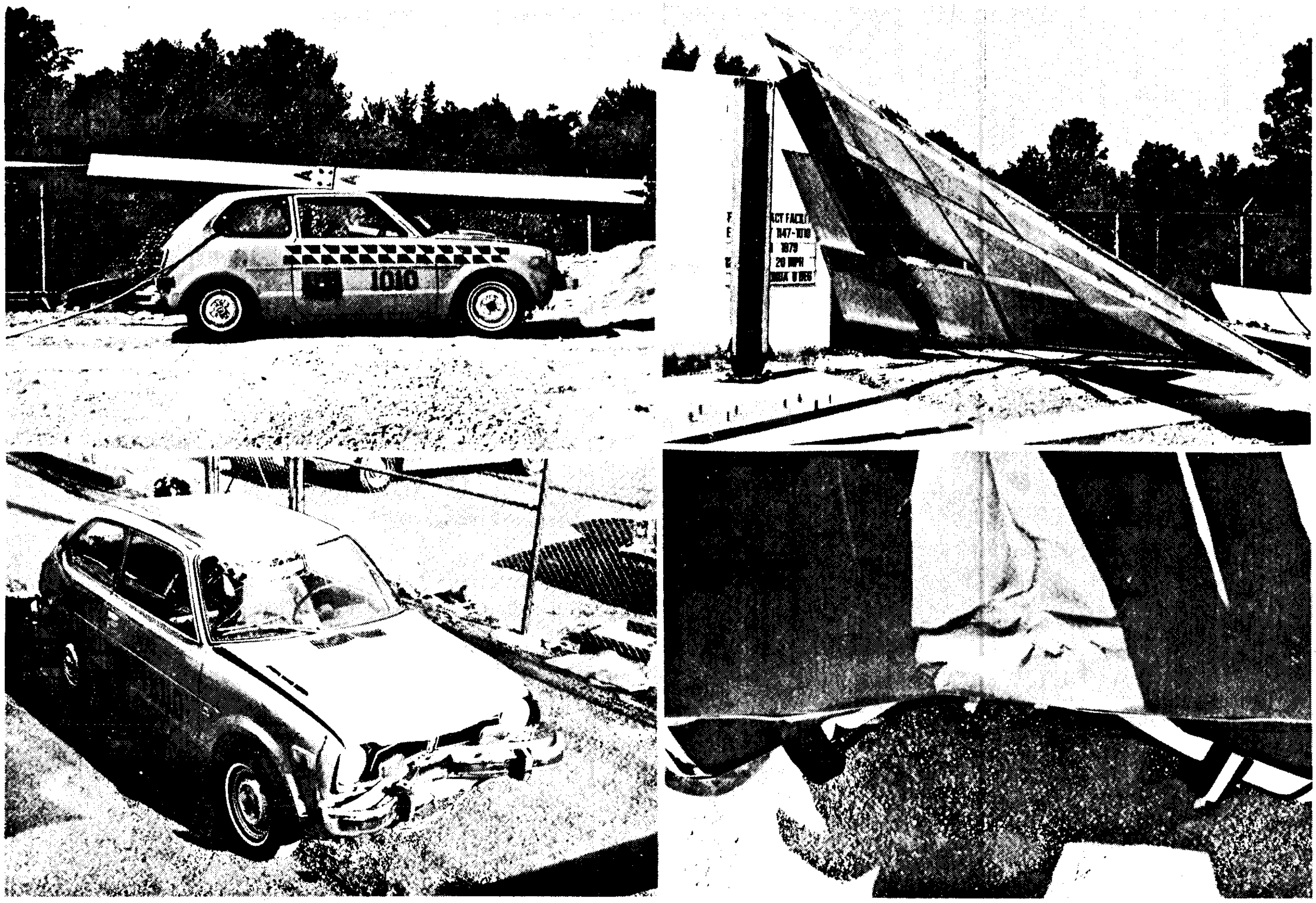

Fig. 86

Representative Post-test Photographs of Test 1147-1010

tested, several types of supports were tested. These supports are shown in Table 33 along with the corresponding full-scale test.

Each of the bogie validation tests is discussed separately below.

TABLE 33. BOGIE SYSTEM VALIDATION TESTS

Test No.	Support Type	Corresponding Full Scale Test
1147-901	55 ft (17 m) Luminaire Alcoa Breakaway Couplings	TTI 3290-3
1147-902	6 in x 8 in (15 cm x 20 cm) Wood Leg Sign	Caltrans
1147-903	Union Metal 3 Bolt Slip Base Luminaire	TTI D15
1147-803	Dual Legged Sign with 8WF20 Legs	ENSCO 1147-802
1147-1002 and -1003	Dual Legged Sign with 12WF45 Legs	ENSCO 1147-1001

Test 1147-901

This validation test was conducted on Alcoa Breakaway Couplings (100-1) with a 55 ft (17 m) MH spun aluminum pole mounted on them. This test is a duplication of ENSCO Test 1147-601 which used a pendulum and TTI full scale test 3290-3 which used a Vega test vehicle. Fig. 87 shows the test set-up and installed Alcoa couplings.

Failure of the couplings was as expected in that they split longitudinally allowing the pole to breakaway. The pole was dented when it fell on the roof-line simulator on the bogie. Fig. 87 also shows the split couplings and the dented pole.

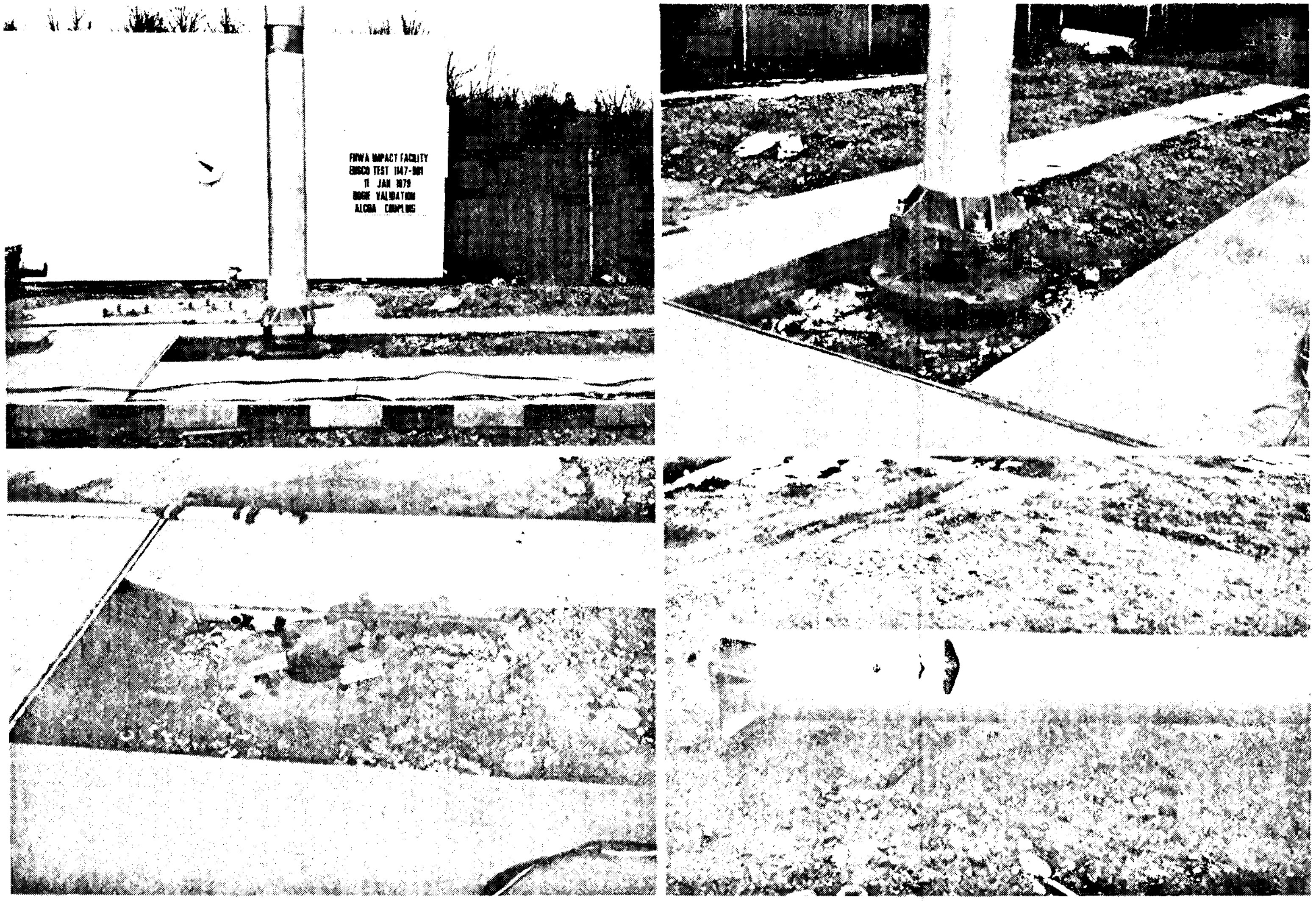

Fig. 87

Representative Photographs of Test 1147-901

A comparison of accelerometer traces for the tests is shown in Fig. 88. Results of these three tests are presented in Table 34.

TABLE 34. COMPARISON OF RESULTS FROM ENSCO TESTS 1147-901 AND -601 AND TTI TEST 3290-3

	Test 1147-901 (Bogie)	Test 1147-601 (Pendulum)	Test 3290-3 (Full-Scale)
Momentum Change (lb-sec)	544	606	590
Peak Deceleration (g's)	8.4	8.0	8.3
Time to Peak Decel. (secs)	0.053	0.061	0.044
Impact Duration (secs)	0.062	0.075	0.075
Vehicle Crush (in)	17	--	--

1 lb-sec = 4.448 Ns, 1 in = 2.54 cm

Test 1147-902

This was a test of a wood post sign. The sign blank was 13 ft x 6 ft-8 in x 1 in (4 m x 2 m x 2.5 cm) thick with aluminum skin over a cardboard honeycomb core. The legs were 6 in x 8 in x 20 ft (15 cm x 20 cm x 6 m) and made from Douglas Fir. Each post was embedded 6 ft (1.8 m) into standard soil as specified in Transportation Research Circular No. 191 [17]. Each leg was drilled laterally at 6 in and 18 in (15 cm and 46 cm) above the ground with a 2½ in (6.4 cm) dia. drill to make it breakaway. Fig. 89 shows the sign-post system as tested.

This impact resulted in stopping the bogie. The impacted leg broke through the upper hole after crushing all the honeycomb. The leg then splintered up about 2 ft (.61 m) on the front side

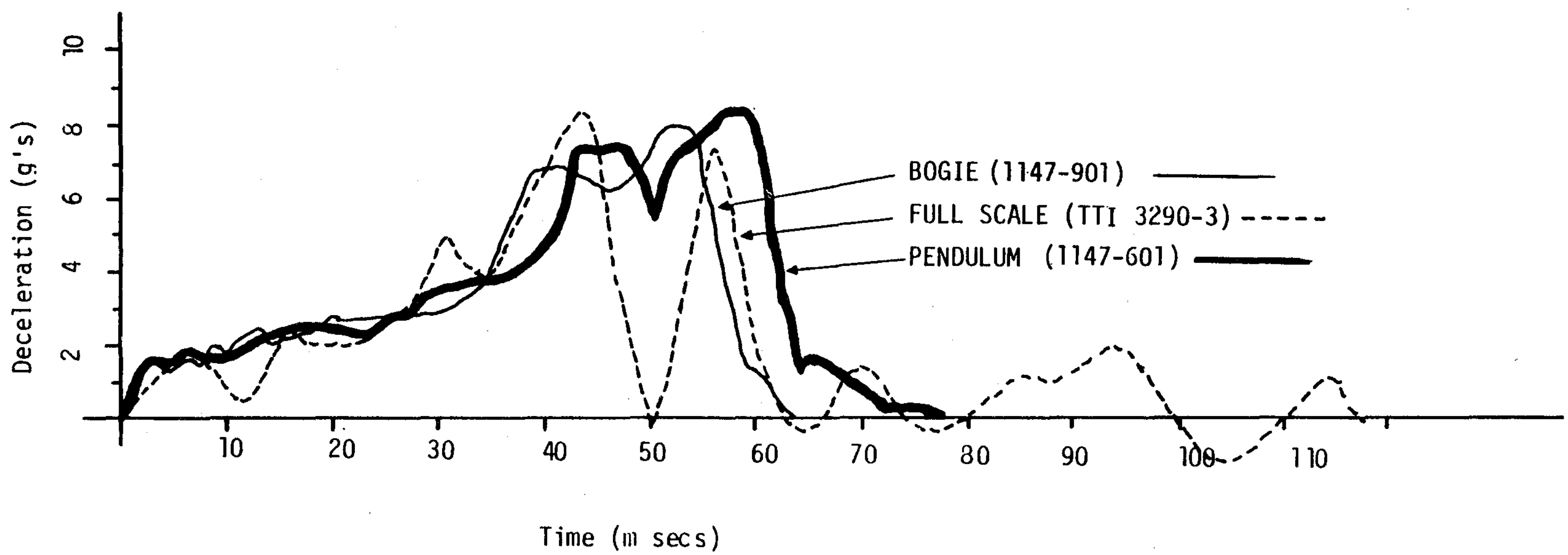

Fig. 88

Comparison of Longitudinal Accelerometer Traces
for TTI Test 3290 and ENSCO Tests 1147-601 &-901

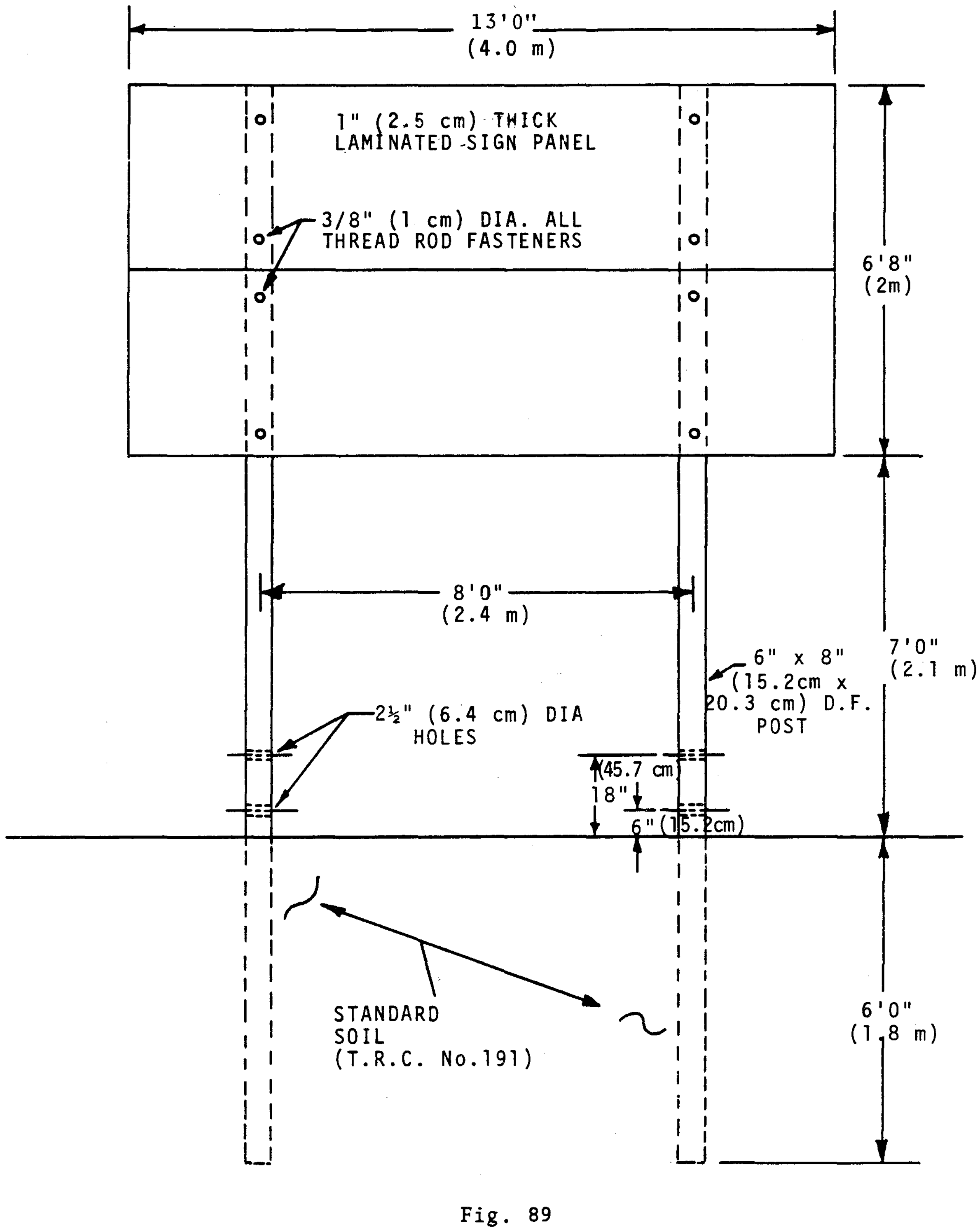

Fig. 89

Dual-Legged Sign with Wood Post and Laminated Sign Panel in Test 1147-902 and down 6 in (15 cm) on the back side. The remaining stub then bent over in the soil slowing the bogie to a stop in about 0.4 seconds. This embedded stub was pushed forward about 27½ in (.70 m) at ground level.

A possible reason the leg did not break below ground level is the soil could not support the loading required to break the post. In a similar test run by the State of California DOT, the post broke below ground level. This test, using a Toyota Sedan resulted in a momentum change of approximately 750 lb-sec (3340 Ns).

Photographs of the test are found in Fig. 90. Test results are given in Table 35.

TABLE 35. RESULTS OF TEST 1147-902

Momentum Change (lb-sec)	(film data)
Peak deceleration (g's)	6.3 g's
Time to Peak Decel. (sec)	0.06
Impact Duration	0.43
Honeycomb Crush (in)	165.5

1 lb-sec = 4.448 Ns, 1 in = 2.54 cm
*This value was found using the "duration of the event" rule according to TRC191[17].

Test 1147-903

This test is on a Union Metal 3-bolt slip base luminaire support. The support was a 35 ft MH steel pole with a 14 in (35.6 cm) lower bolt circle. The slip base bolts were loaded to 15,000 lbs (66,720 N). This test is very similar to ENSCO Test 1147-125 with the pendulum and TTI Test D15 with a Vega subcompact car.

The results of the test were as expected with the pole sliding off the mounting base. The sweeperplate did hit the leading slip base bolt which caused an additional 55 lb-sec (245 Ns) momentum change according to the accelerometer trace.

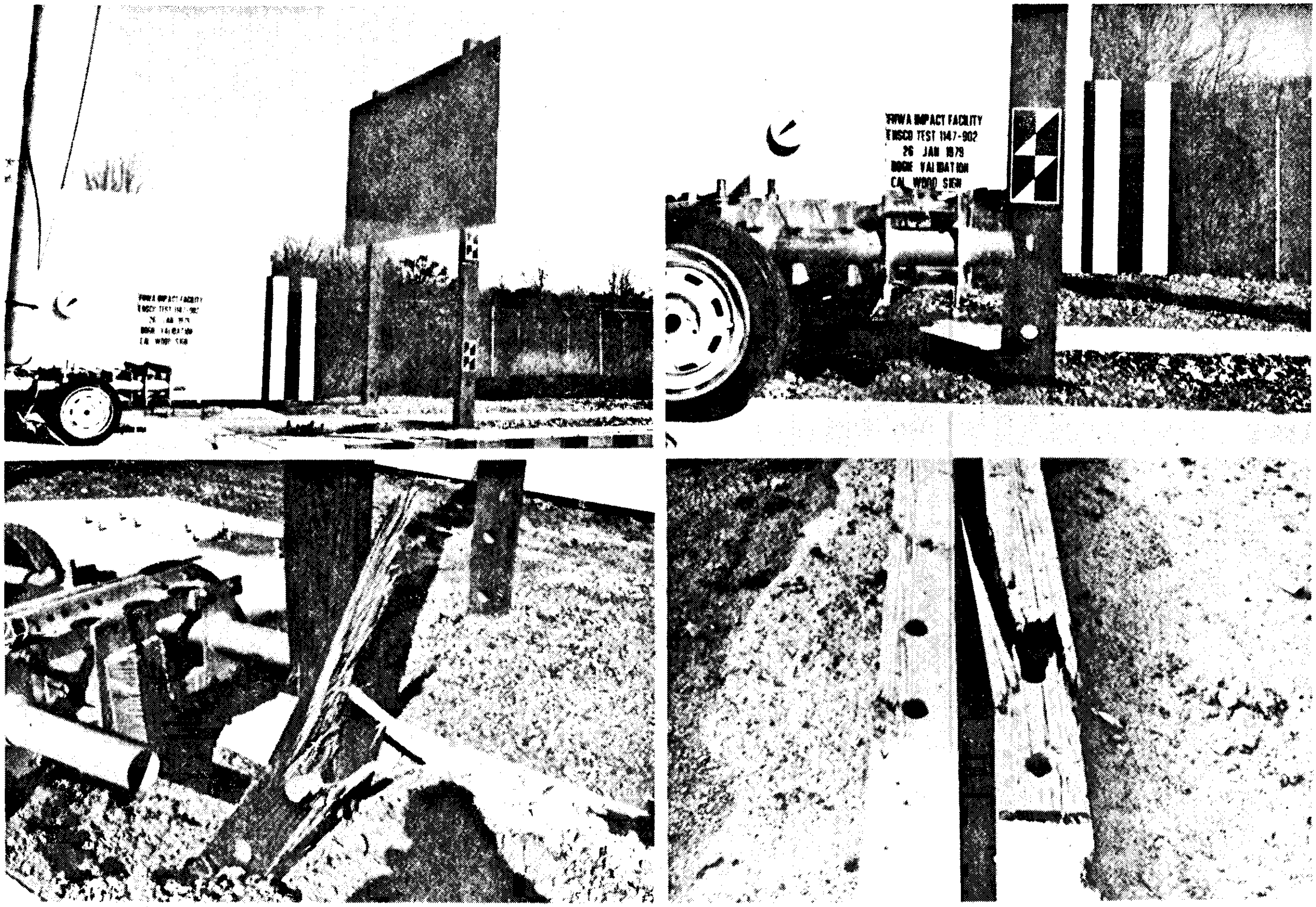

Fig. 90
Representative Photographs of Test 1147-902

Fig. 91 shows the accelerometer traces of the Bogie Test (1147-903), the Pendulum Test (1147-125) and Full-Scale Vega Test (TTI D15). Fig. 92 shows test photographs and Table 36 gives results of the three related tests.

TABLE 36. RESULTS OF TESTS 1147-903 AND 1147-125 AND TTI TEST D-15

	Test 1147-903 (Bogie)	Test 1147-125 (Pendulum)	Test TTI-D15 (Full-Scale)
Momentum Change (lb-sec)	577 (excluding 55 lb-sec bolt impact)	563	560
Peak Deceleration (g's)	9.3	9.3	10.0
Time and Peak Decel. (sec)	0.053	0.055	0.057
Impact Duration (sec)	0.065	0.065	0.065
Crush (in)	17.4	17.5	17.0

1 lb-sec = 4.448 Ns, 1 in = 2.54 cm

Test 1147-803

Test 1147-803 was the first bogie test utilizing a dual-legged sign support with steel legs. This sign is made of a 10 ft x 15 ft x 5/8 in (3 m x 4.5 m x 1.6 cm) plywood blank, 4 aluminum stiffeners and 2 steel 8WF20 legs as shown in Fig. 78. Photographs of the sign, leg, and bogie to sign interface are shown in Fig. 93. This is the same sign leg system used in full-scale Tests 1147-801A and -802.

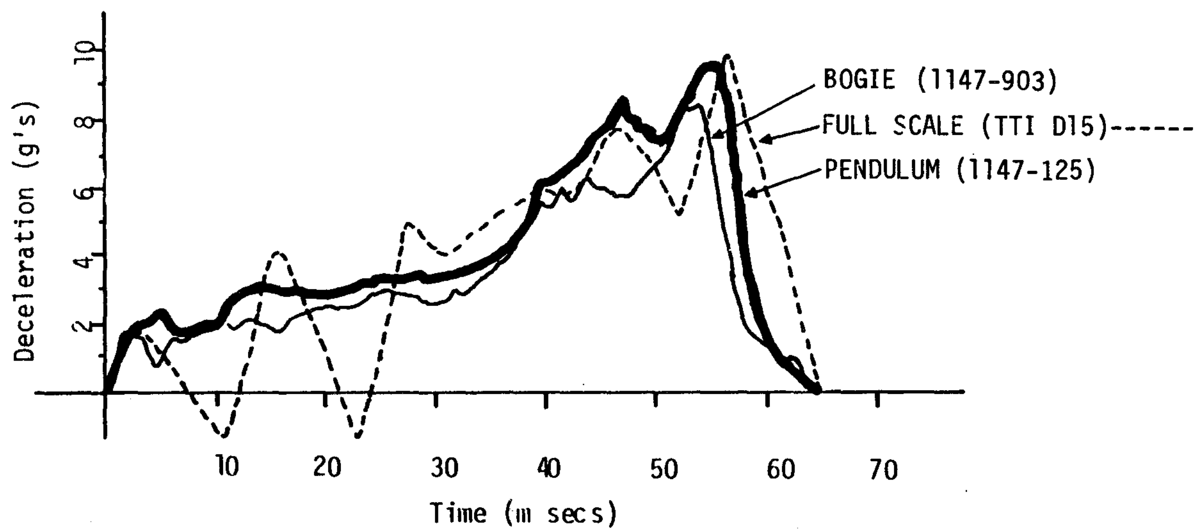

Fig. 91

Comparison of Longitudinal Accelerometer Traces for TTI Test D15 and ENSCO Tests 1147-125 and -903 on Union Metal 3 Bolt Slip Base with 15 Kips Bolt Load

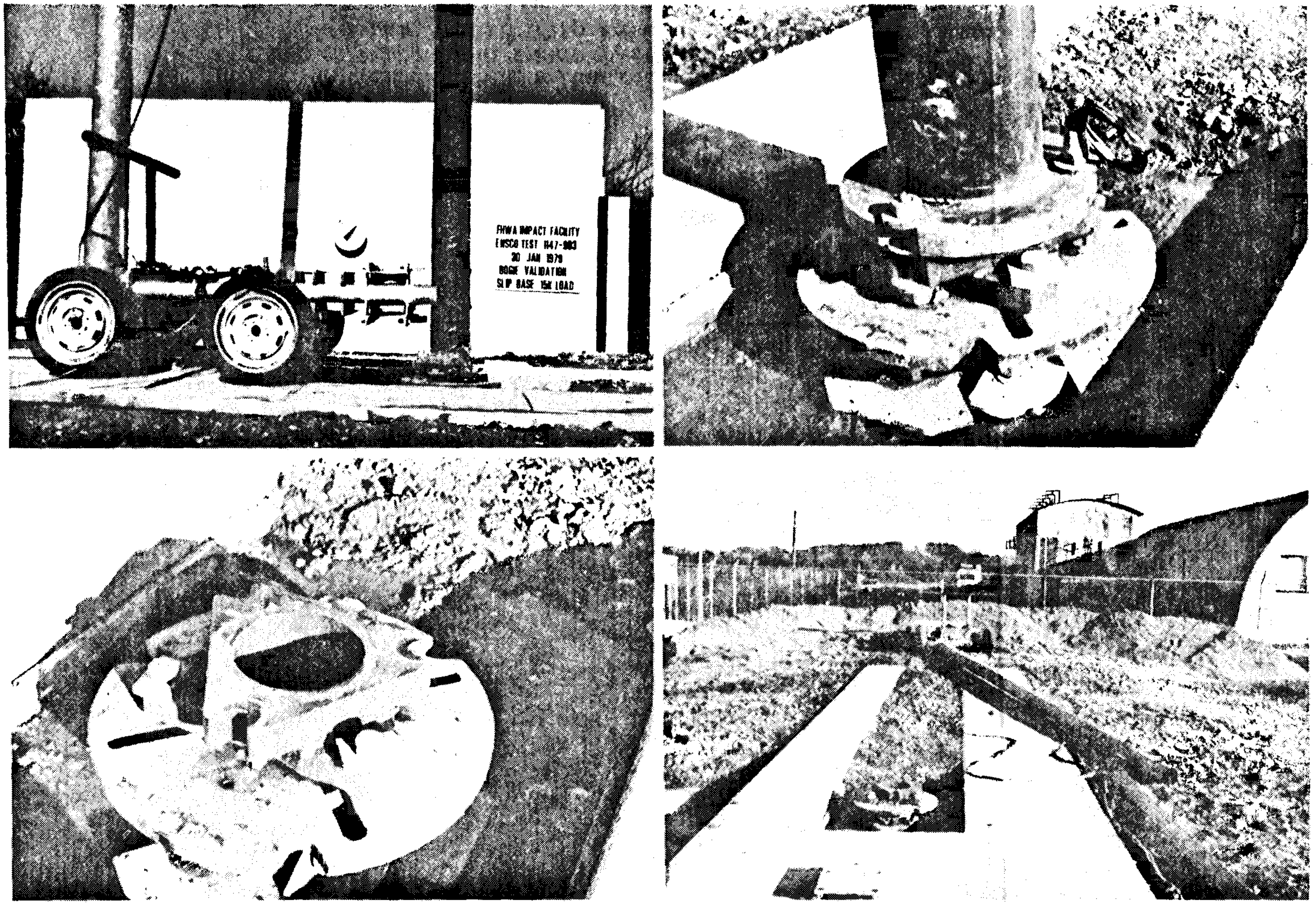

Fig. 92
Representative Photographs of Test 1147-903

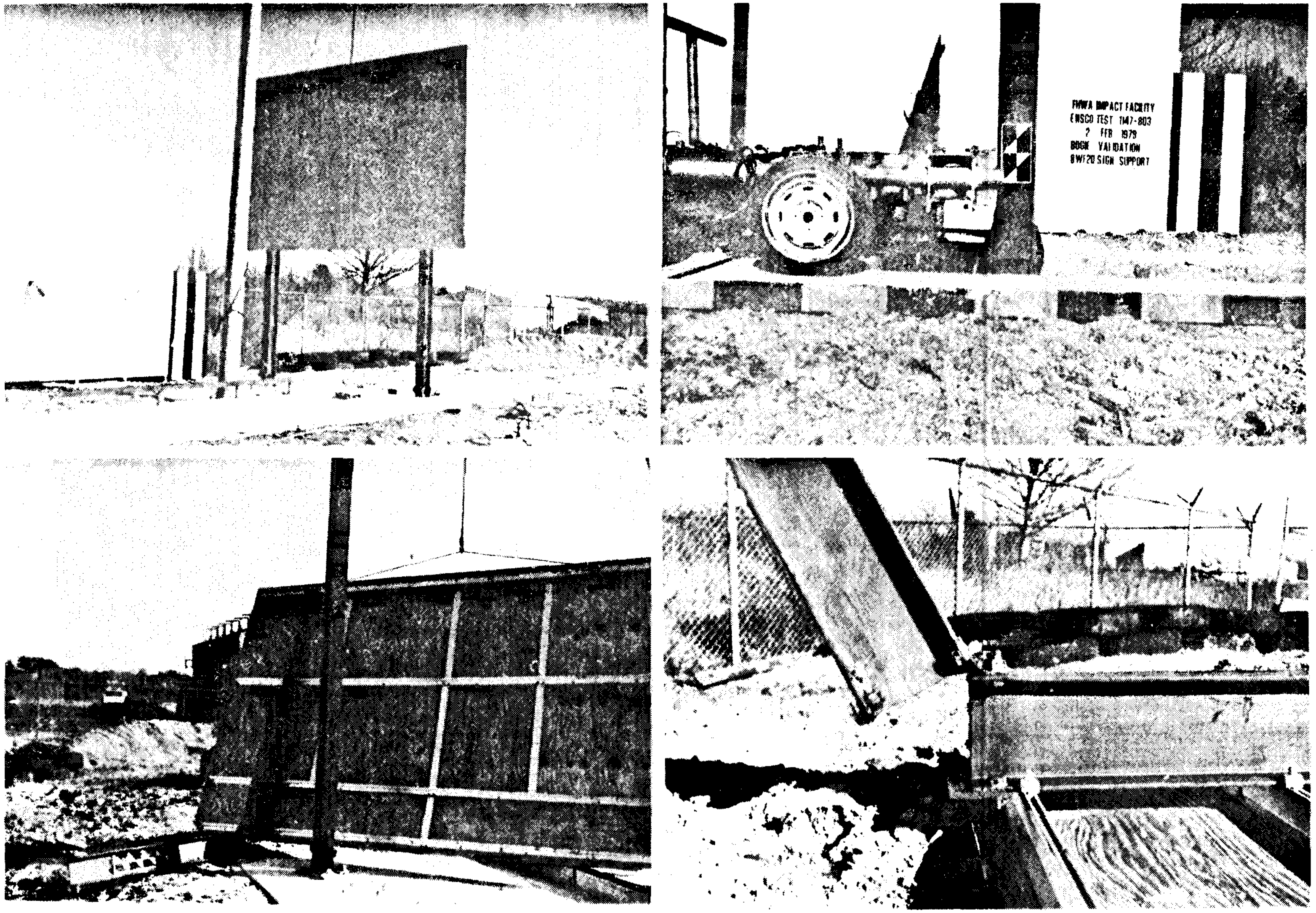

Fig. 93
Representative Photographs of Test 1147-803

The impact of the support was as expected with the bogie honeycomb nose crushing followed by slip base activation and then hinge activation. Hinge activation occurred after the bogie lost contact with the support. The sign then rotated about the standing leg breaking away the aluminum clips and bolts which held it to the leg. The bogie veered off to the left during impact and was then stopped using the onboard braking system. Photographs of the sign following the test are presented in Fig. 93.

Results of this test and the full-scale Vega test (1147-802) are given in Table 37. A comparison of accelerometer traces for Test 1147-802 and -803 is shown in Fig. 94.

TABLE 37. RESULTS OF TESTS 1147-802 AND -803

	Test 1147-802 (Full scale)	Test 1147-803 (Bogie)
Momentum Change (lb-sec)		
Accelerometer	319	467
Film Data	471	652
Peak Deceleration (g's)	5.9	7.4
Time at Peak Decel. (sec)	0.048	0.051
Impact Duration (sec)	0.054	0.063
Crush (in)	11.5	17.5
Time at Slip Base Activation (sec)	0.030	0.050
Deceleration at Base Activation (g's)	32.9	7.0

1 lb-sec = 4.448 Ns, 1 in = 2.54 cm

It was felt that bolt load variations due to use of a torque wrench could account for the increased breakaway force found in the bogie test. For this reason all 1000 series tests were conducted with strain gauged slip base and hinge bolts.

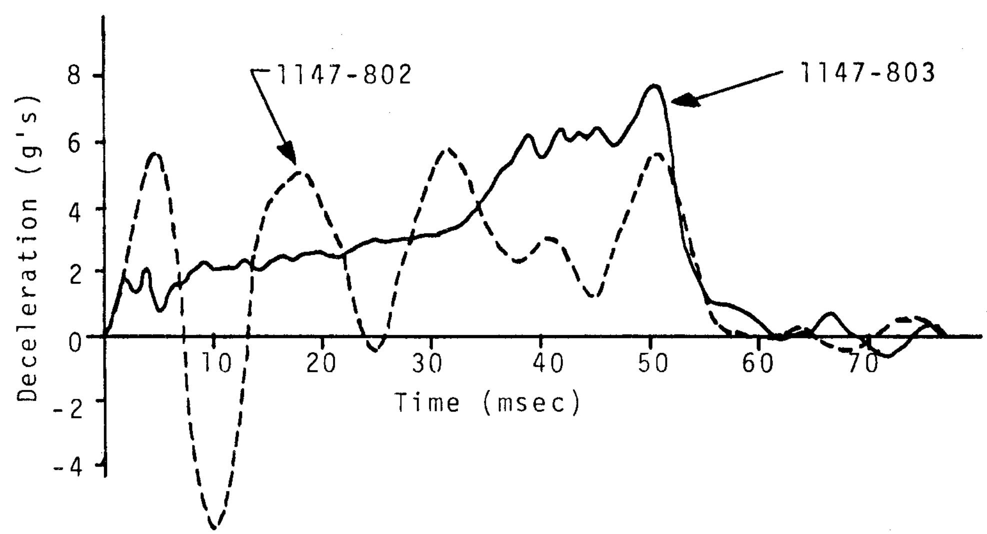

Fig. 94
Comparison of Deceleration-time Traces for Tests
1147-803 and 1147-802

Test 1147-1002

In this test the bogie was impacted into the sign support with the same initial conditions as in full-scale Test 1147-1001. Snagging occurred between the sweeper plate and the leading slip base bolts which launched the bogie and brought it to a halt. The sweeperplate to fraying surface clearance was only 1 in (2.5 cm) which did not allow enough clearance for the sweeperplate to pass over the protruding portion of the slip base bolt. The momentum change for this test was 2188 lb-sec (9732 Ns) since the bogie was stopped.

Representative photographs for this test are shown in Fig. 95. The test results are displayed in Table 38.

TABLE 38. RESULTS OF TEST 1147-1002

Momentum Change (lb-sec)	2177
Peak Deceleration (g's)	17.6 (Sweeperplate impact)
Time to Peak Decel. (sec)	.058
Impact Duration (sec)	.151 (Sweeperplate impact)
Honeycomb Crush (in)	17.5

1 lb-sec = 4.448 Ns, 1 in = 2.54 cm

Test 1147-1003

This test was a repeat of Test 1147-1002 except that the sweeperplate was raised 3 in (7.6 cm) to prevent any further possibility of snagging. The behavior of the sign in this test was very similar to that found in test 1147-1001. The slip base separation was smooth. The sign support again broke free from the sign lower windbeams through failure of the aluminum clip bolts.

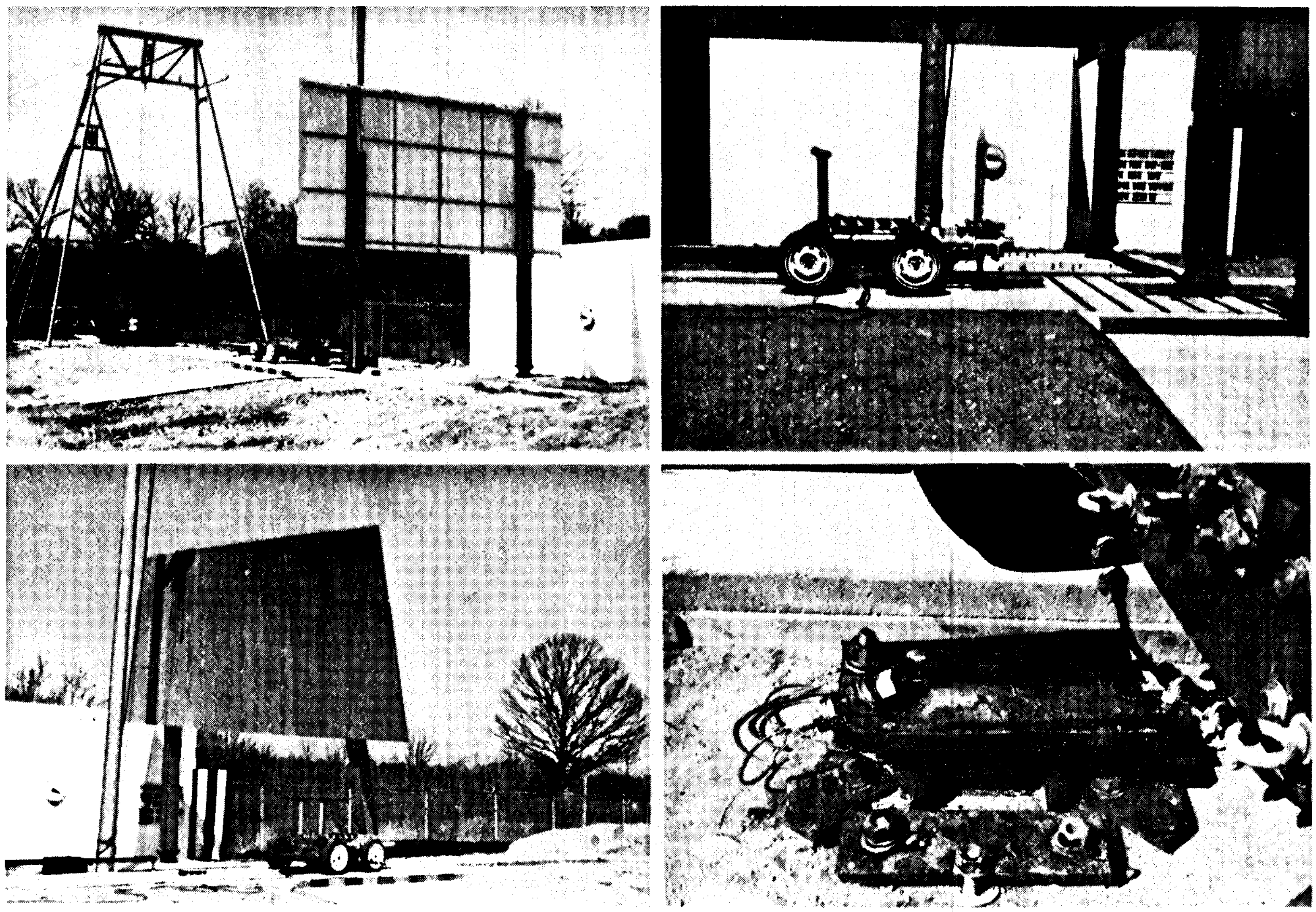

Fig. 95
Representative Photographs of Test 1147-1002

In a frame by frame comparison of movies from Tests 1147-1001 and 1003, the time sequence of the tests was almost identical. Fig. 96 shows a comparison of the traces from the #1 accelerometer for Tests 1147-1001 and -1003 (filtered at 100 Hz). The traces are very similar except for the car body ringing which shows up in the Test 1147-1001 trace. The momentum change for this test was about 680 lb-sec (3024 Ns). The honeycomb crush was 17 in (43 cm).

Representative photographs of test 1147-1003 are shown in Fig. 97. Table 39 gives the test results for this test as compared to Test 1147-1001.

TABLE 39. COMPARISON OF RESULTS OF TESTS 1147-1001 AND 1147-1003

	1147-1001	1147-1003
Momentum Change (lb-sec)	710	680
Peak Deceleration (g's)	10.0	8.8
Time to Peak Decel. (sec)	.060	0.57
Impact Duration (sec)	.071	.067
Honeycomb Crush (in)	13.5	17.0

1 lb-sec = 4.448 Ns, 1 in = 2.54 cm

7.4 BOGIE VEHICLE DUAL-LEGGED SIGN TESTS

Several tests were run utilizing the validated bogie system. These tests can be broken into three categories which are:

- Angled Impacts - Tests 1147-1004 and -1005
- Balanced Hinge Sign - Test 1147-1006 and -1007.
- Honda Bogie Simulation - Tests 1147-1011

Each of these tests is described in the following sections.

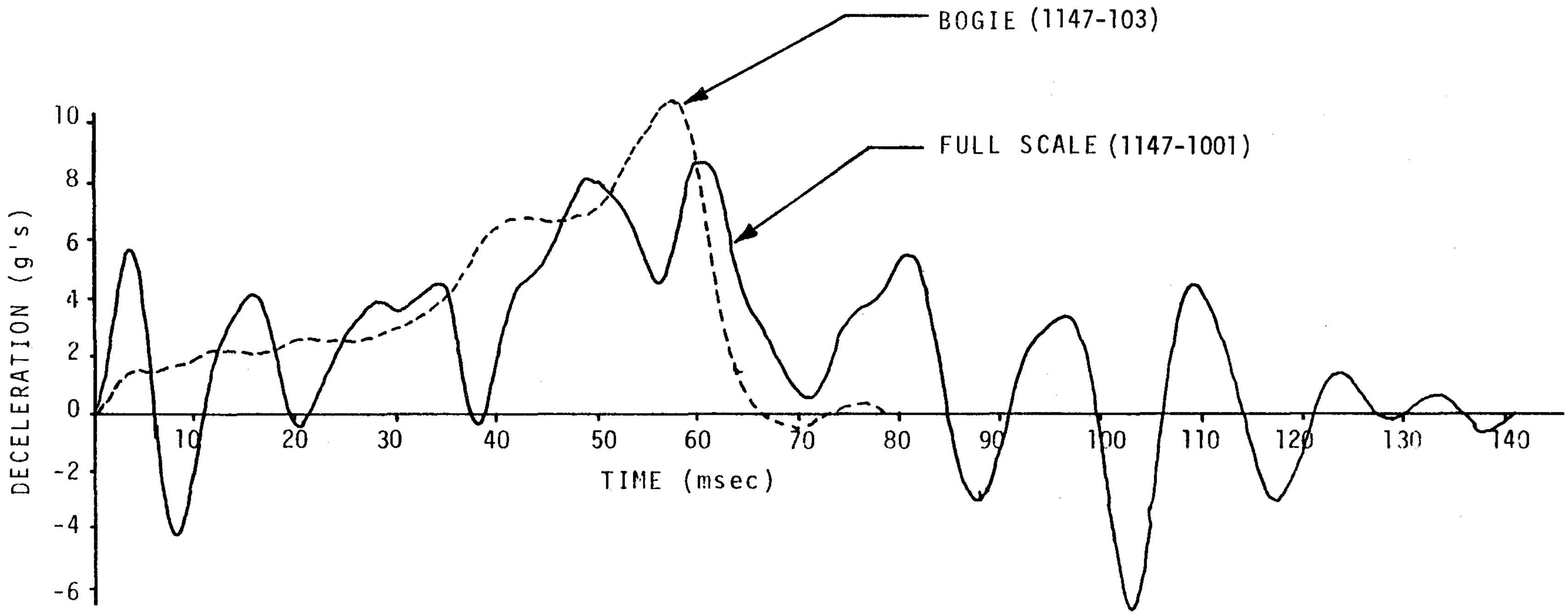

Fig. 96
Comparison of Longitudinal Accelerometer Traces for ENSCO Tests 1147-1001 (Full Scale) and 1147-1003 (Bogie) Filtered at 100 Hz

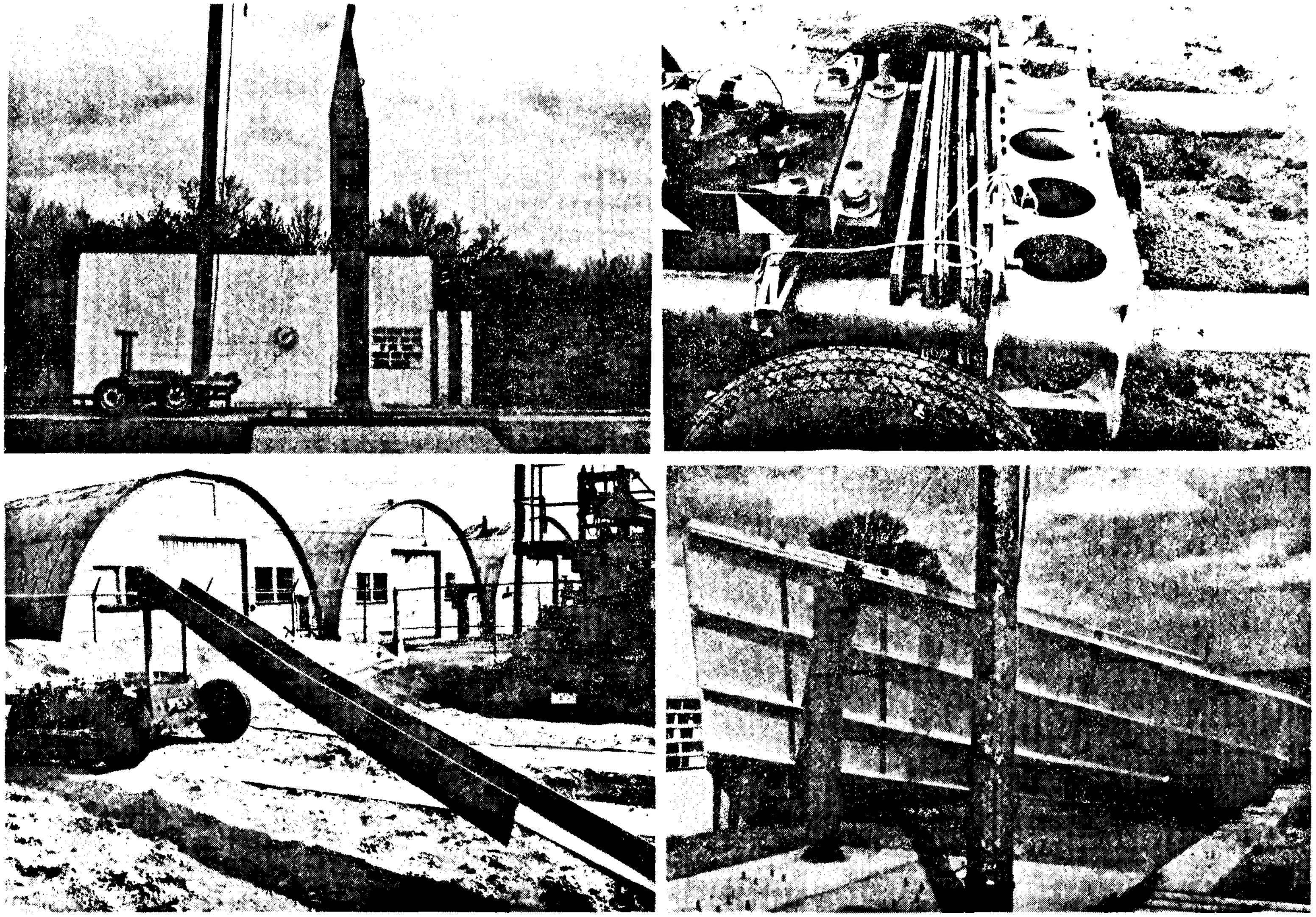

Fig. 97

Representative Photographs of Test 1147-1003

Test 1147-1004

In this test, the bogie was used to impact a sign support at a 15° angle. The sign had a 24 ft (7.2 m) wide x 12 ft (3.6 m) high blank with 12WF45 legs as shown in Fig. 78. This is the same sign tested in the previous 1000 series tests. These tests and Test 1147-1005 were used to evaluate the effectiveness of the slip base during angled impacts. It was felt that the slip base might bind up, especially when impacted at 30°, since the bolt slots have only a 15° angle. In this test the behavior of the sign was very similar to that found in the previous 0° angle tests. The impact angle had no effect on the sign performance. The bogie yawed slightly during the impact to a direction perpendicular to the sign. Following the impact the sign's inertia caused the hinge on the opposite leg to activate and the blank fell over. The momentum change was about 700 lb-sec (3114 Ns).

Representative photographs for this test are shown in Fig. 98. Test results are given in Table 40.

TABLE 40. TEST RESULTS FOR ANGLED IMPACT SIGN TESTS

	Test 1147-1004	Test 1147-1005
Impact Angle (deg)	15	30
Momentum Change (lb-sec)	700	677
Peak Deceleration (g's)	12.7	13.1
Time to Peak Decel. (sec)	.056	.054
Duration of Impact (sec)	17	17

1 lb-sec = 4.448 Ns, 1 in = 2.54 cm

Test 1147-1005

In this test the sign as tested in Test 1147-1004 was impacted at a 30° angle by the bogie. Again there was no noticeable change in performance from the previous tests. The bogie was

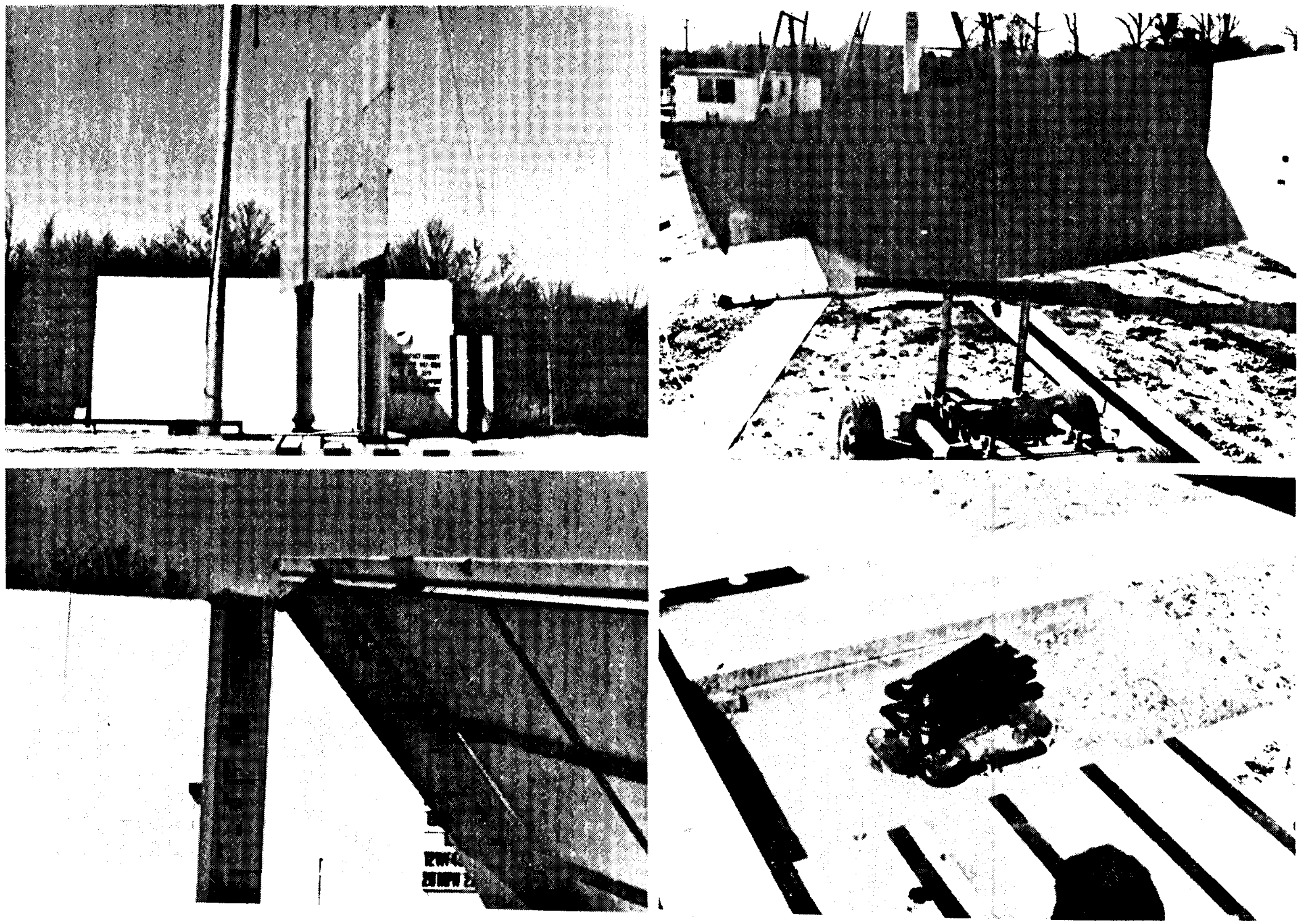

Fig. 98
Representative Photographs of Test 1147-1004

again yawed during impact to a direction perpendicular to the sign. The hinge on the non-impacted leg was again activated as in Test 1147-1004. The momentum change was approximately 677 lb-sec (3011 Ns).

Representative photographs of this test are shown in Fig. 99. Table 40 gives the test results for both angled impact tests.

Test 1147-1006

In all five of the previous 20 mph (32.2 km/h), large sign tests, the upper hinge was not properly activated and breakaway was achieved only through the failure of the aluminum T-slot bolts which fasten the sign blank to the upper support half. Although momentum change levels are acceptable, the damage to the sign can be severe. Also, had steel windbeams and connecting bolts been used, there is concern that the sign support might not have broken away at all. The balanced hinge concept (see Appendix C), eliminates the strong hinge and in theory is a more positive breakaway mechanism. In this test (1147-1006) the balanced hinge concept was tested for the first time. Fig. 100 shows the sign that was tested. The theory behind this sign is that if you pin the sign to the support at the sign CG, the moments will equal at the pin during wind loading. A small shear pin (¼ in dia.) is added at the bottom of the sign to prevent sign movement during wind buffeting.

The shear pin turned out to be the problem of the design. During the test the pin did not shear and the leg separated from the sign blank again through failure of the aluminum T-bolts. The momentum change for this test was 699 lb-sec (3109 Ns).

Fig. 101 shows representative photographs of this sign test. Table 41 displays the test results for this test and Test 1147-1007.

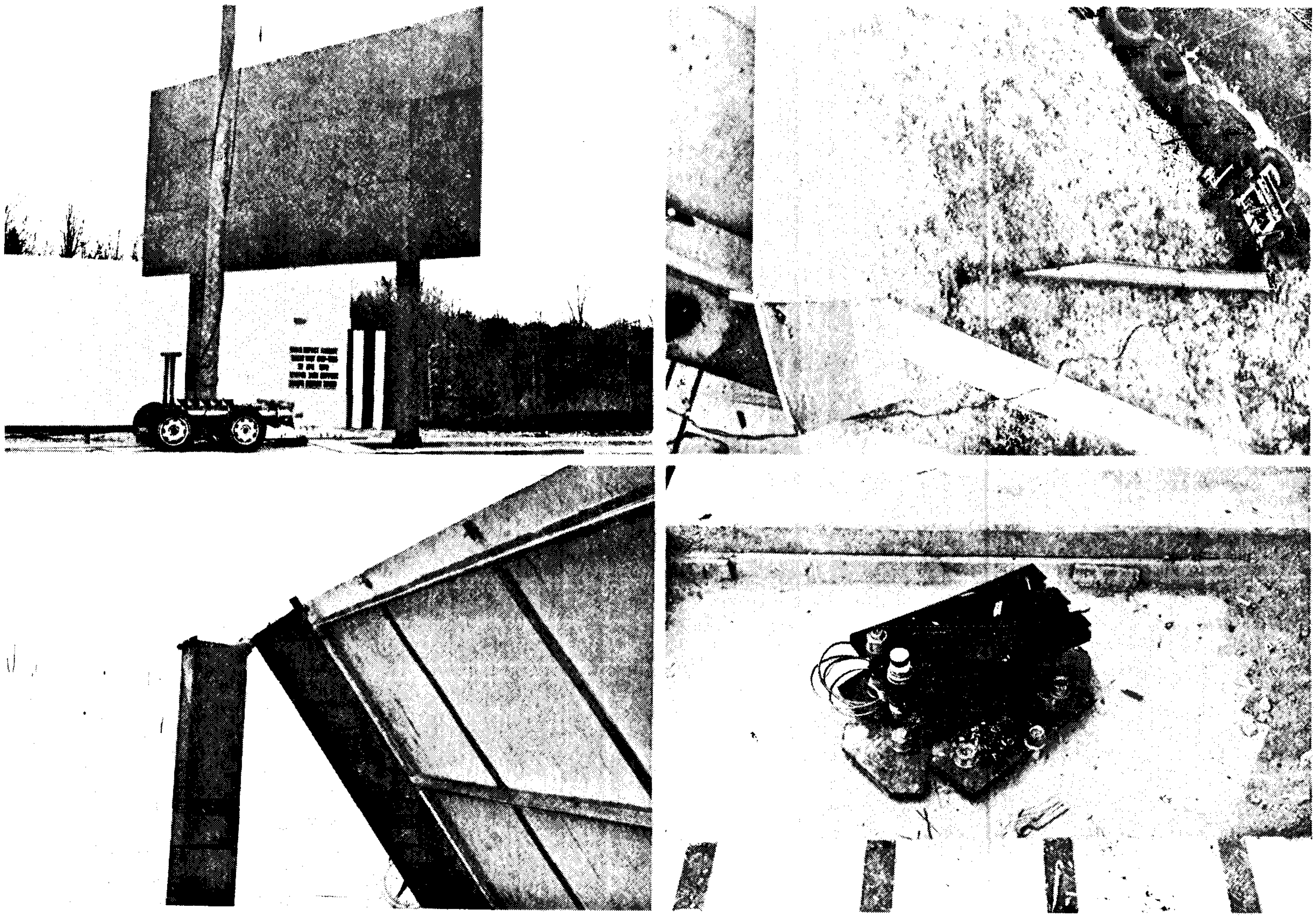

Fig. 99
Representative Photographs of Test 1147-1005

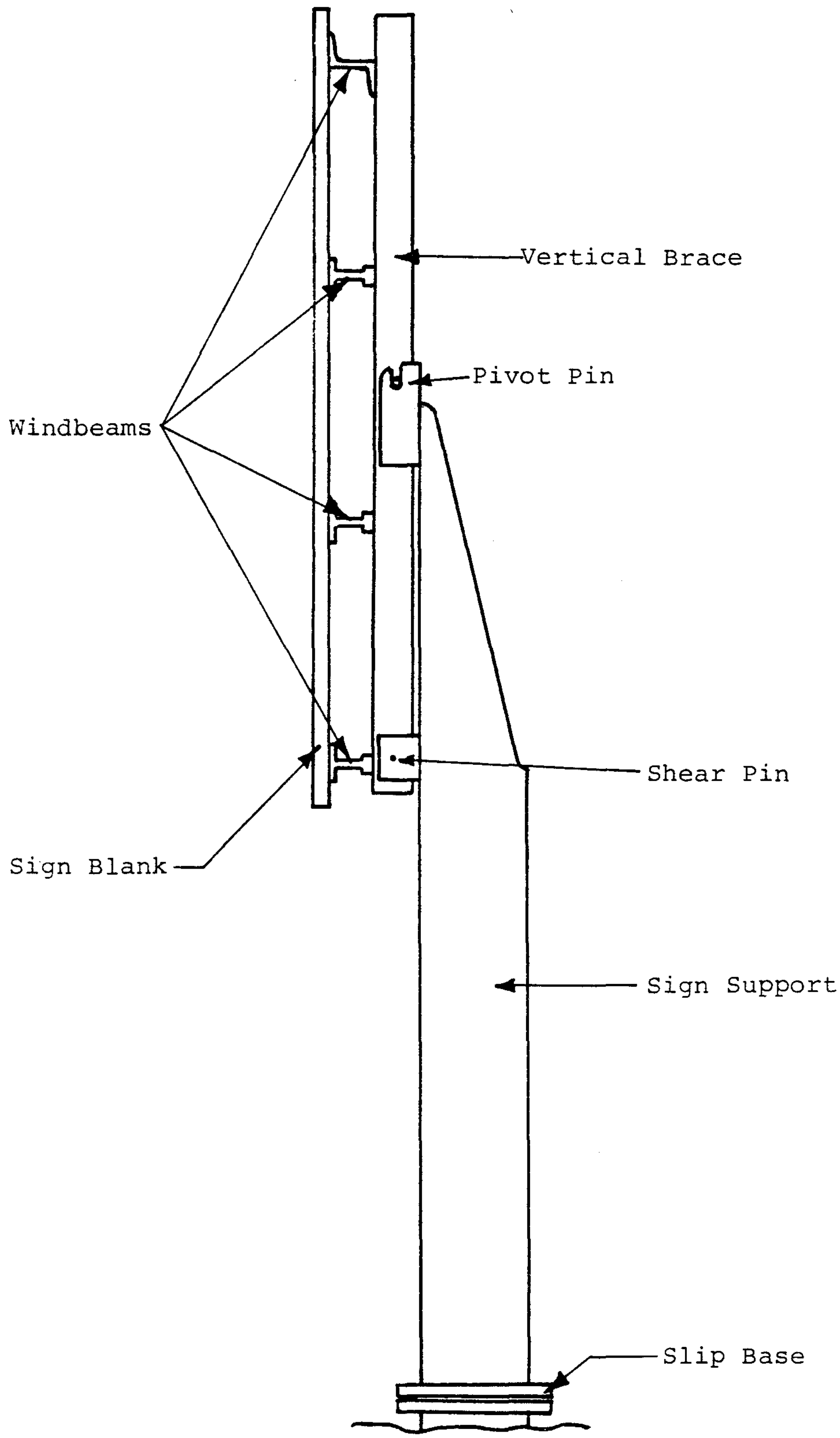

Fig. 100
Balanced Hinge Sign Prototype for ENSCO Tests 1006 & 1007

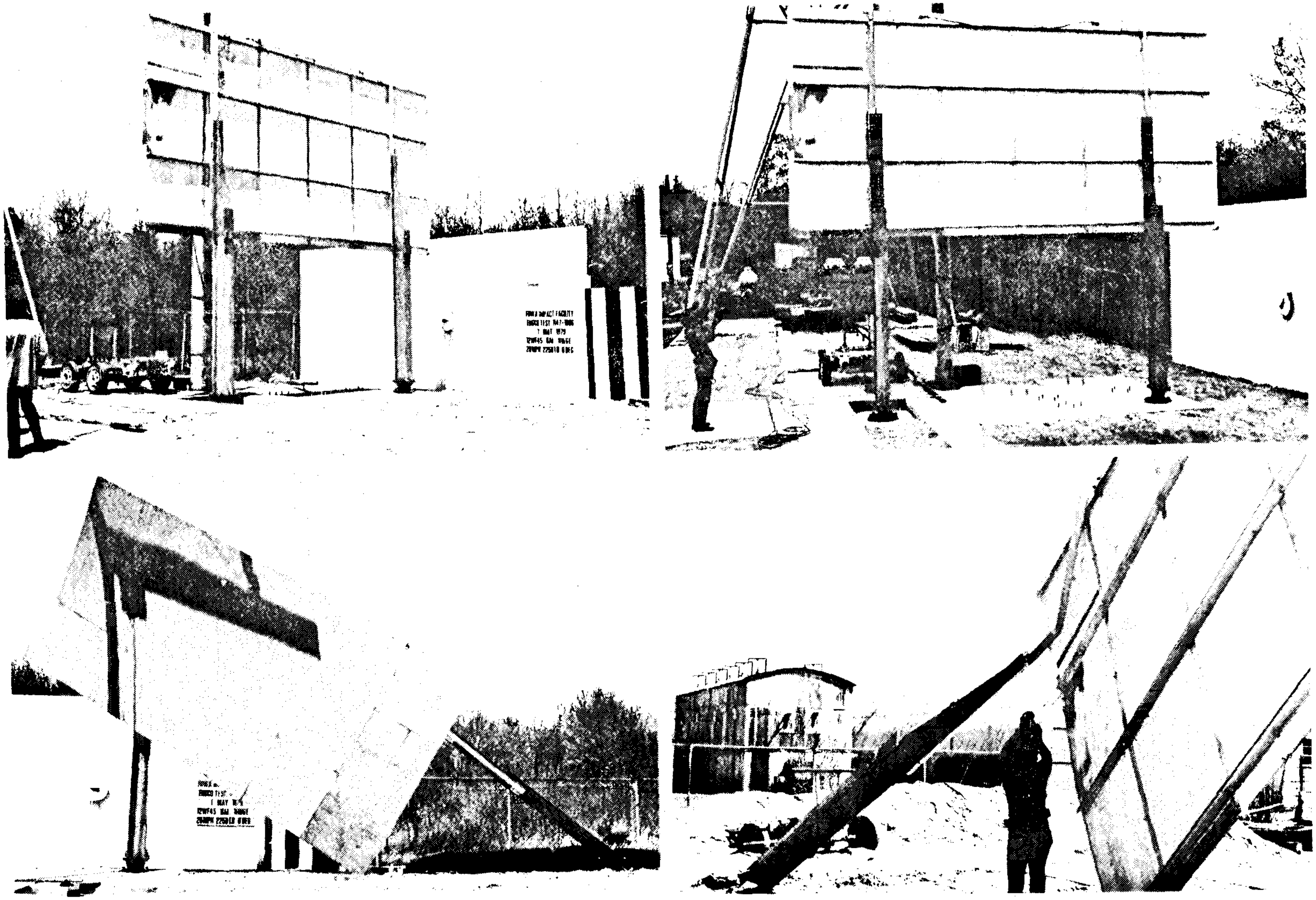

Fig. 101
Representative Photographs of Test 1147-1006

During this test two of the 1 in dia. (2.5 cm) slip base bolts were instrumented to record dynamic forces. One bolt was on the impacted side of the base, the other was on the downstream side. The static load on both bolts was 5000 lb. During impact the impact side bolt load rose to 8520 lb., while the other bolt load rose to 7250 lb. It is believed that these loads were caused mostly by the cocking of the bolts and not so much by an induced impact moment. The inertia of the sign prevents any appreciable impact induced moment.

TABLE 41. TEST RESULTS FOR BALANCED HINGE SIGN TESTS

	Test 1147-1006	Test 1147-1007
Momentum Change (lb-sec)	97	665
Peak Deceleration (g's)	12.5	11.0
Time to Peak Decel. (sec)	.056	.057
Impact Duration (sec)	.064	.065
Honeycomb Crush (in)	17	17

1 lb-sec = 4.448 Ns, 1 in = 2.54 cm

Test 1147-1007

In this test the balanced hinge design was modified to prevent the failure of the aluminum T-slot bolts and, therefore, cause the shear pin to fail. The aluminum bolts were replaced by high strength steel bolts. The shear pin did fail this time, however, only after the leg had rotated about 33°. It appears that a different lower sign connection is required to make this concept work more effectively. Also if the sign is to stay up in the air attached to the non-impacted leg, stronger wind beams and wind beam-to-sign vertical brace attachments are required. This is, however, a requirement for all large dual-legged signs. The momentum change in this test was approximately 665 lb-sec (2958 Ns). Representative photographs are shown in Fig. 102.

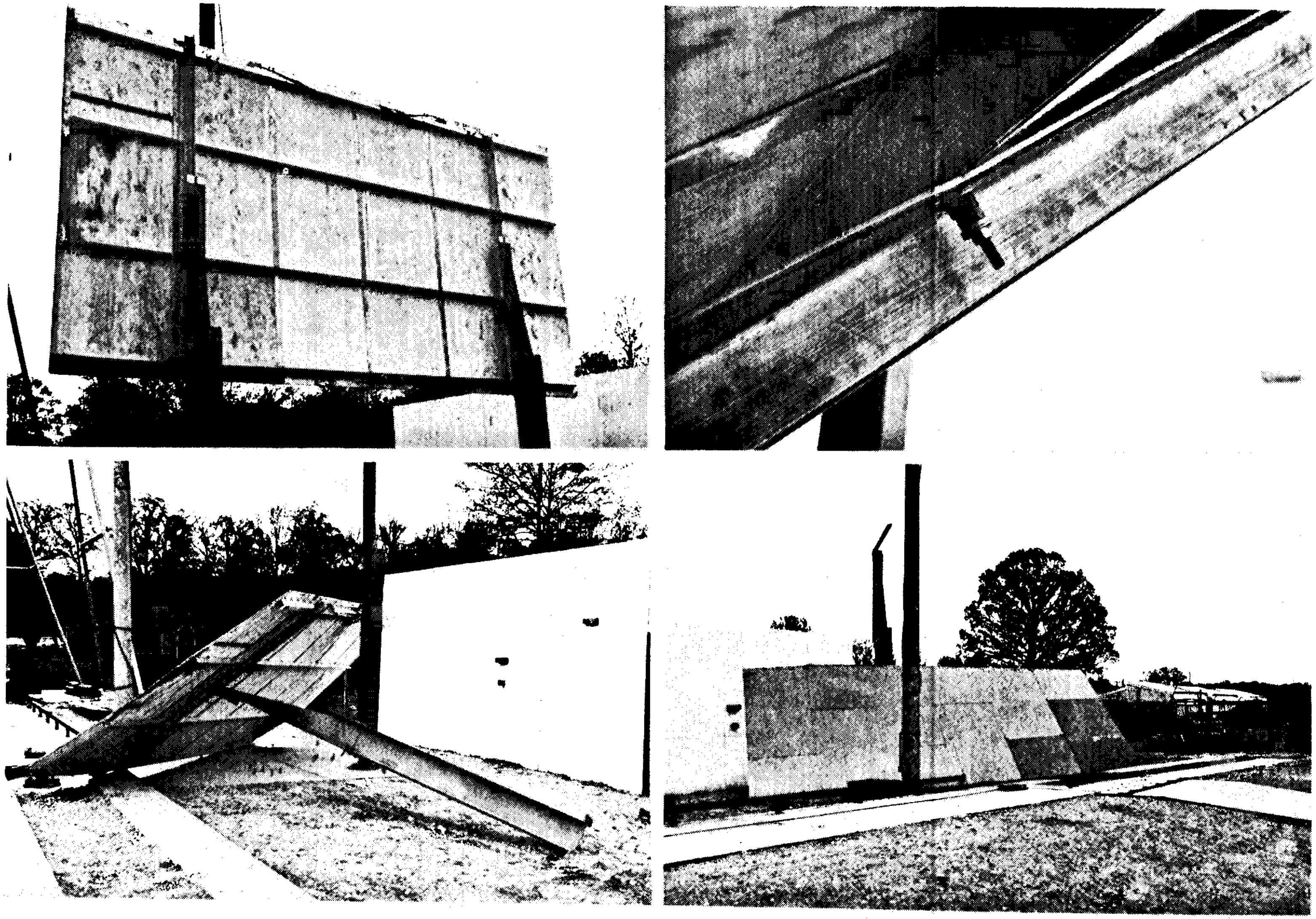

Fig. 102
Representative Photographs of Test 1147-1007

Test 1147-1011

The purpose of this test was to make a first cut at the design of a new pendulum nose designed to simulate a Honda Civic. Full-scale Test 1147-1010 was used as the model for validating the nose. The same sign in Test 1147-1010 was used. This sign has the standard breakaway design with 12WF45 legs.

In this test, weights were removed from the bogie to reduce its weight to 1738 lb (788 kg). A new nose was designed based on test data from Tests 1147-1009 and 1010 where Honda Civics were tested. This nose consisted of three pieces of honeycomb (see Fig. 103) with the characteristics listed in Table 42.

TABLE 42. HONEYCOMB CHARACTERISTICS - TEST 1147-1011

Piece	Location	Pressure	Height	Width	Depth	Dynamic Force
1	Before Sliding Nose	75 psi	10 in	8 in	4 in	7800 lbf
2	Behind Sliding Nose	130 psi	8 in	6 in	8 in	8112 lbf
3	Behind Sliding Nose	230 psi	8 in	8 in	2 in	19136 lbf

1 in = 2.54 cm, 1 psi = 6.89 kPa, 1 lbf = 4.448

The bogie impacted the sign support at 19.7 mph (25.8 km/h). This gave the bogie vehicle a kinetic energy level of 22571 lb-ft (30606 Nm) as compared to 22960 lb-ft (31133 Nm) in Test 1147-1010.

The slip base broke away and the upper hinge did not activate as in Test 1147-1010. The leg partially broke off of the back of

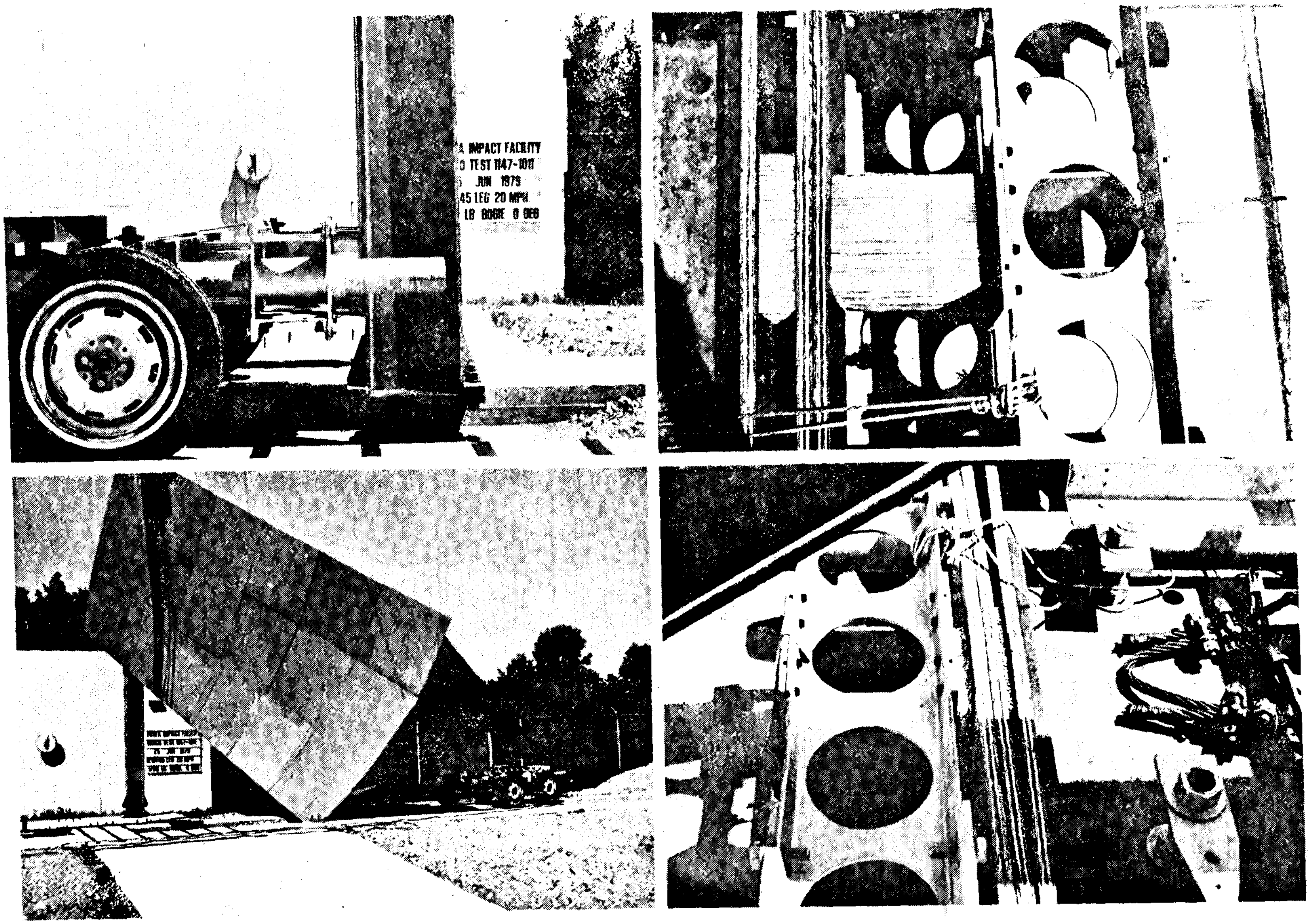

Fig. 103
Representative Photographs of Test 1147-1011

the sign by failing the aluminum clips. However, this time the upper support-to-sign bolts held and the leg consequently did not end up on top of the bogie. The momentum change for this test was 614 lb-sec (2731 Ns), and honeycomb crush was 11.9 in (30 cm).

Fig. 104 compares the time-deceleration traces for Tests 1147-1010 and -1011. It appears that the peak deceleration was late as compared to the full-scale test. This is because honeycomb crush depth was too deep as is borne out by the additional 1.9 in (4.8 cm) of crush. If additional Honda modeling tests are ever run it is recommended that the second piece of honeycomb be shortened by 2 in (5 cm). This will also lower the momentum change to give better correlation.

Representative test photographs are shown in Fig. 103. Table 43 gives a comparison of test results for tests 1147-1010 and -1011.

TABLE 43. TEST RESULT COMPARISON FOR TESTS 1147-1010 AND -1011

	Test 1147-1010	Test 1147-1011
Vehicle	Honda Civic	Bogie (Honda Model)
Momentum Change (lb-sec)	496	614
Peak Deceleration (g's)	13.6	16.7
Time to Peak Decel. (sec)	.030	.045
Impact Duration (sec)	.055	.052
Vehicle Crush (in)	10.0	11.9

1 lb-sec = 4.448 Ns, 1 in = 2.54 cm

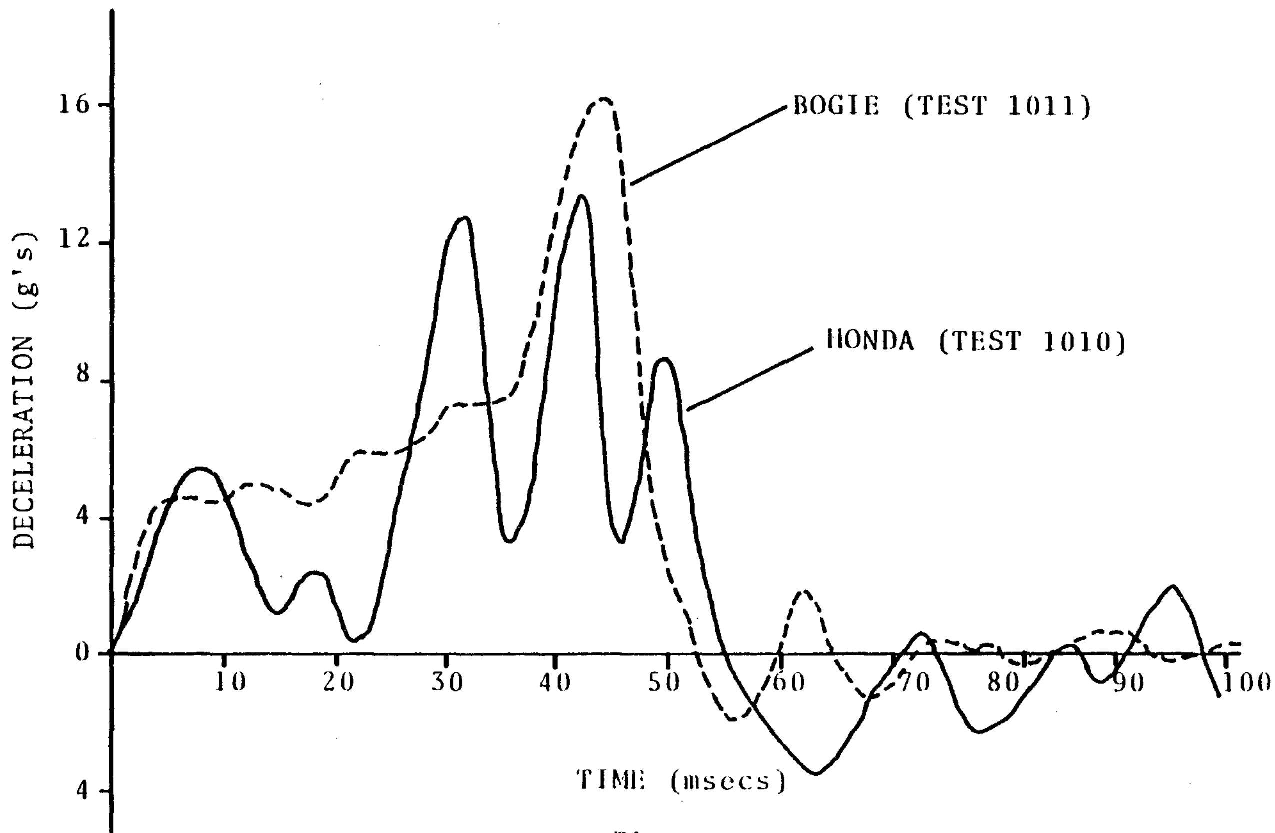

Fig. 104

Deceleration vs Time Traces for Test 1010 and 1011,
Filtered at 100 Hz

8.0 METHOD FOR EXTRAPOLATING DUAL-LEGGED SIGN MOMENTUM CHANGE DATA FROM ONE IMPACT SPEED TO ANOTHER

8.1 INTRODUCTION

This chapter presents an analytical method for extrapolating the momentum change value for vehicle impact tests performed at one speed to another speed. This analytical technique is designed for tests performed on dual-legged signs. The method is a valuable tool for determining the results of tests over a range of impact speeds. It can be substituted for costly full-scale test obtained data. The use of this technique also allows a low-speed bogie vehicle facility to be used to evaluate dual-legged signs.

This type of extrapolation method is currently recommended for luminaire supports when applied in accordance with Transportation Research Circular No. 191, [17]. The method described here is an extension of this process with appropriate corrections for the additional restrictions and components of the sign system.

8.2 BACKGROUND

It has been shown that an impact can be broken into three distinct phases. These three phases are: 1) crushing of the automobile; 2) activation of the breakaway base; and 3) acceleration of the impacted structure by the vehicle. They are related by the following relationship:

$$\Delta MV = \frac{a}{V_0} + b\ V_0,$$

Where a is related to vehicle crush and base activation parameters, b is related to the inertial properties of the system, and V_0 is the impact speed. By assigning low and high speed test values for the above equation, the following results are found:

$$\Delta MV_L = \frac{a}{V_L} + bV_L$$

and $$\Delta MV_H = \frac{a}{V_H} + bV_H$$

Solving for "a" and substituting, the following relationship for MV_H is found:

$$\Delta MV_H = \frac{V_L}{V_H}\,\Delta MV_L \;+\; b\left(V_H - \frac{V_L^{\,2}}{V_H}\right)$$

Hence with the correct value of "b" the momentum change for the high speed can be extrapolated from the low speed data.

It was also shown that for a luminaire support the value of b is defined as:

$$b \equiv M_p\,\alpha\left(\frac{k^2}{k^2+d_o^{\,2}}\right),$$

where M_p = mass of support

α ≑ 1.1*

k = radius of gyration of support about its c.g.

d_o = distance from support c.g. to impact point.

*The value of α is equal to the ratio of the velocity of the point of impact on the support following breakaway to the impact speed of the vehicle. For dual-legged signs this value may differ from 1.1.

Thus, this equation can be used for luminaire supports to extrapolate low speed impact data to a higher speed using only the support inertial parameters.

However when applying this set of equations to dual-legged sign systems, the method of calculating the radius of gyration is more complicated due to the sign blank and stiffeners. The sign system adds mass and inertia to the upper portion of the leg. This is unlike the free-body motion of a luminaire support.

8.3 DETERMINATION OF VARIABLES

Values for M_p, k, and d_o can be found by the following methods:

M_p (Mass of support system):

$$M_p = M_{UL} + M_{LL} + M_e$$

where: M_{UL} = Mass of upper leg (above hinge)

M_{LL} = Mass of lower leg (below hinge)

M_e = equivalent mass due to sign blank stiffness.

The equivalent mass (M_e) is 1/3 the mass of the blank and stiffness on

$$M_e = 1/3(M_b + M_s)$$

The entire blank and stiffener weight is not used since a portion of it is held in place by the non-impacted leg.

k (radius of gyration of support about its C.G.):

$$k = \frac{I}{M}$$

where I = mass moment of inertia of system

M = mass of system.

The mass moment of inertia can be found for each component of the system about its own center of gravity, then moved to the C.G. of the entire system by the parallel axis theorem, or

$$I = \sum_{n}^{i=1} I_i + M_i \ (X_i - X_{CG})^2$$

where n = number of components

I_i = mass moment of inertia of each component

M_i = mass of each component

X_i = location of component C.G.

X_{CG} = location of system C.G.

The value for I for a long slender leg can be approximated by $1/12\ ml^2$. The sign blank and stiffeners require special treatment to compute the value for I. This value is computed in Reference (2) for the sign blank and a similar analysis will generate a relationship for the stiffeners. The equations for I_e is:

$$I_e = \frac{M_b B^2}{36} + 1/3 \sum_{n}^{i=1} M_{si}\ Y_i{}^2$$

where M_b = mass of blank

B = depth of blank

M_{si} = mass of stiffener i

y_i = distance from stiffener i to the center of the blank

n = number of stiffeners.

d_o (distance from C.G. to impact point):

$$d_o = X_{CG} - h$$

where X_{CG} = C.G. of system from ground

h = height of impact from ground.

The center of gravity for the system can be found by a simple summing of equivalent moments about some datum point.

With the above information the ΔMV_H can now be found using the equation given above in section 8.2. This relationship would become the following if 20 mph (32.2 km/h) data was to be extrapolated to predict a 60 mph (96.6 km/h) momentum change:

$$\Delta MV_{60} = 1/3 \quad MV_{20} + 78.2b$$

$$(\Delta MV_{96.6} = 1/3 \ \Delta MV_{B2.2} + 23.8 \text{ M/S b})$$

8.4 LIMITATIONS OF EXTRAPOLATION TECHNIQUE

The method set forth here is based on an extension of earlier research on continuous unrestrained luminaire supports. A serious problem to handle in modeling dual-legged sign systems is the hinge mechanism. In some impacts (especially low speed) the hinge fails to open, thus the leg (upper and lower sections) and sign system have to be accelerated as one unit in the phase 3 segment of the impact. This is the type of system which the extrapolation model can handle. This is a worst case since the maximum amount of mass is accelerated during the impact.

The opposite condition happens during higher speed impacts where the upper leg and sign blank system generate such high inertial forces that the hinge is activated. This results in only the lower portion of the leg being accelerated in Phase 3.

Unlike luminaire supports where higher impact speeds usually generate higher Phase 3 momentum changes, this variable hinge activation mode can result in just the opposite condition. It is this uncertainty on the hinge operation which makes the extrapolation method difficult to use. If the assumption is made that the hinge does not open during either high or low speed impacts, then the model should give a conservative estimate of the high speed momentum change on the low speed impact results.

8.5 TEST RESULTS

During this project, 3 pairs of 20 mph (32.2 km/h) and 60 mph (96.6 km/h) tests were carried out on 8WF20 and 12WF45 sign supports with 15 ft. x 10 ft. (4.6 x 3.1 m) and 24 ft. x 12 ft. (7.3 x 3.7 m) sign blanks respectively using Vega and Honda automobiles. The test set-up and results are presented in Table 44. In each case the hinge did not activate during the initial impact (i.e., during vehicle/support contact) for the 20 mph (32.2 km/h) test. However, the hinge activated early in the impact during all 60 mph (96.6 km/h) tests. In all 60 mph tests, film analysis showed negligible movement of

TABLE 44. TEST SET-UP AND RESULTS

Test II	Speed mph	Leg Type	Leg Lower Length ft.	Leg Upper Length ft.	Sign Blank Length ft.	Sign Blank Height ft.	Sign Blank Stiffeners No.	Hinge Activation	Test Vehicle & Weight lbs.	MV (lb-sec)
1147-802	20	8WF20	7	10	15	10	4	No	Vega 2445	319
1142-801A	60	8WF20	7	10	15	10	4	Yes	Vega 2275	569
1147-1001	20	12WF45	8.5	11.75	24	12	4	No	Vega 2425	710
1147-1008*	60	12WF45	8.5	11.75	24	12	4	Yes	Vega 2478	672
1147-1010	20	12WF45	8.5	11.75	24	12	4	No	Honda 1516	496
1147-1009*	60	12WF45	8.5	11.75	24	12	4	Yes	Honda 1617	369

*15" off center impacts

1 mph = 1.61 km/h = .45 m/s
1 ln = 254 cm = .025 m
1 ft. = 0.30 s m
1 lb. = 0.45 kg
1 lb-sec = 4.45 Ns

the upper leg and sign blank system while the lower leg rotated up. Later in each test the upper leg/sign blank system was rotated and translated, but this was well after contact was lost.

It should also be noted that in both 60 mph (96.6 km/h) tests involving the 12WF45 leg, the test vehicle impacted into the leg 15 in. (38.1 cm) from the center line of the vehicle. However, in the 20 mph (32.2 km/h) tests the impact was on the centerline of the vehicle. This discrepancy in impact location will modify the Phase 1 contribution to the momentum change, but it is felt that this difference should have minimal effect on the results of the extrapolation.

During Tests 1147-801A and 1147-802, a torque wrench was used to tighten the slip base and hinge fuse plate bolts. It was decided after these tests that this may have introduced an error in slip base and fuse plate activation force levels. Here again it is felt that although this may have had some effect on impact results, the effects were minor.

8.6 EXTRAPOLATION RESULTS

Using the methods set forth in Section 8.3, values for k, d_o, and M_p can be found. These values are presented in Table 45 for each sign system tested.

TABLE 45. PARAMETERS FOR EACH LEG-SIGN COMBINATION

Leg/Sign	k(ft)	d_o(ft)	S.R.	*M_p (slugs)	b* (slugs)
8WF20/10' x 20'	4.7	7.1	.303	12.1	3.9
12WF45/12' x 24'	5.6	8.6	.298	30.9	9.7

*where S.F. = $\frac{k^2}{d^2+k^2}$ and $b = 1.05M_p\left(\frac{k^2}{k^2+d_o{}^2}\right)$

1 ft = 30 sm

1 slug = 32.2 fbm = 14.6 kg

The high speed momentum change (ΔMV_H) can be extrapolated using the value for b and the low speed test results.

Since the actual tests were run at slightly different speeds than 20 mph (32.2 km/h) and 60 mph (96.6 km/h), the actual test speed will be used to find MV_H:

$$\Delta MV_H = \frac{V_L}{V_H} (\Delta MV_L) + b(V_H - \frac{V_L{}^2}{V_H})$$

Using this equation and the appropriate values for b, V_H, and V_L the values for ΔMV_H were found and are presented in Table 46.

8.7 COMPUTER RESULTS

To obtain a large sample of vehicle impacts into dual-legged breakaway sign legs, a computer program developed under an earlier contract for FHWA by ENSCO [2] was used. This program simulates an impact of an automobile into a Texas 4 bolt slip base supporting a wide flange I beam post with integral hinge and fuse plate. These legs were modeled along with a 12 ft. x 24 ft. (3.7 x 7.3 m) plywood sign blank with steel I beam stiffeners. Three different sizes of posts were simulated at 20 mph (32.2 km/h) and 60 mph (96.6 km/h). Then the extrapolation method set forth in this chapter was also used to predict the $\Delta MV_{60\ mph}$ ($\Delta MV_{96.6\ km/h}$) from the $\Delta MV_{20\ mph}$ ($\Delta MV_{32.2\ km/h}$). These predicted results could be compared to the simulation result to determine the accuracy of the extrapolation method. These values are found in Table 47.

TABLE 46. EXTRAPOLATION RESULTS

Item No.	Test System Leg/Blank/ Vehicle	Test Number Sequence (20 mph→ 60 mph)	Test Data				Predicted ΔMV_H (lb-sec)	Error ΔMV Predicted / ΔMV Actual
			ΔMV_L (lb-sec)	Actual Speed (mph)	ΔMV_H (lb-sec)	Actual Speed (mph)		
1	8WF20/10' x 15'/Vega	802→ 801A	319	23.3	569	60.4	414	.73
2	12WF45/12' x 24'/Vega	1001→ 1008	710	18.8	672*	58.8	975	1.45
3	12WF45/12' x 24'/Honda	1010→ 1009	496	20.6	369*	58.0	895	2.43

*Data taken from 15" off center impact.
1 lb-sec = 4.45 Ns
1 in = 2.54 cm = .025 m
1 ft = .305 m
1 mph = 1.61 km/h = 0.447 m/s

TABLE 47. COMPUTER AND EXTRAPOLATED RESULTS

Sign/System Post	Computer Predicted ΔMV_{20} (lb-sec)	ΔMV_{60} (lb-sec)	Extrapolated ΔMV_{60} (lb-sec)	Error $\frac{\Delta MV\ ext}{\Delta MV\ pre}$
12'x24' /12 WF 45	772	1016	1079	1.06
12'x24' /10 WF 25	545	659	678	1.03
12'x24' /8 WF 17	412	502	504	1.00

1 ft = .305 m
1 lb-sec = 4.45 Ns

The results of this comparison look very good but are inconsistent when compared to the actual full-scale data.

This inconsistency is due to an incorrect modeling of the hinge forces because of a lack of data which prevents the hinge from opening during 60 mph (96.6 km/h) simulations. Thus the computer simulation modeled a worst-case situation which is similar to that predicted by the extrapolation technique.

9. CONCLUSIONS AND RECOMMENDATIONS

Since 1970 the pendulum has been recognized in one form or another as a tool for testing breakaway luminaire supports. Not until this project, however, has a pendulum configuration evolved that is traceable back to an actual automobile. The previous inability to correlate the pendulum with actual vehicle crash tests has created a distrust in the community for pendulum test results. Under this contract an actual subcompact car was modeled using a crushable nose pendulum and was shown to correlate well with full-scale test results. The question which still remains, however, is what is the "design vehicle". The procedures developed in this project will provide the means to model that vehicle if and when it is found.

Most of the existing designs for breakaway luminaire and sign supports were developed using full size automobiles as test devices. With the current trend toward smaller, more fuel-efficient cars, the question has evolved as to whether or not these breakaway devices are still safe. This project has gone a long way toward answering this question. Most of the existing types of breakaway luminaire supports have been tested and the results have shown that much of the breakaway hardware is safe. The type of hardware that was found to require the greatest work was cast aluminum transformer bases. A major breakthrough was made when simple, low cost modifications were developed for these T-bases, and many of these T-bases are already being installed on our nation's highways. While the pendulum could not be used for testing dual-legged signs, this project did show that a bogie vehicle could. A low-cost test device is now available for testing large highway signs. Not only is this bogie low in per-test cost, but it provides a more controlled and repeatable test procedure than that found in full-scale testing.

This project has not answered all the important questions and has, as in all research, created new ones. The areas that require further research are:

- Due to the difference in hinge behavior for dual-legged signs at 20 mph (32.2 km/h) and 60 mph (96.6 km/h), conclusive test data is not available for validating the momentum change extrapolation technique. Tests of dual-legged signs with locked hinges need to be conducted at 60 mph (96.6 km/h).

- Finding an inexpensive field retrofit modification for the thousands of installed cast aluminum transformer bases remains to be accomplished. The small number of tests conducted under this contract have shown that such a modification may be possible but did not uncover it.

- The correlation procedure used for the crushable pendulum nose development was based on tests of metal breakaway supports. The pendulum has not been validated for base bending or wooden fracturing sign supports.

- The balanced hinge sign support concept could be used to eliminate the troublesome breakaway hinge which occasionally activates in heavy winds, but not always during impact. Further design and testing of the concept is needed in order to bring it into practical use.

- Traffic signal poles are a type of highway support that has been virtually overlooked. It is possible that breakaway concepts can be employed on some of these installations.

- Recently, reports have been circulated relating to fatal side impacts with breakaway supports. This side impact issue has not been investigated, and it could lead to the incorporation of a maximum breakaway force level for breakaway highway supports.

- The corrosion of slip base supports is an area of concern especially in snow-belt states. This situation needs to be researched and, if found to be an actual problem, methods of preventing corrosion lockup must be found.

- As mentioned earlier, the investigation of the "design vehicle" for testing breakaway supports is an important area needing prompt attention.

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APPENDIX A

DESIGN OF A CRUSHABLE HONEYCOMB PENDULUM NOSE TO MATCH A PARTICULAR VEHICLE TYPE

As part of the effort on the present contract DOT-FH-9194, a crushable honeycomb nose was developed. The design criteria for this nose was that it provide an equivalent impact performance to that exhibited by a 1973 Chevrolet Vega. This vehicle was chosen because it represented a typical subcompact vehicle and because full-scale test data was available for validation of the nose design.

DETERMINING THE VEHICLE FORCE-DEFLECTION CHARACTERISTIC

To determine the force-deflection characeristic of a Chevrolet Vega, data from full-scale crash tests were used. Force was obtained from processing accelerometer data after it was low pass filtered at 100 Hz. Films from the same tests were used to obtain crush (deflection)-time data. The data were then combined to yield a force-deflection characteristic for the vehicle. All of the data was obtained from 20 mph head-on impact tests of Vegas into luminaire supports having circular cross sections. Fig. A-1 shows typical force-time, deflection-time curves obtained from the test data. The resulting force-deflection curve is shown on the right.

The greatest vehicle deflection observed in any full-scale test was 17. 5 in (45 cm). Thus no data was being provided for the force-deflection curve beyond this point. Therefore, an actual vehicle was examined to determine what was being crushed after 17.5 in (45 cm). It was found that at this crush depth the front of the engine block was being struck. Since this is a very stiff structure in comparison to the sheet metal, the characteristic is taken "infinitely" stiff at 17.5 in (45 cm) of crush.

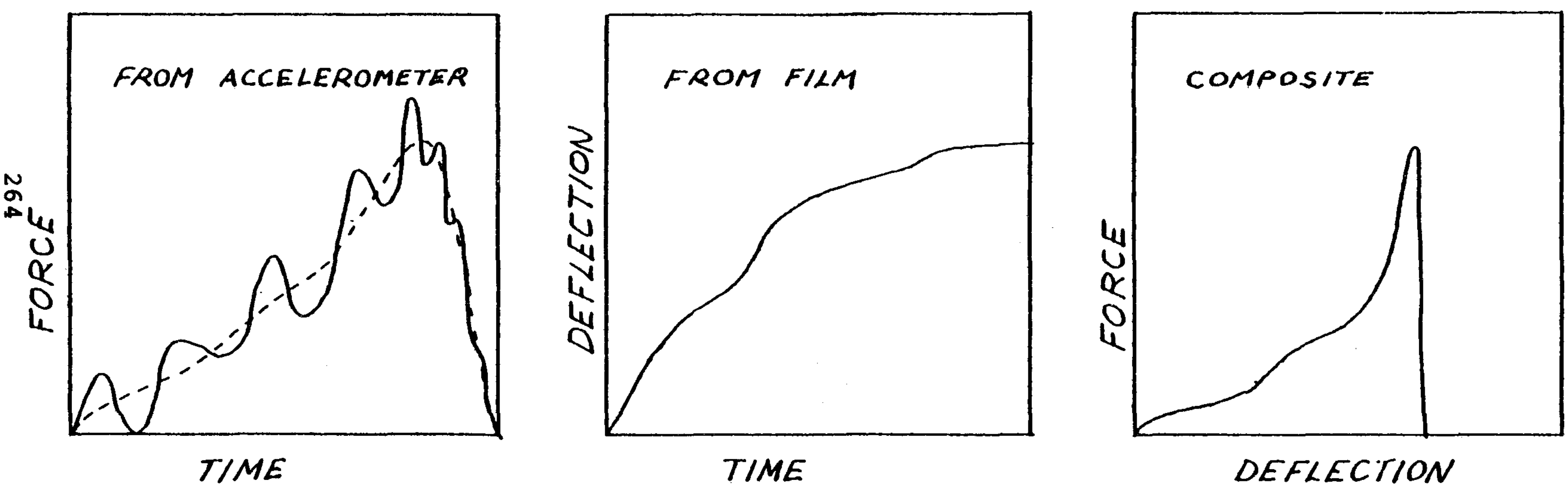


Fig. A-1

Development of Vehicle Force Deflection Curve from Accelerometer and Film Data

MATCHING HONEYCOMB TO THE PROPER FORCE-DEFLECTION CHARACTERISTIC

Once the proper force-deflection characteristic had been determined, it was necessary to configure alumunim honeycomb blocks to reproduce this characteristic. Since a large supply of three grades of honeycomb was on hand, this stock became the basis from which to design. Based on the dynamic crush characteristics of the material as specified by the manufacturer, honeycomb blocks producing various force levels were designed by cutting them to the appropriate cross section. Blocks of various cross sections and lengths were arranged to provide the desired force-deflection characteristics. Then through an iterative process of testing and changing the configuration, the characteristic was fine tuned. The accelerometer traces obtained from the development tests were compared to data from equivalent full-scale tests during this tuning process.

Several configurations of honeycomb stacks were tested during the development phase. In order to obtain a smoother crush characteristic, tapered honeycomb blocks were used in one test. This concept was found too difficult to work with, both from honeycomb cutting and uniform crushing standpoints. Stackups consisting of three, four, five and six blocks of various size honeycomb were tested before the final configuration was determined.

PROVIDING UNIFORM CRUSH OF THE HONEYCOMB BLOCKS

In order to obtain the desired force-deflection characteristic regardless of the size of the impacted structure, it was necessary to install a sliding head in front of the main honeycomb stack. Since this head slides longitudinally on guides it does not jam when hit off center.

The reason for providing uniform crush characteristics regardless of the shape of the support, and whether it is hit off center, is tied to the performance of the vehicle sheet metal.

Basically the sheet metal on the front of a vehicle can be thought of as an assembly of plates and beams. If a plate or beam is loaded near the center, the deflection will be basically the same, regardless of the width of the load provided that load width is much narrower than the member. Thus, a car front end crush characteristic is not very sensitive to the width nor exact location of hit relative to the center of the bumper. However, bare honeycomb is very sensitive to the width of the impacting support and its eccentricity relative to the centerline. Consequently, the sliding head is needed on the front of the honeycomb stack to ensure uniform crush characteristics. In addition, sliding dividers are placed between the honeycomb blocks both to provide attachment points for the blocks and to ensure uniform crush. These dividers must be strong enough to sustain any loading differential between honeycomb blocks of varying cross section.

A block of "soft" honeycomb is placed on the front of the sliding head for the following two purposes: first, it smooths out the initial force levels during the first instant of impact; and, second, it spreads the force over an area of the support equal to that found during an actual vehicle impact.

THE FINAL DESIGN

The final design for the pendulum or bogie vehicle nose, as developed in this contract is shown in Fig. A-2. This nose has the following components:

- A honeycomb block* in front of the sliding head which is 12 in (31 cm) high, 8 in (20 cm) wide, and 4 in (10 cm) in depth. The block is made from aluminum honeycomb with 75 psi static crush strength.

*All honeycomb blocks are precrushed approximately 1/8 to 1/4 in (.3 to .6 cm) to provide uniform crush characteristics.

- A honeycomb block stack behind the head consisting of the following arrangement: Block 1--75 psi, 8 in high, 4 in wide, 4 in deep (517 kPa, 20 cm high, 10 cm wide, 10 cm deep); Block 2--130 psi, 8 in high, 4 in wide, 6 in deep (896 kPa, 20 cm high, 10 cm wide, 15 cm deep); Block 3--230 psi, 8 in high, 4 in wide, 4 in deep (1585 kPa, 20 cm high, 10 cm wide, 10 cm deep); and Block 4--230 psi, 8 in high, 8 in wide, 2 in deep (1585 kPa, 20 cm high, 20 cm wide, 5 cm deep).

- A sliding head weighing in the range of 50 lb ±10 lb (23 kg ±4.5 kg). The head slides easily on tubular guides and is designed not to jam during compression of the honeycomb.

- Plywood dividers between honeycomb blocks.

- An impact height of 18 in (46 cm) measured from the center of the leading honeycomb block to the bottom of the support.

- A rigid sweeperplate located below the pendulum to simulate a vehicle undercarriage with a clearance height of 4 in (10 cm) to support foundation.

- The total weight of the pendulum of bogie, the nose, the sweeper plate, and other components is 2,250 lb. ±50 lb.

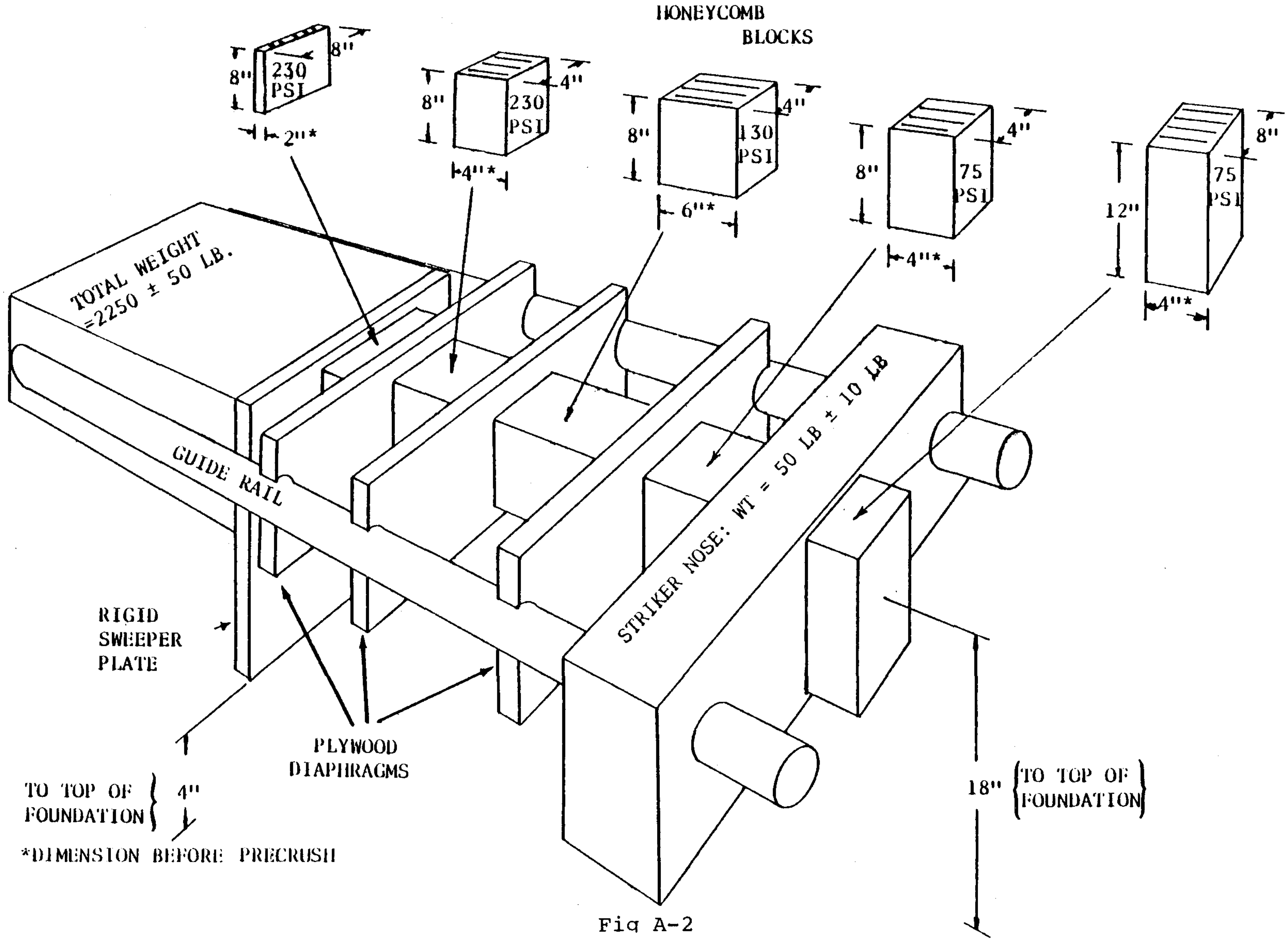


Fig A-2
ENSCO Soft-Nosed Pendulum Configuration

APPENDIX B

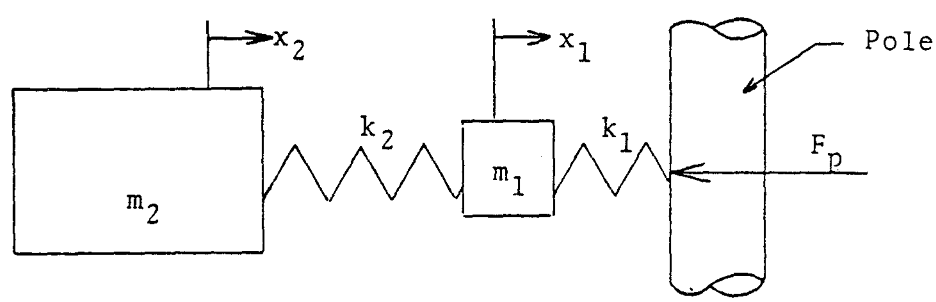
ANALYSIS OF NOSE MASS EFFECTS DURING IMPACT

After reviewing the results of the Tests 1147-101, 102 and 103, it was recognized that the momentum change values were not affected appreciably by either the force deflection characteristics of the honeycomb or the base clamping force. The poles were behaving very much as they would in a rigid pendulum test. It was believed that the mass of the nose and its initial deceleration might alone be great enough to be activating the slip base. A simplified analysis was conducted to determine the possible effects of the nose mass.

The following assumptions were made in this analysis:

Compression of 2" neoprene rubber	= 1" (2.5 cm)
Pole dent depth during impact	= ½" (1.3 cm)
Nose weight (m_1)	= 92 lb. (42 kg)
Pendulum weight (m_2)	= 2,333 lb. (105 kg)
Time to decelerate nose	= .010 sec.
Initial level of pendulum mass deceleration during first instant of impact	= 2½ g's

The pendulum mass and nose are modeled as a spring-mass system as shown here:



Writing the equations of motion for the two masses, we have

$$m_2\ddot{x}_2 = k_2(x_1-x_2) \tag{1}$$

$$m_1\ddot{x}_1 = k_1(x_1) - k_2(x_1-x_2) \tag{2}$$

where $k_1(x)$ and $k_2(x)$ are the spring characteristics for the nose and honeycomb, respectively.

Substituting equation (1) into equation (2), we have

$$k_1(x_1) = m_2\ddot{x}_2 + m_1\ddot{x}_1 \tag{3}$$

Since $k_1(x_1)$ equals the force on the pole (F_p), we can rewrite (3) as:

$$F_p = m_2\ddot{x}_2 + m_1\ddot{x}_1 \tag{4}$$

In other words, the force on the pole is a function of both the nose mass and the main pendulum mass.

To get an estimate of the contribution of the nose inertia, assume the deceleration of the nose takes place uniformly from 29.3 fps (8.9 m/s) to rest in 1½ (3.8 cm) inches. Then:

$$\ddot{x}_1 = \frac{V_i^2}{2x_1} \tag{5}$$

$$= \frac{12(29.33)^2}{2(1.5)} \qquad \frac{(8.9)^2}{2(.038)}$$

$$= 3441 \text{ ft/sec}^2 \quad (1050 \text{ m/sec}^2)$$

$$= 107 \text{ g's}$$

Substituting values into equation (4), we have:

$$F_p = 2333 \text{ lb } (2 - \tfrac{1}{2} \text{ g's}) + 92 \text{ lb } (107 \text{ g's})$$

$$= 15677 \text{ lb } (69{,}731 \text{ N})$$

This analysis shows that the inertia force associated with decelerating the nose mass in itself is nearly sufficient to break away the base. Thus, as observed, the dependence of the momentum change on the honeycomb crush is going to be totally overshadowed by the nose inertia. It was concluded that such a nose was unrealistically heavy and should be reduced in weight for more meaningful simulation of full-scale impacts. A softer impact surface will also have the effect of reducing the initial force spike.

APPENDIX C

BALANCED HINGE DESIGN FOR BREAKAWAY DUAL-LEGGED SIGN SUPPORTS

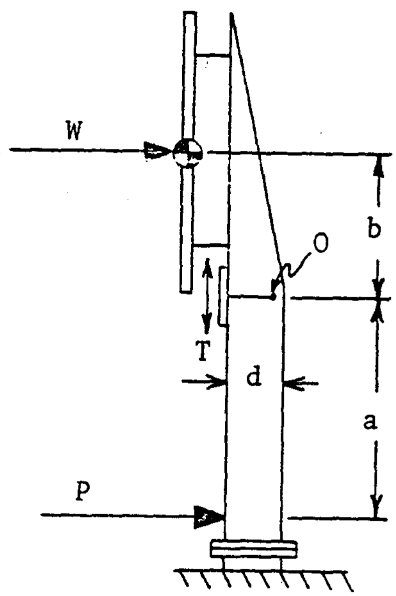
The primary breakaway dual-legged sign support design used in the United States is of the "Texas Slip Base" design. While there are variations to this design in use by the different states, essentially all types are loaded and react in a similar manner. The variations are mainly in size of members, fastener size, type of fuse or slip plate, tension in clamping bolts, etc.

Both legs of the "Texas" type dual-legged breakaway sign support are hinged just below the sign blank. This hinge is held closed by a fuse or slip plate which activates during a vehicle impact load but hopefully not under design wind loads. To achieve this, the fuse plate must be designed to oppose the moment induced during wind loads yet be weak enough to fail during an impact-induced load before the sign blank and the associated stiffeners fail. Fig. C-1 depicts the sign support and the impact and wind loading arrangement.

Static analysis of the moments about the hinge point yields the following equation for the tension in the fuse plate required to keep the sign erect during wind loading (P=0):

$$T = \frac{W \times b}{d} \tag{1}$$

This tension will be designated T_W since it is the tension required to withstand wind loading. This will be the minimum force for which the fuse or slip plate should be designed. In a practical situation, of course, the plate would be designed to withstand this force times a safety factor (SF).



d = support width perpendicular to sign face

W = total wind load on each leg acting at the centroid of the sign

P = load at impact point after slip base separation

T = tension in fuse plate. T_W is tension during wind loading, T_P is tension during impact loading.

a = distance from impact load to hinge

b = distance from centroid to hinge

O = hinge point

Fig. C-1
"Texas" Slip Base Sign Support Loading Diagram

After the slip base separates and the fuse or slip plate activates, the force that is required to activate it is determined by the tension T_W times SF. Again static analysis of the moments about the hinge shows that the minimum force, P, required to activate the plate is

$$P = \frac{T_W \times d \times SF}{a} \tag{2}$$

Substituting equation (1) into equation (2), we arrive at

$$P = \frac{W \times b \times SF}{a} \tag{3}$$

This tells us that the load at the impact point required to activate a breakaway leg of this type becomes larger as W (design wind load), b (distance from centroid of sign to hinge), and SF (safety factor) increase, and smaller as a (distance from hinge to point of impact) increases. A higher load at the impact point not only increases the vehicle loading but increases the moment on the sign blank and therefore the chance of sign failure

Clearly if the design wind load, W, could be reduced, then P would be reduced. However, this is not possible since it is determined solely by the geographic area and the type of sign used. Reducing the safety factor is also not desirable for it is needed to prevent fatigue failure. On the other hand, if the distance, b, is reduced and a is increased, then P would be reduced. Looking at Fig. C-1, it can be seen that by shifting the hinge point upward toward the centroid, both of these goals are accomplished. Indeed for the case $b = 0$, this yields from equation (1) that $T = 0$. Thus for the condition where the hinge is at the centroid (see Fig. C-2), no tension is required in the fuse plate to resist the wind loading. Of course, in a real situation, since wind loading is not uniformly distributed on the face of the sign, the plate tension cannot be exactly zero but it is eminently clear that the size of fuse plate required in this situation can be considerably reduced compared to that required in the current desgin. Essentially the fuse plate can be designed for optimum breakaway performance. Furthermore, with this balanced hinge approach the load at the impact point (P) creates a larger moment at the hinge and consequently is more effective in activating the fuse or slip plate.

A detailed mechanical design for a Balanced Hinge" sign support system is shown in Fig. C-3.

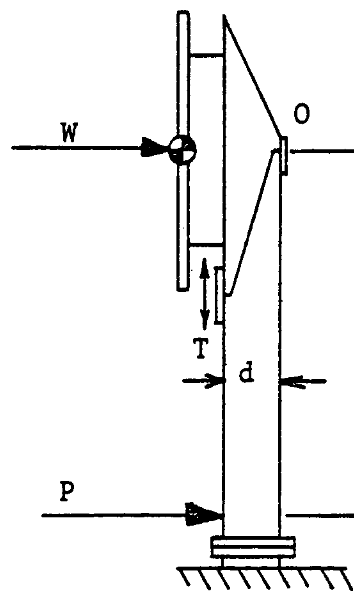


Fig. C-2

"Balanced Hinge" Support Loading Diagram

*U.S. GOVERNMENT PRINTING OFFICE : 1980 0-627-247/2297

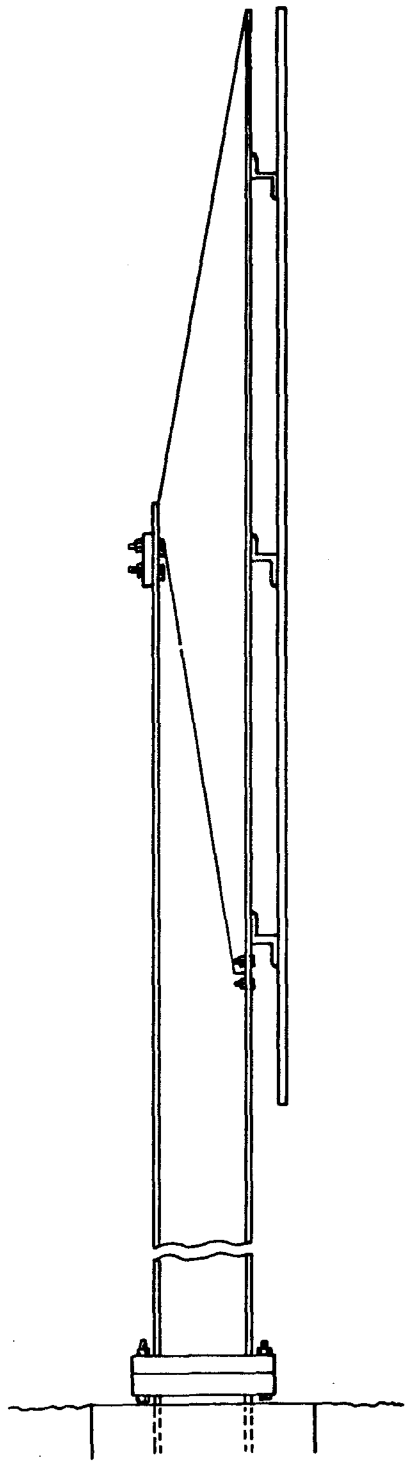


Fig. C-3

Balanced Hinge Breakaway Dual-Legged Sign Support
(J. A. Bloom, Dec 21, 1976)

FEDERALLY COORDINATED PROGRAM (FCP) OF HIGHWAY RESEARCH AND DEVELOPMENT

The Offices of Research and Development (R&D) of the Federal Highway Administration (FHWA) are responsible for a broad program of staff and contract research and development and a Federal-aid program, conducted by or through the State highway transportation agencies, that includes the Highway Planning and Research (HP&R) program and the National Cooperative Highway Research Program (NCHRP) managed by the Transportation Research Board. The FCP is a carefully selected group of projects that uses research and development resources to obtain timely solutions to urgent national highway engineering problems.*

The diagonal double stripe on the cover of this report represents a highway and is color-coded to identify the FCP category that the report falls under. A red stripe is used for category 1, dark blue for category 2, light blue for category 3, brown for category 4, gray for category 5, green for categories 6 and 7, and an orange stripe identifies category 0.

FCP Category Descriptions

1. Improved Highway Design and Operation for Safety

Safety R&D addresses problems associated with the responsibilities of the FHWA 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 balancing the demand-capacity relationship through traffic management techniques such as bus and carpool preferential treatment, motorist information, and rerouting of traffic.

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This category addresses problems in preserving the Nation's highways and includes activities in physical maintenance, traffic services, management, and equipment. The goal is to maximize operational efficiency and safety to the traveling public while conserving resources.

0. Other New Studies

This category, not included in the seven-volume official statement of the FCP, is concerned with HP&R and NCHRP studies not specifically related to FCP projects. These studies involve R&D support of other FHWA program office research.

* The complete seven-volume official statement of the FCP is available from the National Technical Information Service, Springfield, Va. 22161. Single copies of the introductory volume are available without charge from Program Analysis (HRD-3), Offices of Research and Development, Federal Highway Administration, Washington, D.C. 20590.