SAFER TIMBER UTILITY POLES
Volume I

By

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For

THE OFFICE OF SAFETY AND TRAFFIC OPERATIONS
RESEARCH AND DEVELOPMENT
FEDERAL HIGHWAY ADMINISTRATION
DEPARTMENT OF TRANSPORTATION

CONTRACT DTFH-61-83-0-00009

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Prepared by
The Texas Transportation Institute
SAFETY DIVISION

The Texas A&M University System
College Station, Texas

SEPTEMBER 1985

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle	5. Report Date
Safer Timber Utility Poles Volume I - Summary Report	September 1985
	6. Performing Organization Code
	8. Performing Organization Report No.
7. Author(s) Don L. Ivey and James R. Morgan	4859
9. Performing Organization Name and Address Texas Transportation Institute Texas A&M University College Station, Texas 77843	10. Work Unit No. (TRAIS)
	11. Contract or Grant No. DTFH61-83-C-00009
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address Federal Highway Administration Department of Transportation Washington, D.C. 20590	Draft Final Report September 1983 to September 1985
	14. Sponsoring Agency Code

15. Supplementary Notes

Contracting Officers Technical Representative: Charles F. McDevitt

16. Abstract

Two methods of modifying timber utility poles to radically increase the safety of passengers in impacting vehicles have been developed. The first is the Hawkins Breakaway System (HBS). It's development is complete. Performance has been proven by the conduct of full scale vehicle compliance tests. This system is ready for selective implementation. The second is a device called the CAM which functions to prevent vehicle direct impact with a timber pole. It has been subjected to a single feasibility test which did illustrate good potential. The CAM, however, requires further development and appropriate compliance testing before implementation can be considered. Breakaway attachments were also developed for down guy wires and are ready for implementation. A new method of evaluating compliance tests for breakaway timber utility poles has been developed and is described. The "safety philosophy" which forms the basis for the new method may be generally applicable to roadside safety improvements.

17. Key Words	18. Distribution Statement
safety, highway, collision, poles, timber, breakaway, crash cushion, injury redirection	Available through National Technical Information Services, Springfield, VA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		

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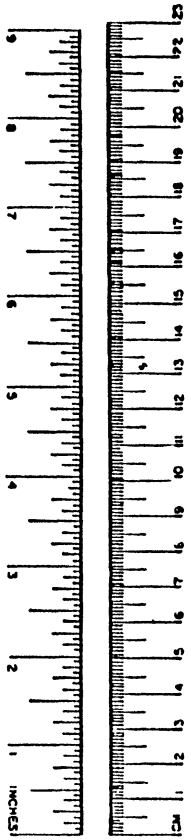
Acknowledgements

Mr. Jesse E. Watson, head of the Electric Power Utilities Training Division of the Texas Engineering Extension Service at Texas A&M University, and his staff members provided excellent council regarding proposed pole line modifications and continual support in the construction and maintenance of test facilities. If the result is compatible with the needs of utility companies it is due in large part to this support. The staff members of TTI's Proving Grounds made contributions beyond their usual high performance level. Mr. Charles F. McDevitt of FHWA Office of Safety and Traffic Operations Research and Development worked closely with the principal investigators throughout the course of the work and acted as liaison with interested utility companies. Mr. McDevitt made many positive contributions to the results of this work. The writers are indebted to all these individuals.

METRIC CONVERSION FACTORS

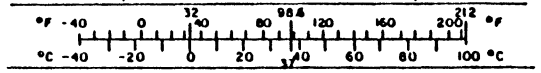
APPROXIMATE CONVERSIONS FROM METRIC MEASURES

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	0.6	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(2000lb)	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



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(10,000m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000kg)	1.1	short tons	
	VOLUME			
ml	milliliters	8.03	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	36	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



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I. INTRODUCTION

General

Timber utility poles on highway rights-of-way carrying power and communication transmission lines are an anachronism. They represent a critical discontinuity in the "forgiving roadside," a concept developed and accepted in the 1960's, one which state DOTs have striven to make a reality ever since. Timber utility poles are different from structures such as signs, luminaire supports, and hydraulic structures. They are owned by someone other than the highway or transportation entity responsible for the roadway. These transportation agencies have been hesitant, except under reconstruction conditions, to require a utility company to move or modify their facilities. There has been no consensus as to precisely who should be responsible for the influence on safety of timber utility poles within the highway right-of-way. In the past, many utility companies seem to have assumed that highway safety is the responsibility of highway agencies. Although at times that attitude may have been justified, it may no longer be in the best interest of pole owners. Devices now exist that provide cost-effective safety treatments for exposed structures without significant detrimental influence on the primary objective, i.e. the transmission of power and information.

Zegeer and Cynecki have done the most definitive job to date in showing the cost effectiveness of several alternatives, including

> "1. Placing utility poles underground,
> 2. Increasing the lateral offset of poles,
> 3. Reducing the number of poles (multiple pole use, increased pole spacings, or using poles on only one side of the road),
> 4. Using combinations of increased lateral offset reduced pole density, and
> 5. Using breakaway poles."[1]

Zegeer and Cynecki have shown there is a cost-beneficial use for each of the alternatives. Results of development and testing of the fifth

alternative are presented in this report.

Breakaway devices for rigid poles and posts along highways were first considered in the later 1950's by the Road Research Laboratory of the Ministry of Transport in England. The slip base concept as applied to ground-mounted signs in the United States was originated by D. L. Hawkins of the Texas Highway Department in the mid-1960's. Hawkins became concerned by collisions with the large ground-mounted signs on the interstate system. The idea occurred to Hawkins when a Pitman safety bar broke on his sickle bar mower. The first feasibility tests was conducted using a dump truck at the Highway Department District Office in Abilene during the summer of 1963. The slip base which is now standard on sign supports was subsequently developed by Hawkins, Olson, Rowan, and Edwards.[2]

The application of the slip base concept to luminaire supports apparently took place almost simultaneously in Crawthorn, England, and in Bryan, Texas, in 1965 and 1966. Hignet credits the idea to P. M. Turner of Cambridge University in a 1967 publication.[3] Edwards also credits Turner with a four-bolt luminaire slip base design.[4] Edwards was apparently the first to design a three-bolt multidirectional slip base.[5]

Breakaway utility poles were first considered in the late 60's after the concept of ground-mounted signs and luminaire supports proved successful. There was concern, however, that the timber utility pole was too heavy for treatment using conventional slip base technology. This was not the case, as demonstrated by the development of slip base supports for large overhead sign bridges by Olson et al.[6]

Up until 1982 most of the work to apply breakaway technology to timber utility poles was performed by Southwest Research Institute (SwRI). Beginning with a 1974 study by Wolf and Michie, various arrangements of holes, grooves, and saw cuts were used to weaken the pole at its base, so the pole would fail more easily during a vehicle impact.[7] Another

weakened zone was introduced near the top of the pole so that the middle section of the pole would breakaway leaving the top portion still connected to conductors.

Following that work, Labra et al. produced and studied over 20 conceptual designs under a Federal Highway Administration (FHWA) study by Southwest Research Institute (SwRI).[8] That study concluded that "RETROFIX," consisting of holes and slots cut into the pole near ground level "provided the best compromise between vehicle impact severity, environmental loading capacity, and costs." This work was reported in 1980.

It appears neither the utility industry nor FHWA considered RETROFIX suitable for implementation. This was based primarily on the fact that the pole was significantly weakened in capacity to withstand environmental loads. There were also other problems which will be examined in a following section. To try to overcome these problems the FHWA modified the SwRI contract to develop a slip base breakaway design. The slip base design tested by Labra et al. on utility poles appears to be an adaptation of the triangular, three-bolt multidirectional slip base developed by Edwards.[9,5] It was designed by Maurice Bronstad and represents the first time conventional slip base technology was applied to a timber utility pole. The slip base modification was tested using both pendulum and automobile impacts. Five vehicle crash tests were conducted which demonstrated the feasibility of the slip base concept for utility poles. Labra et al. published this work in 1983.[9] The problem of pole interaction with conductors was approached by the development of a design to allow the cross arm to detach from the pole or by the detachment of the conductors from the insulators. Crash tests demonstrated that the standard aluminum ties connecting conductors to insulators would usually be stripped free by longitudinal forces in the conductors.

Labra concluded that the SwRI slip base design "...exhibited the best performance (of more than 20 conceptual designs investigated) in terms of the severity of vehicle impact and capacity for environmental loading." That design was considered ready for experimental use.

FHWA fully intended to carry the research further. McDevitt states,

> "Additional research and development work is planned to reduce the cost of the slip base hardware and to develop a new breakaway mechanism that would segment the pole about 16 ft above ground. Additional full-scale tests will also be conducted on poles that carry joint electric and telephone lines and on poles that have multiple cross arms, guy wires, and heavy equipment, such as transformers or switches, in order to better define the performance limits of the slip base concept."(9)

The primary objective of this work was to build on the conventional slip base technology to produce an effective breakaway shear connection at the ground level and to overcome problems of pole detachment, conductor failure and entanglement and the falling pole to develop a breakaway design that would:

- Meet the safety philosophy stated in chapter V and if possible, the requirements of NCHRP Report 230.
- Overcome the factors that had caused reservation on the part of both FHWA and the industry toward selective implementation.

These objectives have been realized. A combination of slip base lower connection and a progressively deforming upper connection has been subjected to five compliance tests. This combination of lower and upper connections has been named the Hawkins Breakaway System (HBS), after D. L. Hawkins, who was the first to suggest slip bases on roadside structures and was influential in their early development. The results are extraordinary. These tests have been compared on an acceleration, velocity change, and probability of injury basis to calculated values for unmodified poles and also have been compared with a statistically derived probability of injury estimate for unmodified poles developed by Mak et al.(10) These comparisons will be detailed in later sections of the report, but the net projected result is:

In collisions from 20 to 60 miles per hour using automobiles from 1,800 to 4,300 lb (GVW) the average probability of severe injury (AIS$\geq$3) has been reduced by 91 percent. In collisions at speeds from 40 to 60

mi/h, the probability of severe injury has been reduced by 97 percent. Zegeer was asked by FHWA to assume the best one might achieve with breakaway poles was a "60 percent reduction in injury and fatal accidents."[1] While this number may not be greatly in error if AIS injuries of 1 or greater are considered, it appears that injuries would be heavily biased to the minor and moderate injury levels (AIS levels 1 and 2). Thus, the selection of average accident injury cost for the breakaway design may be highly inflated, and the HBS modified pole would be cost effective in a wider spectrum of conditions than Zegeer predicted.

Literature

A comprehensive review of the literature on the subject of pole collisions was conducted by Mak and Mason.[10] This review was complete through 1980. It was found to be an invaluable reference source by these writers. For ease of reference it is given in its entirety in appendix A.

The Mak and Mason work must be considered a landmark study in terms of defining the extent of hazards imposed by rigid pole supports and the benefits that accrue from breakaway design. The objectives were "(1) Identify the extent of the pole accident problem; (2) Determine accident and injury severity rates associated with pole accidents; (3) Assess vehicle crashworthiness and highway design and operational characteristics for pole accidents; and (4) Evaluate performance, cost-effectiveness, and injury severity reduction of breakaway versus nonbreakaway poles."

In the period from January 1976 through October 1979, data were obtained from study sites in San Francisco, Los Angeles, Salt Lake City, San Antonio, Dallas, Kentucky, and Washington, DC. These data included a census of all accidents and all pole accidents in 1976, a probabilistically selected sample of 1,014 pole accident events (investigated in depth), and a sample inventory of poles. These data

provided the base for extensive statistical analyses addressing the study objectives. Although poles in general, including sign posts and luminaire supports along with timber utility poles, were studied, specific attention was given to the latter. Here, findings related primarily to timber utility poles will be presented. These primary findings by Mak et al. are:

- "Utility poles were the most frequently struck pole type accounting for 76.1 percent of all pole accidents...

- "Pole accidents are primarily an urban problem with 36.9 pole accidents per 100 miles of highway as compared to only 5.2 for rural areas."

- The authors point out, however, that
  "both urban and rural areas have nearly identical rates of 3.4 pole accidents per billion vehicle pole interactions." In this case the authors mean by interaction simply an opportunity to strike a pole due to a vehicle passage.

- "Pole accidents in rural areas have higher impact severity than urban pole accidents as a result of higher impact speeds. A total of 10.7 percent of rural pole accidents resulted in severe to fatal injuries (AIS$\geq$3) versus only 5.4 percent for urban pole accidents.

- "Velocity change is selected as the major accident severity measure in the analysis of pole performance, supplemented by impact speed and momentum change.

- "Drivers involved in pole accidents are mostly male (76.9 percent) and 25 years old or younger (55 percent) indicating the over-involvement of younger male drivers in pole accidents.

- "Collisions with timber utility poles have the highest frequency of severe to fatal injuries (7.4 percent)...

- "The incorporation of a breakaway design into luminaires and large sign supports is effective in reducing the resultant injury severity."[10]

Mak gives the following summary of the relationship between injury rate and accident severity for nonbreakaway utility poles.

> "There is a 50-50 chance that an occupant in a utility pole accident will sustain some form of injury, AIS≥1, even at a very low impact speed of 6 mi/h (velocity change of 4.7 mi/h or momentum change of 735 lb-s). Injury rates for severe to fatal injuries of AIS≥3 are minimal for low to medium accident severity, e.g., the probability is less than 10 percent for impact speeds below 32 mi/h (29 mi/h velocity change or 4,450 lb-s momentum change), increasing to 50 percent at impact speeds of 50 mi/h (47 mi/h velocity change or 6,700 lb-s momentum change)."

Mak and Mason developed a number of excellent bar graphs, frequency diagrams, and predictive relationships which will be used as supportive information in other parts of this report. Of primary usefulness are the following equations:

$$\%AIS \geq 1 = 22.2 + 16.03 \ln(V) \qquad (1)$$

$$r = 0.82$$

$$\%AIS \geq 3 = \frac{100}{1 + e^{6.08 - 0.121 (V) h}} \qquad (2)$$

$$r = 0.82$$

$$\%AIS \geq 1 = 22.5 + 17.83 \ln (\Delta V) \qquad (3)$$

$$R = 0.93$$

$$\%AIS \geq 3 = \frac{100}{1 + e^{5.62 - 0.12 (\Delta V)}} \qquad (4)$$

$$R = 0.59$$

$$\%AIS \geq 1 = -63.5 + 16.8 \text{ Ln } (\Delta M) \quad (5)$$

$$R = 0.91$$

$$\%AIS \geq 3 = \frac{100}{1 + e^{6.5 - 0.00097 (\Delta M)}} \quad (6)$$

$$R = 0.77$$

%AIS≥1 is the percentage of utility pole impacts in which an injury equal to or greater than AIS-1 occurred

%AIS≥3 is the percentage of utility pole impacts in which an injury equal to or greater than AIS-3 occurred

V is the vehicle impact velocity

ΔV is the change in vehicle velocity during the primary collision and

ΔM is the change in vehicle momentum during the primary collision.

Using these expressions the crash tests conducted in the current study can be evaluated and compared to the probability of injury had the pole been a nonbreakaway.

The Labra, Kimball, and McDevitt report was discussed in the introduction.[9] It represents a significant study of the application of conventional breakaway technology to timber utility poles. It shows conclusively that the system proposed is implementable at selected sites and that the cost of such modifications need not be prohibitive. Five crash tests demonstrated the injury reduction potential of the slip base modification. Several reasonable approaches to the detachment of the impacted pole from the conductors were developed. It provided an excellent starting point for the current study. A slip base test summary is provided by Labra.

> "The slip base device in all crash tests shows its ability to activate when struck by an errant sub-compact car at speeds of 32 to 97 km/h (20 to 60 mi/h). The possibility exists of the segmented pole landing on the vehicle and causing serious injury.

> The alternative of striking the unmodified pole, however, is thought to pose a greater risk to vehicle occupants under identical impact conditions (i.e., speed, impact location, vehicle size). Notably, in all tests, whether or not the CRM (controlled release mechanism) was employed as an upper pole breakaway mechanism, no service line failure was caused by the strip-away action of the aluminum ties."

Another major step taken since Mak and Mason accurately quantified the problem has been taken by Zegeer and Cynecki.[10,1] Their paper "Determination of Cost-Effective Roadway Treatments for Utility Pole Accidents" was published by the Transportation Research Board in 1984. Building on the work of Mak and Mason, Zegeer and Cynecki comprehensively estimated the cost-effectiveness of several utility pole treatments.

They state:

> "The study involved a large-scale data-collection and analysis effort to quantify benefits and costs associated with the following countermeasures: (a) placement of utility lines underground, (b) relocation of poles further from the roadway, (c) reducing the number of poles, (d) combinations of pole relocation and reducing pole density, and (e) use of breakaway poles. Expected accident benefits were computed for various countermeasures based on an indepth analysis of accident and roadway data in four states. Countermeasure costs were obtained from telephone and electric utility companies around the country. Placing the utility lines underground and pole relocation were found to be cost effective for telephone and electric distribution lines for a variety of traffic and roadway conditions. Reducing pole density through multiple pole use was also cost effective in some instances, but increasing pole spacing was generally not cost effective. No countermeasures involving large transmission poles and lines were cost effective within the limits of the analysis. General guidelines were developed for selecting cost-effective countermeasures under various combinations of pole offset, traffic volume, pole density (spacing), roadside conditions, and type of utility poles and lines."

Zegeer and Cynecki assembled a comprehensive data base from 1,534 roadway sections covering 2,519.3 roadway miles. These sections were in

Michigan, North Carolina, Washington, and Colorado. Six to ten years of accident data was acquired for each section. The analysis included more than 9,600 utility pole accidents.

A major accomplishment was the development of a regression model* to predict utility pole accidents. This model is

$$\text{Acc/Mi/Yr} = 9.84 \times 10^{-5} (\text{ADT}) + \frac{3.54 \times 10^{-2} (\text{DENSITY})}{(\text{OFFSET})^{0.6}} - 0.04 \qquad (7)$$

Where

Acc/Mi/Yr	=	number of predicted utility pole accidents per mile (1.6 km) per year (0.999997 MY),
ADT	=	annual average daily traffic volume,
DENSITY	=	number of utility poles per mile within 30 ft (10 m) of the roadway, and
OFFSET	=	average lateral offset of the utility poles (ft) from the roadway edge on the section

Zegeer and Cynecki summarize their findings on countermeasure effectiveness in table 1.

---

* A detailed description of the development of this model is given by Zegeer and Parker.[11]

Table 1. Summary of Effectiveness for Various Utility Pole Countermeasures. (After Zegeer and Cynecki)[1]

Countermeasure	Effect on Utility Pole Accident Frequency	Effect on Utility Pole Accident Severity
Increase Lateral	Causes a reduction in utility pole accidents as computed from predictive model. Some increase in other run-off road accidents may occur (as computed from roadside hazard model).	Assumed to have no effect on utility pole accident severity. However, a reduction in overall severity from 49.3% to 29.0% (I+F) may be expected in urban areas for the utility pole accidents converted to run-off-road accidents.
Underground Utility Lines	Eliminates utility pole accidents, but may cause an increase in other run-off-road accidents (as computed from roadside hazard model).	Reduces average percent of injury and fatal accidents of these accidents converted to run-off-road from 49.3% to 29.0% in urban areas.
Reduce Pole Density (Multiple Pole Use)	Causes a reduction in utility pole accidents, as computed from the predictive model. Some increase in other run-off-road accidents may occur (as computed from the roadside hazard model).	Assumed to have no effect on utility pole severity. However, a reduction in overall severity from 49.3% to 29.0% (I+F) may be expected in urban areas for the utility pole accidents converted to run-off-road accidents due to lower severity of ROR accidents.
Combinations of Increase Lateral Pole Offset and Reduce Pole Density	Causes a reduction in utility pole accidents, as computed from the predictive model. Some increase in other run-off-road accidents may occur (as computed from the roadside hazard model).	Assumed to have no effect on utility pole accident severity. However, a reduction in overall severity from 49.3% to 29.0% (I+F) may be expected in urban areas for the utility pole accidents converted to run-off-road accidents due to lower severity of ROR
Breakaway Pole Feature	Assumed to have no effect.	Effect on severity has not been properly quantified in prior research, since new breakaway devices are being developed and tested. The expected result of 30 to 60% reduction in injury and fatal accidents may be input by the user.

Definitive information on installation and maintenance costs and the savings in accident costs was developed for each countermeasure. The information came from the literature and from selected telephone and electric utility companies throughout the United States. The effectiveness of the countermeasures came from literature on breakaway poles and crash cushions. Pole density and setback effectiveness was determined from equation (7). A comprehensive summary of the conditions under which selected countermeasures are cost effective was developed. It is illustrated by figures 1 and 2.

The author's final conclusions related to breakaway poles are:

1. "The variables that were of primary importance in explaining the variation in utility pole accident experience were traffic volume (average daily traffic), pole offset, and pole density.

2. "Based on average countermeasure costs and expected accident reduction for various situations, a cost-effectiveness analysis was conducted. By using 1981 NSC costs and the severity of utility pole accidents, the average cost of a utility pole accident was computed to be $7,007.

3. "Breakaway pole devices are still being developed and tested, so their final effectiveness is not yet established. However, assuming a 30-percent reduction in injury and fatal accidents, breakaway poles are cost effective only for a few extreme situations. Assuming a 60-percent reduction in injury and fatal accidents, breakaway poles are cost effective under a variety of conditions of pole offset and traffic volume."

The net result of the work of Mak, Zegeer, Mason, Cynecki, and Parker is that both the nature of the utility pole problem and the effectiveness of feasible countermeasures have been defined with some precision. These collective works are all that are needed to evaluate the effectiveness and predict where the implementation of devices such as the Hawkins Breakaway System will be cost effective.

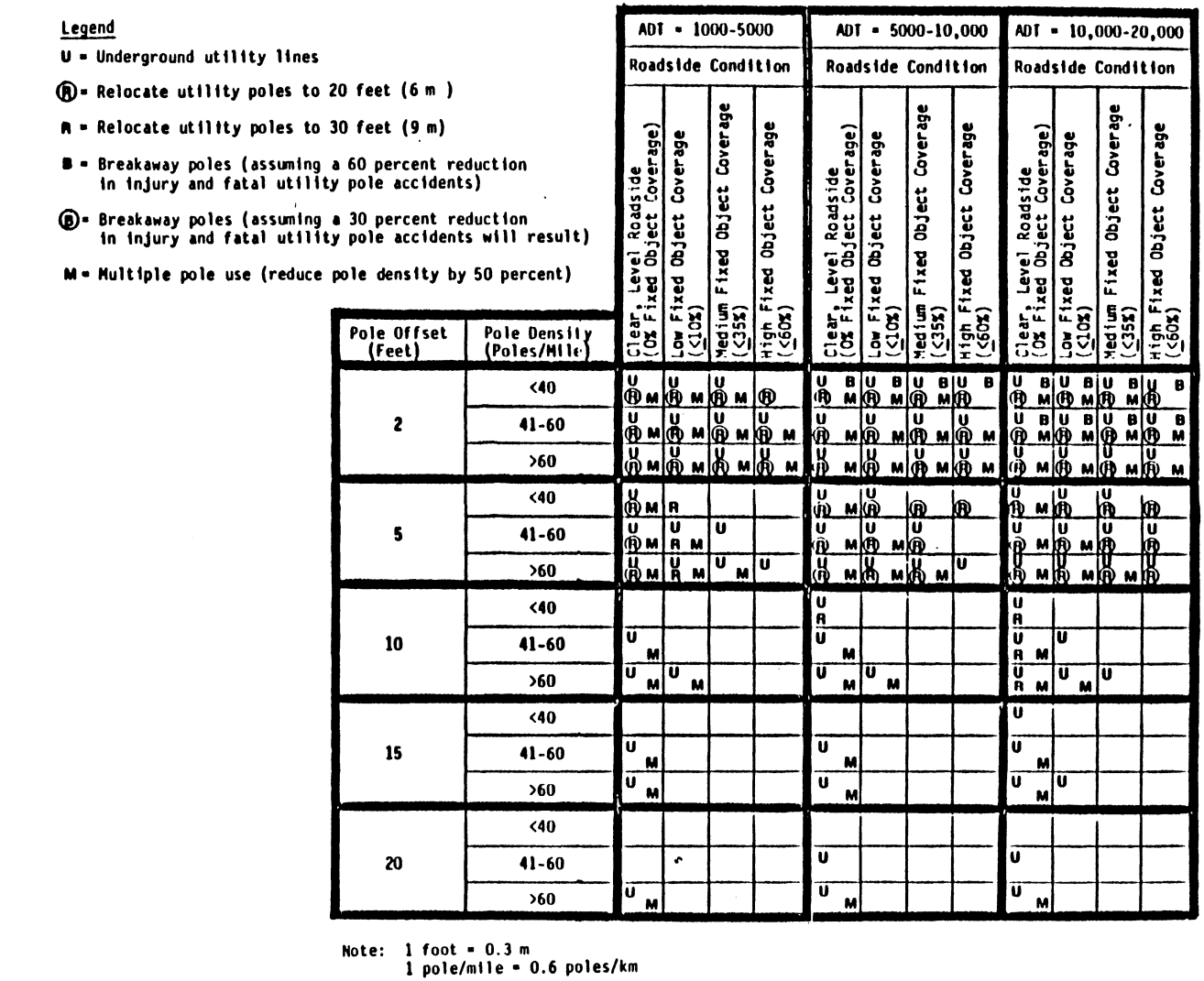


Figure 1. Guidelines for cost-effective countermeasures for utility pole accidents--telephone lines and poles in urban areas (After Zegeer and Cynecki). (1)

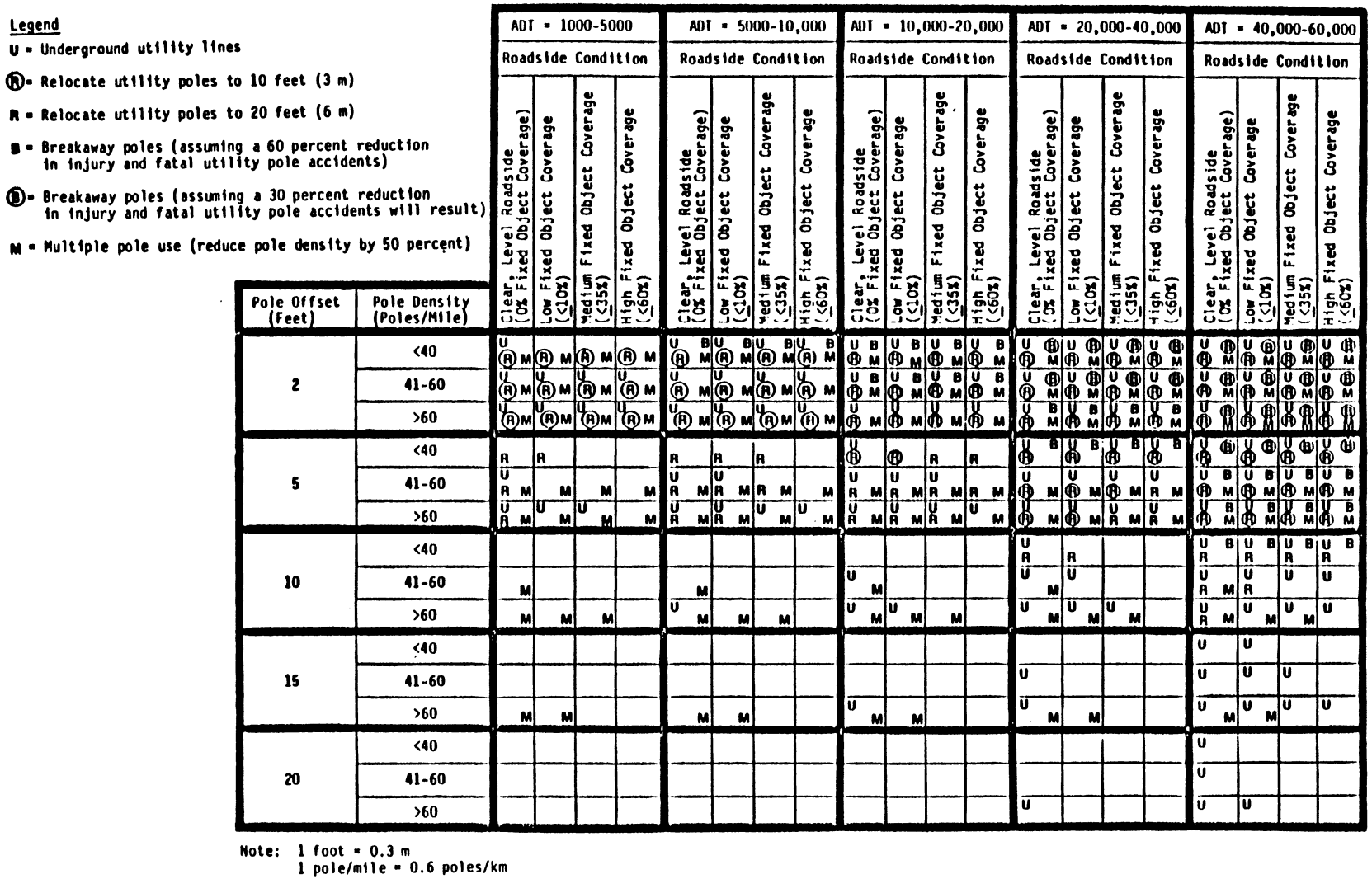


Figure 2. Guidelines for cost-effective countermeasures for utility pole accidents--telephone lines and poles in rural areas (After Zegeer and Cynecki). (1)

II. RESEARCH PLAN

The primary objective of the research plan was to design, develop, and test structural conversions of timber utility poles and their attachments that will function in a breakaway mode to significantly reduce the probability of injury of passengers in an impacting vehicle. As a secondary objective other means of achieving the same objective were to be considered and conceptually designed.

The initial effort, was to review prior research on this subject. The principal staff members conducting this research had been working on this task for the proceeding 2 years, and had complied 48 related reports, articles, and documents. The most pertinent 22 had already been abstracted. Fifteen of these references were written by TTI's staff members. During the course of this work it was only necessary to update that literature survey as new reports became available and to use all documents to the full extent they were helpful in meeting contract objectives.

Analytical studies were used to design breakaway systems and to extrapolate test results to other conditions. Although a number of extent computer codes were studied, it was soon apparent that all of them either suffered from limitations in application to the timber utility pole problem or was unavailable. A relatively simple two-dimensional computer code was developed to meet the design and analysis requirements. It is described in appendix C.

Conceptual designs of different retrofit devices were proposed and considered during numerous staff meetings. Most of these soon exhibited serious drawbacks in terms of design complexity or probable functional inadequacy. Exceptions were the pole band upper connection for Hawkins Breakaway System (HBS), the guy wire breakaway connections, and the "CAM" vehicle deflector.

Following conceptual design, detailed designs of the various components or structural system were developed using both computer modeling and conventional structural analysis techniques. The detailed design of the breakaway attachments developed herein were made in accordance with the procedures outlined in The Lineman's and Cableman's Handbook and with the requirements of the National Electrical Safety Code, NESC.[12,13] Included in these requirements are the environmental loads which should be considered (wind and ice), the static proof tests commonly employed in the field to verify the required load resistance (a horizontal 2,400-lb load at an elevation of 31.5 feet above grade in the case of a 40-foot class 4 pole), and the minimum clearances which must be maintained between electrical conductors and so-called "foreign" conductors (overhead structural support guys, etc.). The static tests outlined below were conducted to establish the load resistance of a modified pole as compared to the inherent resistance of an unmodified pole. Following this stage shop drawings were prepared, the designs were fabricated and subjected to a sequence of tests which usually followed this pattern:

1. Static tests (see appendix B)
2. Pendulum tests (see appendix B)
3. Full-scale vehicle crash tests

The crash test reports, including condition documentation, detailed analysis of the results and conclusions drawn from each are presented in volume III.

A full analysis of the five compliance tests used to verify the implementability of the Hawkins Breakaway System (HBS) was developed using data from the literature on occupant probability of injury. This analysis is presented in chapter IV. These tests were also compared to the requirements presented in NCHRP Report 230.

III. SELECTING COMPLIANCE TESTS FOR BREAKAWAY UTILITY POLES

The most widely accepted criteria for the testing of highway safety structures is NCHRP Report 230.[15] According to the author, Jarvis D. Michie, the implied philosophy of NCHRP Report 230 is to perform "worst case" testing, although this is put in appropriate perspective by a statement, "For these reasons, ... possible in service collisions. This is why the 1,800-lb vehicle at 60 mi/h was suggested as a preferred but not required compliance test for a "Breakaway or Yielding Support" (see Test Designation 63, table 3).[15] There has been a phenomenal reduction of automobile size in this country in the past 20 years. As the size of automobiles in foreign countries continues to decline under the pressure of energy costs, there is a trend to allow smaller vehicles on this Nation's highways. Witness current research in micro-mini compacts sponsored by the National Cooperative Highway Research Program.[16] These pressures, and the recognition that we have never designed for the "worst case" in terms of structural performance testing is producing a consensus of that committee that there are practical limits to vehicle size and shape, outside which it may not always be reasonable to design. This philosophy was discussed in the recent Federally Coordinated Program* meeting where research needs were developed. It was the consensus of that group that practical limits for structural design should be determined. Two research problem statements relating to this problem were developed. They were titled "Vehicle Class Properties" and "Alternative to Roadside Treatments for Smaller Vehicles."

It was only briefly discussed, but it does seem evident that the practical limits for design may be different for different types of structures. For example, it seems reasonable that small ground-mounted signs and mailbox supports could be designed to meet NCHRP Report 230 crash test criteria for a 1,600-lb vehicle. Alternately, it does not seem reasonable that structures having masses up to 60 percent of the mass of

*Meetings of the Select Committee for the Determination of Research Needs, FCP Project 1T, June 5, 6, and 7, and August 22, 23, and 24, 1984.

an impacting 1,600-lb car can be practically designed to provide very low levels of acceleration or velocity change. This should not mean that treatments which can vastly improve the safety of specific structures should not be implemented, even though these practical treatments may not meet popular safety criteria for all vehicles on the roadway. By limiting highway engineers in such a way, the vast majority of drivers could be penalized because it may not be possible to rigorously protect the full spectrum from significant injury. Obviously, this is only an admission of what was already known. It was never possible to protect all with any safety structure application.

It seems apparent now that an alternate philosophy for evaluation of certain highway auxiliary structures could be useful. That alternate philosophy is as follows: A new structural design for a highway auxiliary structure should be strongly considered for implementation if

- The new design results in a significant improvement in safety for the majority of drivers and passengers.
- The new design does not result in a significant deterioration in safety for any group of vehicle occupants.
- There are no other proven designs of equal or better cost-effectiveness that produce a safer condition for a larger spectrum of vehicle occupants.

Although this alternate safety philosophy may seem self-evident, its acceptance could allow use of structures that vastly improve the safety of the traveling public while not meeting all requirements of NCHRP Report 230 or TRC 191.[15,14]

Although it will be shown that utility poles can be modified to meet the NCHRP Report 230 criteria, they will be used here as an example of how the alternate safety philosophy can be applied. Designs for breakaway poles by both Southwest Research Institute and Texas Transportation Institute have been developed that can greatly improve roadside safety. This can be done in a cost-effective way if selective implementation is performed. The appropriate questions that must be answered derive from the "proposed philosophy," that is,

- Will breakaway utility poles result in a significant improvement in safety for the majority of drivers and passengers?
- Will the design result in a significant deterioration in safety for any group of vehicle occupants (in this case, for drivers of very small cars)?
- Are there other proven structural designs of equal or better cost-effectiveness that produce a safer condition for a larger spectrum of vehicle occupants?

It will be shown in chapter IV that breakaway utility poles, implemented at select sites, as suggested by both Mak and Mason and Zegeer and Cynecki will satisfy the "alternate philosophy."[10,11] In order to prove that compliance it was first necessary to test proposed designs to determine if element one was achieved. The approach was to select a series of compliance crash tests that would encompass a clear majority of impact conditions that resulting in injury. The appropriate selection of vehicle size, speed, and attitude (i.e., frontal, side or rear impact area) is the subject of following paragraphs.

First considering vehicle size, although there is a trend toward a population of smaller vehicle vehicles in this country, that trend may be leveling far short of the projections made in 1980. These predictions were based primarily on a report by the National Transportation Policy Study Commission were described by Wootan and Ivey.[17,18,19] It was projected that 50 percent of the automobile population would be subcompact or smaller by 1990. See figure 3. This prediction was made on the assumption that gasoline prices would continue to rise, an assumption that was obviously untrue in the short term.

Observation of trends in automobile weight distribution have been reported by Viner.[20] Based on 1981 car registrations in Texas and 1970 car registrations in California, there are between 11.4 and 24 percent of registered vehicles below the 2,250-lb weight level. See figure 4. Although the minus 2,250-lb vehicle does not appear to be overpowering the population, the 1985 "projected new car sales," again from figure 4, does indicate a dominating increase in vehicles under 3,000 lbs. Considering

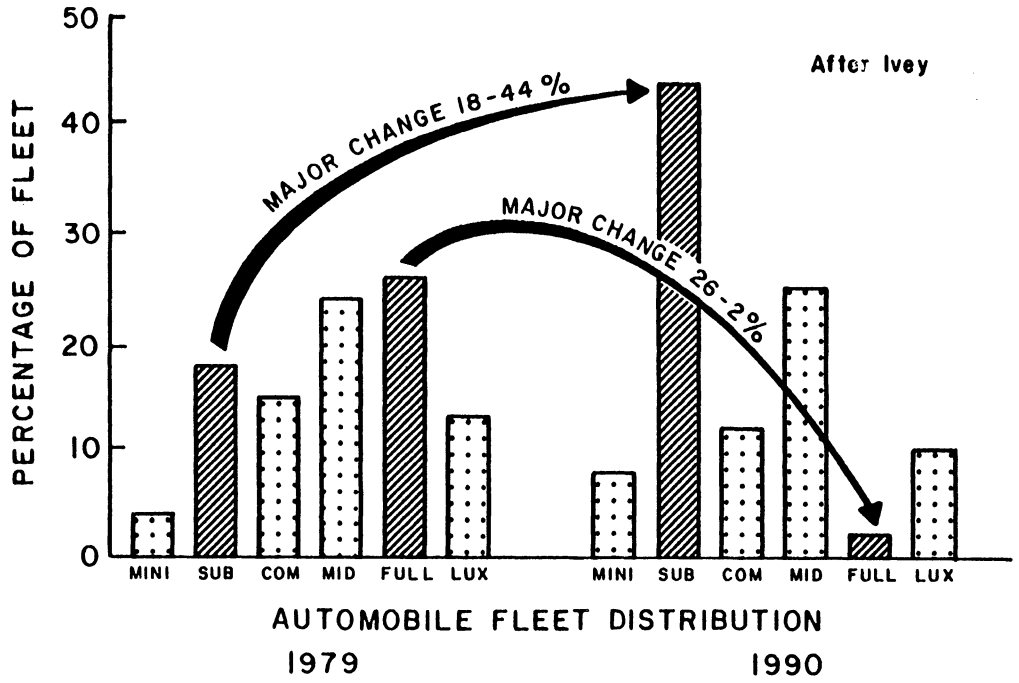


Figure 3. Projected trend toward smaller vehicles.

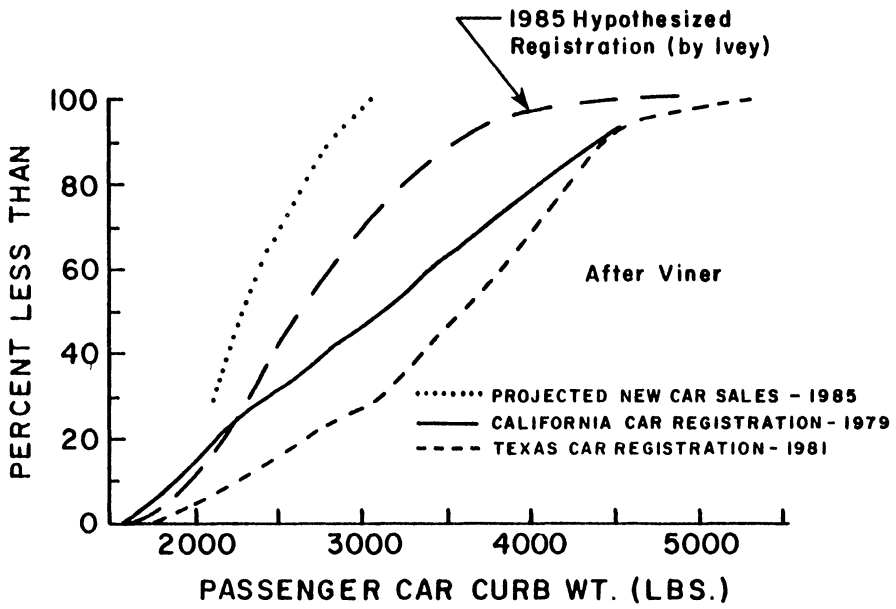


Figure 4. Trends in vehicle weight distribution.

the fact that a small percentage of automobiles on the road are over 10 years old, one might hypothesize the 1985 vehicle registration as shown on Viner's figure 4. This would indicate 80 percent of the vehicles would weigh more than 2,250 lbs and almost all autos would weigh more than 1,600 lbs. Further, it appears that approximately 90 percent of the automobiles will weigh more than 1,800 lbs. From a data base of 1,272 accidents, Mak and Mason show that 9.2 percent of pole collisions involved vehicles weighing less than 2,500 lbs.[10] This appears consistent with the 1981 projected 10 percent from Texas car registration of vehicles under 2,500 lbs, and indicates that small vehicles are probably not over-represented in pole collisions.

Considering now the range of vehicle speeds that might be expected in a pole collision, Mak's analysis is shown by figures 5 and 6.[10] Both these figures indicate that over 87 percent of the pole collisions analyzed occurred between the speeds of 10 and 50 mi/h. More recent data from Mak, Ross, Buth, and Griffin is shown by table 2.[21] This would indicate that 74 percent of pole accidents would occur between 10 and 50 mi/h. The first estimate (87 percent between 10 and 50) is probably better for utility poles since they are more often located on urban, lower speed, roadways.

The final consideration is that of vehicle attitude. Again from Mak's work, figure 7 shows the distribution of damage from pole impacts from which the automobile attitude at impact is inferred.[10] This figure shows that 80 percent of the impacts were frontal with 69 percent being direct frontal and 31 percent being offset to one corner or the other. Seventeen percent could be considered side impacts and 3 percent were rear impacts.

Based on these observations, it is evident that a significant majority of the traveling public can be well served by a breakaway pole design that will provide improvements in safety for vehicles impacting in a forward direction (frontal collision) weighing between 1,800 and 4,500 lb moving between 20 and 60 mi/h. Speeds less than 20 mi/h are not

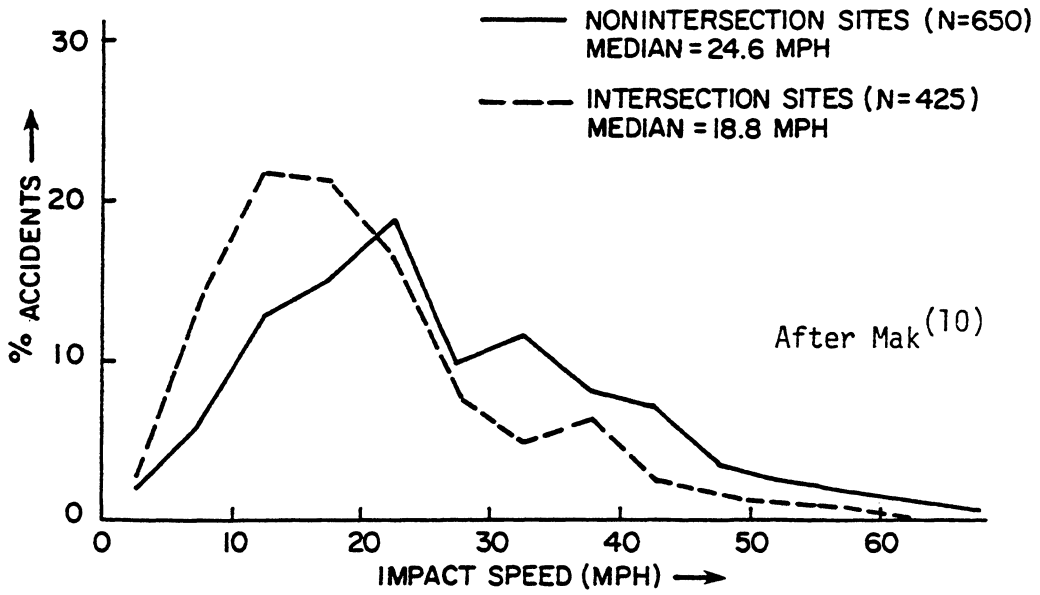


Figure 5. Distribution of impact speed for nonintersection and intersection pole accident sites.

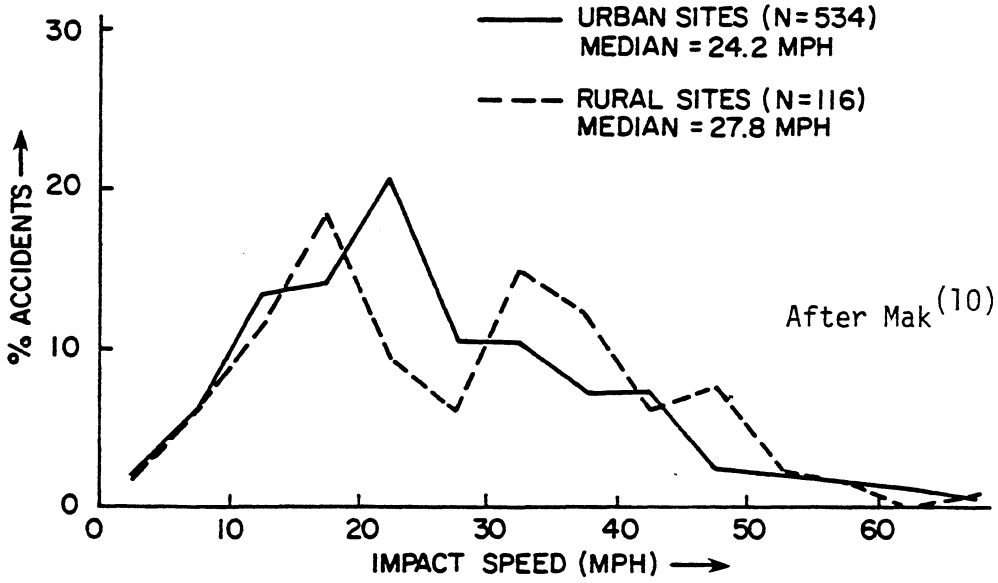


Figure 6. Distribution of impact speed for urban and rural nonintersection pole accident sites.

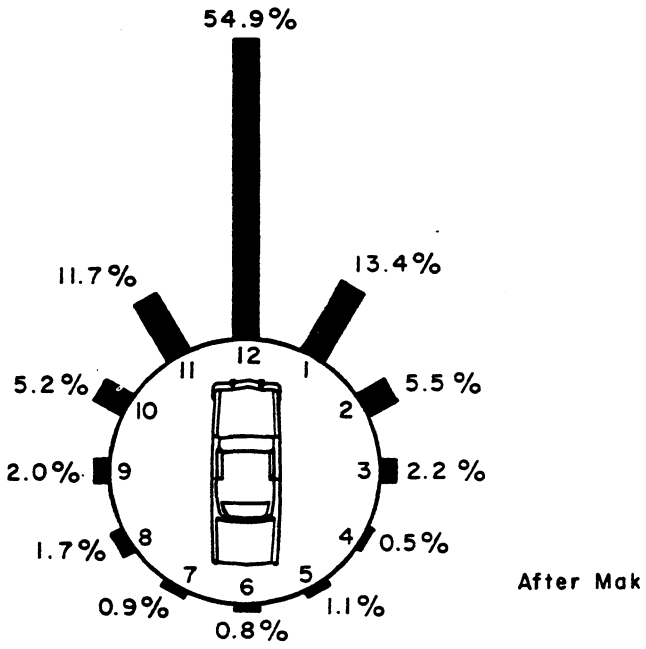


Figure 7. Distribution of vehicle damage by direction of force.

considered since the problem of serious injury is extremely low they do not pose a major injury problem even on nonyielding structures. The speeds of 50 to 60 mi/h were included simply as a conservative measure.

Table 2.
Impact speed probability distribution by functional class.
(After Mak et al)[21]

	Functional Class					
	Urban			Rural		
Impact Speed (mi/h)	Freeway	Arterial	Collector/ Local	Arterial	Collector/ Local	Combined
0-10.0	0.0021	0.1029	0.1810	0.0763	0.0468	0.0905
10.1-20.0	0.0507	0.3086	0.3718	0.1828	0.2437	0.2222
20.1-30.0	0.1547	0.2796	0.2529	0.1984	0.2987	0.2261
30.1-40.0	0.2208	0.1678	0.1202	0.1680	0.2114	0.1743
40.1-50.0	0.2099	0.0822	0.0480	0.1265	0.1137	0.1174
> 50	0.3617	0.0587	0.0259	0.2481	0.0853	0.1695
Total	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

The test matrix shown in table 3 evolved during the course of this work as an appropriate series of compliance tests for breakaway utility poles. This matrix will test the important elements of this design for the appropriate spectrum of collision characteristics.

Ranges of acceptable vehicle weights for each test are selected to preclude the necessity of selecting one specific vehicle for each test condition. The range of speeds selected is an indication of acceptable test variability. The primary reason each test was selected is given in table 3. Of course, other aspects of each test were also evaluated. Specifically the applicable criteria under table 6 of NCHRP Report 230 will be considered (i.e., criterions B, D, E, H, and J).[15] Note criterions F and G can be supplemented by estimating relative

Table 3. Proposed Compliance tests for breakaway utility poles.

Test No.	Vehicle Weight	Vehicle Speed	Vehicle Attitude	Primary Purpose of Test
1	1700-1900	38-42	Frontal, mid 50% (close to center)	Determination of probability of injury reduction for the most critical element of the design spectrum.
2	1700-1900	18-22	Frontal, mid-50% (close to center)	Determination of probability of injury reduction for the lowest kinetic energy level at which pole structural activation would be expected.
3	3200-3600	38-42	Frontal, mid-50% (close to center)	Determination of probability of injury reduction for the mid range of automobile kinetic energy.
4	2300-2700	58-62	Frontal, outer 50% (quarter point of bumper)	Determination of vehicle dynamic reaction to eccentric collision
5	4300-4800	58-62	Frontal, mid-50% (close to center)	Assessment of pole structural integrity at the highest kinetic energy level encompassed by the design spectrum.

probabilities of injury. The primary way each test will be evaluated is by estimating the probability of injury for the specific test of a breakaway pole and comparing that value to the estimated probability of injury for a nonbreakaway pole impacted under similar conditions of vehicle weight, speed, and attitude. A method of estimating these probabilities of injury has been provided by Mak.[10] Figures 8, 9, and 10, respectively, give probability of injury (AIS$\geq$1 and AIS$\geq$3) as a function of impact speed (figure 8), change in velocity (figure 9), and change in momentum (figure 10). A specific test will have all three of these characteristics determined imperially. By using impact speed as the independent variable %AIS$\geq$1 and %AIS$\geq$3 may be determined for a nonbreakaway pole impact from figure 8. By using ΔV, change in vehicle impact velocity, and ΔM, change in momentum values of %AIS$\geq$1 and %AIS$\geq$3 may be determined from figures 9 and 10 for a specific breakaway pole test. A second assessment of probability of injury will be made by using figure 11 as developed by Buth and Ivey.[23] For each crash test performed, it will be compared to the probability of injury estimated for a similar size and speed vehicle impacting a nonbreakaway pole. The result of the single nonbreakaway pole test will be analytically extrapolated to other vehicle impact conditions to produce comparative 0.050-second acceleration values.

The tests proposed in table 3 were designed to illustrate compliance with part (a) of the proposed safety philosophy. Part (b) is not given by these tests. Consideration of part (b), whether the new design results in a significant deterioration of safety for any group of vehicle occupants, can be accomplished to some extent simply by reasoning. First, if the breakaway pole is activated at all, the resulting accelerations on the impacting vehicle must be less than those if it does not breakaway. Therefore, any activation, even at acceleration levels much higher than those proposed by NCHRP Report 230 must reduce the probability of injury due to the primary impact.

The real problem is in considering possible injuries caused by the detached pole coming in contact with vehicle roof structure. There is a

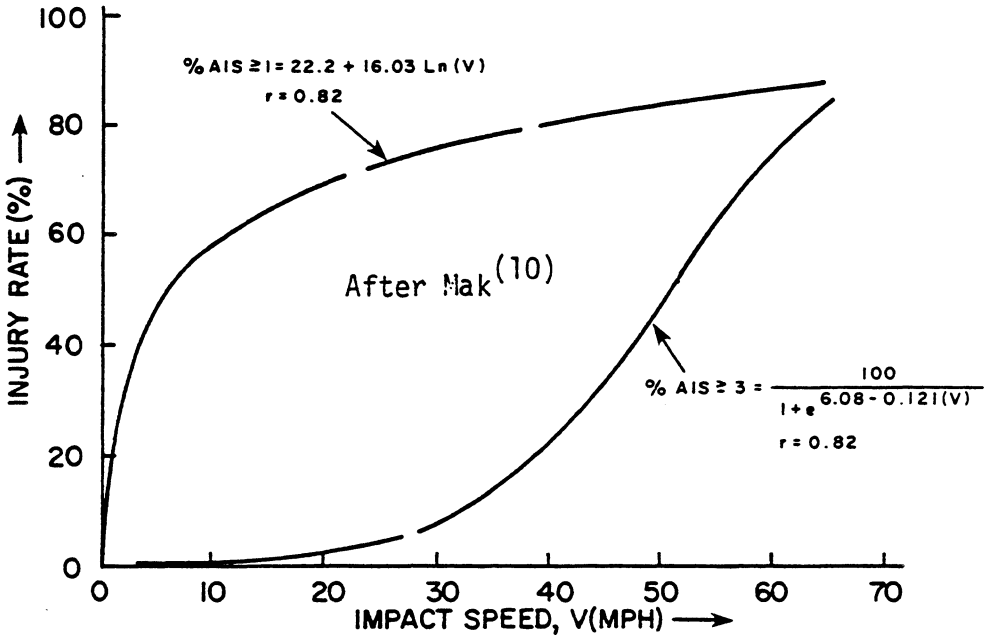


Figure 8. Injury rate as a function of impact speed.

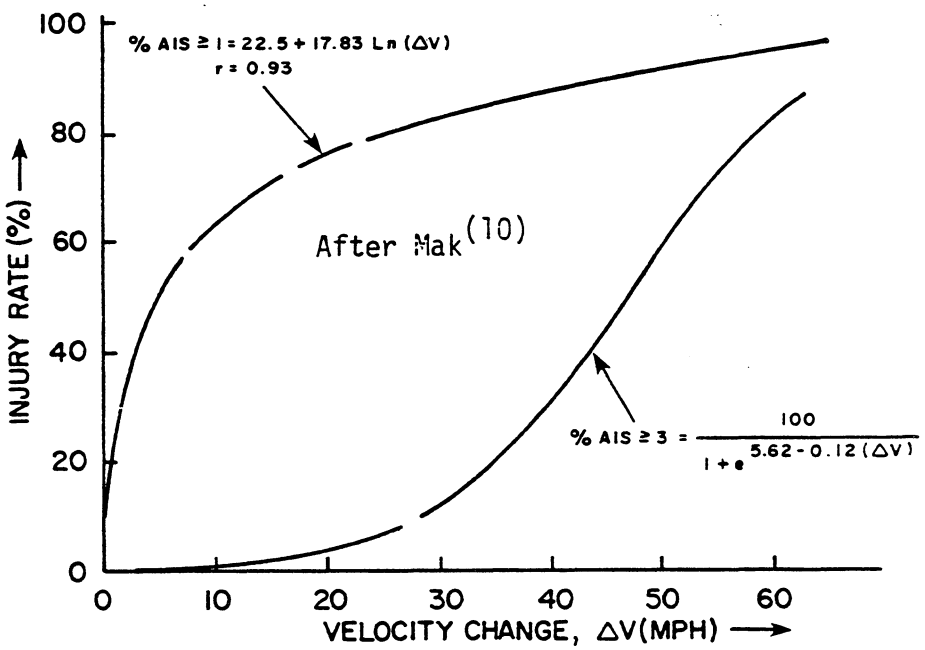


Figure 9. Injury rate as a function of change in velocity.

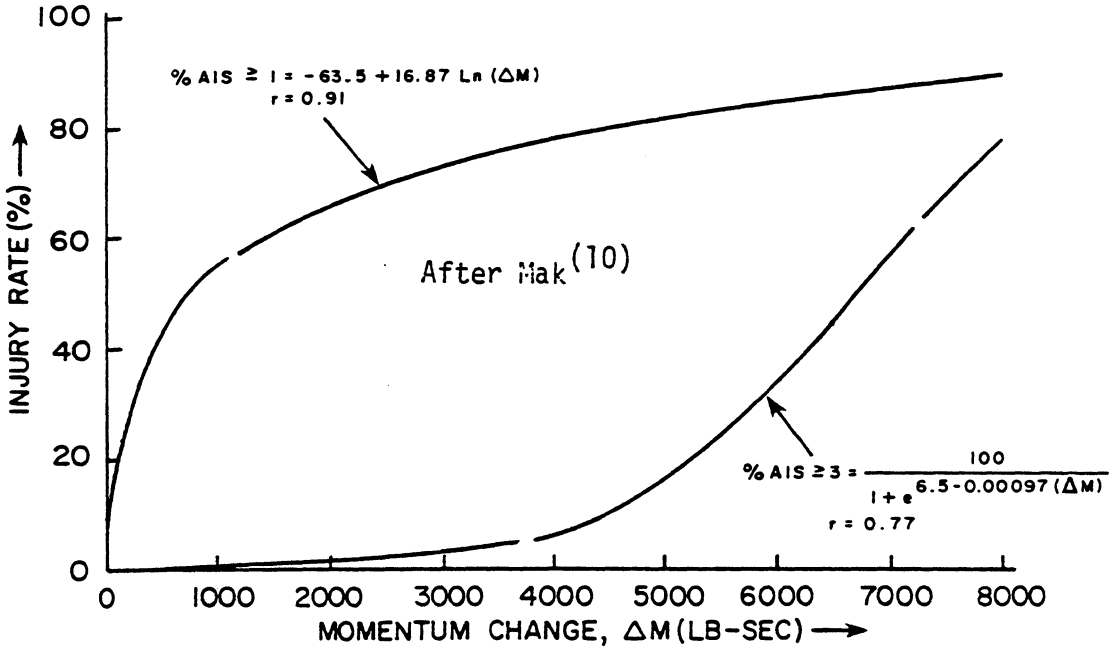


Figure 10. Injury rate as a function of change in momentum.

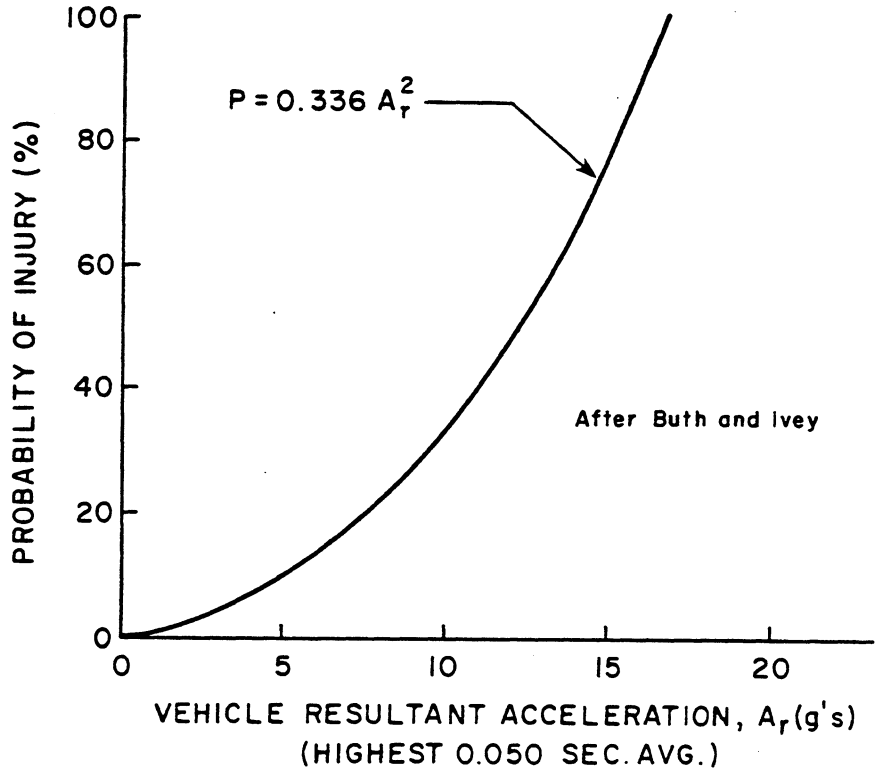


Figure 11. Injury rate as a function of vehicle acceleration values.

certain critical speed at which every car will activate the breakaway features of the pole and then have the pole descend on or at least come to rest on the vehicle top. In general, this will be at a fairly low speed which is inversely proportioned to the vehicle mass. For a 4,500-lb vehicle, it is below 15 mi/h. For a 2,500-lb vehicle, it is below 25 mi/h. For a 1,800-lb vehicle, it is below 30 mi/h. Assessing the loss of safety due to passenger compartment intrusion due to roof damage is difficult. Huelke, through personal investigation of many hundreds of accidents that involve roof damage, has concluded there is no good correlation between vehicle roof deflection and severity of injury.[22] Although this might be considered anecdotal evidence, the large number of cases investigated by Huelke gives weight to his opinion. The most compelling reason Huelke's conclusion may not apply to the detached pole situation is that most of the cases he investigated involve roof deformations that occurred during vehicle rollovers.

Several things are true in the rolling situation that make it quite different from the detached pole situation. These include (a) roof crush during a roll is a vehicle acceleration reduction mechanism, thus it is caused by forces much higher than those due to a detached, descending pole, and (b) occupants are not likely to be in their normal riding position during the time roof crush is taking place.

It seems more compelling for the detached pole situation that passenger compartment intrusion, i.e., roof crush, is at least a rough indicator of probability of injury, and further the potential for such injury becomes larger as the vehicle size decreases. Since we do not have a quantitative relationship between roof crush and probability of injury, it follows that it is very difficult to assess the tradeoff between two situations: (a) when a pole is hit at a relatively low speed and it does not breakaway and (b) when a pole is struck at the same low speed, the breakaway features are activated and the pole detaches, descends and settles on the car.

Labra, Kimball, and McDevitt have stated:

> "The potential exists for a segmented timber pole to fall onto the vehicle and cause significant damage and possible injury; however, the risk of injury to an occupant involved with a vehicle impact into an unmodified pole is believed to be far greater."[9]

These writers agree and would offer the following justification for use of the breakaway design even if the above is incorrect. The speeds at which a pole will descend or settle on top of a specific vehicle are very small in range compared to the potential spectrum of striking speeds. While a vehicle may strike a pole from 5 to 50 mi/h (about 90 percent of the time according to Mak), the speed range through which the pole may contact the top is in most cases not more than 15 mi/h.[10] The probabilities then are in favor of no roof-pole contact, a situation where we know the injury potential of the collision is radically reduced by the breakaway features.

The final question: are there other devices or remedies of equal or better cost-effectiveness that are available for use in reducing the hazard of utility poles? This has been extensively studied. Mak and Zegeer have concluded there are appropriate places to use the breakaway designs, even when their assumed effectiveness in reducing injury is less than that demonstrated by the HBS.[10,1]

Zegeer and Parker state:

> "Breakaway pole devices are still being developed and tested, so their final effectiveness is not yet established. However, for analysis purposes, two levels of effectiveness were analyzed, which were: a 30-percent reduction in injury and fatal accidents, and a 60-percent reduction in injury and fatal accidents (assuming no change in total accident frequency). These reductions would reduce the average cost per utility pole accident to $4,530 and $3,410, respectively. Assuming a 30-percent reduction in injury and fatal accidents, breakaway poles are cost-effective only for a few extreme situations such as ADT's above 20,000 combined with pole offsets of 2 feet (0.6 m) or less and less than 60 poles per mile (37 poles/km). Assuming 60-percent reduction in injury and fatal accidents, breakaway poles are

> cost-effective under a variety of conditions of pole offset and ADT. Costs were assumed to be $1,000 per pole, which includes a replacement of all poles once over a 20-year life."[11]

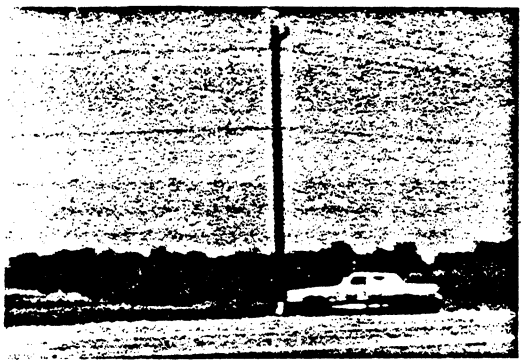
It is therefore submitted that breakaway utility poles, which have been shown by the proposed test matrix to result in major reductions in injury potential (i.e., probability of injury), are one practical and cost-effective solution to many aspects of the utility pole problem, and that under certain circumstances they are in fact the most cost-effective solution. Thus, the requirements of the final question (No. 3) are satisfied.

IV. TEST RESULTS

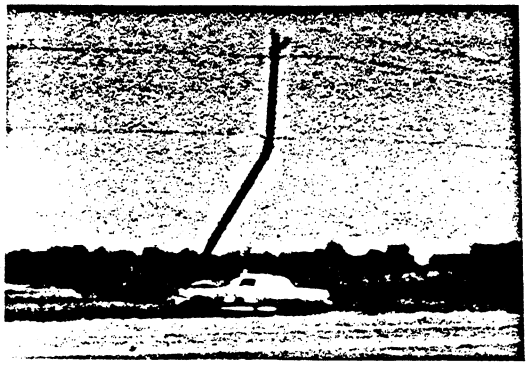
Compliance Crash Tests

A series of compliance tests were performed according to the guidelines outlined in the previous section. The breakaway system utilized for the compliance tests is that identified as the Hawkins Breakaway System (HBS). This system consists of a lower connection (slip base), an upper connection (hinge mechanism), and structural support cables. The slip base and hinge mechanism activate upon impact and are intended to reduce the inertial effects of the pole on the errant vehicle while minimizing the impact on utility service. The slip base is designed to withstand the overturning moments imposed by in-service windloads and at the same time slip when subjected to the forces of a collision. The upper hinge mechanism is sized so as to adequately transmit service loads while hinging during a collision to allow the bottom segment of the pole to rotate out of the way. This upper connection reduces the effective inertia of the pole and minimizes the effect of any variation in hardware attached to the upper portion of the pole during a collision. The overhead guys (one above the upper connection and one below the neutral conductor) are intended to stabilize the upper portion of the pole during a collision and to insure proper behavior of the upper connection. The proper function of the Hawkins Breakaway system is illustrated in figure 12.

For each compliance test a description is followed by a discussion of the results of the test and the performance of the hardware. A summary sheet and a photo of the vehicle after the test are included for each test. These sheets include a pictorial overview of the crash test and an view of the system used. Detailed test reports are available in volume II of this report.



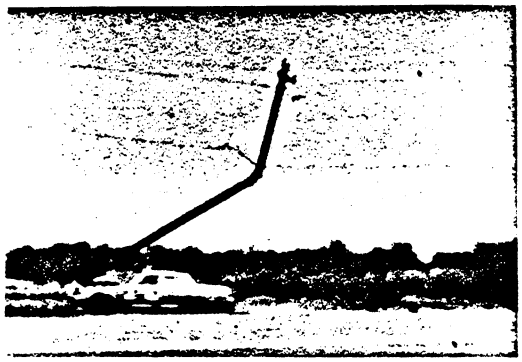
Impact



Slip base activates

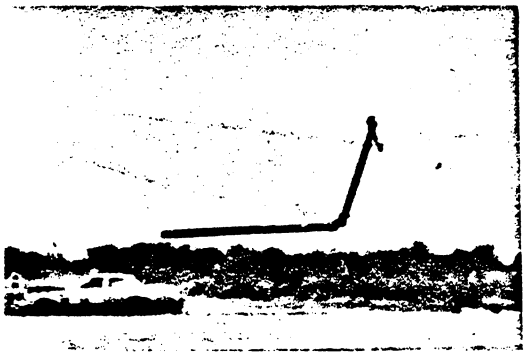
Upper connection starts to bend

Lower part of pole starts to rotate



Upper connection is fully activated

Lower part of pole rotates above vehicle



Vehicle drives under pole

Figure 12. Function of Hawkins Breakaway System during a vehicle collision.

Test 12:

A 1979 Honda Civic was directed into the utility pole at 19.5 mi/h (31.4 km/h). Test inertia mass was 1,775 lb (806 kg) and the gross static mass of the vehicle was 2,115 lb (960 kg). The vehicle was free-wheeling and unrestrained at impact. Impact was such that the vehicle contacted the pole at the centerline of the bumper.

Approximately 0.044 seconds after impact the lower connection slip base began to breakaway. The pole rode with the vehicle 4.3 ft (1.3 m) before contacting the ground. The vehicle then pushed the pole about 8.6 ft (2.6 m) further. The pole tilted back onto the vehicle and hit the left front corner of the roof. The base of the pole swung up and to the right as the pole slid across the roof of the vehicle. The base contacted the ground 10.5 ft (3.2 m) beyond the impact point, bounced up and finally came to rest approximately 14.8 ft (4.5 m) beyond and 6 ft (1.8 m) downstream of the impact point. The upper portion of the pole came to rest on the roof of the vehicle as shown in figure 13.

Damage to the vehicle is shown in figure 13. Maximum crush to the front of the vehicle was 8.0 in (20.3 cm) at bumper height. The hood was crushed downward where the pole layed back onto the vehicle. The roof was crushed downward into the occupant compartment approximately 4 in (10 cm), and the windshield was cracked.

The lower connection slip base functioned as intended. The upper connection did not activate on the test pole or either of the adjacent modified poles. All conductors were unbroken and remained connected to insulators. The utility poles on both sides of the impacted pole were slightly bent at the upper connections.

TEST RESULTS

Results of the test are summarized in figure 14. The maximum 0.050-second average longitudinal acceleration was -6.7 g. Change in

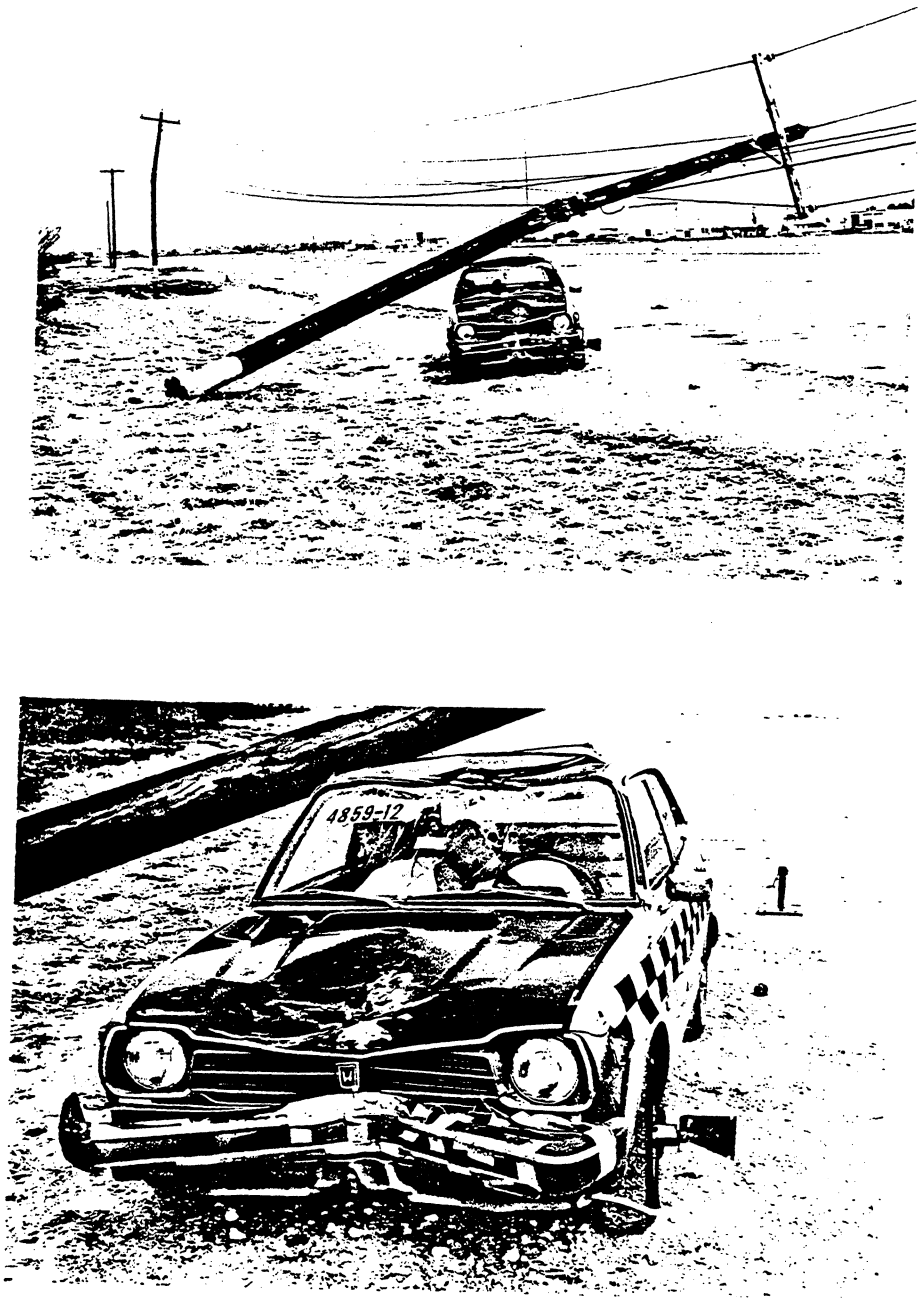
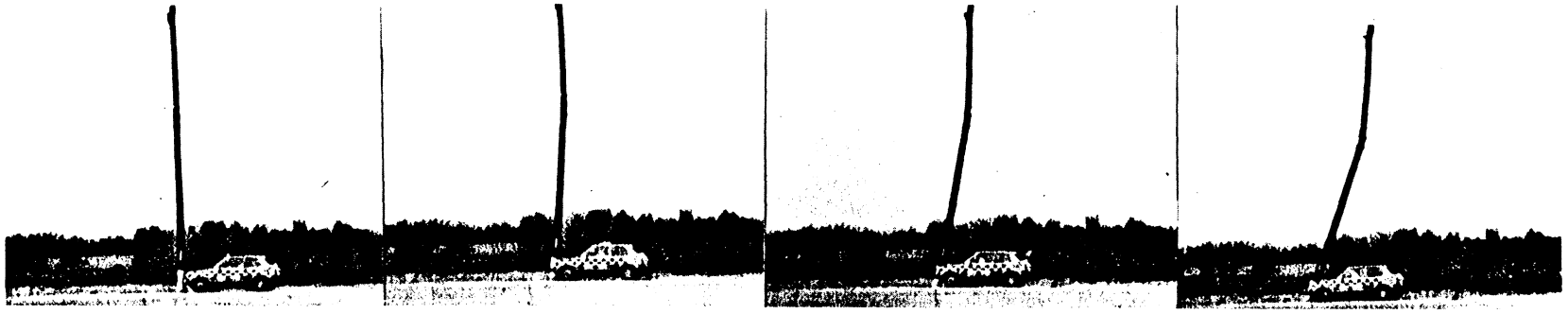
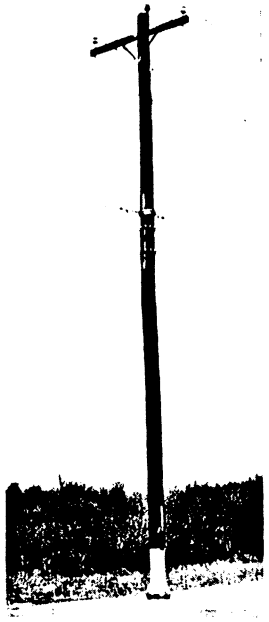


Figure 13. Vehicle after test 4859-12.



0.000 s 0.110 s 0.264 s 0.499 s



Test No.	4859-12
Date	2/20/85
Test Article	Breakaway Wooden Utility Pole
Lower Connection	Slip Base
Upper Connection	Pole Band No. 2
Vehicle	1979 Honda Civic
Vehicle Weight	
Test Inertia	1775 lb (806 kg)
Gross Static	2115 lb (960 kg)
Vehicle Damage Classification	
TAD	12FC3
CDC	12FCEN1
Maximum Vehicle Crush	
Bumper Height	8.0 in (20.3 cm)

Impact Speed	19.5 mi/h (31.4 km/h)
Change in Velocity*	11.3 mi/h (18.2 km/h)
Change in Momentum*	915 lb-s
Vehicle Accelerations (Max. 0.050 s Avg)	
Longitudinal	-6.7 g
Lateral	0.7 g
Occupant Impact Velocity	
Longitudinal	10.1 fps (3.1 m/s)
Lateral	3.5 fps (1.1 m/s)
Occupant Ridedown Accelerations	
Longitudinal	-2.1 g
Lateral	1.9 g

*Impulse period computed from 0 to 0.500 sec.

Figure 14. Summary of results for test 4859-12.

velocity at end of significant vehicle response (0.050 seconds) was 11.3 mi/h (18.2 km/h) and change in vehicle momentum at 0.050 seconds was 915 lb-s.

NCHRP Report 230 contains recommended evaluation criteria and places limits on these for acceptable performance for tests with small vehicles at 20 mi/h (NCHRP Report 230 test 62).[15] The lower connection functioned as intended by breaking away. The upper connection, intended to improve the performance of the system in high speed collisions, did not activate. The pole slowly tilted back onto the vehicle resulting in a maximum crush in the roof of 4.0 in (10.2 cm). The occupant risk factors were within the specified limits. The occupant impact velocity was 10.1 ft/s (3.1 m/s) in the longitudinal direction and 3.5 ft/s (1.1 m/s) in the lateral direction. The maximum 0.010-second average longitudinal and lateral occupant ridedown accelerations were -2.1 g and 1.9 g, respectively. The vehicle came to rest over the lower part of the slip base connection with the upper portion of the pole resting on the roof. Results of this test meet the recommended criteria in NCHRP Report 230, test 62.

Test 13:

A 1980 Chevrolet Malibu was directed into the utility pole at 40.7 mi/h (65.5 km/h). Test inertia mass was 3,365 lb (1,528 kg) and the gross static mass of the vehicle was 3,700 lb (1,680 kg). The vehicle was free-wheeling and unrestrained at impact. Impact was such that the vehicle contacted the pole at the centerline of the bumper.

The lower connection (slip base) broke away as intended. Breakaway was initiated approximately 0.027 seconds after impact, and loss of contact with the vehicle occurred at 0.153 seconds. At approximately 0.218 seconds the vehicle contacted the pole again and pushed it for several feet. The pole rode up front of the vehicle, caught the hood, and finally left contact at 0.498 seconds.

The upper connection did not react as designed but did allow sufficient bending to make it possible for the vehicle to proceed under the pole with no penetration of the occupant compartment. Bending of the upper connection began at about 0.044 seconds. The 1/8-in margin in the straps was only partially punched out; however, the 7/8-in through-bolt in the lower pole band sheared off, thereby allowing a hinge to form at the upper connection (see figure 15). The ground line and all conductors were unbroken and remained connected to insulators. The cables also were undamaged. The poles on each side of the test pole were bent slightly at the upper connections.

The vehicle traveled approximately 162 ft (49 m) beyond impact. The front of the vehicle was deformed with maximum crush at the center front of 18.7 in (47.5 cm) at bumper height (figure 16).

TEST RESULTS

Results of the test are summarized in figure 17. The maximum 0.050-second average longitudinal acceleration was -6.7 g. Change in vehicle velocity over time of contact was 10.8 mi/h (17.4 km/h) and change in vehicle momentum was 1,655 lb-s.

NCHRP Report 230 contains recommended evaluation criteria and places limits on these for acceptable performance for tests with small cars at 20 and 60 mi/h.[15] The test reported herein was conducted with a large (3,700 lb) sedan at 40 mi/h; however, occupant risk factors were computed. The occupant impact velocity in the longitudinal direction was 11.9 ft/s (3.6 m/s) and 6.3 ft/s (1.9 m/s) in the lateral direction. The maximum 0.010-second average longitudinal and lateral occupant ridedown accelerations were -1.4 g and 1.1 g, respectively. The utility pole broke away allowing the vehicle to proceed to a safe, stable stop with no penetration of the occupant compartment.

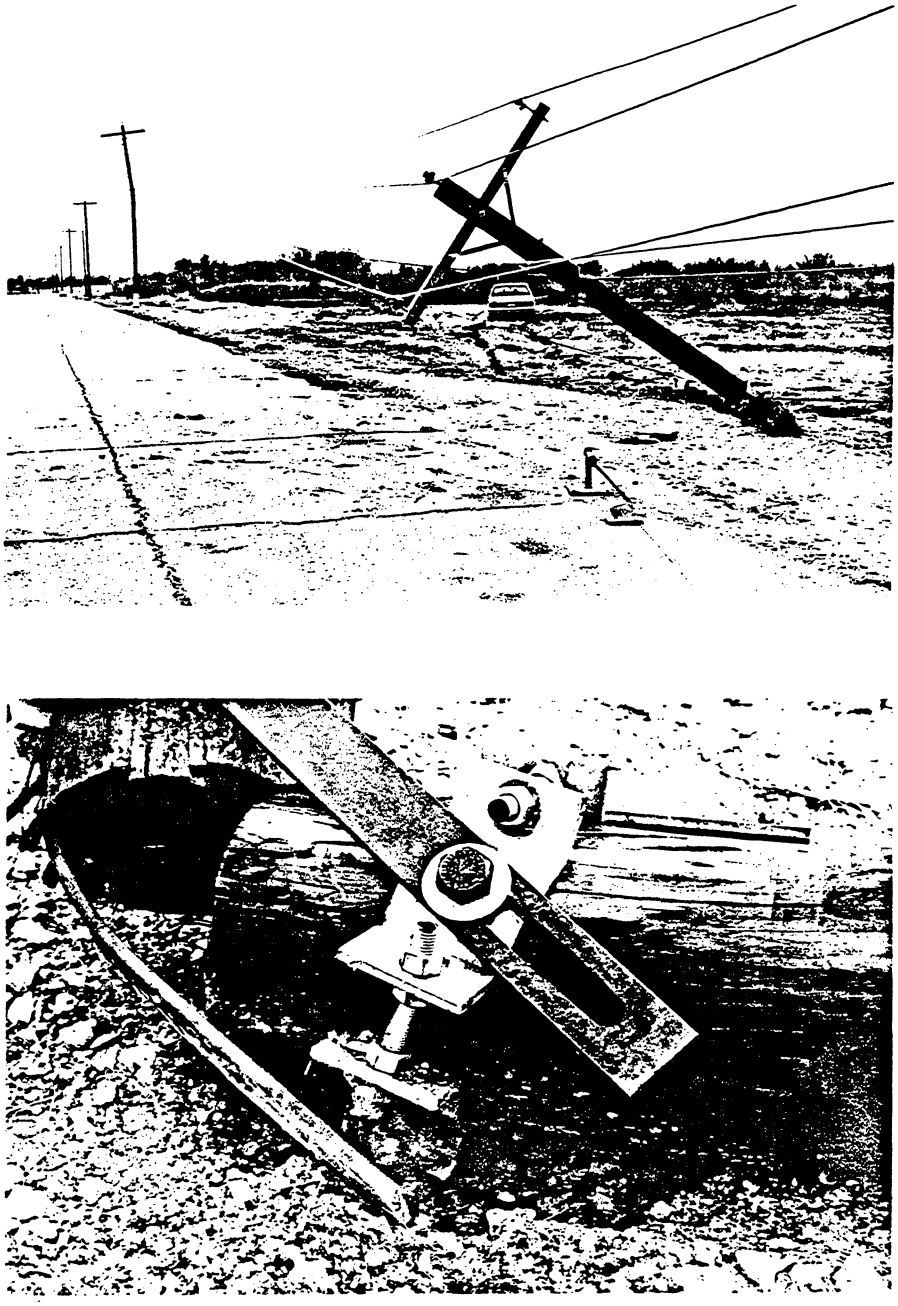
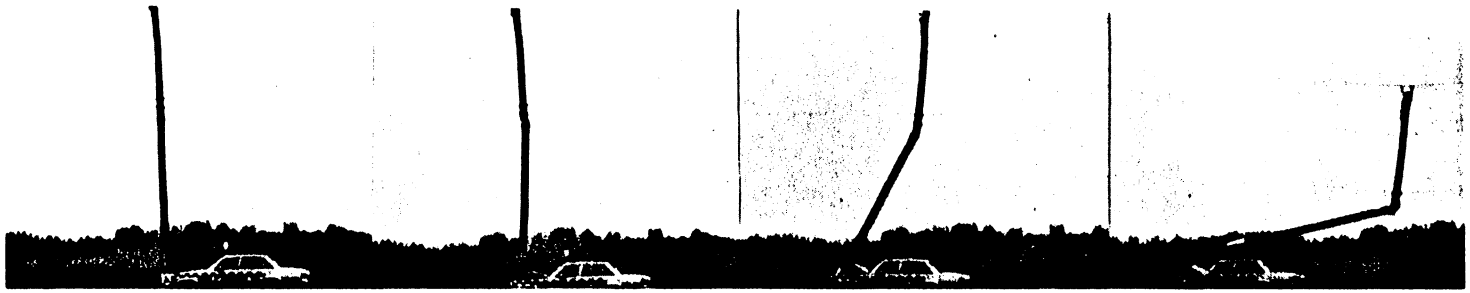
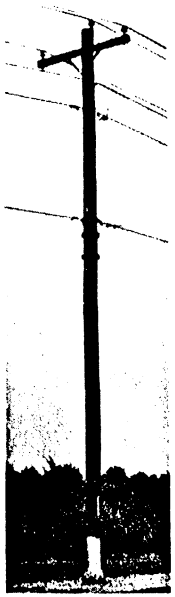


Figure 15. Test installation after test 4859-13.

Figure 16. Vehicle after test 4859-13.



0.000 s 0.049 s 0.243 s 0.607 s



Test No.	4859-13
Date	2/27/85
Test Article	Breakaway Wooden Utility Pole
Lower Connection	Slip Base
Upper Connection	Pole Band No. 2
Vehicle	1980 Chevrolet Malibu
Vehicle Weight	
Test Inertia	3365 lb (1528 kg)
Gross Static	3700 lb (1655 kg)
Vehicle Damage Classification	
TAD	12FC5
CDC	12FCEN2
Maximum Vehicle Crush	
Bumper Height	18.7 in (47.5 cm)

Impact Speed	40.7 mi/h (65.5 km/h)
Change in Velocity	10.8 mi/h (17.4 km/h)
Change in Momentum	1655 lb-s
Vehicle Accelerations (Max. 0.050 s Avg)	
Longitudinal	-6.7 g
Lateral	1.4 g
Occupant Impact Velocity	
Longitudinal	11.9 fps (3.6 m/s)
Lateral	6.3 fps (1.9 m/s)
Occupant Ridedown Accelerations	
Longitudinal	-1.4 g
Lateral	1.1 g

Figure 17. Summary of results for test 4859-13.

Test 14:

A 1975 Chevrolet Vega was directed into the utility pole at 60.0 mi/h (96.5 km/h). Test inertia mass was 2,500 lb (1,135 kg) and the gross static mass of the vehicle was 2,830 lb (1,285 kg). The vehicle was free-wheeling and unrestrained at impact. Impact was such that the vehicle bumper contacted the pole at the quarter point of the vehicle (15 in (38 cm) to the right of the vehicle centerline).

The lower connection (slip base) broke away as intended. Breakaway was initiated approximately 0.017 seconds after impact. Bending of the upper connection began at about 0.032 seconds after impact and loss of contact with the vehicle occurred at 0.168 seconds. The pole continued moving upward while the vehicle proceeded under it.

The upper connection reacted as designed and allowed sufficient bending to make it possible for the vehicle to proceed under the pole with no interference or contact. The ground line and all conductors were unbroken and remained connected to the insulators. The cables were undamaged. The lag bolt pulled out of the crossarm on the pole on the downstream side of the test pole. The pole on the upstream side of the test pole was not damaged.

The vehicle traveled approximately 225 ft (69 m) beyond impact. The front of the vehicle was deformed with a maximum crush at bumper height of 15.0 in (38.1 cm) (figure 18).

TEST RESULTS

Results of the test are summarized in figure 19. The maximum 0.050-second average longitudinal acceleration was -10.2 g. Change in vehicle velocity over time of contact was 11.0 mi/h (17.7 km/h) and change in vehicle momentum was 1,253 lb-s.

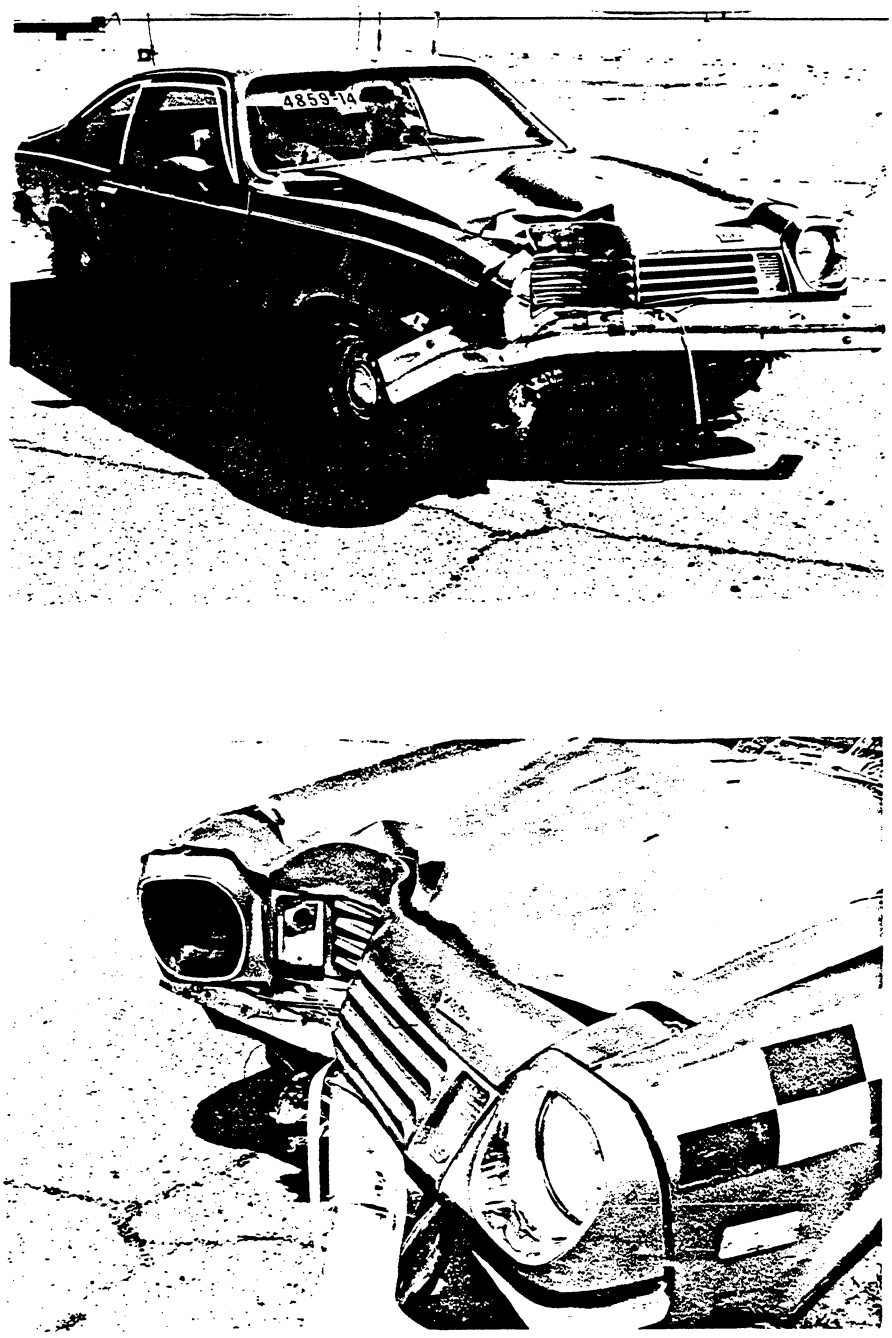
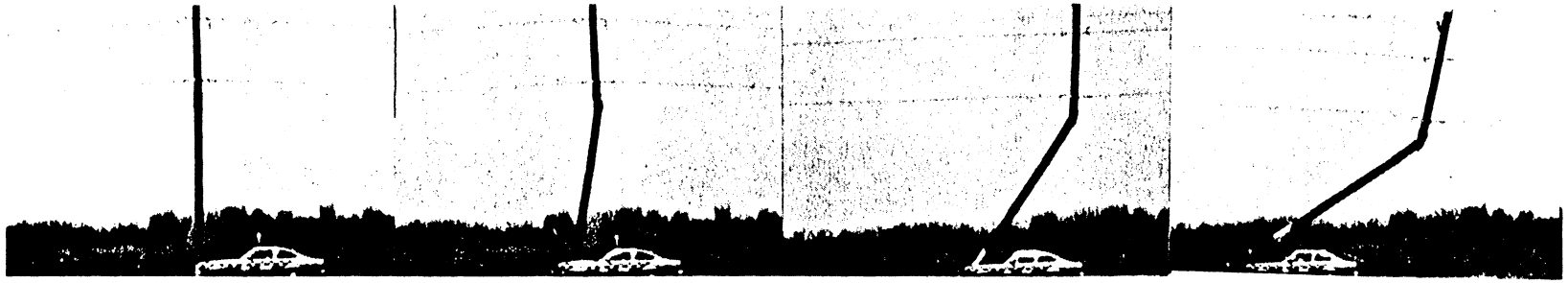


Figure 18. Test vehicle after test 4859-14.



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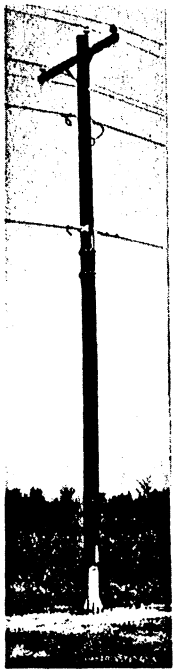


Test No.	4859-14
Date	3/22/85
Test Article	Breakaway Wooden Utility Pole
Lower Connection	Slip Base
Upper Connection	Pole Band No. 3
Vehicle	1975 Chevrolet Vega
Vehicle Weight	
Test Inertia	2500 lb (1135 kg)
Gross Static	2830 lb (1285 kg)
Vehicle Damage Classification	
TAD	12FR3
CDC	12FREN2
Maximum Vehicle Crush	
Bumper Height	15.0 in (38.1 cm)

Impact Speed	60.0 mi/h (96.5 km/h)
Change in Velocity	11.0 mi/h (17.7 km/h)
Change in Momentum	1253 lb-s
Vehicle Accelerations (Max. 0.050 s Avg)	
Longitudinal	-10.2 g
Lateral	- 1.3 g
Occupant Impact Velocity	
Longitudinal	15.6 fps (4.8 m/s)
Lateral	No Contact
Occupant Ridedown Accelerations	
Longitudinal	-1.8 g
Lateral	NA

Figure 19. Summary of results for test 4859-14.

NCHRP Report 230 contains recommended evaluation criteria and places limits on these for acceptable performance for tests with 2,250-lb vehicles at 60 mi/h (NCHRP Report 230 Test 61).[15] The lower connection functioned as intended by breaking away. The upper connection, designed to improve the performance of the system in high speed collisions, activated as intended to allow sufficient bending for the vehicle to proceed under the pole with no penetration of the occupant compartment. The vehicle remained upright and stable throughout the test. The occupant risk factors were within the specified limits. Occupant impact velocity in the longitudinal direction was 15.6 ft/s (4.8 m/s) and the maximum 0.010-second average longitudinal occupant ridedown acceleration was -1.8 g. There was no contact in the lateral direction. The results of this test meet the recommended criteria for NCHRP Report 230 Test 61.

Test 16:

A 1979 Honda was directed into the utility pole at 39.9 mi/h (64.2 km/h). Test inertia mass was 1,826 lb (829 kg), and the gross static mass of the vehicle was 2,160 lb (981 kg). The vehicle was free-wheeling and unrestrained at impact. Impact was such that the vehicle bumper contacted the pole at the centerline of the vehicle.

The lower connection (slip base) broke away as intended. Breakaway was initiated approximately 0.020 seconds after impact. Bending of the upper connection began at about 0.035 seconds after impact. Loss of contact with the vehicle occurred at 0.409 seconds. The base continued moving upward while the vehicle proceeded under it.

The upper connection reacted as designed (see figure 20) and allowed sufficient bending to make it possible for the vehicle to proceed under the pole with no interference or contact. The ground line and all conductors were unbroken and remained connected to the insulators. The cables were undamaged. The pole on the downstream side of the test pole was slightly bent at the upper connection. The pole on the upstream side of the test pole was not damaged.

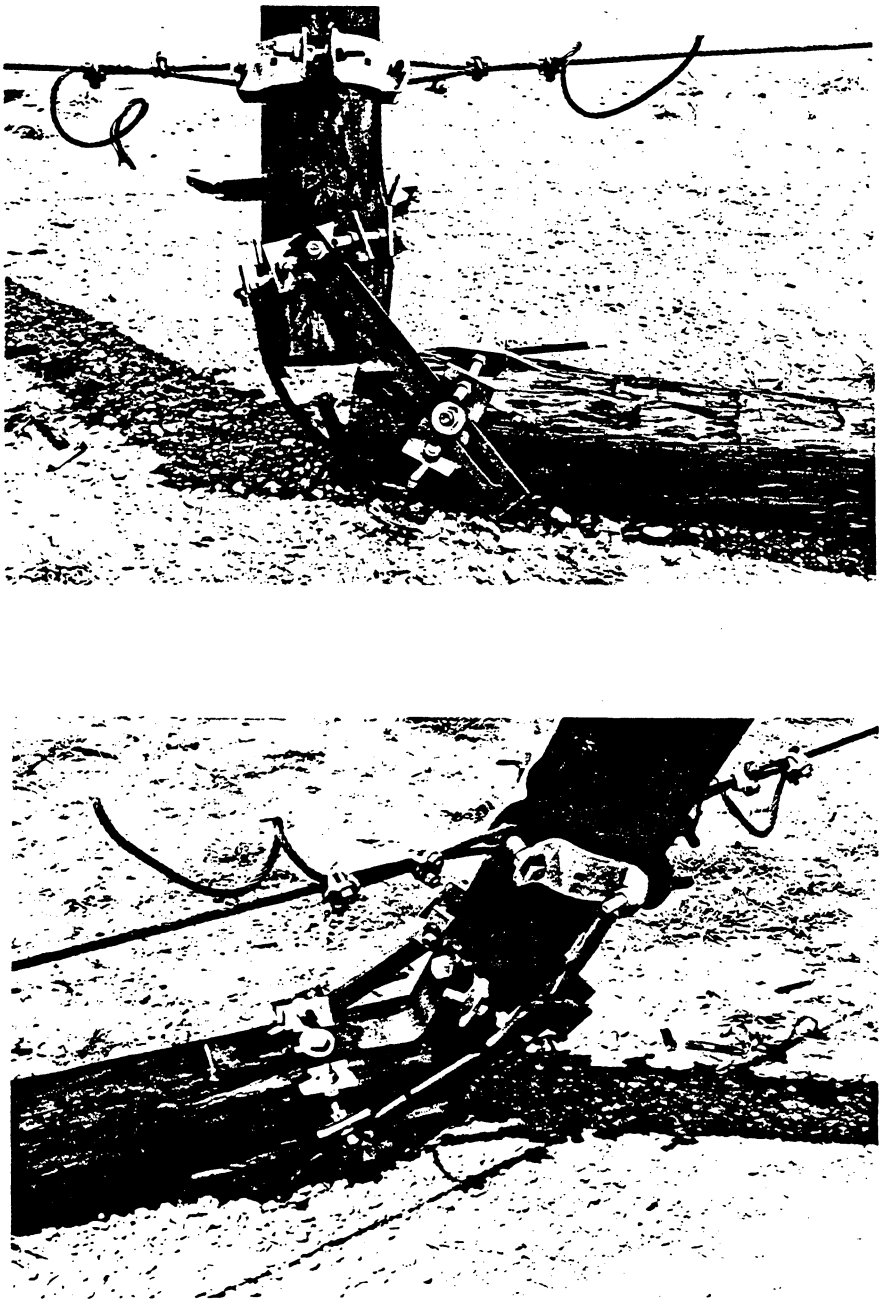


Figure 20. Upper connection after test 4859-16.

The vehicle traveled approximately 225 ft (69 m) beyond impact. The front of the vehicle was deformed with a maximum crush at bumper height of 10.0 in (25.4 cm) (figure 21).

TEST RESULTS

Results of the test are summarized in figure 22. The maximum 0.050-second average longitudinal acceleration was -8.0 g. Change in vehicle velocity over time of contact was 11.5 mi/h (18.5 km/h) and change in vehicle momentum was 957 lb-s.

NCHRP Report 230 contains recommended evaluation criteria and places limits on these for acceptable performance for tests of signs and luminaire supports with small vehicles at 20 and 60 mi/h.[15] This test was conducted at 40 mi/h; however, occupant risk factors were computed and reported for information only. Occupant impact velocity in the longitudinal direction was 12.0 ft/s (3.7 m/s) and 4.2 ft/s (1.3 m/s) in the lateral direction. The maximum 0.010-second average longitudinal and lateral occupant ridedown accelerations were -1.0 g and 0.5 g, respectively. The lower connection functioned as intended by breaking away. The upper connection, designed to improve the performance of the system in high speed collisions, activated as intended to allow sufficient bending for the vehicle to proceed under the pole with no penetration of the occupant compartment. The vehicle remained upright and stable throughout the test.

Test 5:

A 1979 Chrysler Newport was directed into the utility pole at 56.8 mi/h (91.4 km/h). Test inertia mass was 4,331 lb (1.966 kg) and the gross static mass of the vehicle was 4,665 lb (2,118 kg). The vehicle was free-wheeling and unrestrained at impact.

The lower connection (slip base) broke away as intended. Breakaway was initiated approximately 0.026 seconds after impact and loss of contact

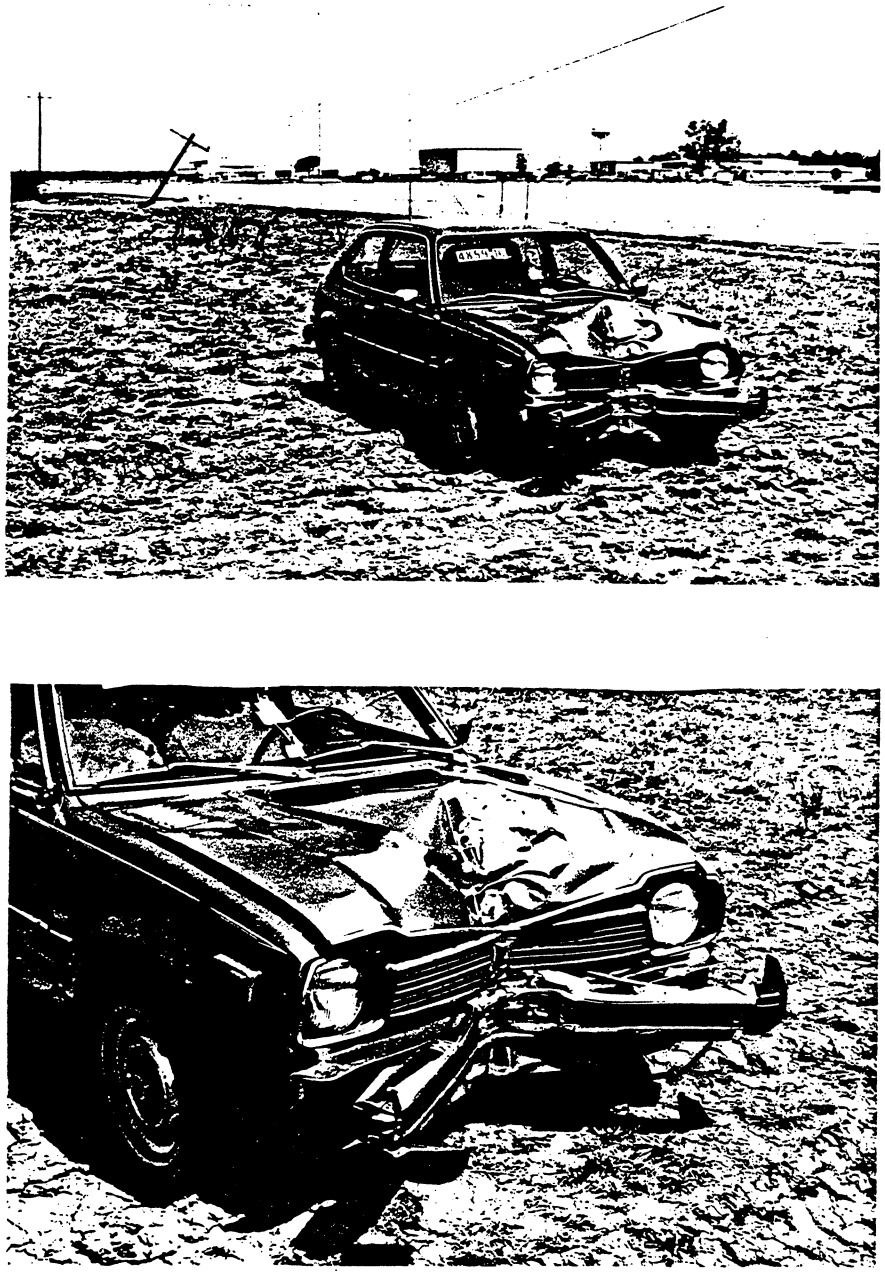
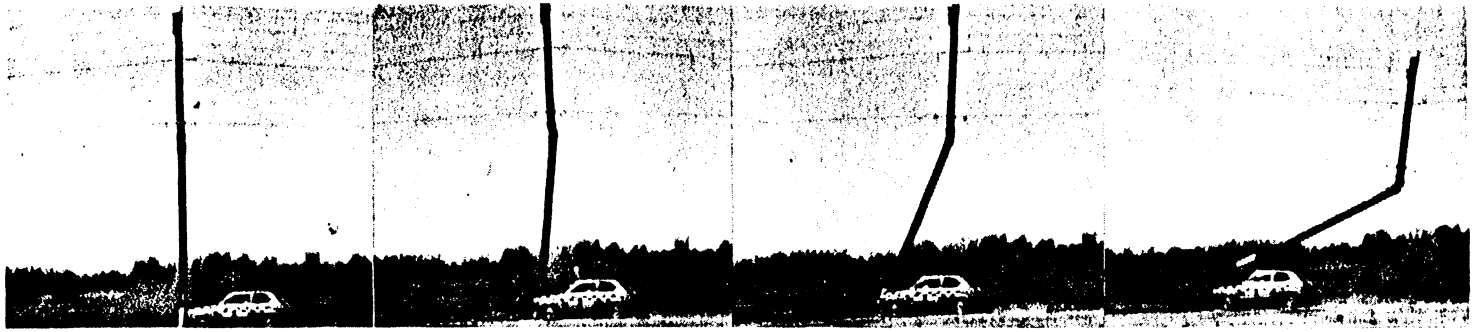
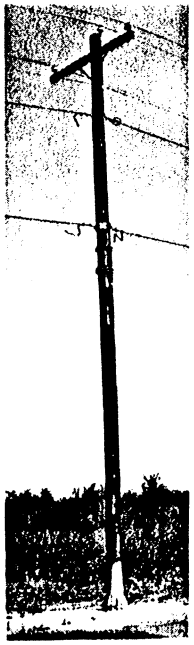


Figure 21. Test vehicle after test 4859-16.





Test No. 4859-16
Date 4/03/85
Test Article . . . . . Breakaway Wooden Utility Pole
Lower Connection . . . . . Slip Base
Upper Connection . . . . . Pole Band No. 3
Vehicle. . . . . 1979 Honda Civic
Vehicle Weight
  Test Inertia . . . . . 1826 lb (829 kg)
  Gross Static . . . . . 2160 lb (981 kg)
Vehicle Damage Classification
  TAD. 12FC2
  CDC. 12FCEN2
Maximum Vehicle Crush
  Bumper Height. . . . . 10.0 in (25.4 cm)

Impact Speed . . . . . 39.9 mi/h (64.2 km/h)
Change in Velocity . . . . 11.5 mi/h (18.5 km/h)
Change in Momentum . . . . . 957 lb-s
Vehicle Accelerations
 (Max. 0.050 s Avg)
  Longitudinal . . . . . -8.0 g
  Lateral . . . . . 0.8 g
Occupant Impact Velocity
  Longitudinal. . . . . 12.0 fps (3.7 m/s)
  Lateral . . . . . 4.2 fps (1.3 m/s)
Occupant Ridedown Accelerations
  Longitudinal. . . . . -1.0 g
  Lateral . . . . . 0.5 g

Figure 22. Summary of results for test 4859-16.

with the vehicle occurred at 0.218 seconds. Shortly thereafter the slip base came off of the base of the pole and rolled under the vehicle.

The upper connection did not react as designed but did allow sufficient bending (see figure 23) to make it possible for the vehicle to proceed under the pole with no interference or contact. Bending of the upper connection began at about 0.042 seconds. Although the 1/8-in margin in the straps did not punch out, the bolts in the pole bands pulled out of the pole thereby allowing a hinge to form at the upper connection. The ground line and all conductors were unbroken and remained connected to insulators. The cables also were undamaged; however, the lower lag screw at the cross arm brace pulled out of the downstream pole.

The vehicle traveled approximately 180 ft (55 m) beyond impact. The front of the vehicle was deformed with maximum crush at the center front of 28.0 in (71.1 cm) at bumper height and 22.0 in (55.9 cm) at hood height (see figure 24).

TEST RESULTS

Results of the test are summarized in figure 25. The maximum 0.050-second average longitudinal acceleration was -4.9 g. Change in vehicle velocity over time of contact was 7.0 mi/h (11.3 km/h) and change in vehicle momentum was 1,487 lb-s.

The occupant impact velocity in the longitudinal direction was 10.7 ft/s (3.3 m/s) and the maximum 0.010-second average longitudinal occupant ridedown acceleration was -0.8 g. There was no occupant impact in the lateral direction. The utility pole broke away allowing the vehicle to proceed to a safe, stable stop with no penetration of the occupant compartment.

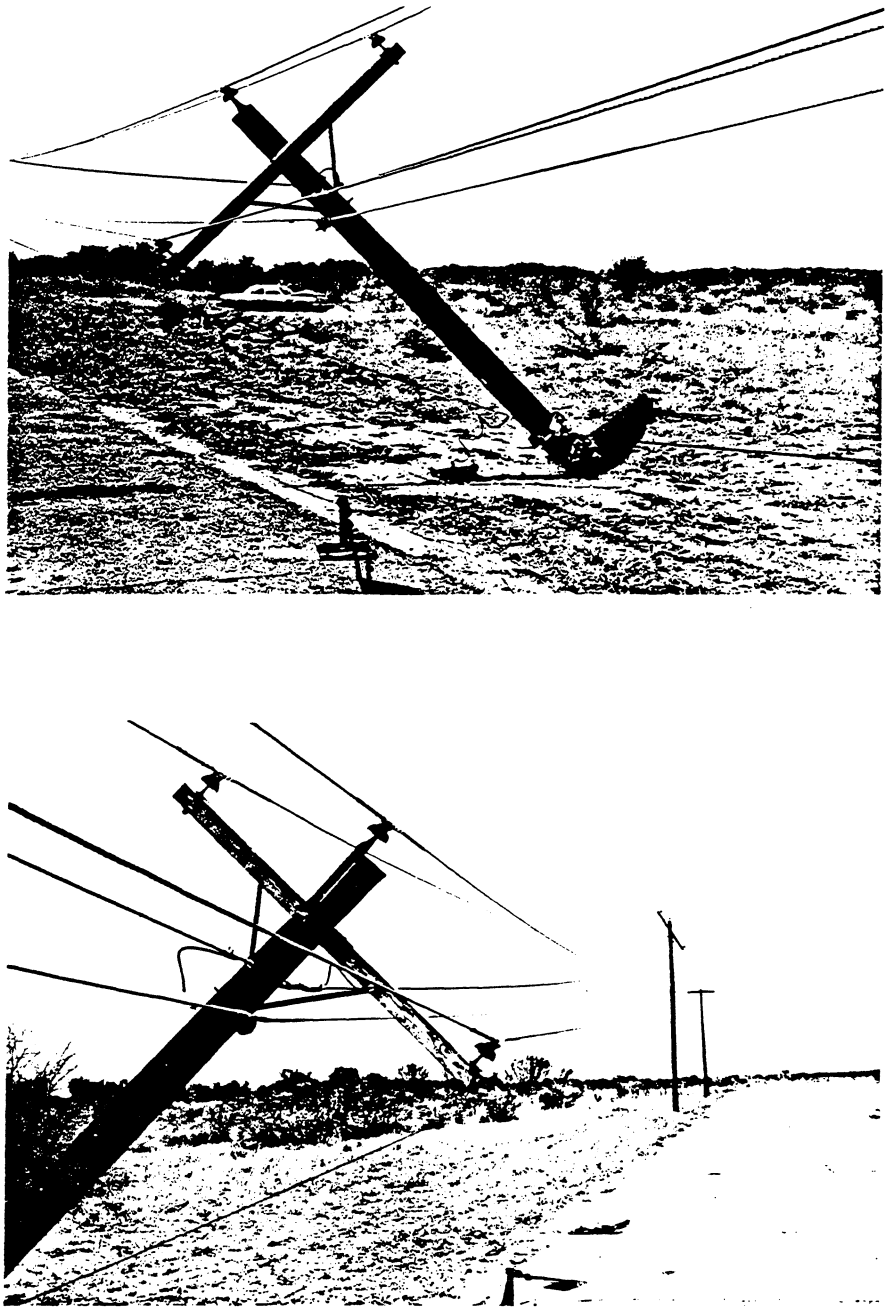
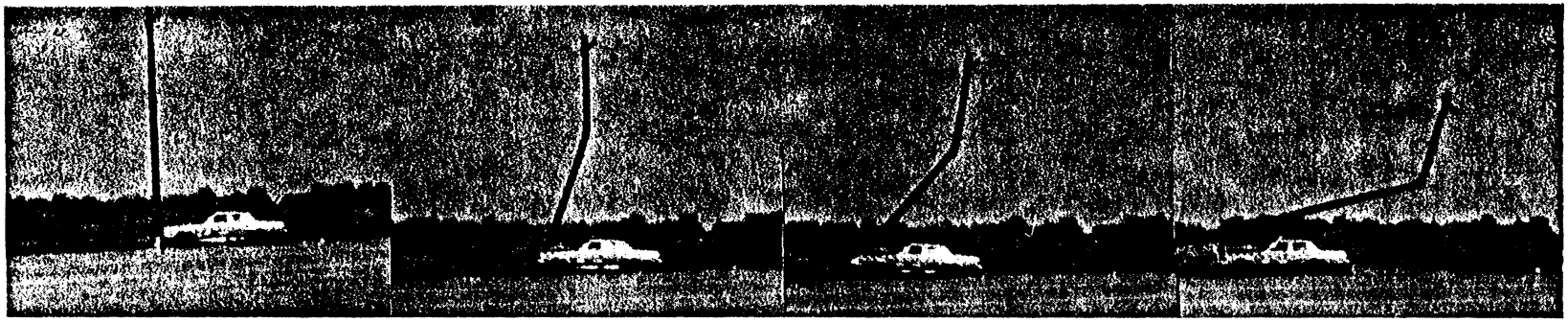
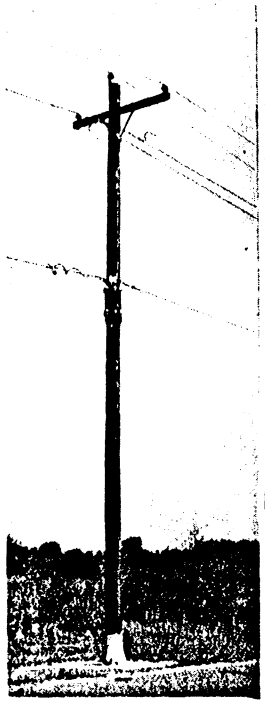


Figure 23. Installation site after test 4859-5.

Figure 24. Vehicle after test 4859-5.



0.000 s 0.101 s 0.218 s 0.415 s



Test No.	4859-5	Impact Speed	56.8 mi/h (91.4 km/h)
Date	6/29/84	Change in Velocity	7.0 mi/h (11.3 km/h)
Test Article	Breakaway Wooden Utility Pole	Change in Momentum	1487 lb-s
Lower Connection	Slip Base	Vehicle Accelerations (Max. 0.050 s Avg)	
Upper Connection	Pole Band No. 2	Longitudinal	-4.9 g
Vehicle	1979 Chrysler Newport	Lateral	0.6 g
Vehicle Weight		Occupant Impact Velocity	
Test Inertia	4331 lb (1966 kg)	Longitudinal	10.7 fps (3.3 m/s)
Gross Static	4665 lb (2118 kg)	Lateral	None
Vehicle Damage Classification		Occupant Ridedown Accelerations	
TAD	12FC4	Longitudinal	-0.8 g
CDC	12FCEN3	Lateral	No Contact
Maximum Vehicle Crush			
Bumper Height	28.0 in (71.1 cm)		
Hood Height	22.0 in (55.9 cm)		

Figure 25. Summary of results for test 4859-5.

Developmental Crash Tests

A series of crash tests was conducted to determine the optimum behavior of a timber utility pole in a collision with an errant vehicle. For the purposes of this research, three options were selected for testing. These options are designated as operational modes BA-1, BA-2, and BA-3. Proper function of each of these operational modes is illustrated in figure 26. Operational mode BA-3 (figure 27) was previously described as the Hawkins Breakaway System. Operational modes BA-1 and BA-2 are described in reverse order below:

Mode BA-2 Operation:

This option consists of a slip base and one structural support cable (overhead guy). The upper hinge mechanism and topmost overhead guy are omitted as compared to BA-3. In this mode, the overhead guy (located approximately midheight on the pole) acts as a pivot point for the pole following activation of the slip base. In this way the trajectory of the pole is limited, and the vehicle is allowed to pass under the pole.

Mode BA-1 Operation:

This option consists only of a slip base. After impact the pole is restrained only by the electrical conductors attached to it. In the event that a lashed telephone cable also is attached to the pole, the steel support strand will act much as the overhead guy in mode BA-2. It should be noted for both BA-1 and BA-2 that the standard tie wraps prevalent in the electric power industry offer little longitudinal restraint. Unless alternate strong attachment methods are used in construction, it is unlikely that the electric conductors will offer any of the performance of the overhead guys used in BA-3.

Test Descriptions

Detailed test reports for all crash tests are available in volume II

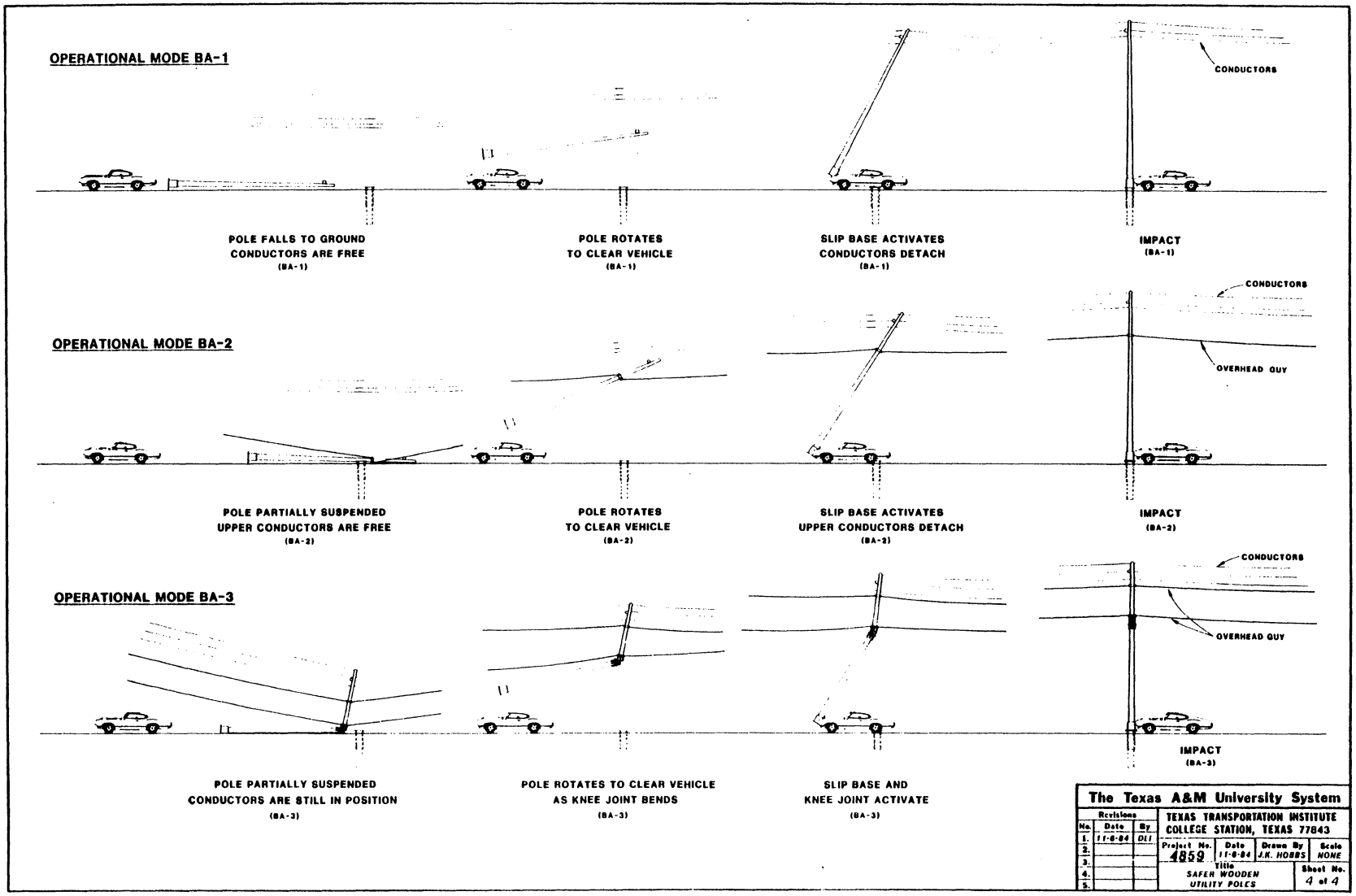


Figure 26. Illustration of the proper function of the three operational modes.

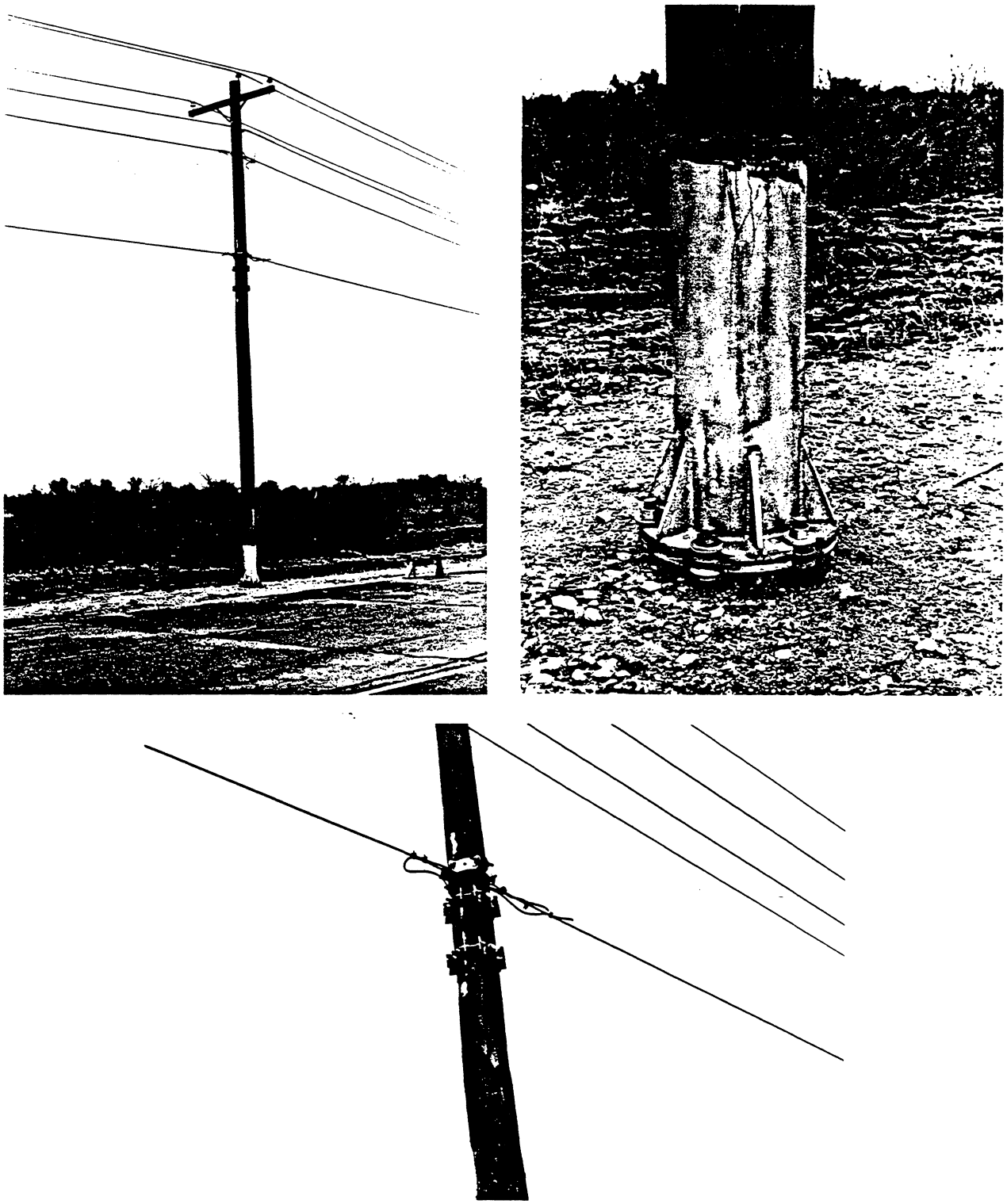


Figure 27. Modified utility pole installation (Typical BA-3 configuration).

of this report. A summary sheet, containing a pictorial overview of the crash test and a view of the system used, and a photo of the vehicle after the crash test are included for each of the developmental tests (figures 28 through 37). For the sake of brevity, only a brief description of the unique features of each test is contained herein.

Test 1: (BA-3):

The slip base and upper connection functioned as intended. The lower overhead structural support cable (1/4 in diameter) snapped and became intertwined with the conductors. The neutral and phase conductors broke loose from their insulators. Subsequently the base of the utility pole came down on the trunk of the vehicle.

Test 2: (BA-1):

The slip base functioned as intended. The neutral and phase conductors broke away from their insulators. The neutral conductor pulled loose at a splice on the down stream end. Subsequently, the base of the utility pole came down on the roof of the vehicle.

Test 3: (BA-3):

The slip base and upper connection functioned as intended. The 1/2 in upper support cables remained intact, allowing the upper hinge mechanism to activate and the vehicle to proceed under the pole with no interference or contact. The neutral and phase conductors were unbroken and remained connected to insulators.

Test 4: (BA-2):

The slip base functioned as intended. The neutral and phase conductors broke away from their insulators and the pole fell to the ground. Although suffering extensive front end damage, the vehicle proceeded under the pole with no interference or contact.

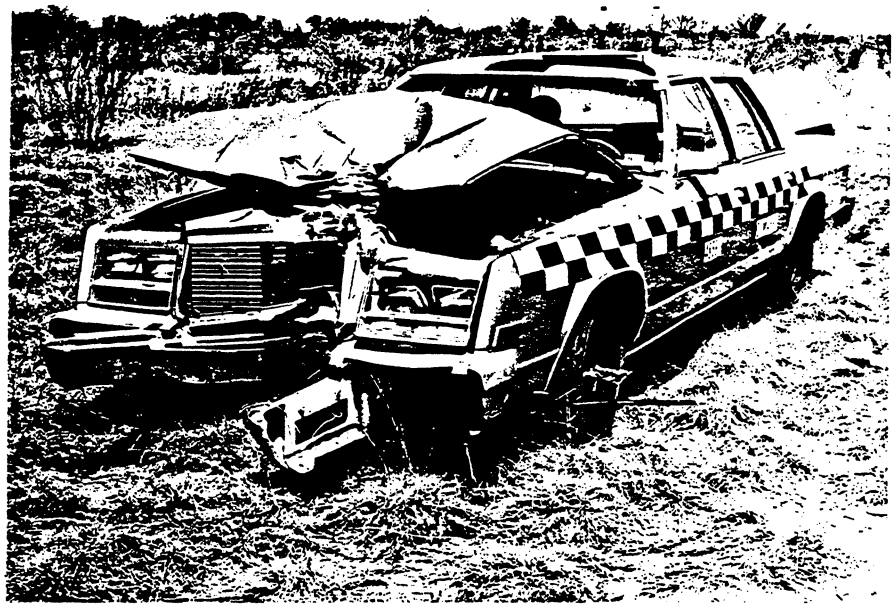
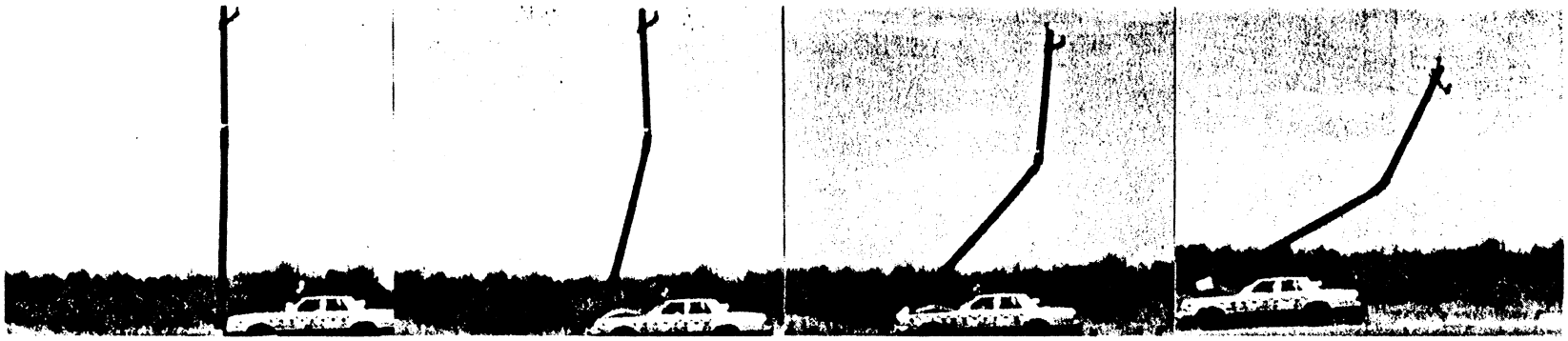
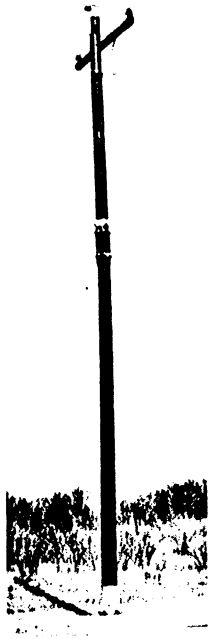


Figure 28. Vehicle after test 4859-1.



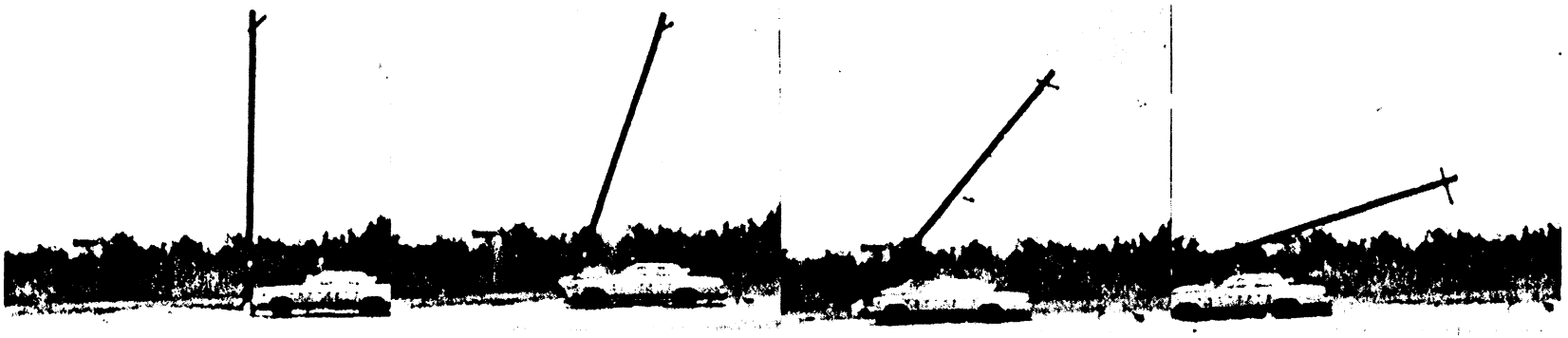


Test No.	4859-1
Date	4/05/84
Test Article	Breakaway Wooden Utility Pole
Lower Connection	Slip Base
Upper Connection	Pole Band No. 1
Vehicle	1979 Chrysler Newport
Vehicle Weight	
Test Inertia	4345 lb (1973 kg)
Gross Static	4690 lb (2129 kg)
Vehicle Damage Classification	
TAD	12FC4
CDC	12FCEN2
Maximum Vehicle Crush	
Bumper Height	18.5 in (47.0 cm)
Hood Height	22.0 in (55.9 cm)

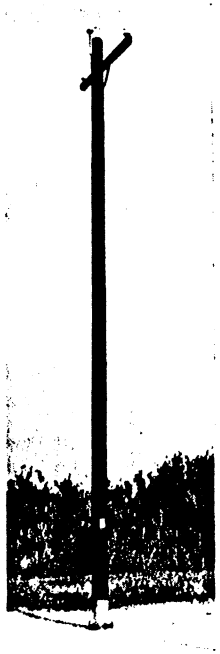
Impact Speed	39.8 mi/h (64.0 km/h)
Change in Velocity	7.0 mi/h (11.3 km/h)
Change in Momentum	1500 lb-s
Vehicle Accelerations (Max. 0.050 s Avg)	
Longitudinal	-5.6 g
Lateral	-0.6 g
Occupant Impact Velocity	
Longitudinal	8.4 fps (2.6 m/s)
Lateral	None
Occupant Ridedown Accelerations	
Longitudinal	-1.1 g
Lateral	No Contact

Figure 29. Summary of results for test 4859-1.

Figure 30. Vehicle after test 4859-2.



0.000 s 0.199 s 0.397 s 0.667 s



Test No.	4859-2
Date	5/15/84
Test Article	Breakaway Wooden Utility Pole
Lower Connection	Slip Base
Vehicle	1979 Chrysler Newport
Vehicle Weight	
Test Inertia	4335 lb (1968 kg)
Gross Static	4675 lb (2122 kg)
Vehicle Damage Classification	
TAD	12FC4
CDC	12FCEN2
Maximum Vehicle Crush	
Bumper Height	22.0 in (55.9 cm)
Hood Height	17.5 in (44.5 cm)

Impact Speed	39.4 mi/h (63.4 km/h)
Change in Velocity	7.8 mi/h (12.6 km/h)
Change in Momentum	1661 lb-s
Vehicle Accelerations (Max. 0.050 s Avg)	
Longitudinal	-5.1 g
Lateral	0.6 g
Occupant Impact Velocity	
Longitudinal	10.0 fps (3.0 m/s)
Lateral	None
Occupant Ridedown Accelerations	
Longitudinal	-0.5 g
Lateral	No Contact

Figure 31. Summary of results for test 4859-2.

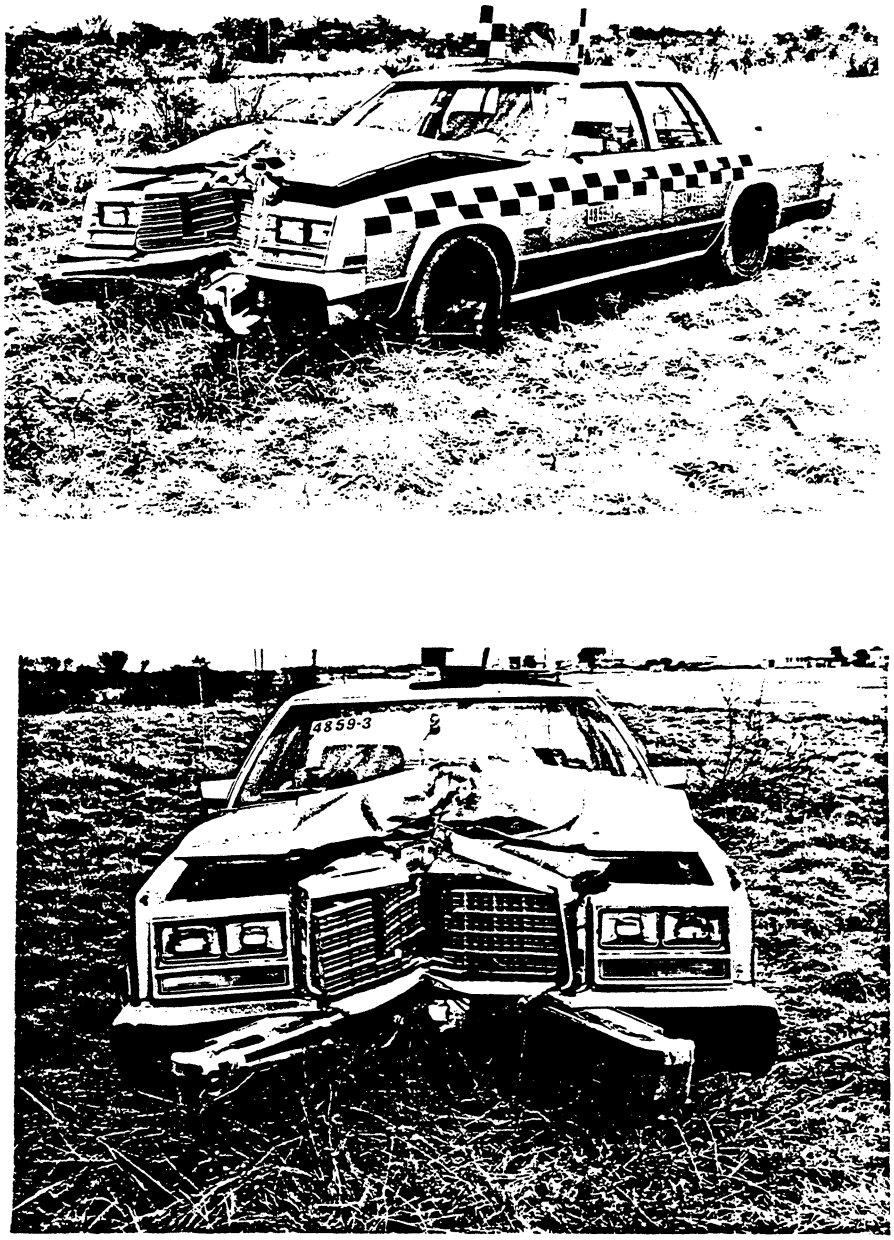
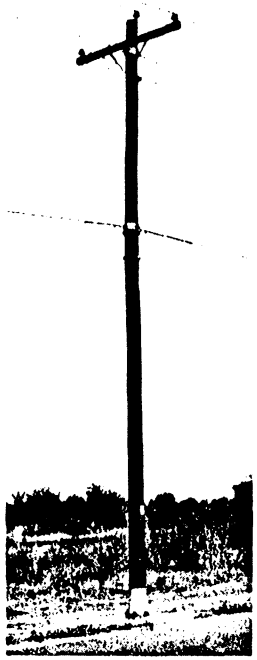


Figure 32. Vehicle after test 4859-3.

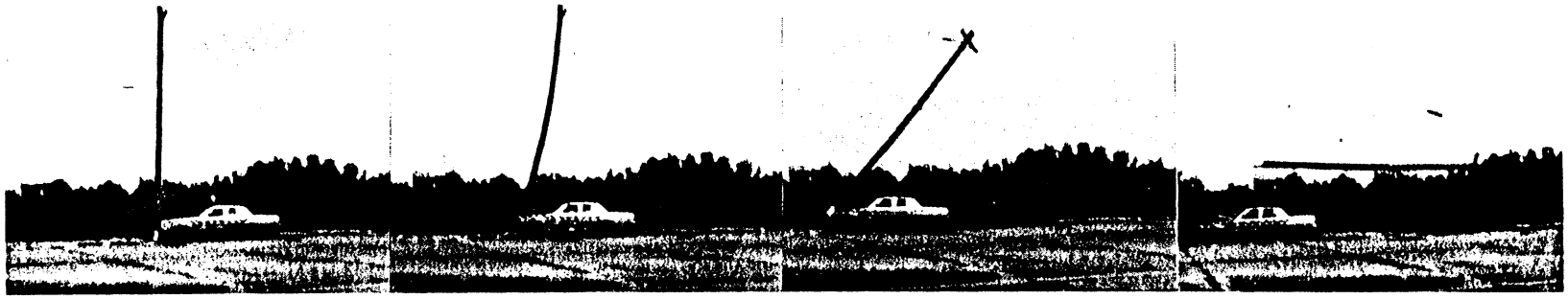


Test No.	4859-3
Date	5/17/84
Test Article	Breakaway Wooden Utility Pole
Lower Connection	Slip Base
Upper Connection	Pole Band No. 2
Vehicle	1979 Chrysler Newport
Vehicle Weight	
Test Inertia	4319 lb (1960 kg)
Gross Static	4660 lb (2116 kg)
Vehicle Damage Classification	
TAD	12FC4
CDC	12FCEN2
Maximum Vehicle Crush	
Bumper Height	19.5 in (49.5 cm)
Hood Height	17.5 in (44.5 cm)

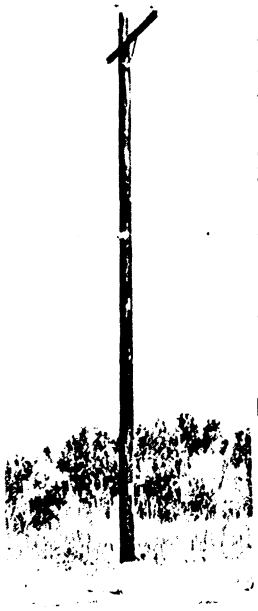
Impact Speed	38.0 mi/h (61.1 km/h)
Change in Velocity	5.5 mi/h (8.9 km/h)
Change in Momentum	1167 lb-s
Vehicle Accelerations (Max. 0.050 s Avg)	
Longitudinal	-4.1 g
Lateral	0.4 g
Occupant Impact Velocity	
Longitudinal	7.5 fps (2.3 m/s)
Lateral	None
Occupant Ridedown Accelerations	
Longitudinal	-0.8 g
Lateral	No Contact

Figure 33. Summary of results for test 4859-3.

Figure 34. Vehicle after test 4859-4.



0.000 s 0.1.06 s 0.291 s 0.582 s



Test No.	4859-4
Date	6/26/84
Test Article	Breakaway Wooden Utility Pole
Lower Connection	Slip Base
Vehicle	1979 Chrysler Newport
Vehicle Weight	
Test Inertia	4315 lb (1959 kg)
Gross Static	4655 lb (2113 kg)
Vehicle Damage Classification	
TAD	12FC4
CDC	12FCEN2
Maximum Vehicle Crush	
Bumper Height	21.0 in (53.3 cm)
Hood Height	13.3 in (33.8 cm)

Impact Speed	40.4 mi/h (65.0 km/h)
Change in Velocity	6.8 mi/h (10.9 km/h)
Change in Momentum	1442 lb-s
Vehicle Accelerations (Max. 0.050 s Avg)	
Longitudinal	-4.4 g
Lateral	0.6 g
Occupant Impact Velocity	
Longitudinal	9.9 fps (3.0 m/s)
Lateral	None
Occupant Ridedown Accelerations	
Longitudinal	-0.2 g
Lateral	No Contact

Figure 35. Summary of results for test 4859-4.

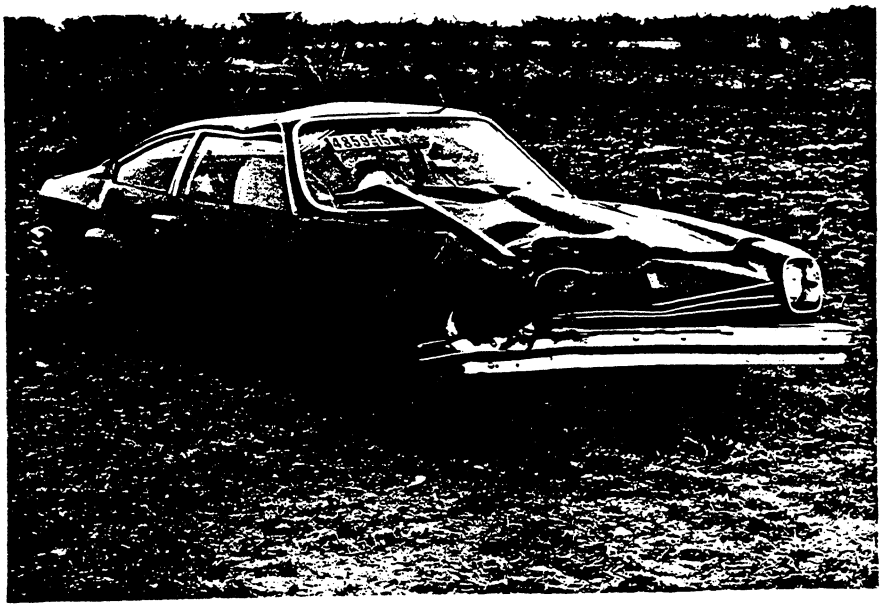
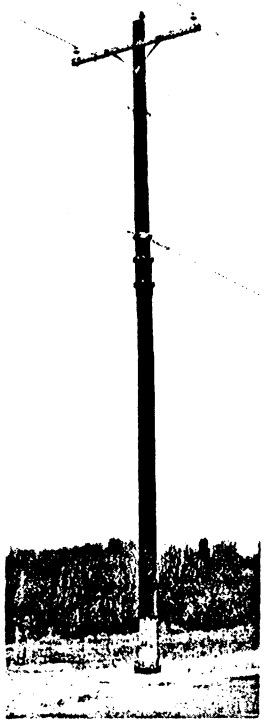


Figure 36. Vehicle after test 4859-15.

0.000 s 0.049 s 0.172 s 0.369 s



Test No.	4859-15
Date	3/7/85
Test Article	Breakaway Wooden Utility Pole
Lower Connection	Slip Base
Upper Connection	Pole Band No. 3
Vehicle	1976 Chevrolet Vega
Vehicle Weight	
Test Inertia	2550 lb (1158 kg)
Gross Static	2890 lb (1312 kg)
Vehicle Damage Classification	
TAD	12FR4
CDC	12FREN2
Maximum Vehicle Crush	
Bumper Height	17.0 in (43.2 cm)

Impact Speed	59.3 mi/h (95.4 km/h)
Change in Velocity	9.7 mi/h (15.6 km/h)
Change in Momentum	1126 lb-s
Vehicle Accelerations (Max. 0.050 s Avg)	
Longitudinal	-8.7 g
Lateral	1.9 g
Occupant Impact Velocity	
Longitudinal	14.0 fps (4.3 m/s)
Lateral	No Contact
Occupant Ridedown Accelerations	
Longitudinal	-1.2 g
Lateral	NA

Figure 37. Summary of results for test 4859-15.

Test 15: (BA-3):

The test was of a small vehicle in a high speed impact at the 1/4 point. The slip base functioned as intended. Although the upper connection straps did not meet the tolerances, the straps on the side opposite impact bent while the bolts on the impact side tore the wood thereby allowing a hinge to form. The vehicle remained upright and stable throughout the initial test period. Post-test roll was considered due to unsymmetrical brake application.

Baseline Crash Test

A crash test with an unmodified 40-foot class 4 wooden utility pole was conducted. The purpose of this test was to determine the benefits obtained from a breakaway system such as the one reported herein.

Description:

A 1980 Dodge St. Regis was directed into the utility pole. Test inertia mass of the vehicle was 4,325 lb (1,964 kg), and its gross static mass was 4,654 lb (2,113 kg). The vehicle was towed into the utility pole using a cable guidance system. The transmission was in neutral, and the vehicle was released to be unrestrained prior to impact. Impact was such that the vehicle bumper contacted the pole at the centerline of the vehicle.

The vehicle impacted the pole at 61.5 mi/h (99.0 km/h). At approximately 0.040 seconds after impact the pole broke and separated at the ground, and at 0.050 seconds the pole cracked 8.3 ft (2.5 m) above the ground. As the vehicle continued forward the base of the pole rose upward. Loss of contact with the vehicle occurred at approximately 0.179 seconds. The vehicle continued under the pole while the top of the pole hit the ground.

The pole splintered and separated 17.0 in (43.2 cm) below the ground

and about 10.0 in (25.4 cm) above the ground as shown in figure 38. The pole was also cracked 99 in (252 cm) above the ground and 243 in (617 cm) above the ground. The upper crack occurred when the top of the pole impacted the ground. All conductors were torn from the crossarm and the crossarm was shattered as shown in figure 39. The broken end of the pole was 50 ft (15 m) from the base.

The vehicle came to rest approximately 250 ft (76 m) from the point of impact. The front of the vehicle was deformed with a maximum crush at bumper height of 29.5 in (74.9 cm) (see figure 40).

Results:

The results of this test are summarized in figure 41. The maximum 0.050-second average acceleration in the longitudinal direction was -8.6 g, and 2.1 g in the lateral direction. Change in vehicle velocity was 11.3 mi/h (18.2 km/h), and change in momentum was 2,226 lb-s.

Occupant risk factors do not apply for this test but were computed and reported for information only. Occupant impact velocity in the longitudinal direction was 15.4 ft/s (4.7 m/s). The maximum 0.010-second average longitudinal ridedown acceleration was 1.0 g. There was no occupant impact in the lateral direction.

Discussion:

The results of this test can be interpreted in various ways. Perhaps the two most meaningful are 1) a determination of the impact conditions under which an unmodified pole will break, and 2) a comparison of impact severities on modified versus unmodified poles. Curves of change in velocity, ΔV as a function of vehicle weight and impact speed (figure 42) indicate that, unless relatively large vehicles and high impact speeds occur, a large ΔV (change in velocity) can be expected in an unmodified pole collision. Speeds ranging from 30 mi/h to 60 mi/h are required to even fracture the pole if commonly available passenger vehicles (4,500 lb to 1,800 lb) are assumed.

Figure 38. Details of pole separation (test 4859-18).

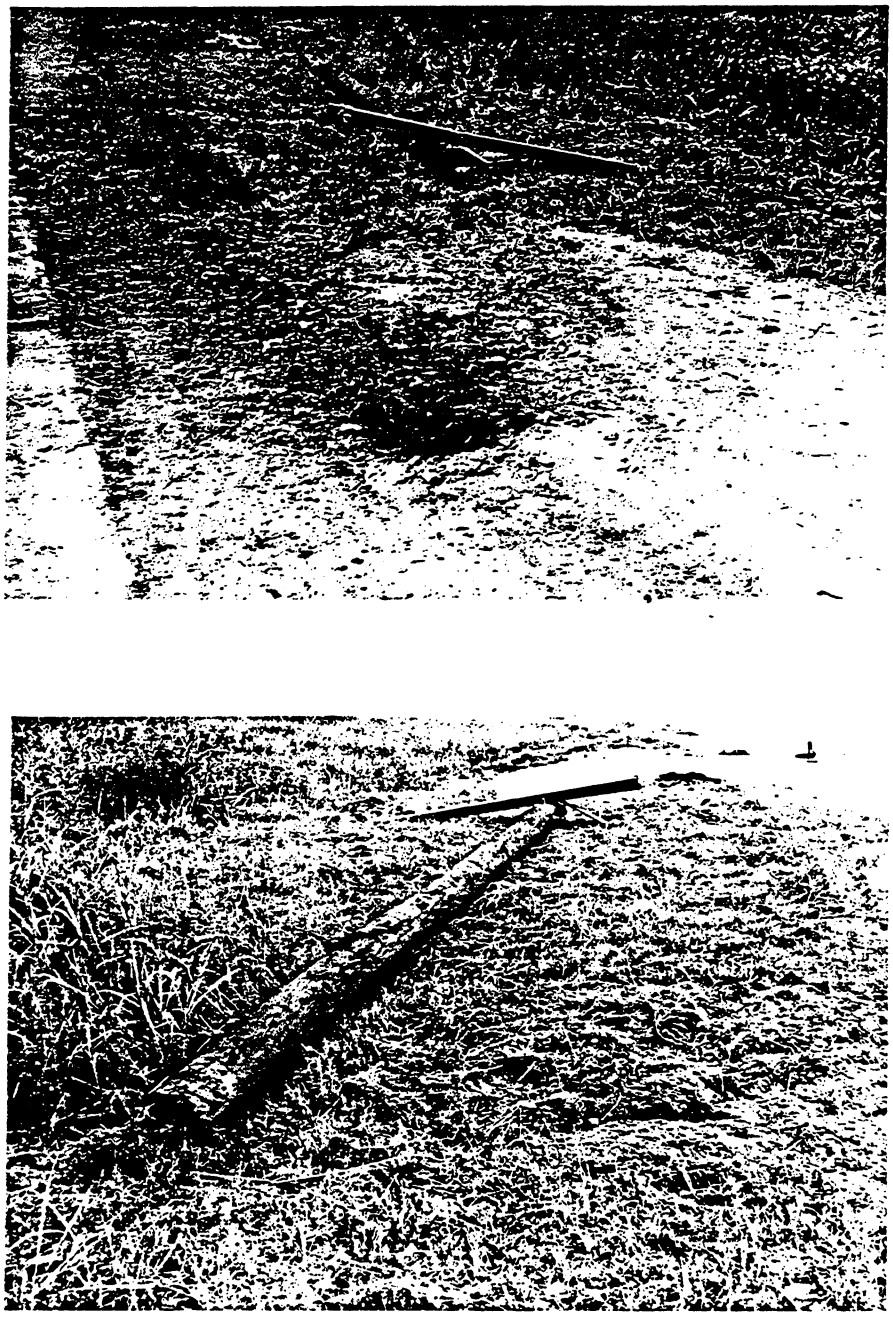
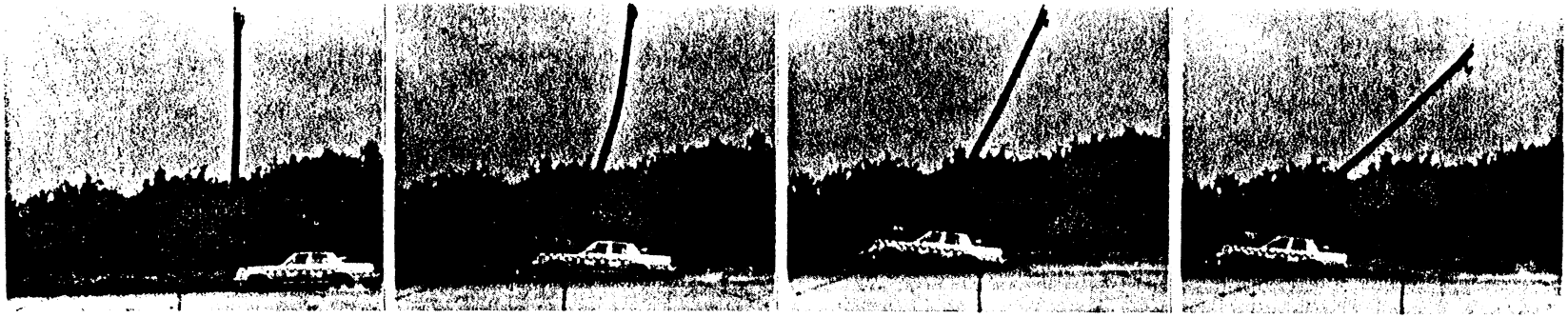
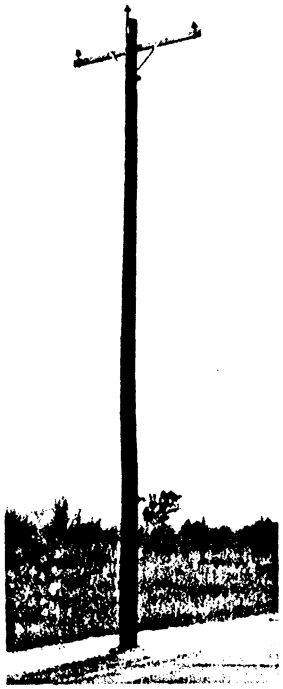


Figure 39. Final resting position of pole after test 4859-18.

Figure 40. Vehicle after test 4859-18.



0.000 s 0.139 s 0.286 s 0.434 s



Test No.	4859-18
Date	4/30/85
Test Article	Wooden Utility Pole
Vehicle	1980 Dodge St. Regis
Vehicle Weight	
Test Inertia	4325 lb (1964 kg)
Gross Static	4654 lb (2113 kg)
Vehicle Damage Classification	
TAD	12FC6
CDC	12FCEN3
Maximum Vehicle Crush	
Bumper Height	29.5 in (74.9 cm)

Impact Speed	61.5 mi/h (99.0 km/h)
Change in Velocity	11.3 mi/h (18.2 km/h)
Change in Momentum	2226 lb-s
Vehicle Accelerations (Max. 0.050 s Avg)	
Longitudinal	-8.6 g
Lateral	2.1 g
Occupant Impact Velocity	
Longitudinal	15.4 fps (4.7 m/s)
Lateral	None
Occupant Ridedown Accelerations	
Longitudinal	1.0 g
Lateral	N/A

Figure 41. Summary of results for test 4859-18.

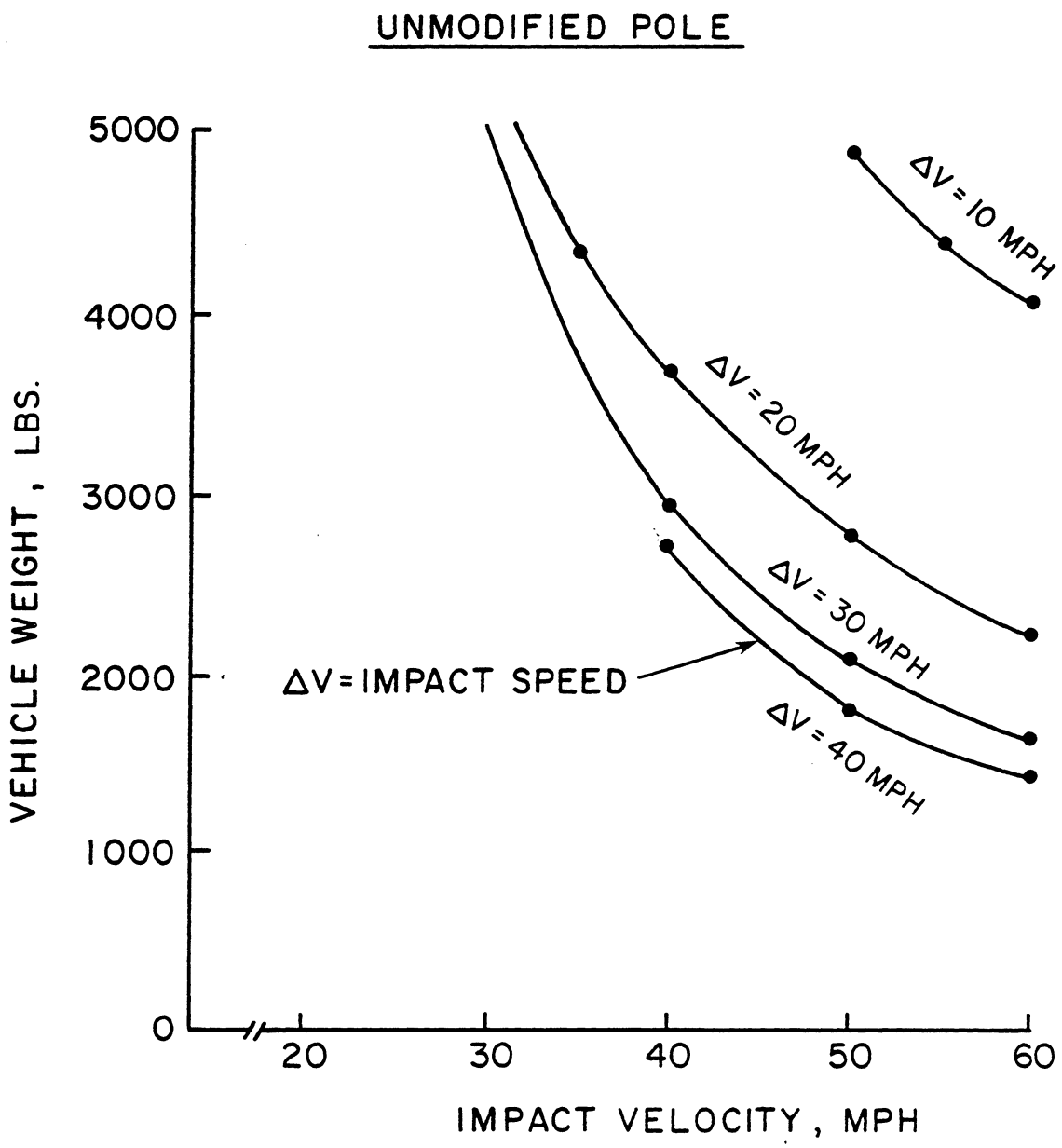


Figure 42. Comparison of curb weight versus impact speed.

Guy Wire Tests

A series of tests was conducted on modified down guy attachment systems. Included in these tests was a test on a standard cable down guy anchor attachment. This test (number 11) dramatically illustrates the potential for destruction and the need for a modified anchorage system. In each case the down guy was installed such that it made a 45-degree angle with the plane of the ground. The vehicle approach path made a 45-degree angle with respect to a line through the anchor and the pole at ground level, with the anchor on the upstream side and the pole on the downstream side on tests 6 through 9, 19, and 11, with the anchor on the downstream side in test 10.

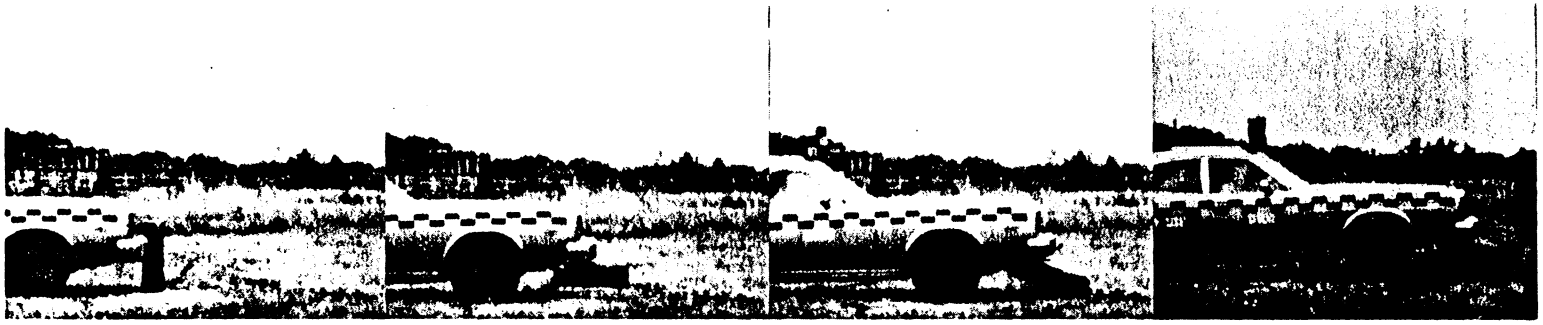
Test Descriptions

Since the results obtained were virtually identical for all of the breakaway systems tested, only the results of the final design and baseline test are detailed herein. A summary sheet is presented for each test (figures 43 through 50). These sheets contain a pictorial overview of the test.

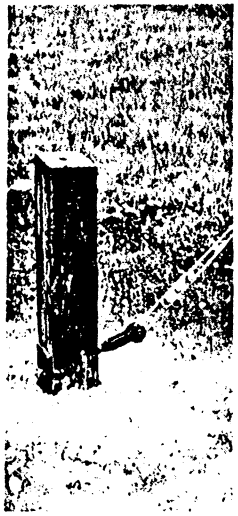
Tests 9, 10, and 19: Breakaway Connection:

The breakaway guy system used in these tests consists of a 3/4 in galvanized pipe transition between the standard guy cable anchor (embedded approximately 8 ft into the ground) and the 3/8 in guy cable. This frangible transition piece is connected to the ground anchor by means of a clevis and pin and to the cable by a clevis, pulley, pin and cable clamp. Standard pipe threads were used to complete the pipe to the clevises. It was anticipated that the root of the thread at the junction with the upper clevis would provide an adequate stress riser to initiate fracture of the 3/4 in pipe.

In tests 9 and 19 the frangible connection functioned as intended. In test 10 (with vehicle impacting the transition from below) the frangible connection did not function as intended. The cable slipped out



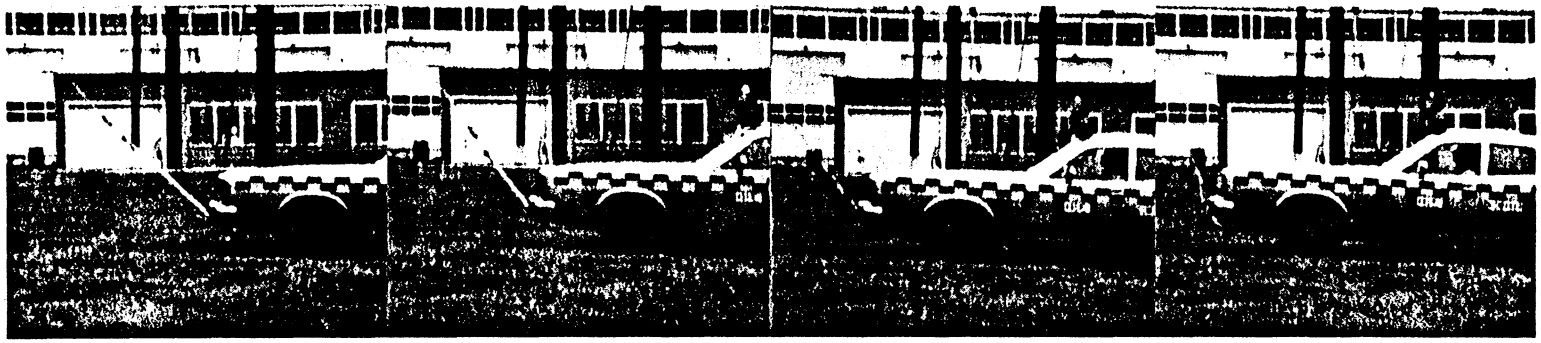
0.000 s 0.054 s 0.109 s 0.163 s



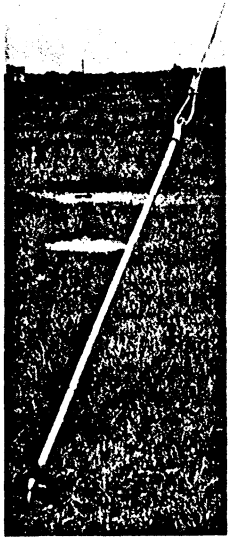
Test No. 4859-6
Date 9/26/84
Test Article . . . . . Breakaway Cable Guy
Connection . . . . . Breakaway Post Anchor
Vehicle. . . . . 1978 Plymouth
Vehicle Weight
  Test Inertia . . . . . 4320 lb (1961 kg)
  Gross Static . . . . . 4660 lb (2116 kg)
Vehicle Damage Classification
  TAD. 12FC0
  CDC. 12FCLU1
Maximum Vehicle Crush. . . None

Impact Speed. . . . . 29.1 mi/h (46.8 km/h)
Change in Velocity. . . . . 0.8 mi/h (1.3 km/h)
Change in Momentum. . . . . 157 lb-s
Vehicle Accelerations
  (Max. 0.050 s Avg)
    Longitudinal. . . . . -1.1 g
    Lateral . . . . . 0.3 g
Occupant Impact Velocity
    Longitudinal. . . . . None
    Lateral . . . . . None
Occupant Ridedown Accelerations
    Longitudinal. . . . . No Contact
    Lateral . . . . . No Contact

Figure 43. Summary of results for test 4859-6.



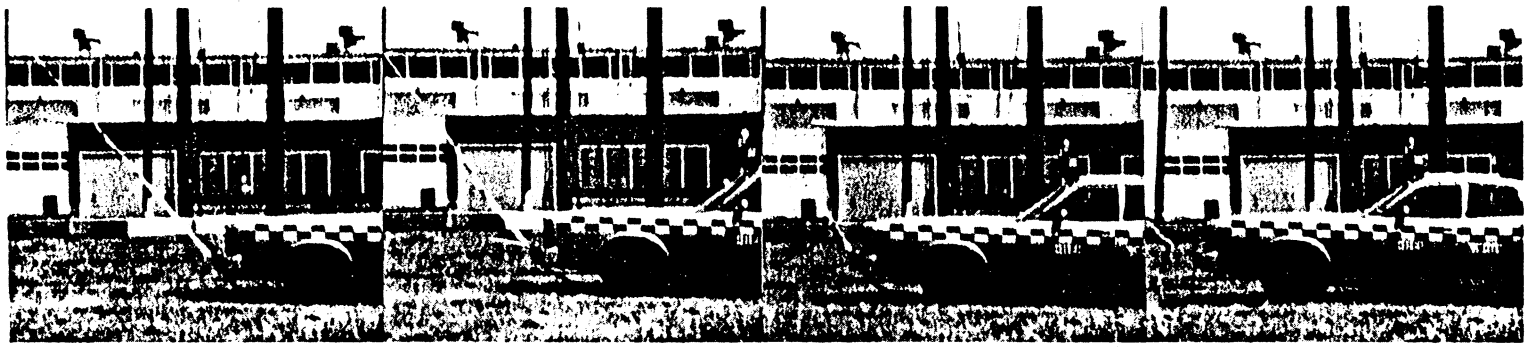
0.000 s 0.053 s 0.106 s 0.133 s



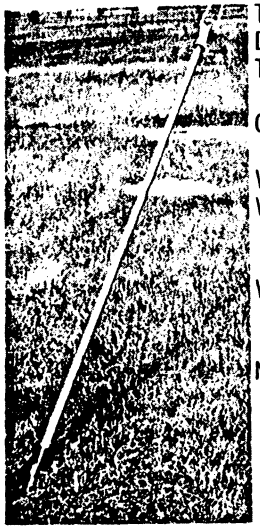
Test No.	4859-7
Date	9/26/84
Test Article	Breakaway Cable Guy
Connection	1 in. pipe with 1/4 in. holes
Vehicle	1978 Plymouth
Vehicle Weight	
Test Inertia	4320 lb (1961 kg)
Gross Static	4660 lb (2116 kg)
Vehicle Damage Classification	
TAD	12FCO
CDC	12FCLU1
Maximum Vehicle Crush	None

Impact Speed	30.0 mi/h (48.3 km/h)
Change in Velocity	1.6 mi/h (2.6 km/h)
Change in Momentum	315 lb-s
Vehicle Accelerations (Max. 0.050 s Avg)	
Longitudinal	-0.9 g
Lateral	0.5 g
Occupant Impact Velocity	
Longitudinal	None
Lateral	None
Occupant Ridedown Accelerations	
Longitudinal	No Contact
Lateral	No Contact

Figure 44. Summary of results for test 4859-7.



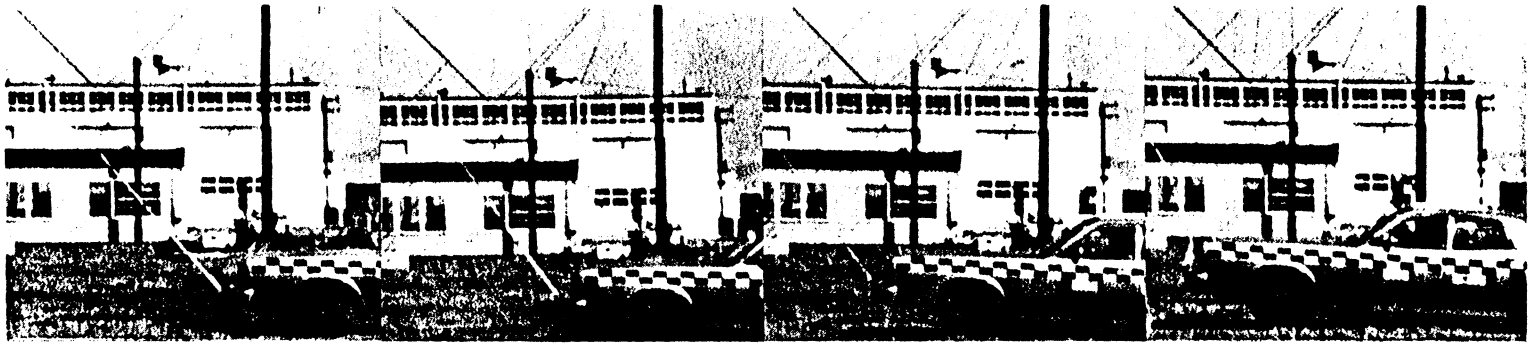
0.000 s 0.053 s 0.106 s 0.160 s



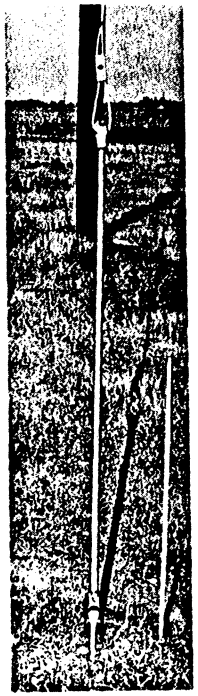
Test No. 4859-8
Date 9/26/84
Test Article . . . . . Breakaway Cable Guy
Connection . . . . . 1 in. pipe with 60 deg V-grooves
Vehicle. . . . . 1978 Plymouth
Vehicle Weight
  Test Inertia . . . . . 4320 lb (1961 kg)
  Gross Static . . . . . 4660 lb (2116 kg)
Vehicle Damage Classification
  TAD. 12FCO
  CDC. 12FCLU1
Maximum Vehicle Crush. . . None

Impact Speed. . . . . 29. 7 mi/h (47.8 km/h)
Change in Velocity. . . . . 1.2 mi/h (1.9 km/h)
Change in Momentum. . . . . 236 lb-s
Vehicle Accelerations
  (Max. 0.050 s Avg)
    Longitudinal. . . . . -0.7 g
    Lateral . . . . . 0.3 g
Occupant Impact Velocity
    Longitudinal. . . . . None
    Lateral . . . . . None
Occupant Ridedown Accelerations
    Longitudinal. . . . . No Contact
    Lateral . . . . . No Contact

Figure 45. Summary of results for test 4859-8.



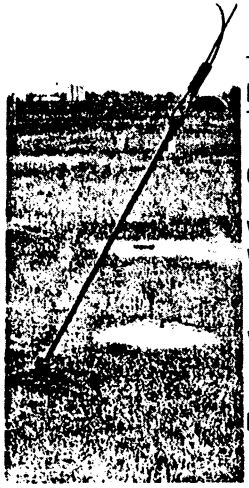
0.000 s 0.053 s 0.112 s 0.171 s



Test No.	4859-9	Impact Speed.	30.1 mi/h (48.4 km/h)
Date	9/26/84	Change in Velocity.	1.3 mi/h (2.1 km/h)
Test Article	Breakaway Cable Guy	Change in Momentum.	256 lb-s
Connection	3/4 in. pipe	Vehicle Accelerations (Max. 0.050 s Avg)	
Vehicle.	1978 Plymouth	Longitudinal.	-0.7 g
Vehicle Weight		Lateral	0.2 g
Test Inertia	4320 lb (1961 kg)	Occupant Impact Velocity	
Gross Static	4660 lb (2116 kg)	Longitudinal.	None
Vehicle Damage Classification		Lateral	None
TAD.	12FCO	Occupant Ridedown Accelerations	
CDC.	12FCLU1	Longitudinal.	No Contact
Maximum Vehicle Crush.	None	Lateral	No Contact

Figure 46. Summary of results for test 4859-9.

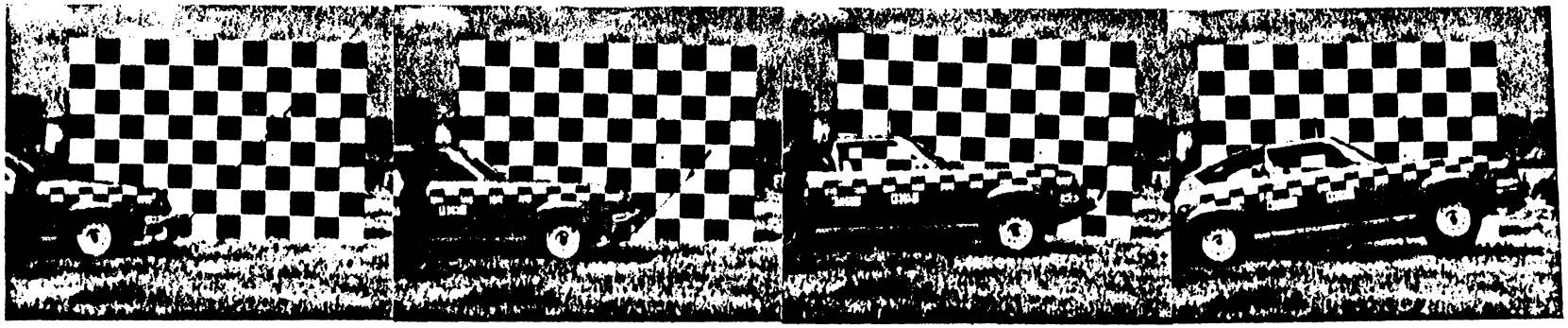
0.000 s 0.081 s 0.162 s 0.247 s



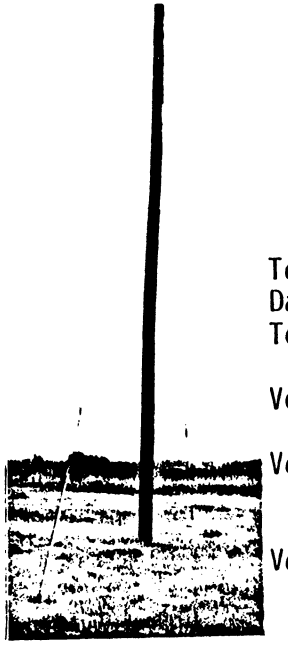
Test No.	4859-10
Date	9/28/84
Test Article	Breakaway Cable Guy
Connection	3/4 in. pipe (reverse hit)
Vehicle	1978 Plymouth
Vehicle Weight	
Test Inertia	4320 lb (1961 kg)
Gross Static	4660 lb (2116 kg)
Vehicle Damage Classification	
TAD	12FL1
CDC	12FLEN1
Maximum Vehicle Crush	
Bumper Height	0.0 in. (0.0 cm)
Hood Height	4.0 in. (10.2 cm)

Impact Speed	29.1 mi/h (46.8 km/h)
Change in Velocity	3.1 mi/h (5.0 km/h)
Change in Momentum	610 lb-s
Vehicle Accelerations (Max. 0.050 s Avg)	
Longitudinal	-1.1 g
Lateral	0.4 g
Occupant Impact Velocity	
Longitudinal	None
Lateral	None
Occupant Ridedown Accelerations	
Longitudinal	No Contact
Lateral	No Contact

Figure 47. Summary of results for test 4859-10.



0.000 s 0.091 s 0.191 s 0.287 s



Test No.	4859-19
Date	8/23/85
Test Article	Breakaway Cable Guy
Vehicle	1977 Chevrolet Vega
Vehicle Weight	
Test Inertia	2955 lbs (1342 kg)
Vehicle Damage Classification	
TAD	12FCO
SAE	12FZLU1

Impact Speed	19.7 mi/h (31.7 km/h)
Change in Velocity	3.0 mi/h (4.8 km/h)
Change in Momentum	402 lb-s
Occupant Impact Velocity	
Longitudinal	None
Lateral	None
Occupant Ridedown Accelerations	
Longitudinal	N/A
Lateral	N/A
Maximum Vehicle Crush	
Bumper Height	nil

Figure 48 . Summary of results for test 4859-19.

of the cable clamp at the upper clevis and fracture did not occur. The vehicle sustained no damage in tests 9 and 19 and only minor cosmetic damage in test 10.

Test 11: Nonbreakaway (Standard Connection):

The final test was intended to be a baseline test. The system used in this test consists of a 3/8-in guy cable which is attached at the ground to a standard guy anchor and to the pole by means of standard industry hardware. No breakaway hardware was utilized in the test installation. The extensive vehicle damage (see figure 49) resulting from this test clearly demonstrates the need for breakaway hardware on guy cable installation.

DESCRIPTION

A 1978 Plymouth was directed into the standard cable guy. The only damage to the vehicle prior to this test was a 4-in tear in the front edge of the hood. Impact velocity was 29.5 mi/h (47.5 km/h). Test inertia mass of the vehicle was 4,320 lb (1,961 kg), and its gross static mass was 4,660 lb (2,116 kg). The vehicle was free-wheeling and unrestrained at impact.

Approximately 0.135 seconds after impact the vehicle began riding up the cable and by 0.196 seconds the front wheels were off the ground. As the vehicle continued forward the cable cut into the vehicle and the cable anchor began pulling out of the ground. The cable on the opposite side of the utility pole pulled out of the clamp, and, subsequently, the utility pole broke at ground level. At 0.713 seconds the pole impacted the right side of the vehicle. Shortly thereafter the pole broke about 12 ft from ground level, and at 0.833 seconds the pole hit the windshield. The vehicle came to rest approximately 10 ft from the impact point.

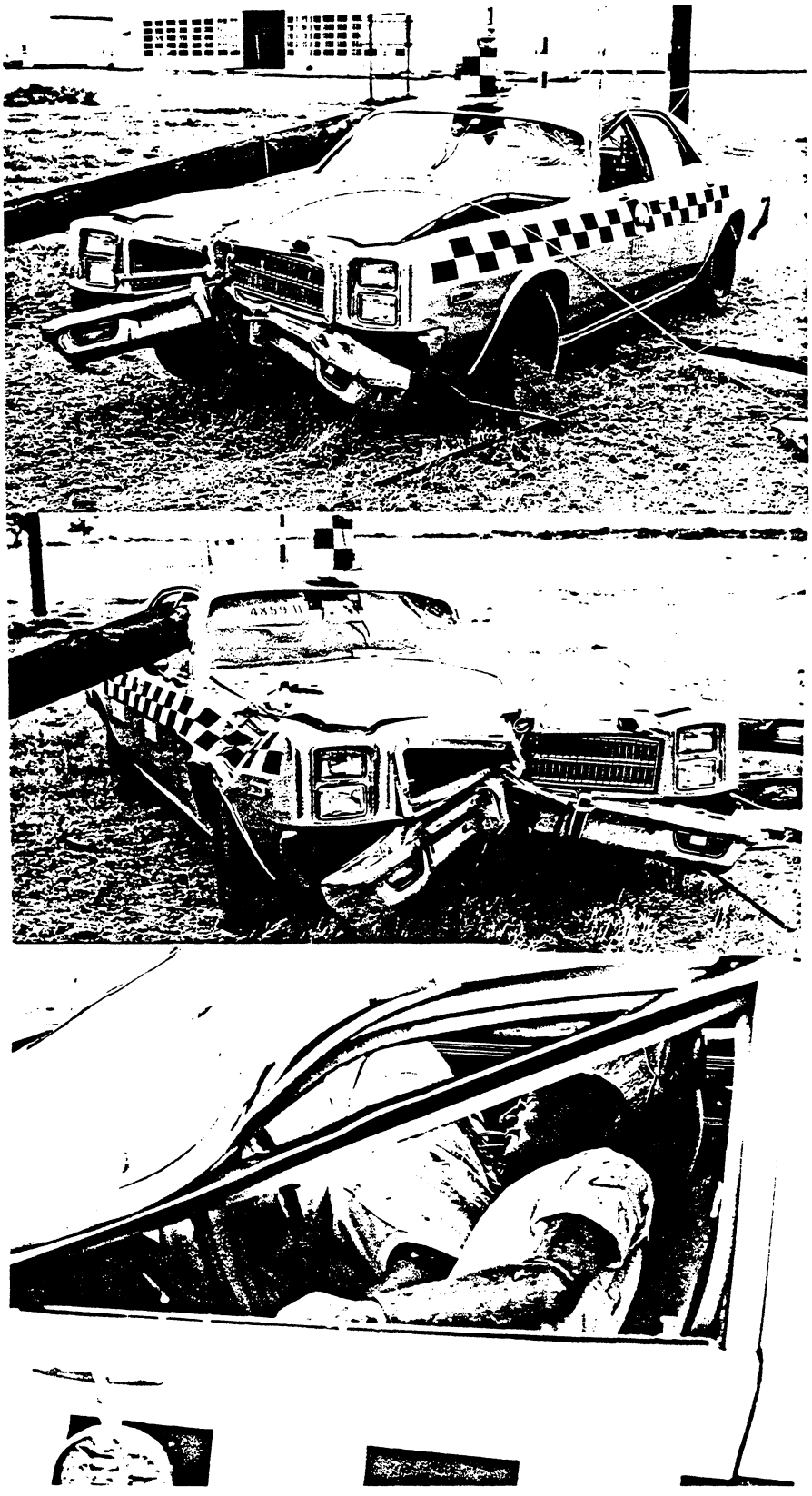
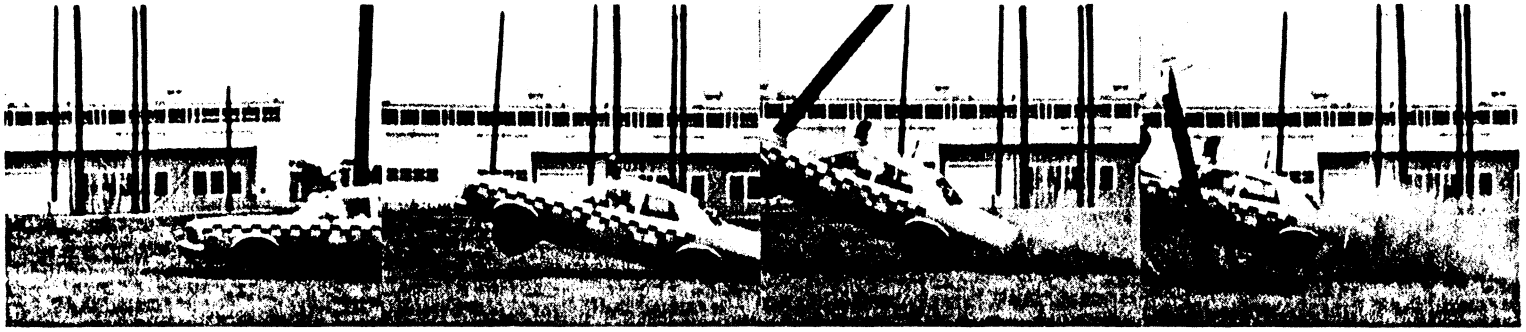


Figure 49. Vehicle After Test 4859-11.

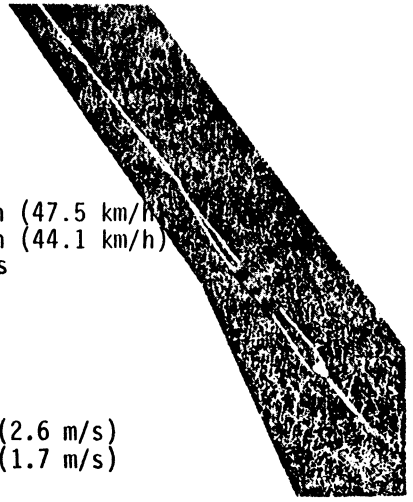
RESULTS

Results of the test are summarized in figure 50. The maximum 0.050-second average longitudinal acceleration was -3.8 g and -3.7 g lateral. Change in vehicle velocity at 1.500 seconds was 27.4 mi/h (44.1 km/h), and change in vehicle momentum was 5,392 lb-s.

Occupant impact velocity in the longitudinal direction was 8.6 ft/s (2.6 m/s) and 5.6 ft/s (1.7 m/s) in the lateral direction. The highest 0.010-second occupant ridedown acceleration in the longitudinal and lateral directions were -6.5 g and -5.7 g, respectively. The cable guy did not yield and there was penetration of the occupant compartment. The installation did not meet the structural adequacy or vehicle trajectory requirements of NCHRP Report 230.[15]



0.000 s 0.368 s 0.718 s 0.956 s



Test No.	4859-11	Impact Speed	29.5 mi/h (47.5 km/h)
Date	9/28/84	Change in Velocity	27.4 mi/h (44.1 km/h)
Test Article	Unmodified Cable Guy	Change in Momentum	5392 lb-s
Vehicle	1978 Plymouth	Vehicle Accelerations (Max. 0.050 s Avg)	
Vehicle Weight		Longitudinal	-3.8 g
Test Inertia	4320 lb (1961 kg)	Lateral	-3.7 g
Gross Static	4660 lb (2116 kg)	Occupant Impact Velocity	
Vehicle Damage Classification		Longitudinal	8.6 fps (2.6 m/s)
TAD	12FC4	Lateral	5.6 fps (1.7 m/s)
CDC	12FCENZ	Occupant Ridedown Accelerations	
Maximum Vehicle Crush		Longitudinal	-6.5 g
Bumper Height	17.0 in (43.2 cm)	Lateral	-5.7 g
Hood Height	5.0 in (12.7 cm)		

Figure 50. Summary of results for test 4859-11.

CAM Test

Introduction:

It is recognized that there are a number of cases in which the breakaway option is not a feasible one. In these cases, the researchers wished to give the utilities an option to the relatively expensive options of either relocating the pole or moving the utilities underground. Toward this end a test was run on a unique system. The purpose of this test was to determine the impact characteristics of the hybrid barrier system and to determine the feasibility of such a barrier. An experimental collision barrier/crash cushion system (CAM) was installed on the pole at ground level.

Test Installation:

A typical power line installation was set up for testing. The installation consisted of a line of several class 4 wooden utility poles with four conductors running continuously from pole to pole. One of the utility poles was modified as shown in figure 51. A detailed description of this modification follows. A lower cable also was added to simulate other utility lines such as phone or television cables.

The CAM is designed as a hybrid collision barrier/crash cushion system. It consists of three basic elements as shown in figure 52. These elements are a crushable ring, thrie-beam guardrail, and a support post with directional slipbase.

If the barrier is struck by a vehicle on the traffic side (Mode AL, figure 53), a redirection, similar to that afforded by a conventional guardrail, is provided by the thrie-beam guardrail. In this mode the CAM is a thrie-beam guardrail with support posts at 6.4 ft (2.0 m) spacing (one post provided by the utility pole and one provided by the support post). It is important that the slipbase be designed so as to not activate during a mode AL collision.

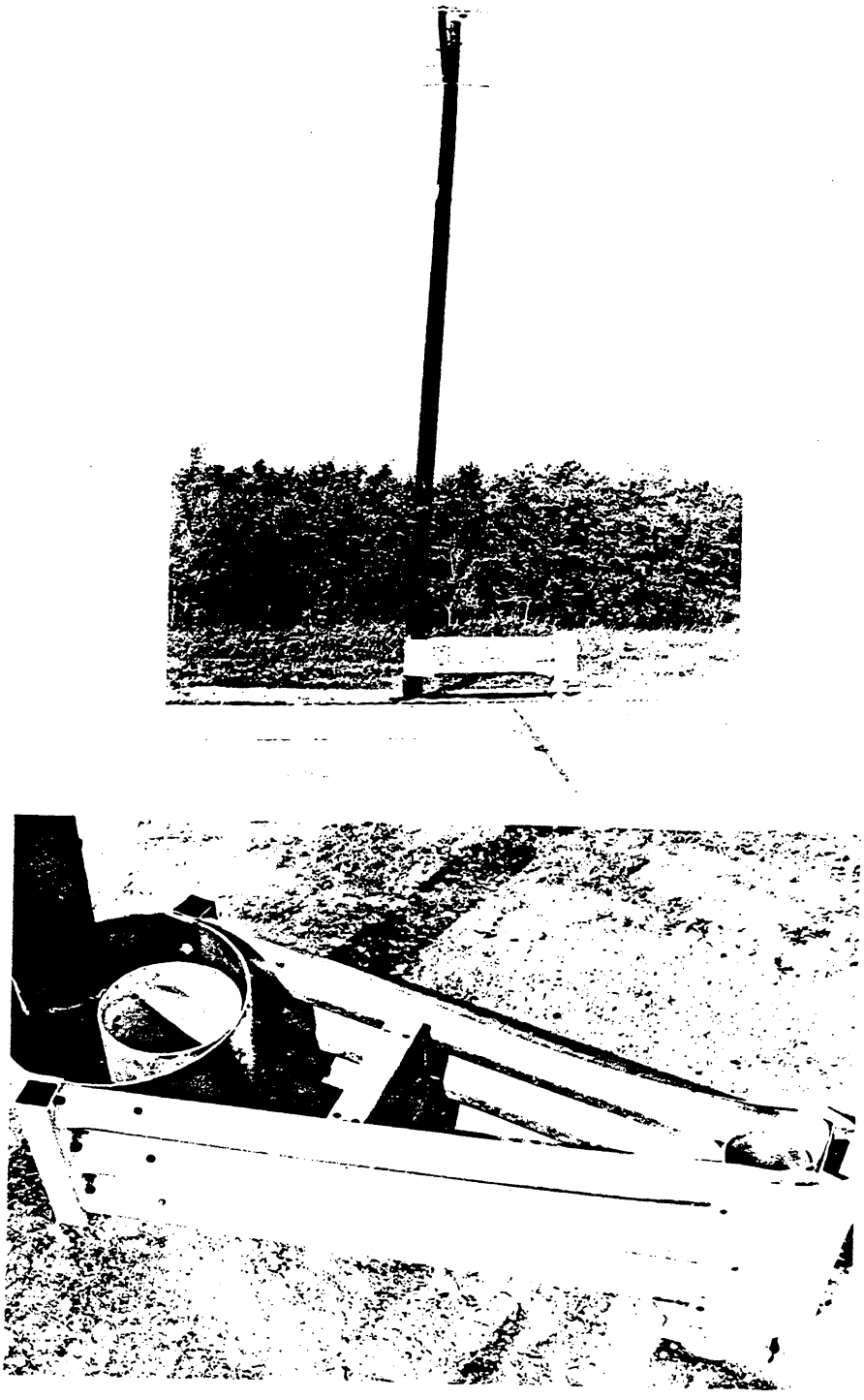


Figure 51. Test installation before test 4859-17.

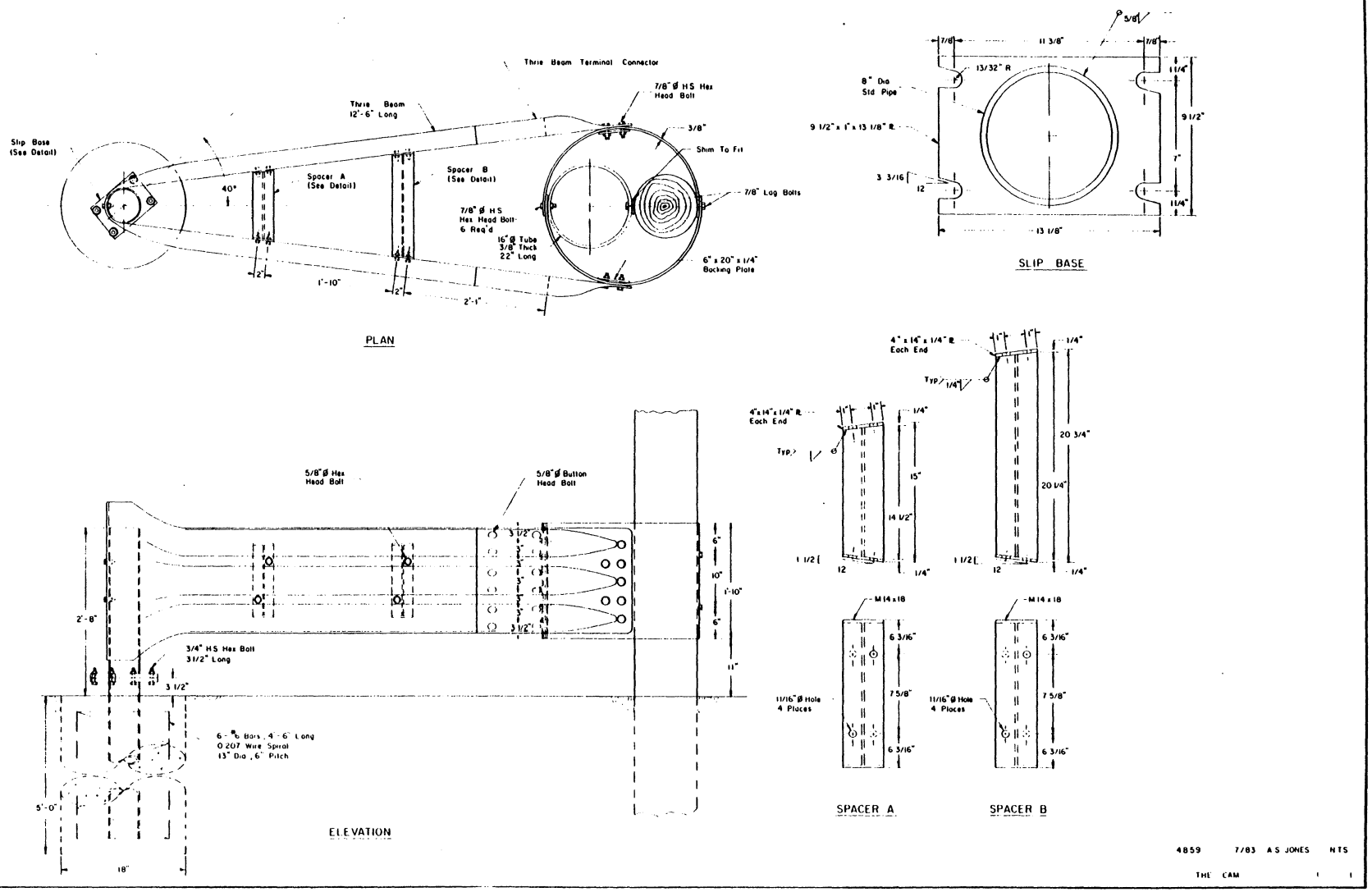
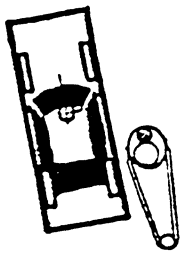


Figure 52. Details of CAM.

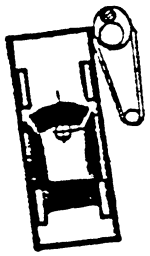
POSITION 4

Completion of Redirection



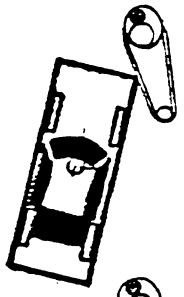
POSITION 3

Start of Redirection



POSITION 2

Collision



POSITION 1

Pre-Collision

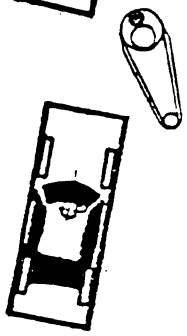


Figure 53. Operational Mode AL

If the barrier is struck head-on by a vehicle (Mode AR, figure 54), the barrier acts first as a crash cushion and then as a CAM moving the vehicle to a new trajectory to the outside of the pole. As shown in figure 54, when the errant vehicle strikes the CAM head-on the slipbase activates following an initial phase of deformation to the car. Once the slip base has activated, the crushable ring (or collapsing cylinder) is deformed and the CAM begins to pivot about the pole, thus averting a head-on collision of the vehicle with the pole.

The CAM collision barrier protects the passengers from an intense deceleration and also minimizes damage to the pole. Utility service is not interrupted, and the barrier (and pole if need be) can be restored to operating condition at the convenience of the utility company or highway entity.

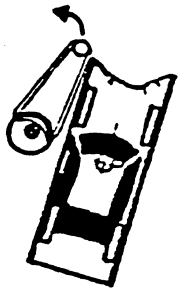
DESCRIPTION

A 1977 Ford Granada was directed into the CAM at 41.0 mi/h (66.0 km/h). Test inertia mass of the vehicle was 3,360 lb (1,525 kg), and its gross static mass was 3,679 lb (1,670 kg). The vehicle was towed into the CAM using a cable guidance system. The transmission was in neutral, and the vehicle was released to be unrestrained prior to impact.

The vehicle impacted the CAM at 15 degrees to the centerline of the device. Shortly after impact the front of the vehicle deformed around the support post and began pulling it up from its slip base. At approximately 0.043 seconds after impact the support post broke away from the slip base and the vehicle began pushing the CAM to the right. The pole began to shift in the ground, and at 0.095 seconds the lag screws attaching the CAM to the pole pulled out. The vehicle continued forward pushing the CAM and at 0.505 seconds the side of the vehicle impacted the pole and CAM. The vehicle came to rest approximately 50 ft (15 m) from impact. The CAM rotated about the pole approximately 336 degrees and is shown in its final position in figure 55.

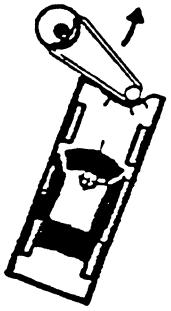
POSITION 4

Car clears pole



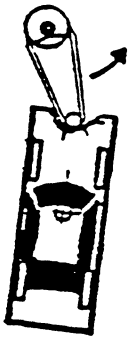
POSITION 3

Barrier shoves car to the right



POSITION 2

Cylinder A collapses , slip base activates and barrier starts cam action



POSITION 1

End of barrier deforms front of car

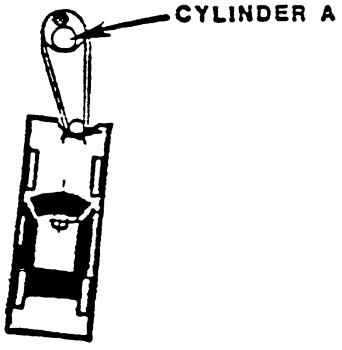


Figure 54. Operational Mode AR

Figure 55. Final positions of CAM and vehicle after test 4859-17.

The pole shifted in the ground a maximum of 16 in (41 cm). This deflection eliminated the need for total collapse of the inner ring, as well as eliminating the available force necessary to collapse the ring. The major damage to the pole occurred as it bent in response to the primary force applied by the vehicle through the CAM. While this pole would need to be replaced, it remained standing, thereby allowing repair to be at the convenience of the utility company rather than in an emergency situation as would occur in a head-on collision. It is anticipated that a more substantial foundation (higher strength surrounding soil or soil plate) would result in collapse of the inner ring, and reduce damage to the pole.

The front of the vehicle was deformed as shown in figure 56. Maximum crush was 16.0 in (40.6 cm) at bumper height. The rear door on the left side was dented when the side of the vehicle impacted the pole and CAM. The windshield was broken moderately in two places where the two anthropomorphic dummies struck.

RESULTS

Results of this test are summarized in figure 57. The maximum 0.050-second average acceleration in the longitudinal direction was -10.4 g, and -5.8 g in the lateral direction. Change in vehicle velocity at 0.500 seconds (just prior to secondary impact of the side of the vehicle with the pole) was 29.0 mi/h (46.7 km/h), and change in moment was 4,435 lb-s.

NCHRP Report 230 contains recommended criteria and places limits on these for acceptable performance for tests with vehicles at 20 and 60 mi/h (32 and 97 km/h).[15] This test was performed at 40 mi/h (64 km/h), however, occupant risk factors were computed and are reported for information only. Occupant impact velocity in the longitudinal direction was 29.4 ft/s (9.0 m/s), and 7.2 ft/s (2.2 m/s) in the lateral direction. The maximum 0.010-second average longitudinal and lateral ridedown accelerations were -4.4 g and -3.2 g, respectively.

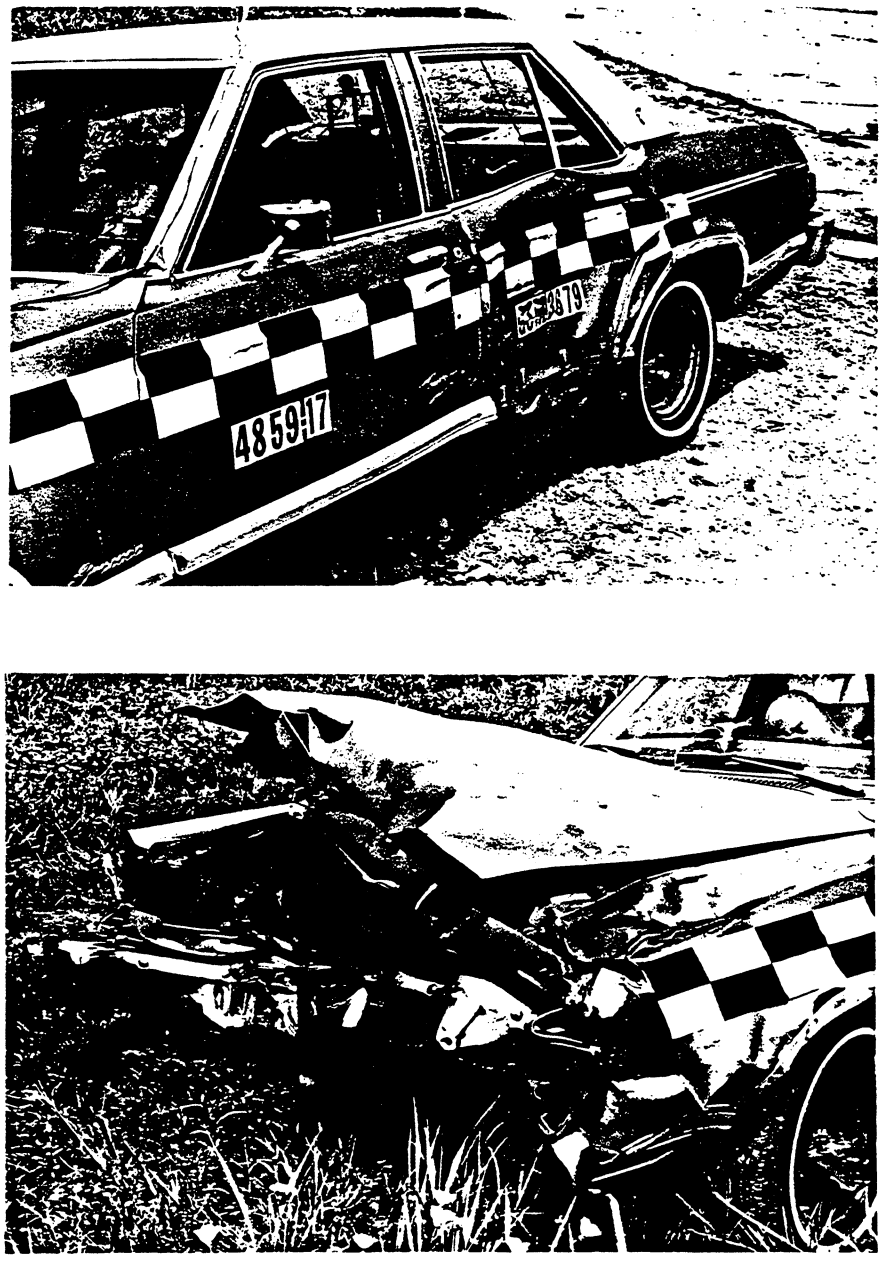
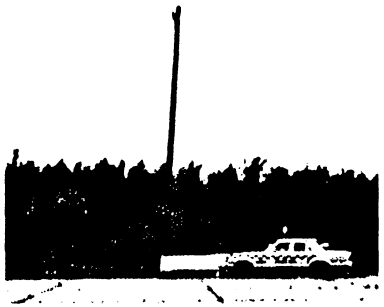
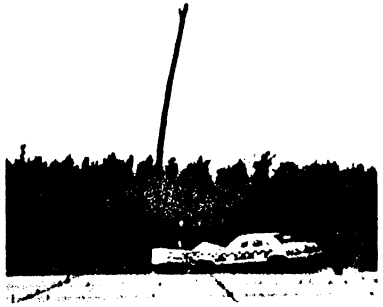


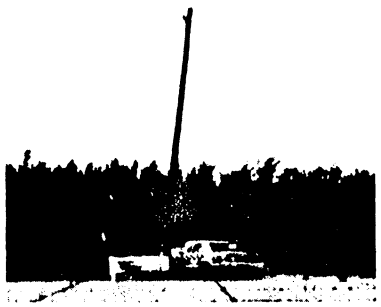
Figure 56. Vehicle after test 4859-17.



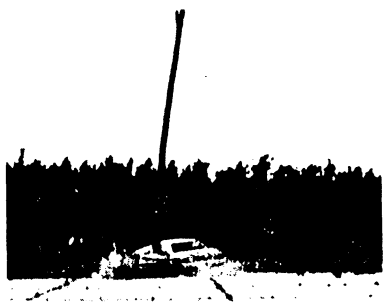
0.000 s



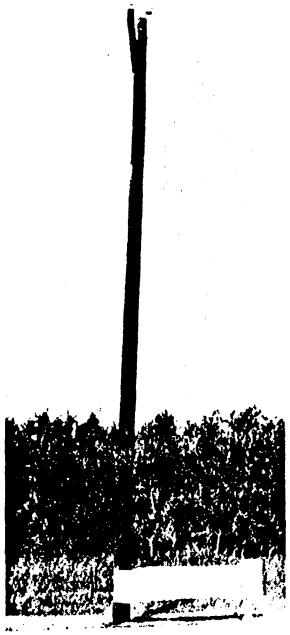
0.138 s



0.430 s



0.659 s



Test No.	4859-17
Date	4/23/85
Test Article	Modified Wooden Utility Pole
Modification	CAM
Vehicle	1977 Ford Granada
Vehicle Weight	
Test Inertia	3360 lb (1525 kg)
Gross Static	3679 lb (1670 kg)
Vehicle Damage Classification	
TAD	11FC5
CDC	11FCEN2
Maximum Vehicle Crush	
Bumper Height	16.0 in (40.6 cm)

Impact Speed	41.0 mi/h (66.0 km/h)
Change in Velocity*	29.0 mi/h (46.7 km/h)
Change in Momentum*	4435 lb-s
Vehicle Accelerations (Max. 0.050 s Avg)	
Longitudinal	-10.4 g
Lateral	-5.8 g
Occupant Impact Velocity	
Longitudinal	29.4 fps (9.0 m/s)
Lateral	7.2 fps (2.2 m/s)
Occupant Ridedown Accelerations	
Longitudinal	-4.4 g
Lateral	-3.2 g

* Computed to 0.500 (just prior to secondary impact)

Figure 57. Summary of results for test 4859-17.

HBS Performance

The compliance tests outlined in table 3 were conducted and reported under Test Results. Table 4 shows how the tests conducted compare to the compliance tests proposed. All numbers in parenthesis are empirical test data. In this table changes in velocity, changes in momentum and maximum average 0.050-second accelerations are empirically determined. The probability of injury estimates (%AIS$\geq$1, %AIS$\geq$3 and %PI) are made in the following ways.

Method 1. %AIS$\geq$1 and %AIS$\geq$3. For the test conducted this estimate can be made using figure 9 and the velocity change (ΔV) or using figure 10 and the momentum change (ΔM). For the hypothetical case of the same vehicle conditions on a nonbreakaway pole, figure 8, and the vehicle impact speed (V) may be used to make the AIS estimates.

Method 2. Probability of Injury, percent. This estimate can be made using figure 11 and the highest average 0.050-second acceleration level determined from the test. For the hypothetical case of the same vehicle conditions on a nonbreakaway pole the acceleration level must be calculated to obtain PI estimate from figure 11..

Although one may see the comparison between any two injury rate levels for any test by examination of table 5, it is somewhat easier to compare those levels using figures 58 and 59. These bar graphs were developed for each nominal test speed using method 1 (i.e., Mak's curves, figures 8, 9, and 10).[10] In figure 58 it is seen that a significant improvement is shown. This injury rate (AIS$\geq$1) is decreased by about 28 percent. In contrast to this, figure 59 shows a much less decrease in the AIS$\geq$3 injury rate. This decrease, for the five compliance tests conducted, averages 91 percent. It is apparent from figure 59 that the reduction becomes more pronounced as the speed increases. There is a slight advantage at 20 mi/h, progressing to a major improvement at 60 mi/h.

Table 4. Compliance tests for breakaway utility poles.

Test No.	Vehicle Weight (Test Inertia Mass, lbs)	Vehicle Speed V, mi/h	Vehicle Attitude	Primary Purpose of Test
1 (16)*	1,700-1,900 (1,826)	38-42 (39.9)	Frontal, mid 50% (close to center)	Determination of Probabilityof injury reduction for the most critical element of the design spectrum.
2 (12)	1,700-1,900 (1,775)	18-22 (19.9)	Frontal, mid-50% (close to center)	Determination of probability of injury reduction for the lowest kinetic energy level at which pole structural activation would be expected.
3 (13)	3,200-3,600 (3,365)	38-42 (40.7)	Frontal, mid-50% (close to center)	Determination of probability of injury reduction for the mid range of automobile kinetic energy.
4 (14)	2,300-2,700 (2,500)	58-62 (60.0)	Frontal, outer 50% (quarter point of bumper)	Determination of vehicle dynamic reaction to eccentric collision
5 (5)	4,300-4,8000 (4,331)	58-62 (56.8)	Frontal, mid-50% (close to center)	Assessment of pole structural integrity at the highest kinetic energy level encompassed by the design spectrum.

*Numbers in parenthesis refer to test numbers described in the text.

Table 5. Injury rate levels for compliance tests.

Test No.	Change in Velocity			Change in Momentum			0.050-Seconds Average Acceleration		Probability of Injury for Unmodified Pole		
	ΔV mi/h	AIS≥1 %	AIS≥3 %	ΔM lb-s	AIS≥1 %	AIS≥3 %	g's	PI %	AIS≥1 %	AIS≥3 %	PI %
1 (16)*	11.5	66.0	1.42	957	52.3	0.38	8.0	21.5	81.3	22.4	100
2 (12)	11.3	65.7	1.39	915	51.5	0.36	6.7	15.1	70.2	2.5	60
3 (3)	10.8	64.9	1.31	1655	61.5	0.74	6.7	15.1	81.3	22.4	66
4 (14)	11.0	65.3	1.34	1253	56.8	0.50	10.2	35.0	87.8	76.5	79
5 (5)	7.0	57.2	0.83	1487	59.7	0.63	4.9	8.1	72.6	2.58	26.5

*Numbers in parenthesis refer to test numbers described in the text.

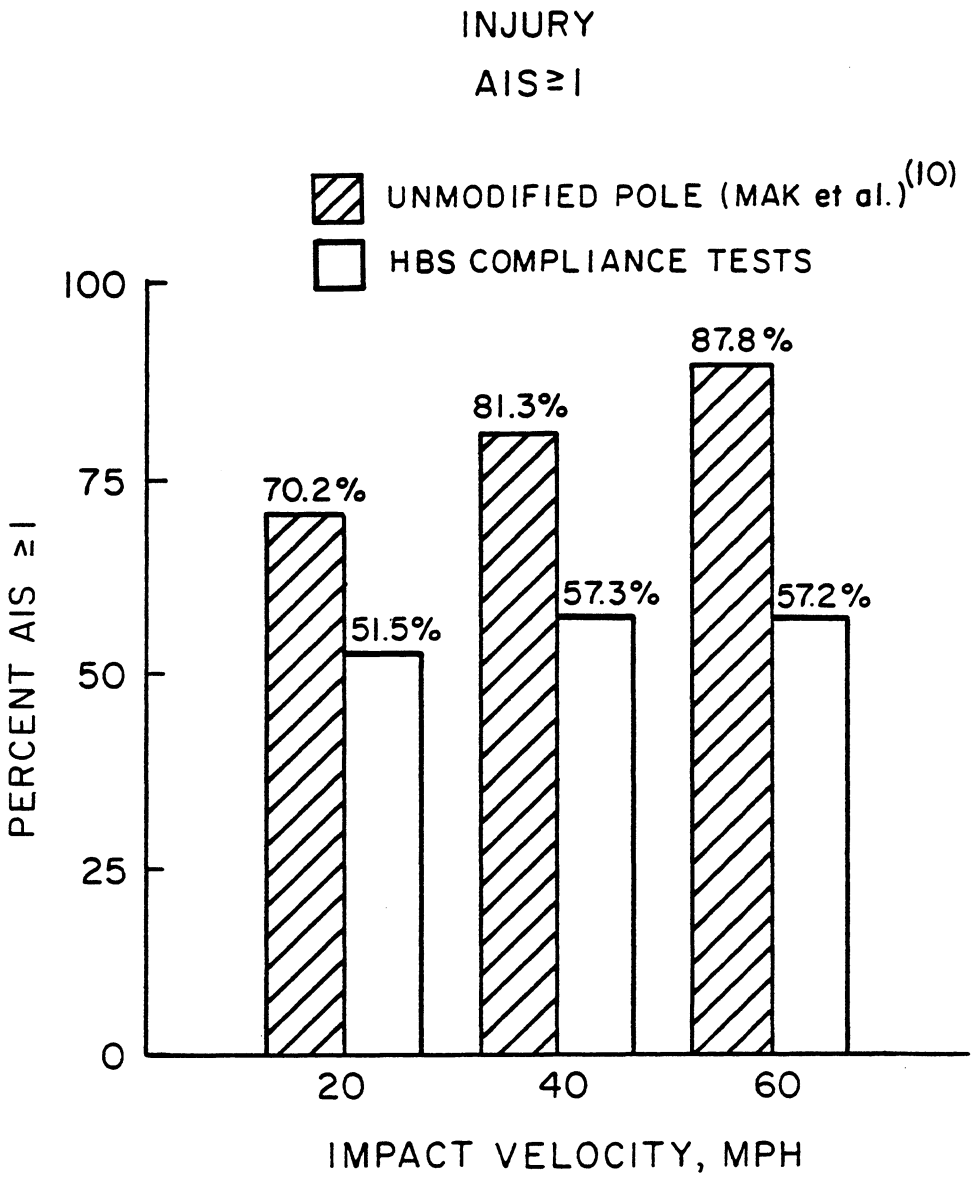


Figure 58. Comparison of injury levels from HBS compliance tests with unmodified pole injury levels (% AIS $\geq$ 1).

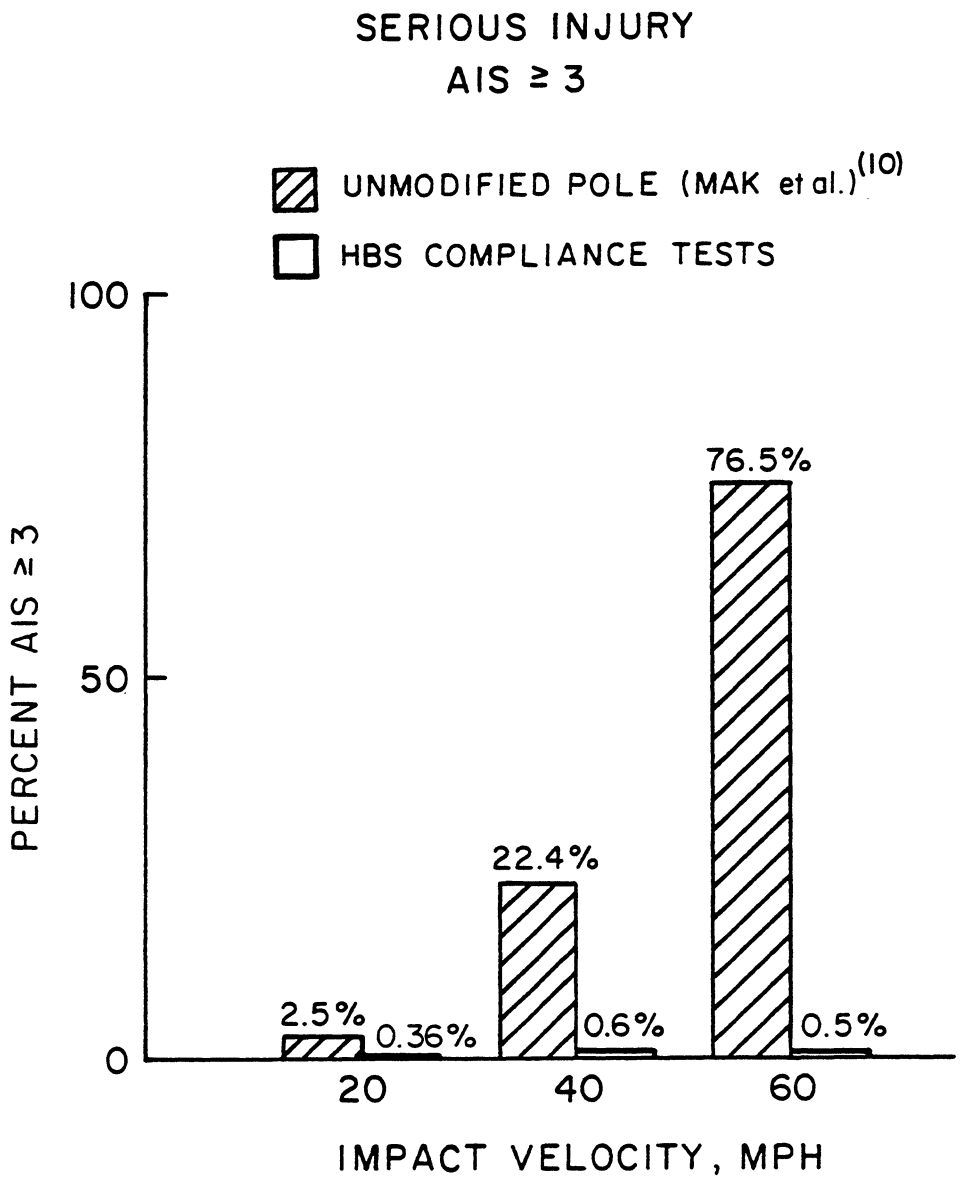


Figure 59. Comparison of injury levels from HBS compliance tests with unmodified pole injury levels (% AIS $\geq$ 3).

Since Mak's statistically derived curves do not discriminate for vehicle weights, the computer code given in appendix C was used to simulate the collisions shown by table 6.[10] The data from table 6 and the maximum force needed to fracture a 40-ft class 4 pole as estimated by test 4859-18 was used to generate figures 60 and 61. Method 2 was used to develop these curves. The difference between curves A and B shows the improvement from nonbreakaway to HBS poles (figure 60) as vehicle weight varies. This figure, for 40 mi/h impacts, shows a major shift in curve A as vehicle weight increases from 3,000 to 3,500 lb. This is the zone where nonbreakaway poles become breakaway as the kinetic energy of the impacting vehicle becomes sufficient to fracture the pole. If vehicle weight becomes very large, e.g., 80,000 lb, curves A and B will converge. The same curve shift is not seen in figure 61, since nonbreakaway poles will be fractured by all vehicles weighing from 1,800 to 4,500 lbs at impact speeds of 60 mi/h. Comparing method 2 with method 1, probability of injury (PI) is significantly higher than %AIS$\geq$3 but significantly lower than %AIS$\geq$1. Had Mak chosen to derive the relationship for AIS$\geq$2 the results might have been reasonably close to the method 2 curves.[10] The reduction of injury rate using method 2 averages about 75 percent for 40 mi/h collisions and about 50 percent for 60 mi/h collisions. The reduction in PI, percent is most significant for vehicles weighing less than 3,000 lbs for the 40-mi/h condition.

Finally, using all available test data and the computer simulations shown by table 6, figure 62 was constructed. This figure shows the various zones of interaction between vehicles and HBS-modified poles. It also shows the calculated failure boundary for unmodified class 4 timber utility poles. The activation boundary for the HBS occurs at about 10 mi/h for small vehicles and will decrease slightly as vehicle weight increases. As speed increases, the next zone is where the lower connection is activated and the pole is pushed in front of the impacting vehicle. The vehicle then stops and the pole leans on or descends on the vehicle. The pole falling velocity is so low that significant passenger compartment intrusion will not occur. This was illustrated by compliance test 2. In the next zone the vehicle will go completely under the pole

Table 6. Computer analysis summary.

Vehicle Speed (mi/h)	Maximum Crush (ft)	Maximum Force (lb)	Time of Maximum (second)	Velocity Change (mi/h)	Momentum Change (lb/s)	0.050 second Average Acceleration	Probability of Injury, % (Based on Velocity Change) AIS≥1	Probability of Injury, % (Based on Velocity Change) AIS≥3	Probability of Injury, % (Based on Momentum Change) AIS≥1	Probability of Injury, % (Based on Momentum Change) AIS≥3	PI, %
4500 lb VEHICLE @ 3.6G/FT											
60	2.58	41830	0.0415	6.9	1414	6.18	56.9	0.8	58.9	0.6	12.8
40	1.87	30220	0.0435	5.1	1045	4.53	51.5	0.7	53.8	0.4	6.9
20	1.08	17510	0.0475	3.2	656	2.76	43.2	0.5	45.9	0.3	2.6
3500 lb VEHICLE @ 5.5G/FT											
60	2.32	44660	0.0375	8.6	1371	7.70	60.9	1.0	58.4	0.6	19.9
40	1.68	32290	0.0395	6.4	1020	5.57	55.6	0.8	53.4	0.4	10.4
20	0.98	18890	0.0435	4.0	638	3.56	47.2	0.6	45.5	0.3	4.3
3000 lb VEHICLE @ 6.5G/FT											
60	2.28	44550	0.0375	9.9	1353	8.85	63.4	1.2	58.1	0.6	26.3
40	1.65	32210	0.0385	7.3	998	6.52	57.9	0.9	53.0	0.4	14.3
20	0.97	18830	0.0425	4.6	629	4.10	49.7	0.6	45.2	0.3	5.6
2600 lb VEHICLE @ 7.2G/FT											
60	2.32	43390	0.0375	11.3	1338	10.07	65.7	1.4	57.9	0.5	34.1
40	1.68	31350	0.0395	8.3	983	7.42	60.2	1.0	52.7	0.4	18.5
20	0.97	18250	0.0435	5.2	616	4.64	51.9	0.7	44.9	0.3	7.3
2250 lb VEHICLE @ 7.9/FT											
60	2.36	42010	0.0385	12.8	1312	11.46	68.0	1.7	57.6	0.5	44.2
40	1.71	30330	0.0395	9.4	963	8.44	62.5	1.1	52.4	0.4	23.9
20	0.99	17560	0.0445	5.9	605	5.25	54.1	0.7	44.6	0.3	9.3
1800 lb VEHICLE @ 8.8G/FT											
60	2.48	39210	0.0395	15.6	1279	13.95	71.5	2.3	57.2	0.5	65.4
40	1.78	28260	0.0415	11.5	943	10.24	66.0	1.4	52.0	0.4	35.2
20	1.02	16170	0.0455	7.1	582	6.27	57.4	0.8	43.9	0.3	13.2

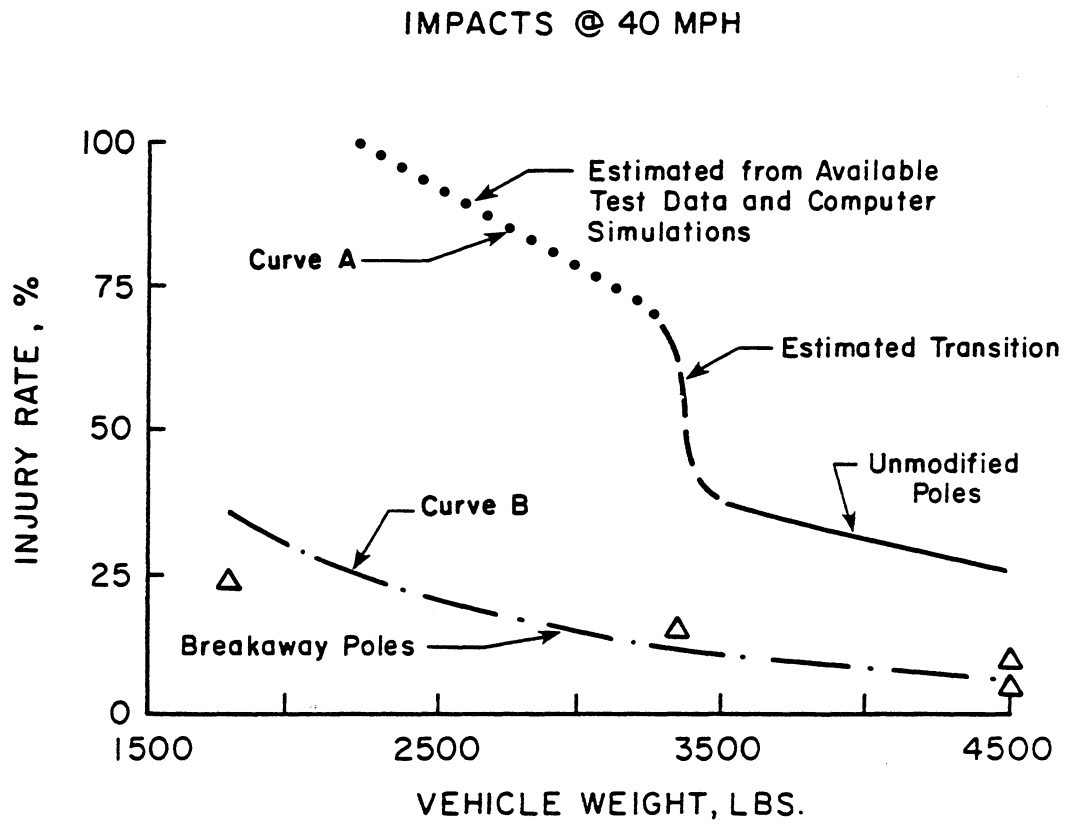


Figure 60. Comparison of injury rates between breakaway and nonbreakaway poles as a function of vehicle weight for 40 mi/h collisions (rates from table 6, Method 2).

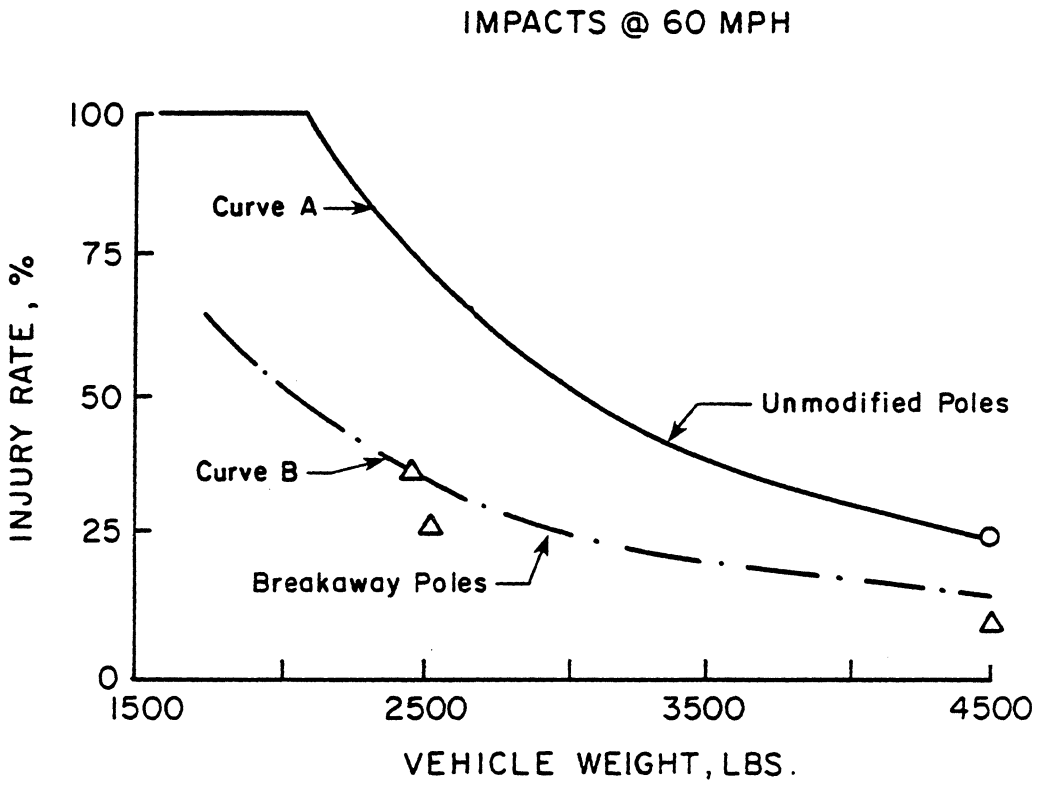


Figure 61. Comparison of injury rates between breakaway and nonbreakaway poles as a function of vehicle weight for 60 mi/h collisions (rates from table 6 , Method 2)

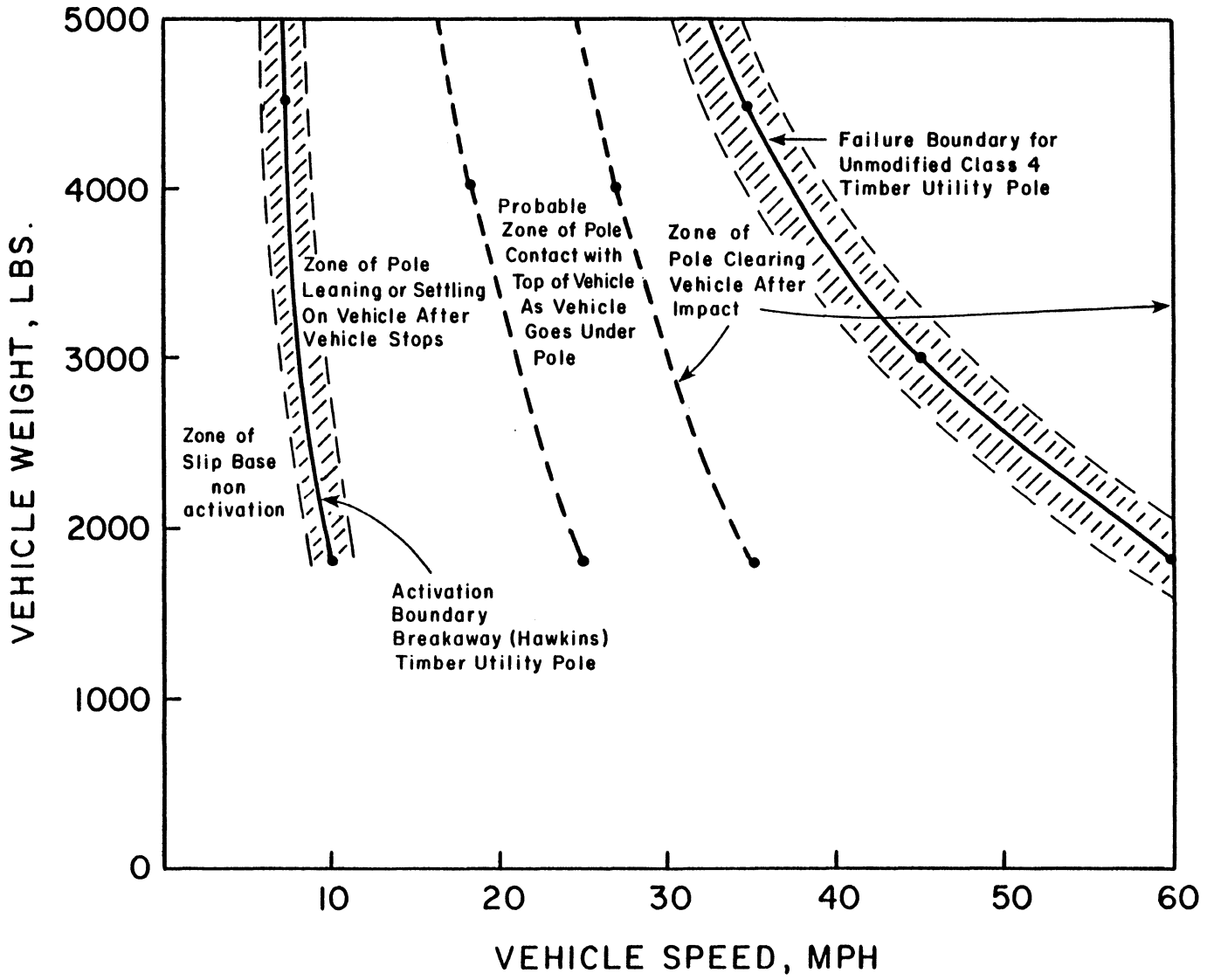


Figure 62. Zones of vehicle-pole interaction.

but the pole will make contact with roof or trunk structure as the vehicle moves through. Passenger compartment intrusion will be minimal in this zone due to the rotation of the lower pole segment to a position where it will glance off or be pulled across the roof structure. This zone is not precisely defined but will vary as vehicle structural stiffness and coefficient of restitution varies. Finally the zone where the pole clears the vehicle after impact is everywhere to the right of curve C. This is the zone illustrated by compliance tests 1, 3, 4, and 5.

Compliance with NCHRP Report 230

It should be recognized that the recommendations for Timber Utility Poles were considered extremely tentative by the writers of NCHRP Report 230. Completely successful breakaway devices for these structures had not been achieved and the writers were not sure whether that goal could be reached. Those recommendations for "Occupant/Compartmental Impact Velocity" and Occupant Ridedown Acceleration were based more on what the authors considered possible than on what would be preferred. In table 8 of NCHRP Report 230 an acceptance factor of 1.33 was recommended. This resulted in values of ΔV of 30 ft/s and acceleration of 15 g's. It appears now that breakaway timber utility poles can achieve better results than these values recommended in 1981. This can be seen by comparing the results of NCHRP Report 230 recommended tests for "Breakaway or Yielding Supports" to those values of velocity change and acceleration given above. This comparison is given in table 7. The required tests are 60 and 61 although in this case test 62 is substituted for 60, 62 being a more rigorous demanding test. The other test conducted was not required but is described as a possible supplementary test in table 4 of NCHRP Report 230. This is test number S64, an 1,800 lb vehicle at 40 mi/h impacting at the center of the bumper.

The HBS results are well below the maximum values given by NCHRP Report 230 for Timber Utility poles and fundamentally meet the requirements for signs and luminaire supports. They are well within the requirements for Ridedown Accelerations and with one exception meet the

Table 7. Compliance with NCHRP Report 230.

NCHRP Test Designation	TTI Test Designation	Weight		Speed		ΔV		a	
		Suggested lb	Achieved lb	Suggested mi/h	Achieved mi/h	Suggested ft/s	Achieved ft/s	Suggested g's	Achieved g's
61 (Sub. for 60)	4859-14	2250	2500	60	60.0	30	15.6	15	1.8
62	4859-12	1800	1775	20	19.5	30	10.1	15	2.1
564	4859-16	1800	1826	40	39.9	30	12.0	15	1.0

Occupant/Compartment Impact Velocity. That exception is test 61 where a ΔV of 15.6 ft/s was observed, compared to a recommended limiting value of 15. Considering the variability in crash testing one would not be overly concerned by this result. It appears that an acceptance factor higher than the 1.33 might be appropriate for timber utility poles.

V. IMPLEMENTATION RECOMMENDATIONS

Design Recommendation - Timber Utility Pole

A breakaway design for 40-ft class 4 timber utility poles has been developed based upon the tests reported in the previous section. This design is for operational mode BA-3. As shown in figure 63, this system consists of three basic modifications to an existing (or new) timber utility pole. The modifications used are a slip base (lower connection), a "plastic" hinge (upper connection), and overhead guys (structural support cables). These devices are described below, and details are presented in figures 64 and 65.

Lower Connection - Slip Base:

A lower shear plane is created through installation of a slip base at an elevation of 3 in above grade. The elevation of the slip base is intended to avoid snagging on the underside of an errant vehicle. This shear plane consists of two 5/8-in thick plates separated by a 26-gage keeper plate (intended to maintain a 15 1/2-in-diameter bolt circle) and by 2-1/2-in diameter by 1/8-in washers. The base plates are connected to each other by six 1-in-diameter high strength bolts, with 2 1/2-in by 1/4-in washers. These bolts are torqued to 200 foot pounds. Connection of the wooden utility pole to the slip base is through a steel pipe or mechanical tubing (see alternatives 1, 2, and 3, figure 66). These tubes are nominally 12 inches in diameter and 30 inches long, and are welded to the base plates. In addition, the base plates are braced by 5/8-in-thick stiffners which are welded to both the base plate and the steel tube.

Moderate trimming of the timber pole, to accommodate the slip base, can be accomplished without seriously affecting the bending strength. However, reductions in moment of inertia of the pole in excess of 30 percent occur with trimming greater than 1/2 in. It should be noted that these reductions are reductions in the factor of safety of 4.[13] While excessive trimming should be avoided, the increased ductility provided by

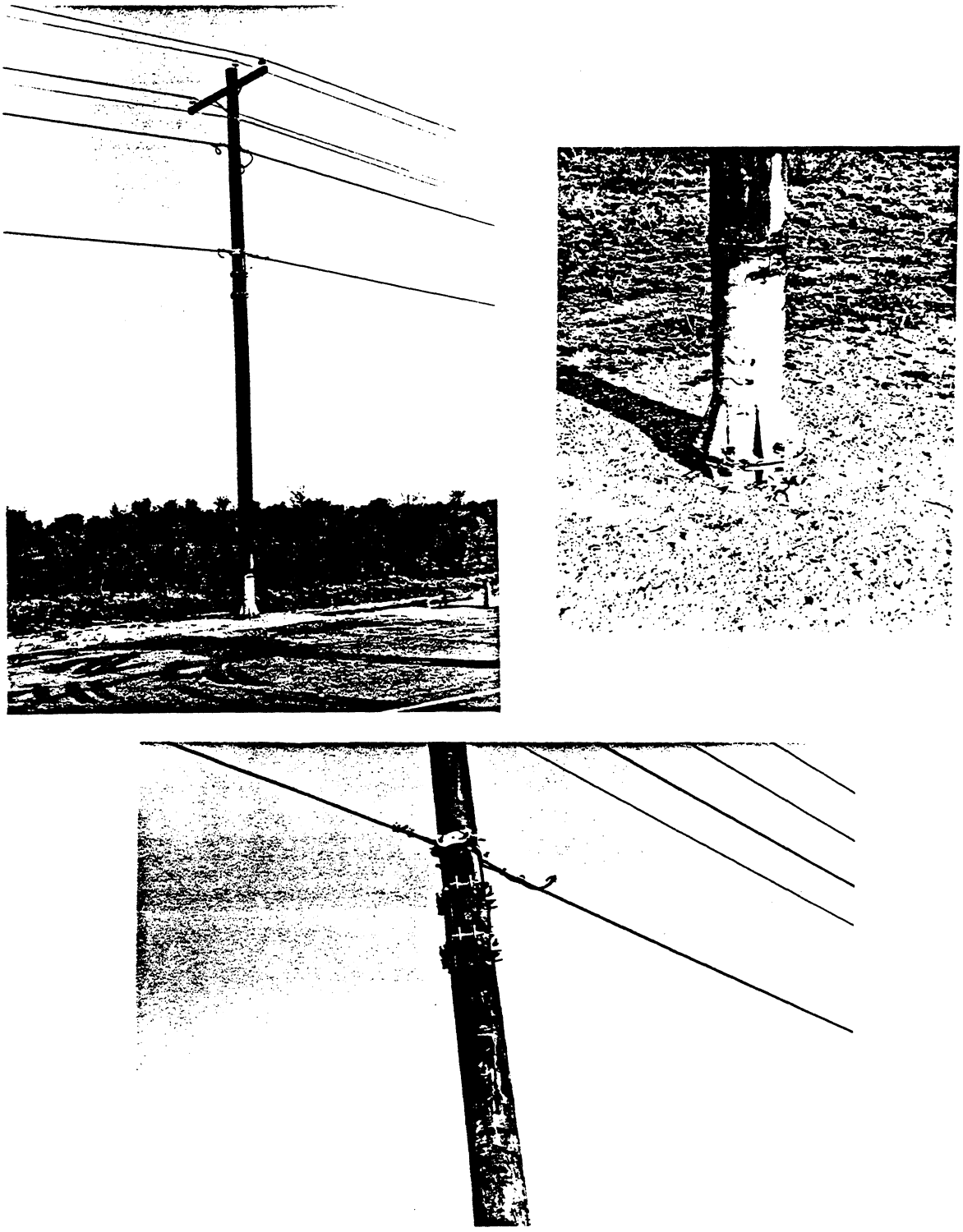


Figure 63. Modified utility pole installation.

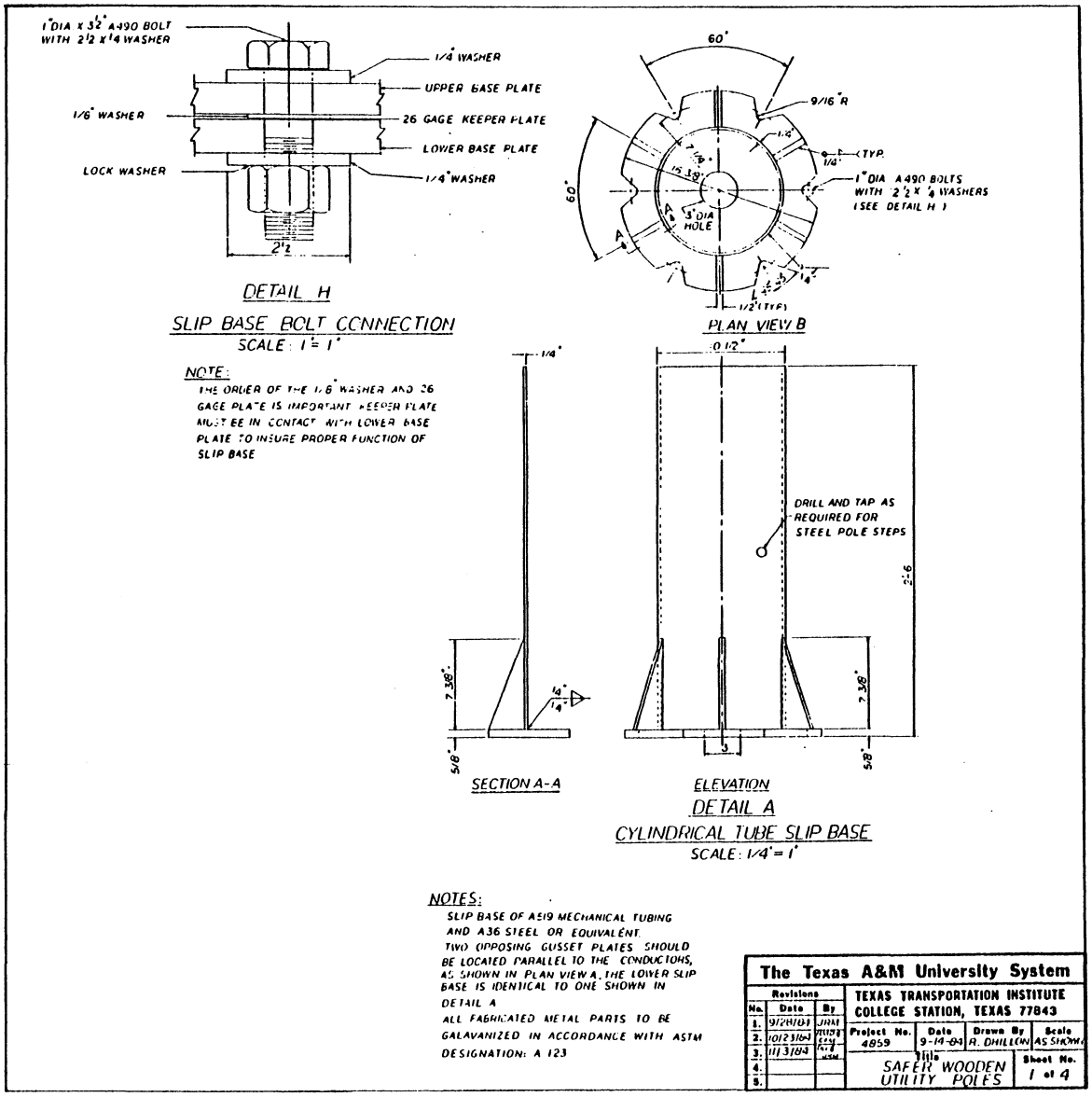


Figure 64. Lower connection - slip base.

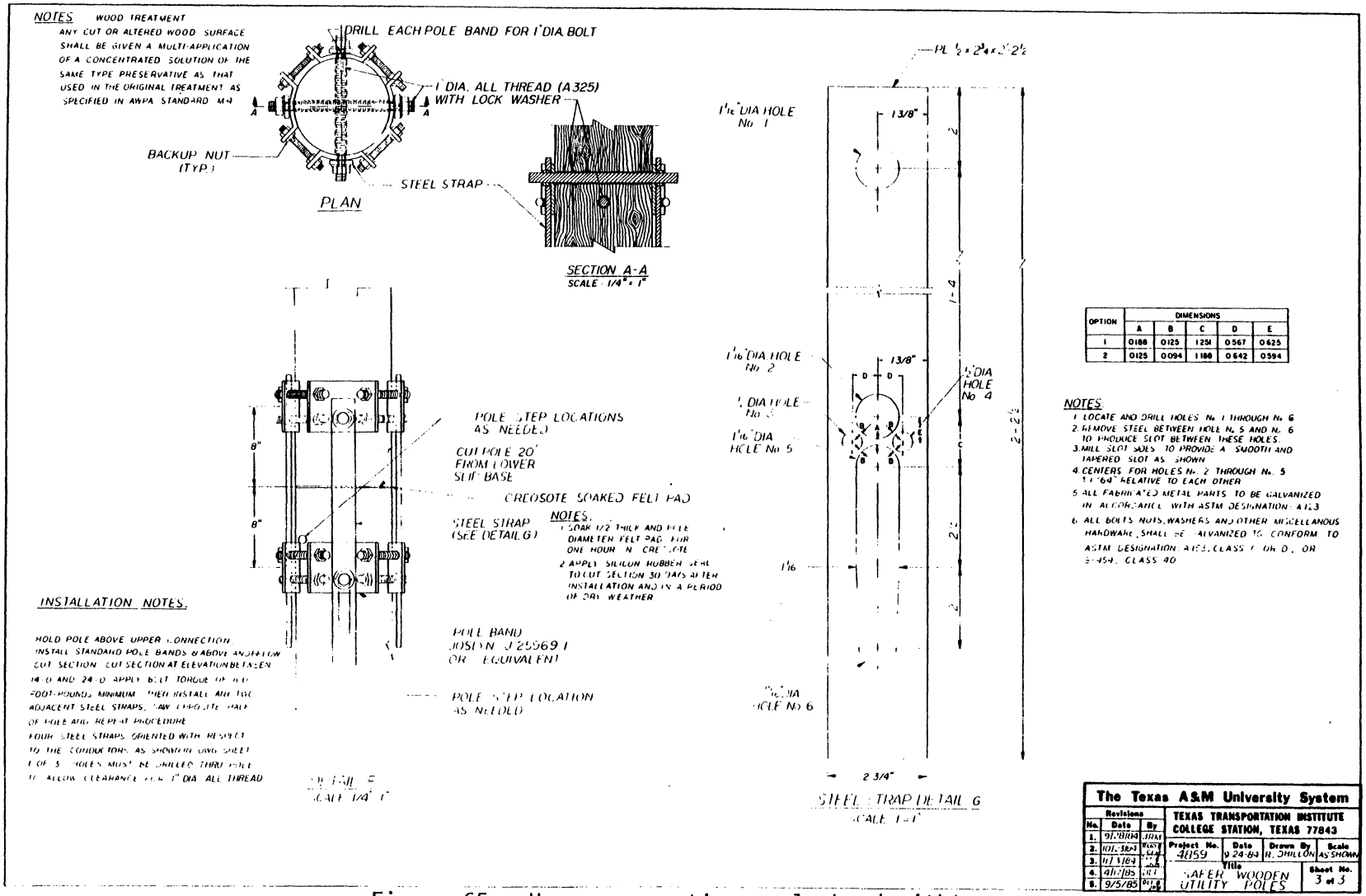


Figure 65. Upper connection -pole band with modified slotted straps.

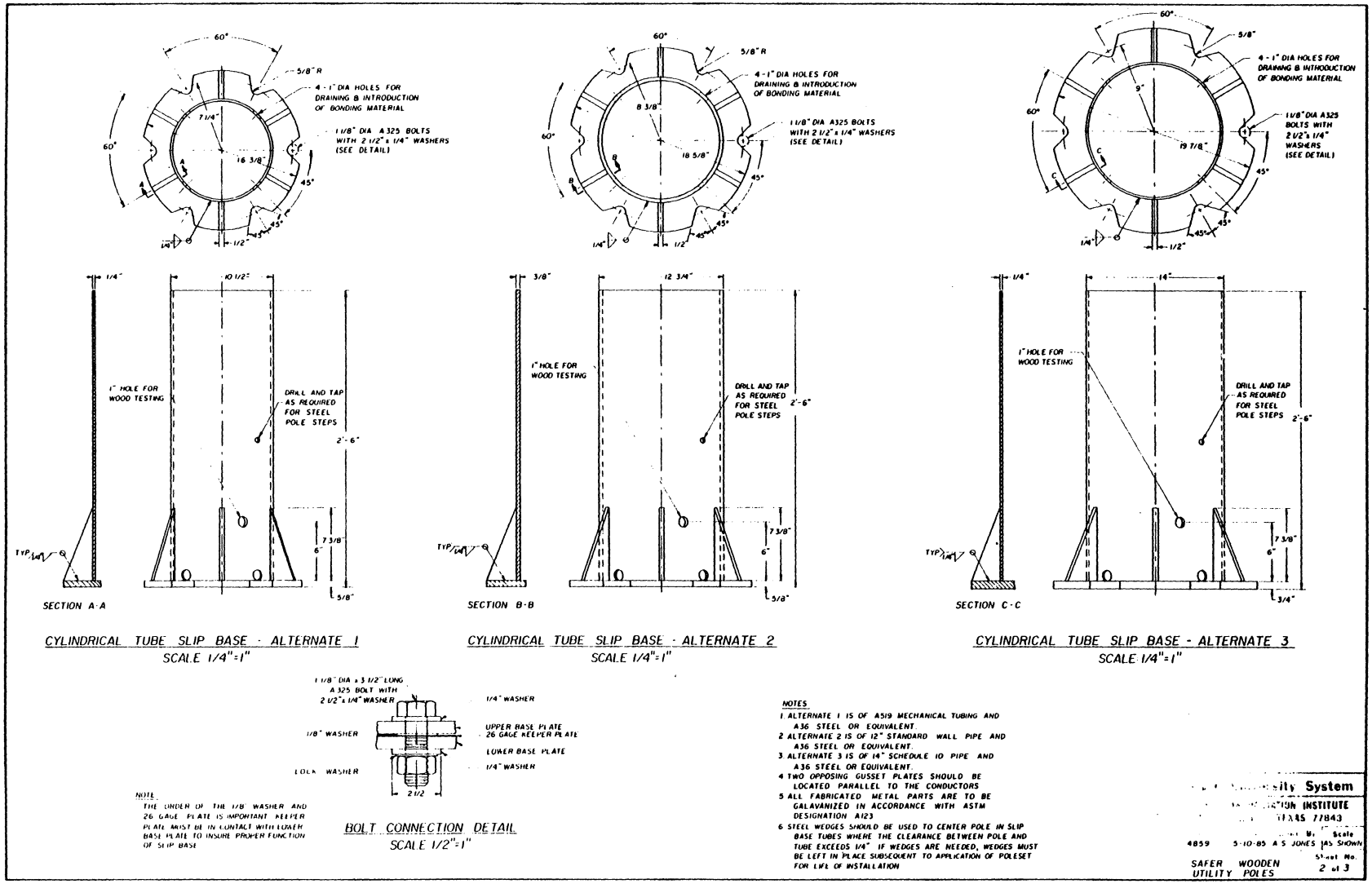


Figure 66. Alternate slip base connections.

the upper connection can accommodate some reduction in the bending strength without affecting the overall performance of the pole line. It is recommended that slip base tube sizes be chosen that will minimize the need for trimming. Gaps of up to 1/4 in can be filled with a material such as Poleset* or equivalent. This material is a high density foam which is commercially available for use in backfilling and protecting poles set in ground. The moment capacity of these designs is in excess of 76,800 ft/lb-s.

Upper Connection

A moment-sensitive upper connection was selected based on the results of static bending tests and developmental crash tests. This connection consists of two-four part pole bands installed above and below a saw cut through the pole. The straps are detailed in figure 67 as Joslyn part number J25969-1. The pole bands (and straps) are further secured to the pole by means of 1-in diameter through bolts as shown in figure 65. At the bottom pole band, the bolts pass through a bolt hole which is separated from a 4 1/2-in long slot by a 3/16 in section of steel. Initial sending resistance is provided by the strength of this 3/16-in margin. Once the margin is punched out, resistance is offered by friction between the straps and bolts, and by bending of the straps. Once significant rotation has occurred, the bolts bear on the end of the slot, thereby providing the required ultimate bending strength.

The utility industry assumes that a 2,400-lb horizontal load at a distance of 2 ft below the top of the pole represents a factor of safety of 4 in the bending resistance of the pole.[12,13] Load versus rotation curves are presented in figure 68. Also in figure 68, are comparisons of the loads achieved with the safety factor.

* Forward Enterprises, Inc., Houston, Texas

J25969 Heavy Duty Pole Band Assemblies

Ultimate tensile strength: 40,000 Lbs.
Band Section: 3/8" X 5"
Connecting Link Mounting Positions: At Thru-Bolt Adapters only

Catalog No.*	Pole Dia. Range (in.)	Weight Each
J25969.1	8 - 10½	61.3
J25969.2	9½ - 13½	65.2
J25969.3	12½ - 16½	71.7
J25969.4	15½ - 19½	78.4
J25969.5	18½ - 21	82.2

*Add suffix "G" to Catalog No. to include a J22180 Grounding Lug Assembly.

NOTE: Excerpt from Joslyn Product Information Bulletin Number 355, May 1984.

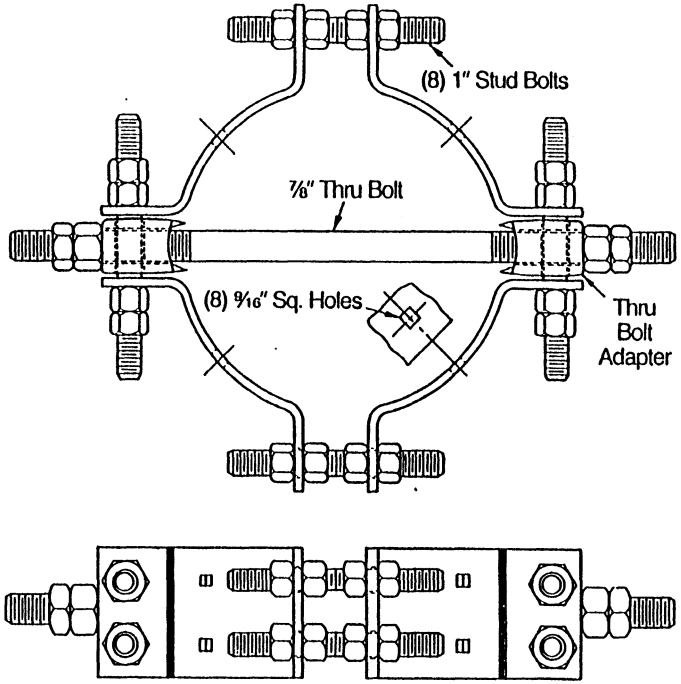


Figure 67. Joslyn heavy duty pole band assemblies.

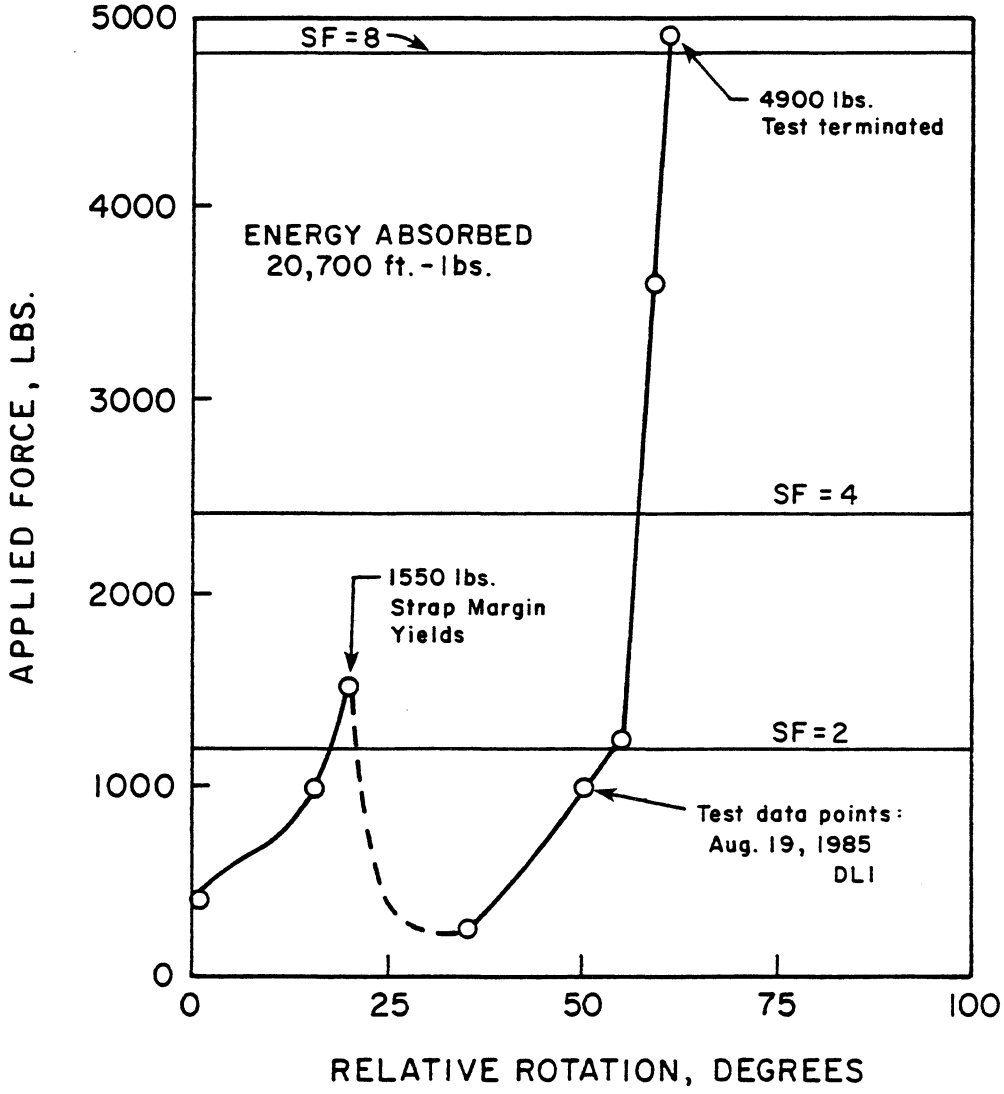


Figure 68. Upper connection load-rotation characteristics. (HBS heavy duty upper connection)

Overhead Guy - Structural Support Cables:

Steel support cables (1/2-in wire rope) were placed immediately above the upper connection and near the cross arm (at minimum NESC clearance below the neutral). The lower structural cable serves as a pivot point for the lower pole segment when the pole is struck by an errant vehicle. This cable could be, in many cases, eliminated on poles where a telephone cable is present. In these cases, a more secure attachment of the telephone support strand to the pole would serve the same purpose. The upper steel cable serves to stabilize the upper pole segment and minimize damage to the electrical conductors. In light of the results obtained in this study, it does not appear that Standard industry tie wraps can transfer sufficient load to the conductors (from the pole) to avoid using the upper steel overhead guy. Together these structural cables facilitate the activation of the upper hinge mechanism and stabilize the upper pole section during impact and during the subsequent motion of the pole.

Design Recommendation - Down Guy:

As dramatically illustrated in test number 11 a collision between an errant vehicle and a down guy can be very serious. In many ways this hazard is as serious, if not more so, than other roadside hazards. A modified down guy ground anchor attachment was chosen to mitigate this hazard. In addition to lessening the severity of an impact, this design increases the visibility of the down guy thereby avoiding some of the problem.

A 6-ft-long transition piece, made of galvanized pipe, was added between the guy cable and the anchor. This frangible transition piece is connected to a standard embedded ground anchor with a clevis and pin. Connection of the down guy to the transition section is through a clevis, pulley, pin and cable clamp (see figure 69). In both cases, attachment of the galvanized pipe to the clevis is accomplished with standard pipe threads. A stress riser, adequate to initiate fracture in the event of an impact, is provided by the root of the thread at the junction between the galvanized pipe and the upper clevis.

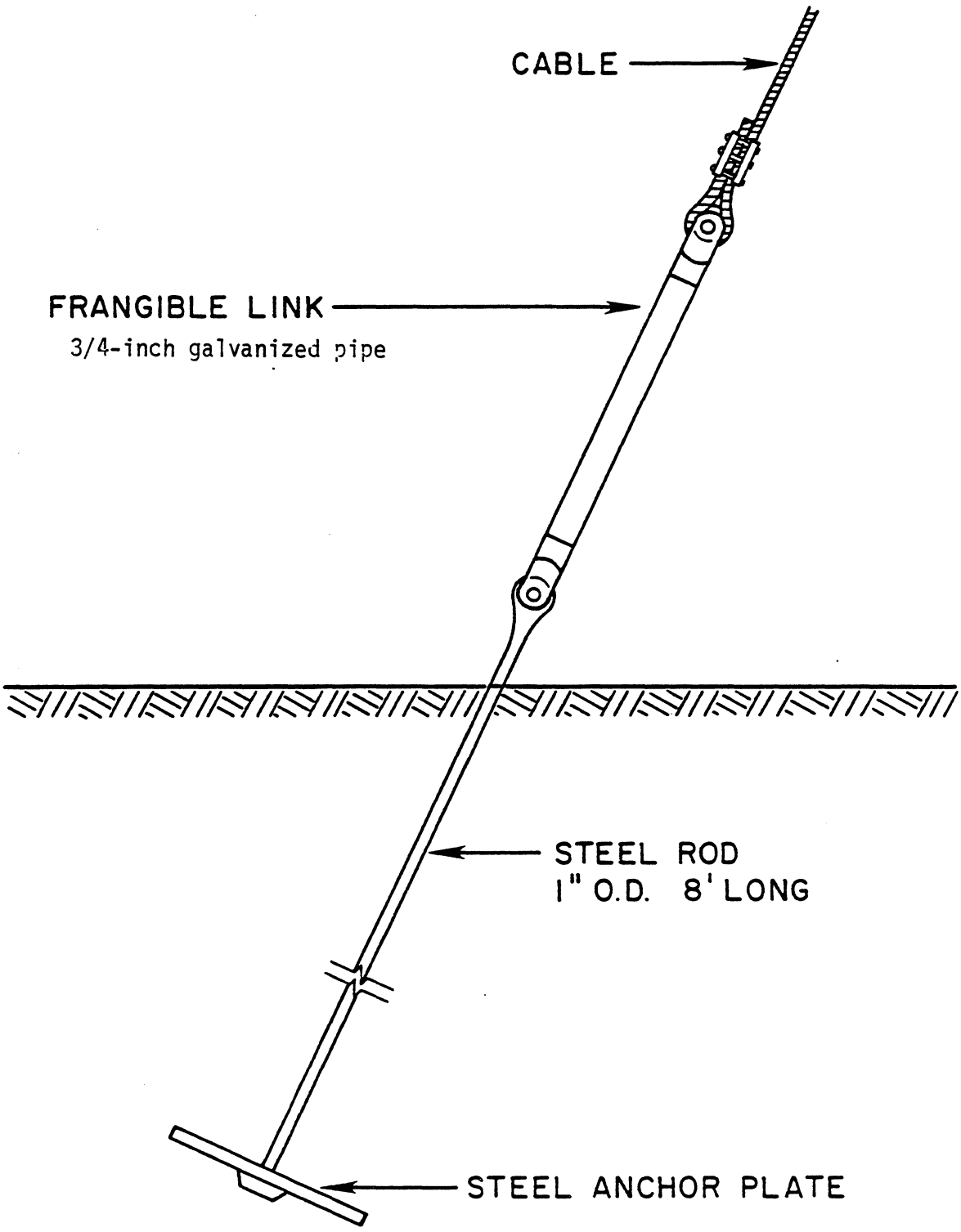


Figure 69. Detail of modified down guy attachment system.

UTILITY INDUSTRY
BENEFITS AND CONCERNS

Utility Industry Concerns:

Until now, an increase in the safety of vehicle occupants seemed to be the only benefit a utility company would derive from the implementation of a safety program requiring pole modifications. There are now other demonstrable benefits, but before they are discussed, industry concerns will be described.

Utility companies have consistently expressed concern with respect to any proposed safety treatment of utility poles which involved reducing pole capacity to withstand environmental loads. Companies have been more responsive to safety improvements such as increasing setbacks and undergrounding. A summary of industry concerns relative to designs that lower the load bearing capacity of timber poles would include: (a) an increased failure rate of poles under severe environmental conditions, (b) the possibility of the "Domino" effect if one weakened pole is struck by a vehicle, (c) accelerated wood decay if the chemically treated zone is penetrated by pole modification and (e) danger to maintenance personnel.

There may well be legitimate concerns with respect to some breakaway designs such as "RETROFIX," but they should be weighed against the extremely significant improvement to safety if the safety modification is applied on a highly selective benefit-cost basis. Some critics of breakaway designs have emphasized real or perceived negative aspects while failing to adequately consider the significant benefits to the utility industry that could accrue from safety programs that included selective implementation of a breakaway pole design.

The current program of research was dedicated to finding a breakaway solution to the safety problem, so that as companies develop "an awareness ... of high risk areas," a stated goal of the utility industry task group, they will have an option other than costly relocation or undergrounding.

In order to do so, valid industry concerns about breakaway designs needed to be overcome. The Hawkins Breakaway System (HBS) does precisely that. The following paragraphs explain how each area of concern has been addressed in the development of the HBS.

Strength Aspects

Applied to a 40-ft class 4 pole, the slip base hardware of the HBS will resist the full horizontal load of 2,400 lb or a ground line moment of 76,000 ft-lb. [One static test (volume II) was taken to 3,200 lbs, a second went to 4,900 lb. Neither pole failed and each could be restored by replacement of the vertical upper connection straps.] This capacity will not degrade as quickly as an unmodified pole does when aging progresses. By transferring the critical pole sections for bending to point 34 inches above and 28 inches below the ground line the structural integrity of the pole is normalized (the actual failure load is more predictable). Concerning the upper connection, at a point approximately 20 ft above the ground line, the connection will obviously resist much more than the full 2,400 lb lateral test load (factor of safety 4.0). There will be a significant notation of the upper pole segment gradually increasing to about 15 degrees at a lateral force of 1,500 lbs. See figure 68. This rotation will increase quickly to an angular deflection between 30 and 40 degrees when the yield margin of one or two upper straps is punched out. The full moment capacity of the pole upper connection will then be developed after the critical straps slip to their deflection limits. The Hawkins Breakaway system will absorb, prior to failure, 250 percent of the energy absorbed by an unmodified pole at the 2,400 lb proof load. This built in ductility of the pole will also be discussed under Cost-Effectiveness.

Wood Decay

The HBS, by protecting the pole in its most vulnerable area by a combination of additional preservative, "Pole Set"* and steel casing, will

*Or other non-environmentally decaying filler.

greatly increase the service life of a pole subjected to normal environmental conditions. This vulnerable area is slightly above the ground line and down to two feet below ground. The steel casing of the Hawkins system will protect 34 in above and 28 in below the ground level.

The upper connection requires penetration of the preservative zone where the section is cut and where holes are drilled for the through bolts. These zones may be treated by field application of preservative or by shop application if replacement poles are prepared before proceeding to the field. Periodic inspection and reapplication will be required, but the section where the field treated wood is exposed is normally elevated 20 ft above the critical section for pole rot.

The Domino Effect

Tests have shown the HBS is not subject to the domino effect as a result of vehicle impacts. Even unmodified poles can succumb to this effect when wind and/or ice loads exceed design expectations. A pole line modified by the Hawkins system should prove tougher in resisting catastrophic failure than unmodified pole lines. Under excessive short duration wind loads, poles could bend at the upper connection, absorbing the energy and remain fundamentally intact, continuing to perform their primary function, while conventional poles might fail close to the ground line and collapse completely.

Benefit-Cost

The benefit-cost approach, where all societal costs are considered, is the only appropriate way to consider the HBS for implementation. These societal costs include those due to construction, maintenance and accidents. There never will be a justification for making all poles on highway rights-of-way breakaway. This system is meant to be applied on an extremely selective basis, a priority basis, only where its use is the most cost-effective choice among all alternatives for increasing safety, and further only where the societal benefit-cost ratio is greater than

one. By selectively employing this system in a well planned intracompany safety program, it is contended a power or communication company can cut its own maintenance costs, decrease interruptions of service to the public and increase public and employee safety. It is recognized this opinion remains to be proven by implementation. It will be.

Employee Safety

Over the life of a pole line the HBS is tougher (will resist greater environmental energy loadings) than conventional pole lines. Although inspection and maintenance will be required to assure all hardware elements remain in proper alignment and condition, poles so modified should be safer for employees. When a pole is struck by an errantly controlled vehicle, the utility maintenance employee will be greeted by a "short" pole with conductors still intact, rather than a pile of fractured timber and stretched, severed and tangled conductors. Planned structural deformations are controllable and predictable. Unmodified poles are daily broken by automobiles.

Encroachment on the Roadway

After a collision a pole modified by the HBS will remain in approximately the same position laterally (perpendicular to the direction of traffic movement) as it was originally. The upper segment may lean somewhat toward the roadway and the cross arms will be lowered by about 20 ft. The result is that some elements of the cross arms and conductors may protrude slightly into the traveled way if the pole is closer than five feet from the face of the curb or the edge of the traveled way. Although the potential does exist under these conditions for upper structure to be struck by a passing vehicle, the risk is not considered important compared to the damage potential if an unmodified pole is down.

In order to reduce the risk further, reflectorized material or paint might be used on cross arms and upper pole elements where HBS installations are very close to the traveled way.

The HBS has not yet evolved to the optimum design, it is somewhat costly and not without some potential for maintenance problems. There is no doubt selective field application of the system will discover the need for changes yet to be appreciated. The writers are convinced, however, that the proven advantages to public safety, and the degree to which the concerns of the utility industry have been accommodated, place the system in a appropriate position for selective, prioritized field implementation.

Development of a Safety Program

Utility companies should find significant advantages in formulating and pursuing a safety program. State DOT's have had that experience since the 1960's. The most progressive have experienced major benefits from informed and efficient safety programs. In the following paragraphs the writers have suggested the form such a program might take. This is only a general approach and specific details would necessarily be a function of the operating characteristics of individual companies. The steps that might be considered include the following:

a. Conduct a survey of maintenance personnel to determine what poles have required the most maintenance due to vehicle impacts in the last 5 years.

b. Develop a maintenance reporting system so that all maintenance activities due to vehicles impacting utility facilities are documented.

c. Develop an arrangement with local law enforcement officials so that accidents involving utility facilities are recorded by acquisition of hard copy accident reports or acquisition of the pertinent accident from an automated file.

d. Develop a rational for assignment of resources to safety improvements. This might be a joint program with the appropriate highway agency. Depending on the size of the utility and the area encompasses, the appropriate level of resource assignment might not be significant from the viewpoint of a utilities primary objective. It should be significant as a planned effort to gradually increase roadway safety. As the

cost-effective and the extremely positive public and liability aspects become obvious, whatever the original resource designation, it will probably be recognized as advantageous to increase it. In any case, the yearly expenditures will probably be less than the cost of loosing a single significant law suit.

e. Adapt a current cost-effectiveness program based on the data from items a, b, and c, to determine priorities for use of the designated resources. An adaptable benefit-cost methodology is given by Zegeer. Zegeer is currently preparing a document giving instruction on the application of the methodology to specific safety programs.[1] A more general and perhaps somewhat more sophisticated computer code has been developed by Sicking and Ross on the Federal Highway Administration project DTFH-82R-00078, (Roadside Safety Technology Text and Guide). Both of these programs can be used effectively by a utility company.[16]

f. Prioritize the cost-effective areas each year to develop an implementation plan. Begin with the most cost-effective and do as many safety improvement projects each year as designated resources will allow.

g. Monitor all accidents and maintenance costs relative to the safety enhanced sites to determine the degree to which the modifications are reducing overall costs and decreasing injuries and deaths.

Advantages to Utility Companies

Many of the characteristics of the recommended breakaway system and of a benefit-cost program for selective implementation have been discussed in other parts of this report. Here the advantages of a safety program and the highly selective implementation of the HBS will be restated with brief discussion. The reader will be referred to other parts of the report for supportive information. When the advantage is documented by engineering data or experience it will be so stated. When an advantage is the opinion of the writers it will also be stated. The advantages are:

a. Improved Facility Reliability

At the present time when a nonbreakaway timber utility pole is struck at high speed there is significant destruction of conductors as well as the pole. In almost all cases the HBS will prevent conductor damage. (This is documented by the crash tests reported.) Under extreme wind gusts, when some nonbreakaway poles might fail close to the ground line bringing down and damaging conductors, poles modified by the HBS will simply bend at the upper connection, absorbing the energy transmitted by the short duration, intense wind gust, thus preserving the integrity of the transmission facility. (Writer's opinion based on static tests of the HBS.)

b. Reduction of Pole Rot

The installation of a protective sleeve and grouting material around the timber pole to a level 28 in below ground should provide much better resistance to pole rot, have a positive effect on maintenance costs and improve facility reliability. In terms of cost this advantage is in a trade off position with the increased costs of carefully maintaining the upper connection. (This advantage is based on the opinions of individuals from utility companies in New England. The tube length was increased to 30-in to produce this advantage.)

c. Enhanced Credibility

A specific safety program dedicated to the reduction of deaths and injuries, where selective safety modifications were made on a benefit-cost prioritized bases, would greatly enhance the reputation of utility companies with the highway safety community. The defendability of cases involving nonbreakaway poles, where safety improvements would not be cost-effective would be substantially improved. Just as many state DOT's have found in the past twenty years, the best protection is knowledge of the problem and prioritized safety improvement, using the safety funds available or designated in the best way. (This is based on the experience of the writers with many State DOT's.) Utility companies will begin receiving letters from people

thanking them for saving their lives, and fewer interrogatories from attorneys representing severly injured plaintiffs. (This is based on the writers experience in observing the implementation of highway safety structures for the past twenty years.)

and night working conditions. It should be noted that initial installation of the HBS would most likely take place during more favorable working conditions and would possibly involve a larger number of poles than would a repair operation. However, it is assumed that the overall cost of the two operations would be similar.

- Based on the results of the compliance tests reported, it appears that most other types of class 4 construction could be treated in a similar manner, with similar results.

2. Guy Wire Breakaway (GWB)

- GWB meets the requirements of NCHRP 230.

- A series of frangible down guy anchor attachments was developed and tested. It was found that a single galvanized steel pipe insert performs satisfactorily. The test speeds were 20 and 30 mi/h.

- This low-cost modification to down guy anchorage systems greatly reduces the severity of an accident. In this way contact with down guys prior to impacting a breakaway utility pole can be accommodated.

- The tensile strength of the down guy is not reduced by the pipe insert.

3. Cam Redirecting Structure (CRS)

- At a speed of 40 mi/h results of the single feasibility test on CRS met the requirements of NCHRP Report 230.

- The Cam Redirecting Structure (CRS) has the potential to protect vehicle occupants by preventing direct collisions with a utility pole.

- CRS has the potential to minimize the damage sustained by a utility pole due to vehicle collision. It thus may be a major aid in increasing transmission system reliability and decreasing maintenance costs. Both pole and conductors should be protected from damage if the CRS works as designed for a wide spectrum of vehicle collisions.

- The CRS requires further development before implementation can be recommended.

4. Roadside Safety Philosophy

- The proposed "Roadside Safety Philosophy" is logical, practical, and constitutes an evaluation framework that has the potential for better use of limited safety improvement funds.

The Hawkins Breakaway System (HBS) and the Guy Wire Breakaway (GWB) are ready for selective implementation and field evaluation. Used in a benefit-cost prioritized safety improvement program, they hold the potential to make a significant reduction in the 1,600 deaths and 100 thousand injuries that occur annually due to collisions with timber utility poles. There are also significant advantages to utility companies that will occur as selective implementation is undertaken.

Detailed conclusions regarding each of the above subjects are:

1. Hawkins Breakaway System (HBS)

- The Hawkins Breakaway System (HBS) has been adapted and applied to 40-foot class 4 timber utility poles (4/0 construction). The primary system developed for this type of construction consists of a slip base, an upper hinge mechanism, and overhead guy support cables (described in chapter 5). This adaptation of the HBS virtually eliminates the chance of serious injury over a wide range of vehicle collisions.

- Excellent performance of HBS has been achieved for vehicles ranging in weight from 1,800 lb (Honda Civic) to 4,500 lb (full size sedan) at speeds from 20 to 60 mi/h. Mak has found that there is little chance of serious injury at speeds lower than 20 mi/h, even for an unmodified pole.[10]

- HBS meets the requirements of NCHRP Report 230.

- It is estimated that the initial cost of a new HBS installation in a single pole modification will be $1,675 (including $800 for the slip base, upper connection, overhead guys, and miscellaneous hardware; $570 for equipment and labor; and $125 for a new pole). Following a collision in which the HBS is fully activated, repair cost are estimated at approximately $1000 (including labor, equipment, a new pole, and replacement of some of the breakaway hardware). If the pole in the field is still serviceable, these costs may be reduced. Installation
  3S could be accomplished by a
  ;er/derrick and insulated aerial
  iod. Cost estimates are based on
  a trattic congested area, energized electrical power lines,

VI. CONCLUSION

A breakaway design for the modification of timber utility poles which will radically increase the safety of passengers in impacting vehicles has been developed and comprehensively tested. It is called the Hawkins Breakaway System (HBS). This system not only accomplishes the goal of increasing safety but exhibits characteristics of significant advantage to a utility company.

A guy wire breakaway (GWB) device has been developed and tested. It consists of a six foot length of 3/4-in galvanized pipe which acts as a breakable insert into a downguy. The characteristics of this device are also a distinct improvement to vehicle passenger safety, while the strength of the guy wire is not impaired.

A second structure to prevent automobile impacts with timber poles is called the Cam Redirecting Structure (CRS). It is a redirecting device that is unique in the way aspects of crash cushions, slip bases, and guardrail to prevent direct impacts with utility poles. It has been subjected to a single feasibility test with good results. Further development is required before this device is ready for implementation.

A statement of safety philosophy applicable to the evaluation of roadside structures has been prepared. It can be used as the basis for the evaluation of any proposed safety improvement relative to roadside geometry and structures. It was used here to develop compliance tests for breakaway utility poles and to evaluate the results of those tests.

Analysis of the literature relative to the cost effectiveness of breakaway utility poles reveals there will be a positive societal benefit-cost in carefully selected applications.

APPENDIX A
Review of Pertinent Literature Through 1980*
by King K. Mak

Numerous research studies have been conducted on single-vehicle, run-of-the-road type of accidents and their relationships to environmental, vehicle, and human factors in search of safety countermeasures that may reduce or eliminate the frequency and severity of such collisions. A few of the studies address specifically pole accidents, though most of them consider the entire spectrum of roadside hazards. Parallel research efforts have been directed at the design and development of safer roadside appurtenances, such as improved barrier systems and breakaway devices for poles, that will lessen the severity of impacts with them.

The ensuing literature review summarizes some of the most recent and significant findings and is categorized into the following areas of interest:

1. Extent of pole accident problem
2. Effects of roadway and roadside features
3. Breakaway base concepts
4. Cost-effectiveness evaluation.

Portions of this literature review were presented in the Phase I report for this study (2). The presentation in this chapter is an updated version of that literature review with the inclusion of recently completed studies and additional areas of interest not previously covered.

2.1 EXTENT OF POLE ACCIDENT PROBLEM

It is well documented that single-vehicle, fixed-object collisions account for a disproportionate number of fatalities and injuries relative

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*This appendix is Chapter II of the Report "Accident Analysis - Breakaway and Non-breakaway Poles Including Sign and Light Standards Along Highways" by King K. Mak and Robert L. Mason DOT-HS-805-605, August 1980.

to their occurrence. On nationwide basis, the National Safety Council (1) estimated that, during 1976 to 1978, 4.3 percent of all accidents involved single vehicles striking fixed objects and they accounted for 9.3 percent of all fatal crashes. This problem is more pronounced in urban areas where the corresponding figures were 5.0 and 13.3 percent, respectively, as compared to 2.7 and 6.7 percent for rural areas. The ratio of fatal to total accidents appears to be even higher for metropolitan areas. Wright and Mak (3) reported that, in Atlanta, single-vehicle accidents comprised 8.6 percent of all accidents while accounting for 32.3 percent of the fatal crashes.

Poles, including wooden utility poles, luminaires, signs, and signal supports, are among the most frequent objects struck in both urban and rural areas. The definition of a pole varies widely between the various studies. For instance, some studies may include only utility poles and luminaires while others group sign posts together with mailboxes, delineator posts, etc. Thus, a comparison of figures between studies may be somewhat misleading.

In a study by Jones and Baum (4) on twenty urban/suburban areas throughout the United States, it is found that utility poles were the first object struck in 21.1 percent of single-vehicle accidents with luminaires and signal supports accounting for another 7.6 percent. Perchonok, et al (5) reported that 16.9 percent of non-rollover single vehicle impacts on rural two-lane highways involved poles, 10.4 percent of which were utility poles, based on data collected from six states, one each from the six different census regions. Kurucz, et al (6) found that pole impacts accounted for 22 percent of all fixed objects struck in Dade County, Florida.

Similar results were reported in an Australian study by Fox, Good and Joubert (7). In 1976, pole collisions accounted for 5.9 percent of fatal and 4.5 percent of injury accidents in the state of Victoria, Australia. For the Melbourne metropolitan area, the corresponding figures were 8.6 and 5.8 percent, respectively. In terms of fixed-object collisions only, poles were involved in 22.2 percent of fatal and 32.9 percent of injury accidents for the state of Victoria and 45.3 and 51.9 percent, respectively, for the Melbourne metropolitan area. Another study by Vaughan (8) reported that, in New South Wales during 1973, 2.1 percent of all crashes involved single vehicles colliding with poles, accounting for 6.4 percent of all fatal and 4.6 percent of all injury accidents.

The severity of pole impacts is much higher than that of all accidents. Several of the studies cited above (4,5,7,8) reported that over half of pole accidents were injury producing. Impacts with poles, particularly utility poles, are found to be anywhere between 1.5 to 4 times more likely to result in a fatality than are all accidents.

As for individual pole types, utility poles have received the most coverage. In 1973, Wentworth (9) summarized the available data on utility pole collisions and concluded that such data were limited. In a follow-up paper, Graf, Boos, and Wentworth (10) again found that there were only scanty data available on utility pole accidents and estimated that

collisions with utility poles accounted for more than five percent of all fatalities nationwide or 15 percent of fixed-object accident deaths. The authors also pointed out other problem areas such as lack of standards for locating utility poles and insufficient legal authority for the states to undertake corrective measures, and urged the establishment of warrants for such countermeasures as underground placement of utilities and breakaway modifications.

The study by Jones and Baum (4) and the Australian study by Fox, Good, and Joubert (7) are the two most comprehensive studies on pole accidents. The first study addressed only wooden utility pole accidents while the Australian study combines wooden utility poles, luminaires, traffic signal, and tramway poles under the general category of poles. The results of these two studies deserve special attention and are presented separately in the next subsection.

Accident data on collisions involving luminaires and sign supports ar very limited. A few studies have investigated luminaire collisions on rural and interstate highways (11,12), but the emphasis was on the development and evaluation of breakaway concepts and not on accident data analysis. Carlson, et al (13) studied a small number of luminaire and sign accidents and concluded that the breakaway devices performed satisfactorily in reducing the severity of impacts with luminaires and sign supports, despite the small sample size.

2.1.1 Selected Pole Accident Studies

In the study by Jones and Baum (4), data on over 8,000 single-vehicle accidents including 3,270 utility pole accidents, were collected from 20 urban/suburban areas during 1975, consisting of police accident reports and a supplemental roadway inventory. The major findings and conclusions of the study are as follows:

- Utility poles were the most frequent objects struck in urban areas, accounting for 21.1 percent of objects struck for an estimated 2.2 percent of all urban accidents.

- Utility pole accidents were overrepresented on roads with speed limits of 30-40 mi/h and widths of 30-50 feet, as the result of higher than average pole densities.

- Utility pole accidents were overrepresented on straight roads. For curves, left curves were overrepresented as compared to right curves. Also, utility pole accidents frequency was higher for right side than for left side departures. In terms of vertical alignment, utility pole accidents were overrepresented on level roads.

- Utility pole accidents had, with the exception of rollovers, the highest probability of injury of all single-vehicle accidents with over 50 percent being injury producing a fatality rate of 0.8 percent.

- Injury severity increased with higher impact speeds and pole circumference (used to indicate stiffness). Pole offset and spacing did not appear to affect the severity of utility pole accidents.

- The mean societal cost of a utility pole accident was $9,978 (1975 dollars), including $161 in pole repair costs. Comparing to the average cost of $5,900 for run-off-road accidents, the authors concluded that a countermeasure should cost no more than $4,078 for each pole accident expected over its lifetime in order to be warranted.

- Restraint use by vehicle occupants may be the most cost-beneficial countermeasures to the utility pole problem. Underground replacement and relocation of poles are too expensive and unlikely to be cost-effective. The use of breakaway modification may be too expensive and, also, it may increase the probability of rollover. Protecting all utility poles with barriers and attenuators is probably too expensive to warrant its implementation except at particularly dangerous sites.

In the Australian study by Fox, Good, and Joubert (7), 879 pole accidents were investigated during an eight-month period in 1976-1977. Control information was obtained for a random sample of 795 pole sites and 627 vehicles. The key findings of the study are summarized as follows:

- Seventy percent of pole accidents resulted in property damage only. However, in terms of fatal accidents per 100 casualty accidents, pole accident severity is 1.5 times greater than an average accident.

- Sixty-eight percent of pole accidents were at non-intersection sites, nearly half of which involved horizontal curves. The majority of struck poles at curved sites were on the outside of the curve. Pole collisions were considerably more severe at non-intersection sites than at intersections. Also, pole accidents at curves were slightly more severe than on straight roadways.

- Pole accidents are four times more likely to occur on wet than on dry roads. Thirty-eight percent of the pole accidents occurred under wet roadway conditions.

- Sixty-nine percent of pole accidents were frontal impacts. Side and oblique impacts were generally more severe than frontal impacts because of higher occupant space penetration.

- The study uses the concept of 'relative risk' in its analysis, which measures the accident involvement of poles with a given attribute relative to their numbers in the population of all poles. Variation of relative risk is established for individual

attributes or site characteristics. A total relative risk can then be obtained by multiplying the individual relative risks. For major road non-intersection sites, the following site characteristics are included: road width, ADT, horizontal curvature, pole location with respect to start of curve, superelevation, skid resistance, lateral offset and pole location on inside-outside of curve. For intersection sites, the site characteristics are: intersection type, ADT, grade, divided/undivided roadway, skid resistance, and pole lateral offset.

- Pole removal is the most effective method of loss reduction when costs are not considered. Installation of crash barriers or attenuators would not be cost-effective.

- Breakaway or wrap-around luminaire poles produce significantly lower accident costs than rigid luminaire poles with little or no additional costs.

- The arguments sometimes advanced against pole removal or breakaway modification for fear of hazardous secondary collisions with pedestrians, fixed-objects, or other vehicles, are unfounded and, even if they exist, the effects would be insignificant compared with benefits derived.

2.2 EFFECTS OF ROADWAY AND ROADSIDE FEATURES

2.2.1 Effects of Roadway and Traffic Characteristics

There have been a number of studies to determine relationships between accidents and roadway and roadside features. These studies are mostly similar in concept and design. Typically, they have involved taking an inventory of traffic and geometric design features for a selected number of roadway sections and determining the accident rates associated with these sections. Statistical models are then developed relating the accident rates to the various measures of traffic and roadway design characteristics.

One of the earliest studies in this area was conducted in 1957 by the Oregon State Highway Department (14). In this study, predictive equations were developed for total accidents per mile on rural two-lane highways. The study concluded for total accidents per mile on rural two-lane highways. The study concluded that traffic volume is the most important predictor for accidents. A similar study by Head (15) in 1959 for urban extension of state highways in Oregon found that the best predictors are, in order of importance, number of adjacent commercial units, number of traffic signals and intersections, speed, ADT, and pavement width.

Cribbins, et al (16) reported in 1967 on the effects of certain roadway and operational characteristics on accidents on multilane highways. Highway characteristics that were found to be correlated with

all injury accidents were: access-point index, signalized openings per mile, speed limit, traffic volume, and level of service.

Hutchinson and Kennedy (17) reported in their study of encroachments onto highway medians found that curves, approaches to curves, and areas immediately downstream from grade separation structures were regions of more frequent encroachments.

In a 1968 National Cooperative Highway Research Program study (18), Kilberg and Tharp related accident rates to design elements of rural highways using data from five states. The study concluded that:

1. The number of single-vehicle accidents decreased with increased ADT.

2. The presence of gradients, curves, intersections, and structures increased accident rates and the single-vehicle accident rate was primarily affected by the presence of curvature or structures.

3. The larger the number of roadway factors present simultaneously, the higher the accident rate.

4. Partitioning of curvature and grade by a magnitude of four degrees and four percent, respectively, showed no change in the accident rates.

Cirillo, Dietz, and Beatty (19) studied the effects of roadway geometrics on accidents on the interstate system using data collected from 20 states. The results of the study suggested that geometrics accounted for only a small proportion of the variance in accident frequency and that interstate highways are generally improved to the point where variations in geometrics are relatively minor and have little influence on accident frequency and severity.

Chapman (20) examined accident data for a 29-mile section of the Pacific Highway in New South Wales for which the ADT was practically constant throughout its length. He concluded that most of half of the accidents occurred at random while the remainder could be associated with roadway design features. Chapman further reported that the percentage of single-vehicle accidents decreased exponentially with increasing flow on four-lane expressways.

Dart and Mann (21) conducted a study in 1970 to determine the contribution of roadway geometrics to accidents and to predict the accident potential of sections of Louisiana highways. The study concluded that only 46 percent of the variations in accident rates could be explained by geometric factors with pavement cross slope and the number of traffic conflicts per mile as the two key variables. On the other hand, the factors of continuous and marginal obstructions had the least effect on accidents.

Wright and Mak (3) studied the relationships between single-vehicle, off-road, fixed-object accidents and traffic, roadway design, and socioeconomic characteristics on urban two-lane roadways. The study concluded that accident rates are most closely related to average daily traffic, horizontal alignment, and number of intersections per mile.

A study by Wright and Robertson (22) on 300 fatal fixed-object crashed in Georgia concluded that more than 26 percent of fatal crash sites had horizontal curvature greater than 6 degrees combined with downhill gradient of 2 percent of steeper as compared to only 8 percent of comparison sites with such roadway characteristics and should therefore receive the first priority for roadside hazard modification.

Perchonok, et al, (5) recently completed a study on the relationships between single-vehicle accident frequency and severity and roadway and roadside features. Data on over 9,000 single-vehicle accidents were collected from six states, consisting of police accident reports, supplemental field forms filled in by investigating police officers and roadway inventory. Approximately 85 percent of the data was collected on rural two-lane undivided roadways and the remainder on multilane divided highways. Some of the more significant findings are summarized as follows:

- Horizontal alignment was one of the key factors related to the occurrence of accidents with over 40 percent of those sampled occurring at curves. For undivided highways, left curves were overrepresented versus right curves, especially for drivers who were unfamiliar with the roadway or had been drinking.

- Downgrades were overrepresented on accident locations for undivided roadways. Horizontal and vertical alignments interacted to create a condition favorable to the generation of accidents. Let curves on downgrades appeared to be particularly hazardous.

- Accident frequencies were higher immediately after horizontal or vertical curves than they were farther downstream, suggesting an overrepresentation of problems originating at the beginning of curves.

From the results of the studies cited above, it appears that there are considerable variations, even inconsistencies, between the findings of the various studies. Roadway design features, primarily traffic volume, horizontal and vertical alignment and number of intersections and access points, do exert some influence on accident occurrence, especially on rural highways. However, the relationships are not overwhelming with less than half of the variations in accident frequency or rate explained in most cases. This illustrates the complex nature of accident occurrence with roadway features as one of the many influencing factors. Also, the effectiveness of safety countermeasures through modification of roadway features would correspondingly be limited in light of the marginal relationships.

2.2.2 Effects of Roadside and Departure Characteristics

Another facet of single-vehicle, run-of-road type accidents is the effect of roadside and departure characteristics. Once an errant vehicle leaves the roadway, the departure and roadside characteristics will affect the type of collision that ensues.

Stonex (23) measured lateral encroachment distance for accidents on the General Motors Proving Ground and found that 80 percent of obstacles struck were within 30 feet and 90 percent within 50 feet of the roadway. Hutchinson and Kennedy (17), in a study on median encroachments on interstate highways in Illinois reported slightly larger encroachment distances and an average departure angle of 10.9 degrees.

Garrett and Tharp (24) analyzed 324 accidents which occurred on the Ohio Turnpike during five months in 1967. The mean departure angle was found to be 19 degrees with an average departure speed of 60.6 mi/h. The latter two studies reported about 20 percent of the errant vehicles travelled a lateral distance of more than 40 feet which was slightly higher than that arrived at by Stonex.

Perchonok, et al (5) found that right-side departures were more prevalent than left-side departures and at a lower encroachment angle of 13.5 degrees as compared to 18.6 degrees for left-side departures. Also, non-tracking vehicles had larger departure angles with a mean of 22.8 degrees as compared to 14.3 degrees for tracking vehicles. The proportion of non-tracking vehicles was larger on the inside of curves, on grades, and in adverse road surface conditions.

The study reported that 87 percent of the first impacts were within 30 feet of the roadway with a median value of 12 feet. For impacts with wooden utility poles, 36 percent were within the first six feet of lateral offset with less than 10 percent beyond 30 feet. The authors concluded that the likelihood of hitting a wooden utility pole decreased five percent for each six feet of increased offset. Also, impact speed decreased moderately with pole offset exceeding 24 feet.

In the Australian study by Fox, et al (7), it is shown that utility poles located within 5 feet or so of the road edge have a higher-than-average probability of being struck and that the probability decreases in a near-linear fashion with increasing lateral offset up to 10 feet after which there is a little reduction. Similar results were obtained in the study by Jones and Baum (4) in which they found that 50 percent of all utility pole accidents occurred with an offset of 4 feet or less and 74 percent were within 10 feet.

Wright and Robertson (22) concluded that a vast majority of fatal run-off-the-road accidents could have been avoided by eliminating roadside hazards within 50 feet of the road edge. Jones (25) reported that, by relocating utility poles from curbside to a lateral offset of six feet on a two-mile stretch of four-lane roadway in Knoxville, Tennessee, pole accidents were essentially eliminated on that roadway segment.

Other studies have looked at roadside design features with respect to run-off-road accidents. Hutchinson and Kennedy (17) recommended median cross-slopes of 10:1 so that the operator of an errant vehicle would have a better change of regaining control and returning to the roadway. Similarly, Dunlap, et al (26) concluded that a 12:1 or flatter slope was necessary for median dyke sideslopes.

Weaver, Marquis, and Olsen (27) investigated sideslope designs and concluded that return maneuvers could be accomplished by an errant vehicle without rollover on embankments of 3:1 or flatter slopes for encroachment angles up to 15 degrees at speeds up to 60 mi/h. A trapezoidal ditch configuration with front slope of 4:1 or flatter was found to be the most desirable cross section from a safety standpoint. Other roadside features, such as drainage inlet grates, earth berms, and curbs, have also been evaluated (28,29,30).

It is difficult to relate the findings from these studies to actual accident experience One obvious concensus is that the greater the lateral offset of fixed objects, the lower the probability of collisions involving the fixed objects. The handbook on highway safety design and operating practice (31) recommends the use of a 30-foot clear recovery area, wherever possible. However, such clear recovery areas are oftentimes not possible, especially in urban areas where right-of-way widths are restricted due to developments along roadsides. There is currently little information on the safety levels associated with different widths of clear recovery zones. A study is now underway in the National Cooperative Highway Research Program which will provide much more insight into this area.

2.3 BREAKAWAY BASE CONCEPTS

The hazard posed by rigid poles and posts along highways has long been recognized. Since the first research in the area of breakaway devices by the Road Research Laboratory* of the Ministry of Transport in England in the late 1950's, numerous breakaway devices have been developed, tested, and manufactured. Widespread use of breakaway luminaires and sign supports, in conjunction with other safety improvements, have provided the driving public a much safer roadside environment, especially on the interstate system.

Of the twenty or so different breakaway designs currently in use, they all share the same objective which is to limit the amount of force and energy imparted to the impacting vehicle and its occupants by incorporating some form of failure mechanism into the pole base or the pole itself. Presently, safety performance of breakaway supports is evaluated according to Transportation Research Circular No. 191 which stipulates that the impacting vehicle should experience no more than an 1,000 lb-s momentum change and, preferably, less than 750 lb-s.

The various breakaway designs and performance data are discussed in the following subsections for each pole type.

*Now known as the Transportation and Road Research Laboratory

2.3.1 Wooden Utility Poles

Wooden utility poles pose the greatest hazard to impacting vehicles and their occupants, yet advances in the design and development of breakaway devices for wooden poles have been the slowest of the various pole types. In comparison to metal supports for luminaires and signs in which a high level of breakaway performance has been achieved, the wooden pole presents much more demanding constraints, such as:

- The behavior of wood is much less predictable than metal.
- Utility poles are subjected to greater loadings including vertical loads such as weight of transformers and service lines and transverse forces due to unbalanced line tension, wind and ice loadings on service lines. Because of such environmental loading requirements, utility poles are generally more massive with a potentially higher inertia/velocity change effect on the impacting vehicles and occupants.
- The utility pole is part of a system, interconnected to adjacent poles by varying numbers and patterns of service lines. There is concern that when one in a series of poles is struck and breaks, the whole series would fall in a domino fashion.

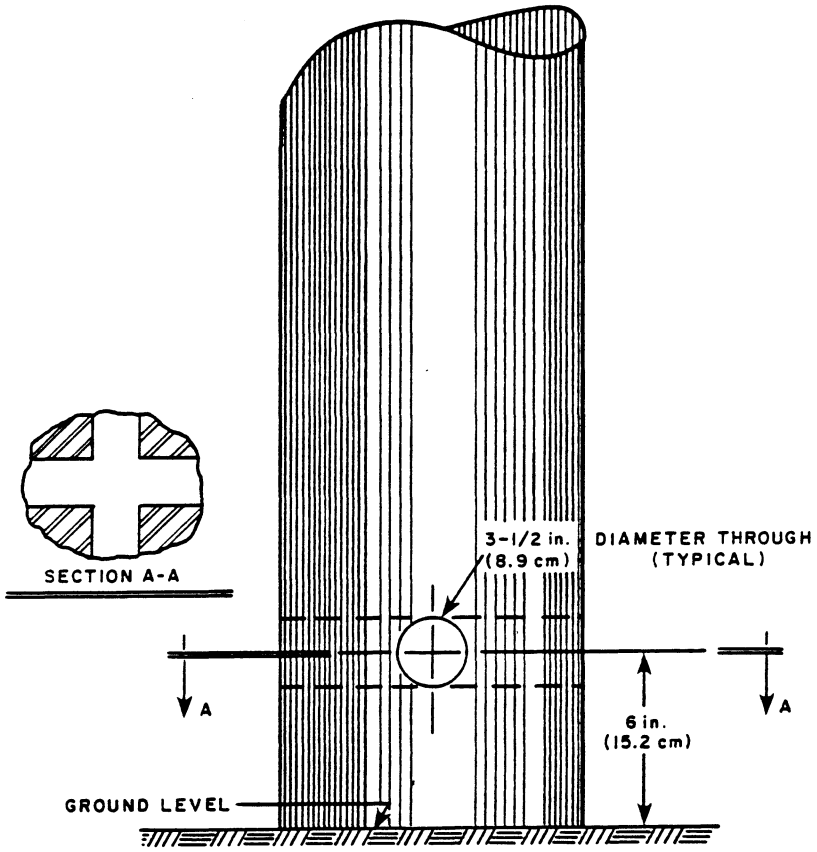
Most of the research and development work on breakaway utility pole concepts has been conducted by Southwest Research Institute. In a 1974 study by Wolfe, et al (32), two holes, drilled 90 degrees apart near the base, supplemented by a circumferential groove, were used to weaken the pole so as to provide the desired breakaway characteristics (see figure 70). A second weakened zone was produced near the top of the pole so that, in the event the pole was contacted and broken, the middle section would breakaway while the top portion of the pole would be supported by the service lines.

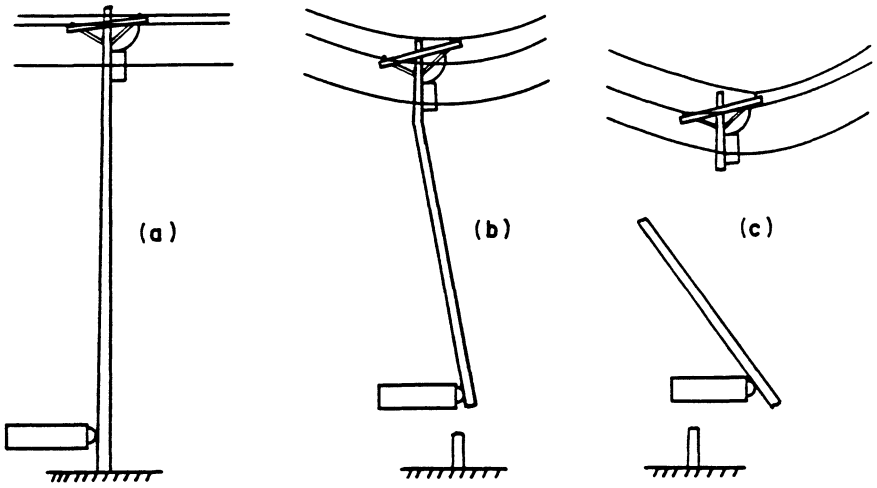
Several objections were raised by utility companies regarding this breakaway concept, including:

- The bored holes would severely reduce the environmental strength of the pole so that the pole might break under severe ice and/or windstorm conditions which could then create a disasterous chain reaction of downed poles.
- The boring of holes in the pole would also greatly decrease its service life, rendering it more susceptible to rotting.
- The test conditions did not adequately simulate real-life situations and thus the results are somewhat questionable.

In a recently completed study by Labra (33), 20 conceptual designs including the aforementioned concept were investigated. The study concluded that the "RETROFIX" design, which consists of patterns of holes and slots cut into the utility pole near grade, provides the best

TWO-HOLE BREAKAWAY POLE CONCEPT





Utility pole fracture sequence: (a) before impact, (b) lower section fracture, and (c) complete fracture

Figure 70. Two hole breakaway pole concept.

compromise between vehicle impact severity, environmental loading capacity, and costs. Figure 71 shows a schematic diagram of the RETROFIX design illustrating the patterns of holes and slots. A crossarm release mechanism is also provided to facilitate breakaway at the upper portion of the pole so that the middle section would break away upon impact. The modified pole retains nearly 90 percent of the moment loading capacity while providing breakaway characteristics close to the specified performance criteria. The cost for the RETROFIX modification was estimated to average $90 (1979) which makes the design economically feasible. This RETROFIX design seems very promising although it is still in the developmental stage.

2.3.2 Luminaires

Breakaway designs for luminaires can be categorized into four major classes according to the failure mode employed, namely:

1. Frangilbe base
2. Progressive shear base
3. Slip base
4. Other

The frangible cast aluminum transformer base is the oldest breakaway design for luminaires in use today. This design has received widespread use because of its low initial and maintenance costs and its simplicity in that there are no extra steps involved in the installation or manufacturing of these bases. Figure 72 shows a schematic diagram of the cast aluminum transformer base. The frangible base is designed to fracture at or below certain recommended base fracture energy (BFE) so that the momentum change criteria will be met. However, this design, with the exception of one manufacturer, fails to meet the new AASHTO breakaway requirements in that the resultant momentum change is higher than the recommended maximum in both laboratory pendulum and full scale crash tests (34).

There are several other breakaway designs based on the same principle as the frangible cast aluminum transformer base for the method of failure. The most notable of these are the frangible cast aluminum shoe base, the frangible cast aluminum insert, and the frangible aluminum shoe base with an integral riser. All these frangible bases have essentially the same BFE and perform similarly in that they perform reasonably well in collisions above 25 mi/h, but not so well at slower speeds (11,12,35-39). The use of these show bases and inserts has been mainly that of upgrading existing non-breakaway bases without a complete change in the base of the pole.

Another type of transformer base in use is the progressive shear steel transformer base (see figure 73). This base design uses the shear strength of spot welds or steel rivets around the skirt to provide for the "progressive" failure of the base on impact. This design was widely accepted in the early and mid-1960's because it was less expensive and readily available. However, testing of the base has shown that it will

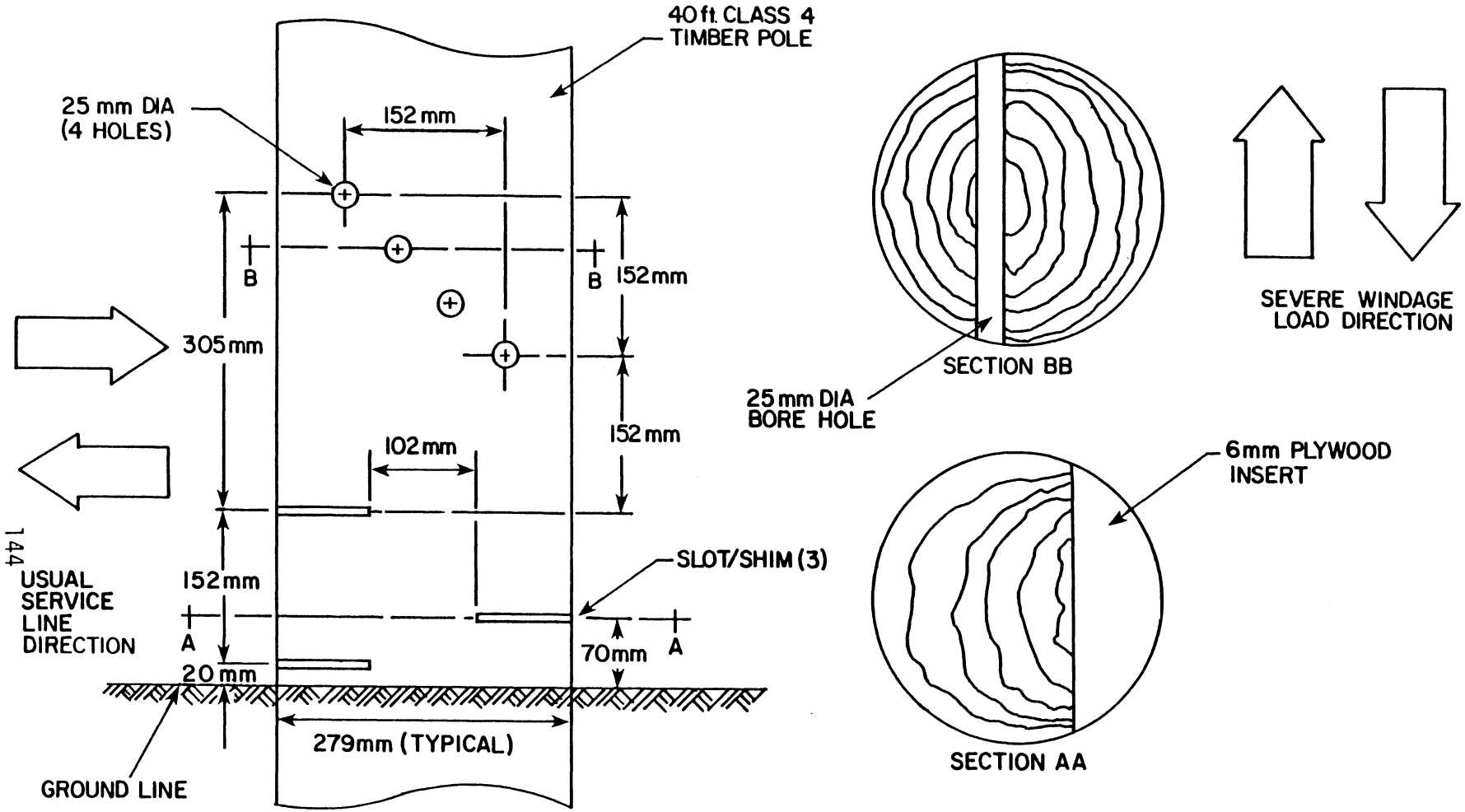


Figure 71. RETROFIX breakaway pole design.

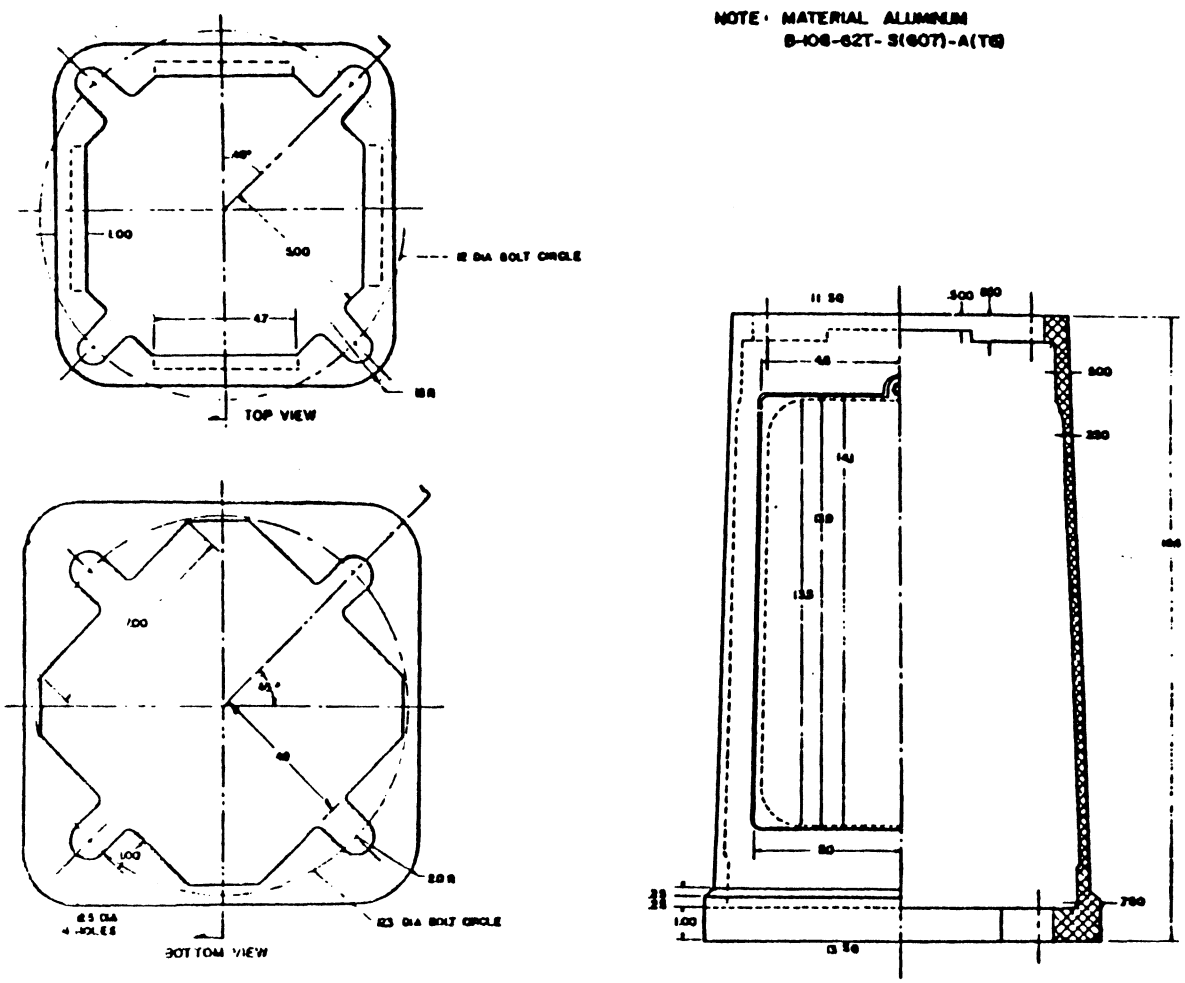


Figure 72. Cast aluminum transformer base.

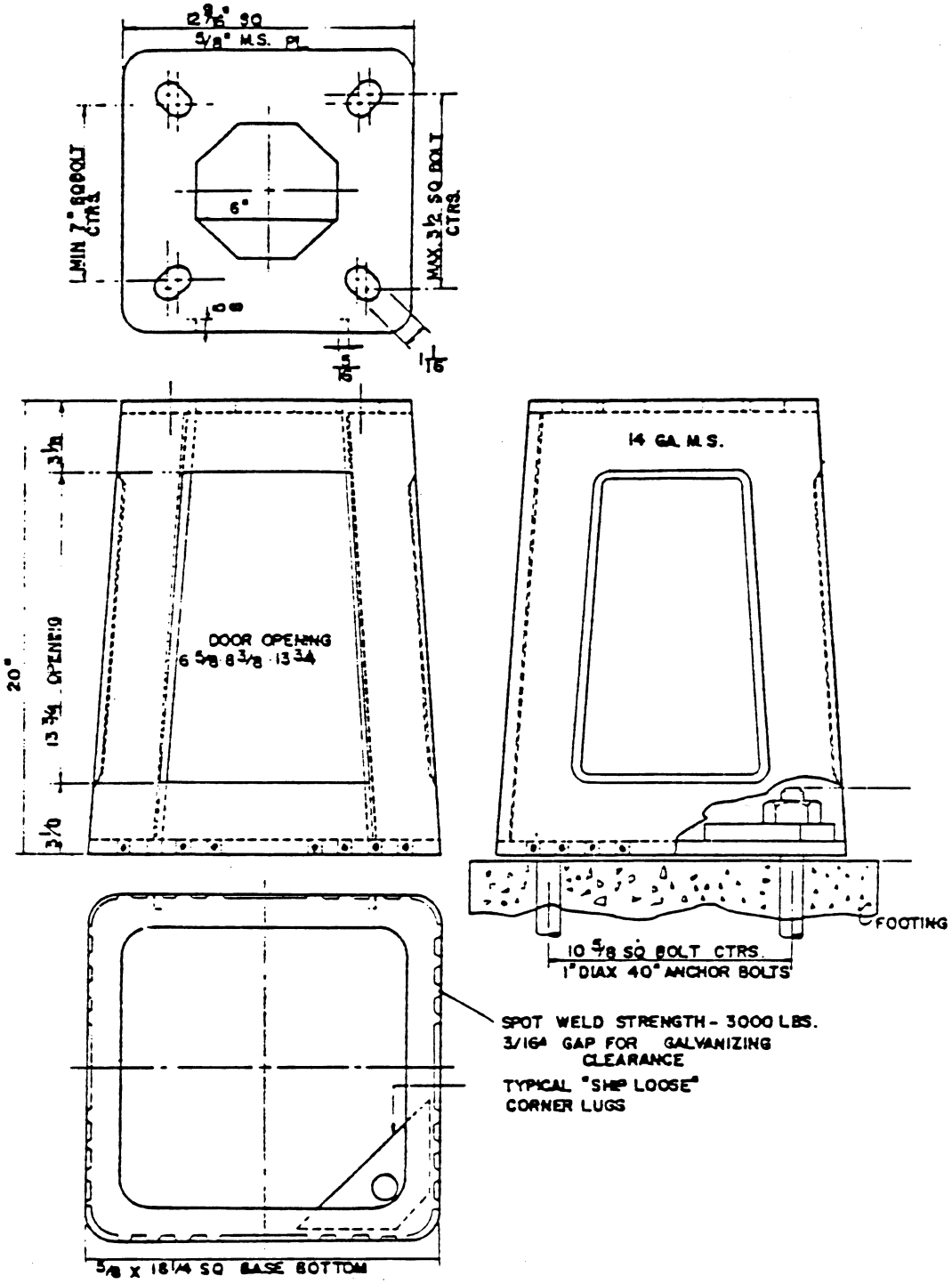


Figure 73. Progressive shear steel transformer base.

perform at acceptable levels only when struck at speeds of greater than 30 mi/h by a large vehicle.

The frangible bases and the progressive shear bases utilize some type of fracture of the metal in the base to attain the breakaway characteristics. A totally different breakaway concept is used in another design known as the slip base design. The most notable is the triangular slip base design developed by the Texas Transportation Institute (see figure 74). Other variations of the slip base design include the Cambridge slip base by the Road Research Laboratory in England (which is the earliest attempt in using slip bases for breakaway luminaires), the unidirectional slip base, and those by General Motors and Union Metal.

The slip base design consists of two plates with cut slots. One of the plates is welded to the base and the other to the luminaire support and the two plates are bolted together at the slots using a redetermined torque. Upon impact, the top plate, with the luminaire support attached, slides in the direction of vehicle travel. Thus the bolts are forced to slide out of the slots, freeing the luminaire support to move with the vehicle.

Testings of the slip bases have shown that the slip base design meets the specified safety performance criteria. Based on results of several studies (11,23,35,36,38,40,41), the slip base design appears to perform the best although it should be cautioned that the testing and reporting procedures were not exactly the same in the various tests which could bias the results of the comparison.

There are other breakaway concepts for luminaire supports that are less common in use, such as the notched-bolt insert, the notched aluminum coupler, and the fluted aluminum breakaway coupling. These designs use necked-down or fluted sections in the bolts or couplings to decrease the energy needed for fracture upon impact. The fluted aluminum couplings have shown acceptable performance according to the specified AASHTO requirements (34). However, the notched designs have a tendency of failing in an area other than the necked-down sections, thus failing to meet the specified safety performance criteria (41).

An alternative design was recently developed in Sweden, called the ESV lighting column, which reduces the probability of any subsequent collisions. The column consists of steel rods spot-welded to a thin sheet steel skin. Upon impact, the spot welds fail and the rods and skin act as independent weaker structures which deform as the vehicle is brought gradually to rest. Since the column is not broken, it has the advantage of trapping the errant vehicle and reducing the probability of any secondary collisions. The disadvantage is that the column is destroyed after each collision resulting in high repair/replacement costs. Test results have shown that this design significantly reduces the average and peak vehicle deceleration though it is not comparable to the AASHTO specifications because of the different failure mechanism (42,43).

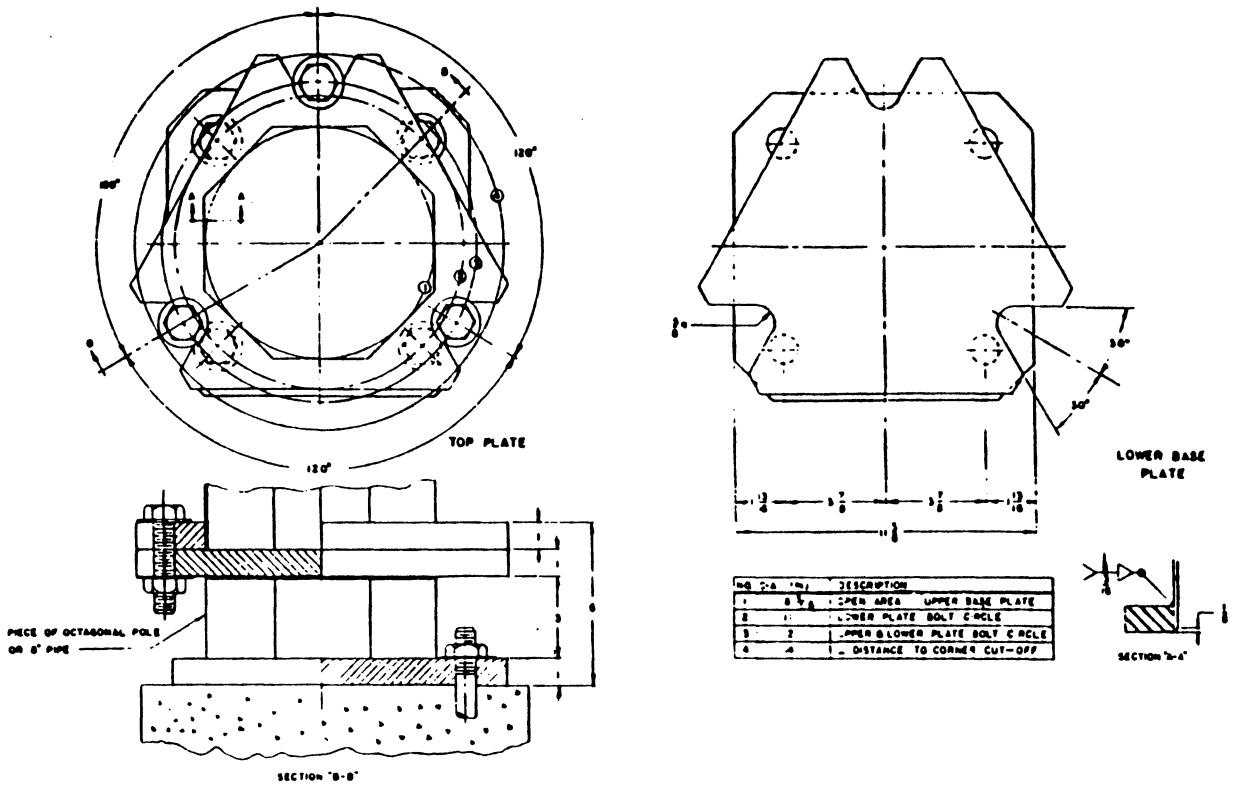


Figure 74. Triangular slip base (TTI).

Another breakaway concept is the use of the fiberglass instead of metal for the pole material. Structurally, fiberglass has a high strength-to-weight ratio so that fiberglass poles can be much lighter in weight and, consequently, lower in breakaway energies and resultant accident damage and injury severity. Fiberglass luminaire poles are currently in service in several countries and appear to be performing satisfactorily. Again, the disadvantage is that the column is usually destroyed after each collision, requiring replacement by a new pole.

2.3.3 Sign Supports

Discussions on breakaway designs for sign supports are divided into three categories according to the size of the support. Overhead sign bridge supports are necessarily massive in nature with grave consequences when impacted. A few systems have been designed to provide breakaway supports for overhead sign bridges, but they are still in the experimental stages (44,45,46). The major concern is that if one of the supports is broken, the sign bridge could fall down onto the roadway, creating an extremely hazardous situation.

The supports for large roadside signs are also fairly massive since the signs and legends must be large enough to be legible from a great distance because of the high travel speeds on roadways where they are used, such as interstate highways. The horizontal slip base design (see figure 75) is used exclusively for these large sign supports. For multiple support signs, an additional hinge joint is provided on the support just below the bottom of the sign face, thus allowing the struck support to bend upward upon impact without damaging the sign (47). Tests with the horizontal slip base design have shown excellent results well within the specified performance criteria.

Slip base designs, either of the horizontal, inclined slip, or triangular types, or used for small signs with great success. The inclined bases, at either 10 or 20 degrees, are designed to give the support and sign an upward acceleration so that the sign will pass over the top of the vehicle at impact speeds above 10 to 30 mi/h (48). At lower speeds, the sign might fall back on top of the vehicle. The inclined slip base is designed to be struck in only one direction for proper performance as compared to the horizontal slip base which can be hit from either direction and the triangular slip base which is multi-directional.

Signs with slip base breakaway designs are used mostly on high speed roadways. On lower speed roadways, most of the small sign supports are of the base bending type, such as pipe with pipe coupling and small U-section formed steel posts strapped to a short piece of pipe anchored in the ground. Wooden posts have also been used extensively as sign supports. From studies in California and at TTI, (49,50,51), the wooden posts can be easily made into a breakaway design by drilling holes in the post or cutting a notch in it. However, the performance of weakened wooden posts is quite unpredictable due to imperfections in the wood and the posts could fail in a different mode than is intended.

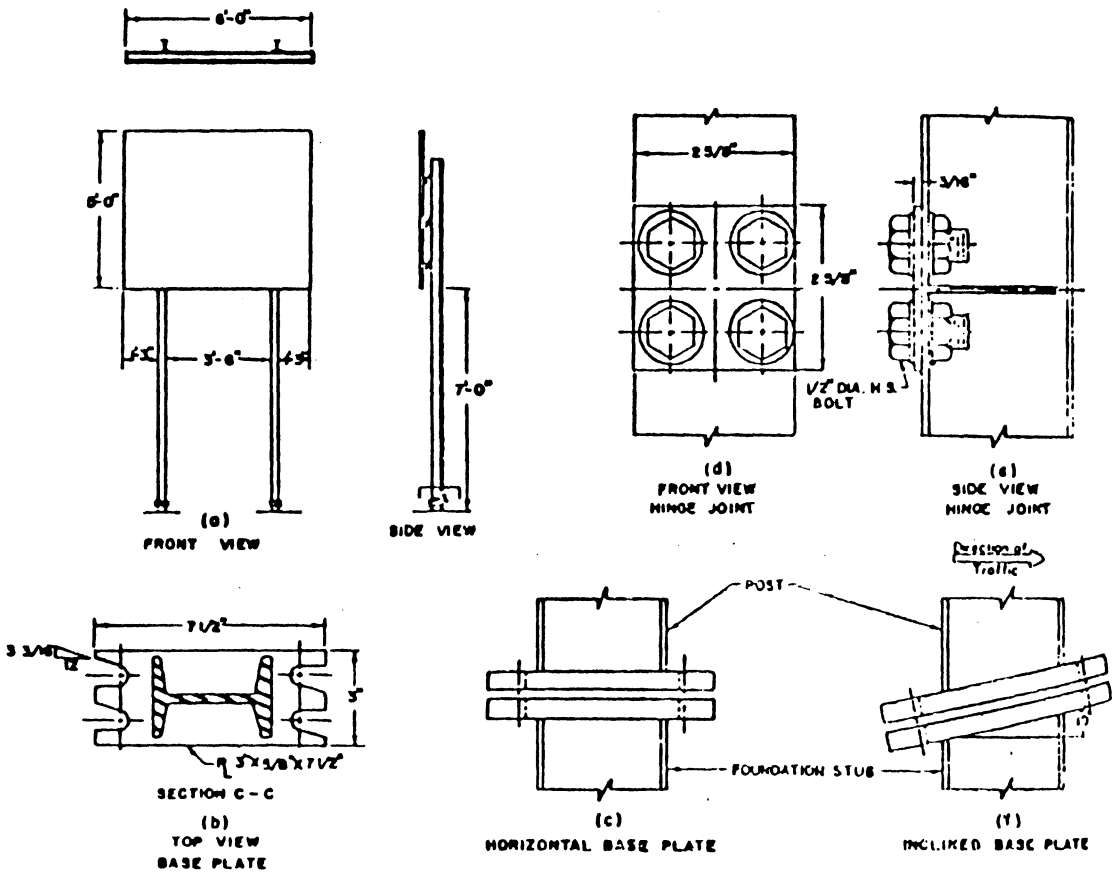


Figure 75. Horizontal and inclined slip base.

2.4 COST EFFECTIVENESS EVALUATION

The purpose of cost-effectiveness evaluation is a two-fold. First, it sets forth a method of comparing alternative safety countermeasures at specific high locations. Second, it provides a means to simultaneously determine which locations should be improved and which alternative safety countermeasure should be implemented at each chosen location (53).

The basic process of cost-effectiveness evaluation is very simple. Typically, a number of candidate highway locations are identified for potential safety improvements. Several alternative countermeasure would be identified for each location and the expected costs and effectiveness would be determined for each of these alternatives. Then, using some form of cost-effectiveness evaluation technique, the most cost-effective set of locations would be determined as well as the alternative countermeasure that should be used at that location.

Over the years, numerous cost-effectiveness evaluation techniques have been developed and implemented by governmental agencies at the federal, state, and local levels. A survey and review of most existing methods is provided in two references (53,54) which are excellent sources of information regarding cost-effectiveness evaluation. For the purpose of this report, only a brief discussion on the most common techniques will be presented.

The benefit-cost method is the most commonly used approach for evaluating alternative countermeasures. Benefits are expressed in terms of expected reduction in accident costs which are compared to expected costs associated with implementation of the countermeasure under consideration. The determination of costs associated with implementation of a countermeasure is a relatively simple task. The cost estimates are generally calculated on an annual or present worth bases, including initial installation, operating and maintenance costs. Other indirect costs, such as traffic delay, air and noise pollution, may also be included.

The determination of accident costs has long been an area of controversy. The major objection is the assignment of a dollar amount to an injury or to a fatality which some people argue is inappropriate. Even for those who agree on the use of monetary values for accident costs, there is no consensus on what the costs should be. The two major accident cost estimates are provided by the National Highway Traffic Safety Administration (55) and the National Safety Council (56) and they differ significantly from each other. The major difference in the cost estimates is the inclusion of the value of an individual's future earnings in the NHTSA figures.

In order to avoid the issue of accident costs, some of the methods use effectiveness as a direct measure. Effectiveness can be defined in terms of reduction in the number of accidents, injuries, or fatalities or some pseudomeasures such as hazard index which is basically a weighted scoring system. Using this approach, a countermeasure is evaluated on the

basis of cast required to achieve a particular effect, e.g., $10,000 for reduction of each injury accident.

Another major problem area is the general lack of information on the estimated effectiveness of individual safety countermeasures. For example, much would the accident frequency and severity be reduced if a line of utility poles is relocated from a lateral offset of two feet to 10 feet? Fifteen feet? Answers to such questions are unavailable on many of the safety countermeasures and, even if available, some are questionable in their validity and accuracy. Solomon, et al (57) and Council and Hunter (58,59) pointed out in their studies that many countermeasures have not been evaluated or have only been poorly evaluated.

Once the costs and benefits or effectiveness are established, there are numerous methods that can be applied to assess the cost-effectiveness. Benefit/cost ratio is the most commonly used method which simply divides the expected benefits by the estimated costs to obtain a ration. If the B/C ratio is equal to or greater than one, the countermeasure is cost-effective, but it is not cost-effective if the ratio is less than one. This simple benefit/cost ratio method has many drawbacks and is generally being replaced by better approaches such as incremental benefit-cost analysis and dynamic and integer programming.

One particular cost-effectiveness model, developed by Glennon (60) deserves special mention since it deals specifically with roadside hazards. A probabilistic approach was adopted in Glennon's model in which a cost-effectiveness ratio is defined as the annualized cost for the reduction of one fatal or non-fatal injury accident. The expected number of fatal plus non-fatal injury accidents per year, or hazard index, is calculated as follows:

$$H = V\ [P(E)]\ [P(C/E)]\ [P(I/C)]$$

where

H = Hazard index or expected number of fatal plus nonfatal injury accidents per year

V = Vehicle exposure

P(E) = Probability of encroachment

P(C/E) = Probability of a collision, given an encroachment

P(E/C) = Probability of an injury (fatal or nonfatal), given a collision.

The probability of encroachment is derived form previous work by Hutchinson and Kennedy (17). The probability of a collision is calculated based on the object size and location while severity indices are established for various roadside objects. The cost-effectiveness ration is then calculated by dividing the cost by the expected reduction in the hazard index for the particular countermeasure under consideration. However, Glennon's model is based largely on theory, and the necessary

input data, such as encroachment frequency, accident probability, and injury probability, are not always available and some of the assumed values are open to question. Nevertheless, Glennon's model has gained much popularity and has been extended to non-freeway facilities (61).

As for the cost-effectiveness of safety countermeasures for pole accidents there is very limited information currently available. Jones and Baum (4) used a benefit-cost approach and concluded that, in order for a utility pole countermeasure to be cost-effective, it could not cost more than $4,078 per expected utility pole accident. Based on this figure, the study concluded that most countermeasures, such as pole removal, relocation, attenuation, and breakaway modification, would probably be too expensive to be cost-effective.

In the study by Fox, Good, and Joubert (7), a benefit-cost methodology was also advocated and illustrated with hypothetical examples. The authors pointed out that the costs and benefits of countermeasures would vary from site to site and should be considered on a case-by-case basis. Council and Hunter (59) also used a benefit-cost approach in their study. Effects of countermeasures were estimated and expressed in terms of expected percent reduction in accident frequency for various severity levels. Glennon (60) assigned severity categories to various roadside features based on which hazard indices could be calculated and compared for the cost-effectiveness evaluation.

2.5 SUMMARY AND DISCUSSIONS

The more recent and significant findings from previous studies are summarized in this chapter, including the following four general areas of interest:

1. Extent of pole accident problem.
2. Effects of roadway and roadside features.
3. Breakaway base concepts.
4. Cost-effectiveness evaluation.

2.5.1 Extent of Pole Accident Problem

Single-vehicle fixed-object accidents, according to estimates by the National Safety Council for the years 1976 to 1978, accounted for 4.3 percent of all reported accidents, but constituted 9.3 percent of all fatal accidents. Thus, single-vehicle fixed-object collisions are 2.2 times more likely to result in fatalities than an average accident. Poles--utility poles, luminaires, sign and traffic signal supports--are the most frequently struck objects in urban areas and among the more frequently struck objects in rural areas. The resultant injury severity of pole collisions, particularly those involving utility poles, is very high. Over half of these pole impacts are injury producing and the injury frequency ranks right behind that corresponding to rollovers and impacts with bridge abutements.

The referenced studies have concentrated mainly on the frequencies of pole accidents and contain little or no information on exposure measures. In contrast, this study will examine not only the frequency of pole collisions, but also the accident rates by taking appropriate exposure measures into consideration. Further, the aspect of unreported pole accidents will also be studied.

2.5.1 Effects of Roadway and Roadside Features

Various roadway and roadside features, such as traffic volume, horizontal and vertical alignment, number of intersections and access points as well as pole density/spacing and lateral offset have been found to exert some influence on the occurrence of pole accidents. Considerable variations, even inconsistencies, however, exist between the findings of the referenced works.

Results from this study will shed more light on the characteristics of pole accident sites. But there is not sufficient evidence to quantify the effects of the various roadway and roadside features in order to assess the effectiveness of safety countermeasures that are aimed at the reduction in the frequency of pole accidents.

2.5.3 Breakaway Base Concepts

State-of-the-art technologies in breakaway base concepts have been greatly advanced through years of research, development, and testing. The breakaway designs currently in use are based on the AASHTO standard of a maximum momentum change of less than 1,100 lb-s and preferably below 750 lb-s. However, there is a general lack of data in the evaluation of the performance of the various breakaway designs under real-world conditions. This study is one of the first comprehensive efforts to assess the performance of various pole types using indepth accident data.

2.5.4 Cost-Effectiveness Evaluation

Numerous cost-effectiveness evaluation techniques and models are available or are in operation for assessing the cost-effectiveness of safety countermeasures. Cost associated with a safety countermeasure are readily available so that the problem lies in the determination of effectiveness. This study will provide an assessment of the effectiveness of breakaway modifications. However, in order to properly address the pole accident problem, the effectiveness of other alternative countermeasures, especially those affecting the frequency of pole accidents, must also be determined in order to select the optimal or the most cost-effective countermeasure(s) for the particular situation(s) under consideration.

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