

TIMBER POLE SAFETY BY DESIGN

by

DON L. IVEY and JAMES R. MORGAN

A PAPER SUBMITTED

to the

TRANSPORTATION RESEARCH BOARD

for the

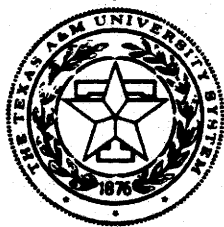
65th ANNUAL MEETING

JANUARY 1986

WASHINGTON, D.C.

Prepared by

The Texas Transportation Institute
SAFETY DIVISION



The Texas A&M University System
College Station, Texas

NOTICE

This report is based on work performed under the Federal Highway Administrations Contract DTF461-83-C-00009, "Safer Timber Utility Poles". Charles F. McDevitt is the Contracting Officers Technical Representative. For more detailed information the report "Safer Timber Utility Poles," Volumes 1 and 2 will be available after November, 1985. The contents of this report reflect the views of the Texas Transportation Institute, which is responsible for the facts and accuracy of the data presented. The contents do not necessarily reflect the official policy of the Department of Transportation.

INTRODUCTION

1. 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. Traditionally, 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.

2. 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 fall more easily during a vehicle impact.⁽⁷⁾ Another weakened zone was introduced near the top of the pole so that under impact conditions the middle section of the pole would breakaway, leaving the top portion still connected to the utility lines. The

best of these designs was called RETROFIX.

3. It appears both the utility industry and Federal Highway Administration decided RETROFIX should not be implemented. This was based primarily on the fact that the pole was significantly weakened in capacity to withstand environmental loads. To try to overcome the strength problem and other concerns of industry the Federal Highway Administration contracted with SWRI to develop a slip base breakaway design. The slip base designed by Bronstad for utility poles appears to be an adaptation of the triangular, three bolt multi-directional slip base developed by Edwards.^(9,5) It represents the first time conventional slip base technology was applied to a timber utility pole.

4. The primary objective of this work was to build on the conventional slip base technology to produce a more 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 an implementable breakaway design. This objective has been realized. A combination of a 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 after D. L. Hawkins, who was the first to suggest slip bases on roadside structures.⁽²⁾ 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. The compliance tests conducted meet the criteria defined by NCHRP 230. The test selection was made using a new statement of safety philosophy described in detail in the full report.⁽²⁵⁾

These comparisons will be detailed in a later section of the report, but the net result is:

5. 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~~2~~³) has been reduced by 91%. In collisions at speeds from 40 to 60 mi/h the probability of severe injury has been reduced by 97%.

These reductions are far in excess of what most researchers considered probable. Zegeer used example values of 30% and 60% reduction in injury and fatal accidents in his benefit-cost studies for FHWA.⁽¹⁾

While the 60% value may not be unreasonable if AIS injuries of 1 are considered, it appears that injuries would be heavily biased to the minor and moderate injury levels (AIS levels 1 and 2). Thus, Zegeer's selection of average accident injury cost for the breakaway design may be inflated, and the Hawkins Breakaway System would be cost effective in a wider spectrum of conditions than was predicted.

6. The HBS design consists of a slip base (similar to those developed by TTI 17 to 20 years ago for use on sign and luminaire supports,⁽²⁾ an upper hinge mechanism, and structural support cables (overhead guys), Figure 1. These mechanisms 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 wind loads 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 por-

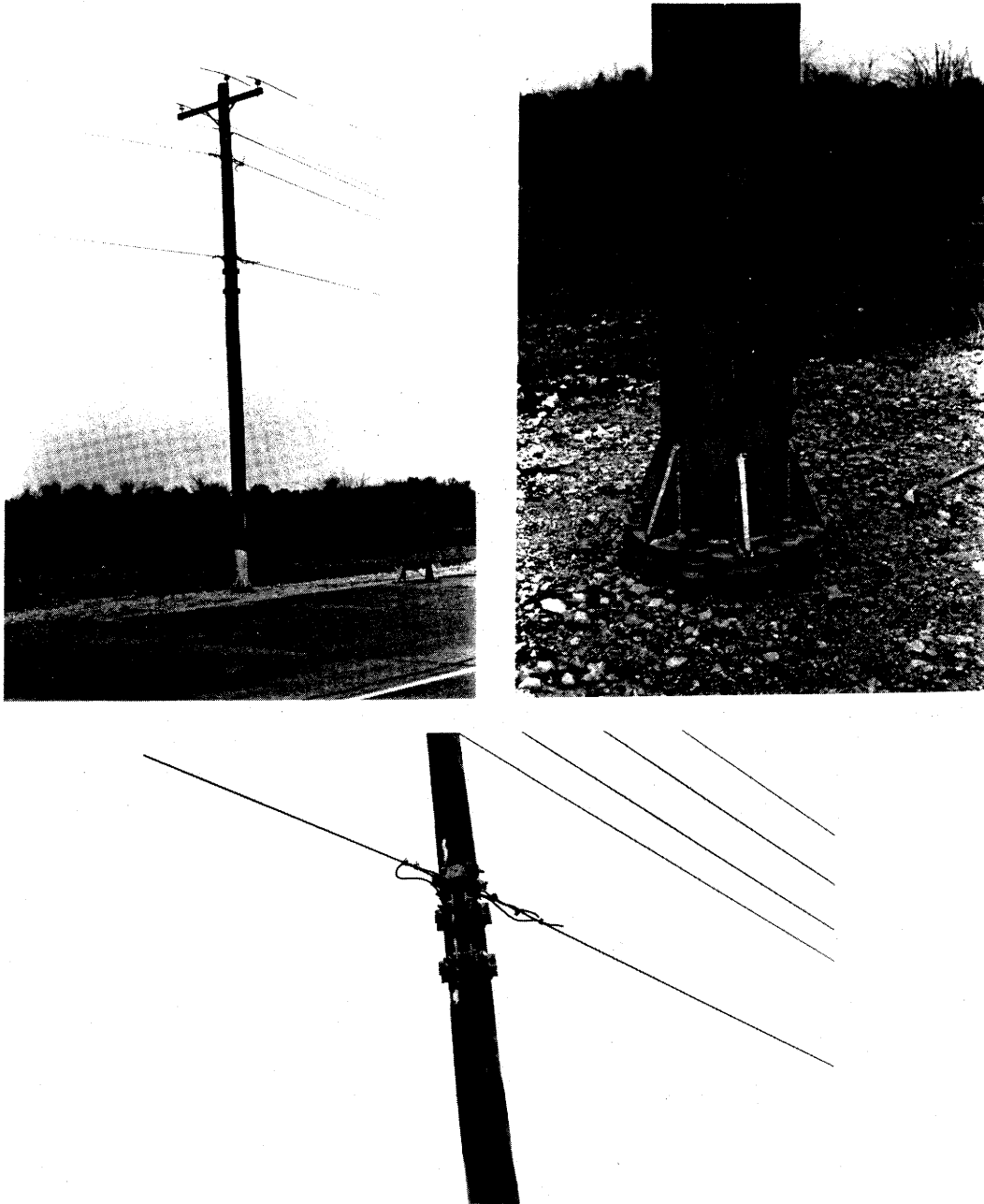


Figure 1. Modified utility pole installation (Typical BA-3 configuration).

tion of the pole during a collision. The entire HBS system is designed to achieve the industry standard safety factor of four before ultimate failure. This design has been verified by static tests.

The way the HBS performs is shown by Figure 2.

7. A series of tests were conducted to verify the performance of the HBS. In selecting the most appropriate test it was necessary to define and adhere to a specific safety criteria. That criteria is:

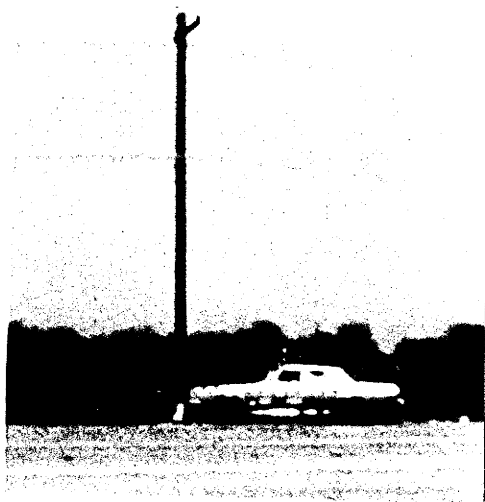
A new structural design for a highway auxiliary structure should be strongly considered for implementation if

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

8. Although this safety criteria may seem self-evident, its acceptance could allow use of structures that vastly improve the safety of the travelling public while not meeting all requirements of NCHRP Report 230 or TRC 191.^(15,14) Although the HBS does meet the requirements of NCHRP 230 and TRC 191 it will be used here as an example of how the alternate safety criteria can be applied.

9. The specific case under consideration is that of utility poles.

1. Will breakaway poles result in a significant improvement in safety for the majority of drivers and passengers?
2. 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)?
3. Are there other proven structural designs of equal or better



Slip base activities

Impact

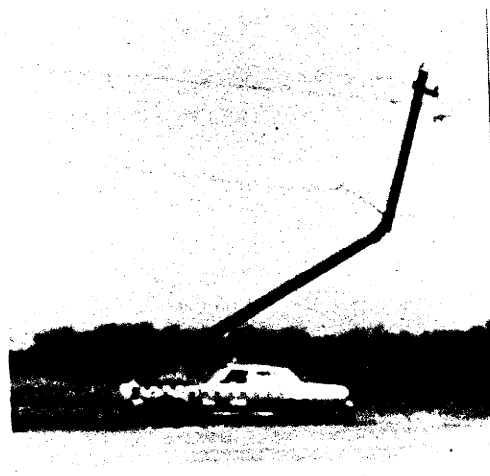


Upper connection starts to bend

Lower part of pole starts to rotate

Upper connection is fully activated

Lower part of pole rotates above vehicle



Vehicle drives under pole



Figure 2, Function of Hawkins Breakaway System During a Vehicle Collision.

cost-effectiveness that produce a safer condition for a larger spectrum of vehicle occupants?

10. It will be shown in later sections that breakaway utility poles, implemented selectively, as suggested by both Mak and Mason and Zegeer and Cynecki will satisfy the proposed criteria.^(10,11) In order to prove that compliance it was necessary to test proposed designs to determine if element one was achieved. The approach to that was to select a series of compliance crash tests that would encompass a clear majority of impact conditions.

11. The tests so selected are shown by Table 1. The primary purpose of each test is shown in the final column. The actual test conditions achieved are shown in parenthesis. For example in test 1 the actual vehicle weight was 1,826 lbs. and the speed determined at impact was 39.9 mph.

HBS PERFORMANCE

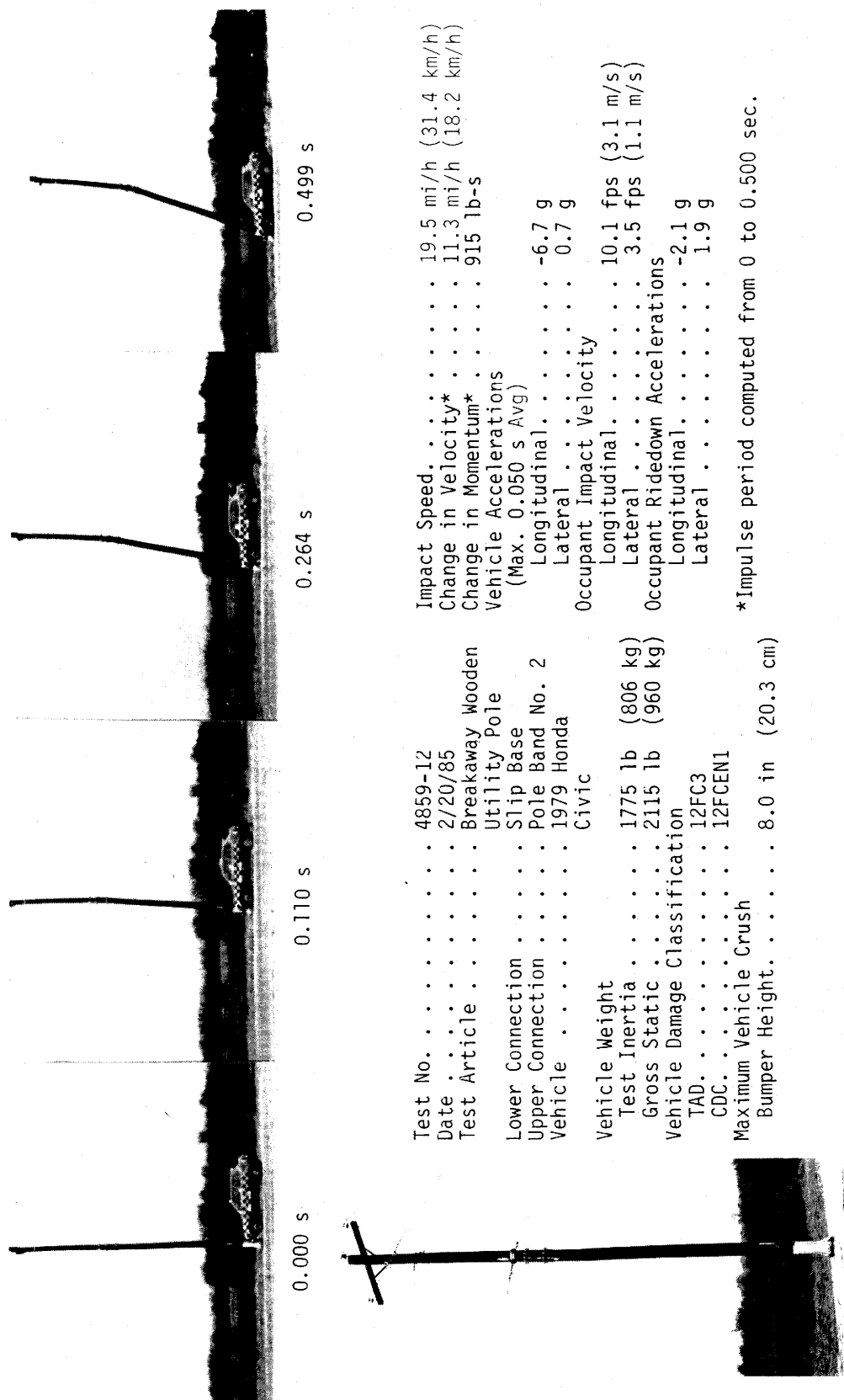
12. The compliance tests outlined in Table 1 were conducted. The results are detailed by Summary Sheets, Figures 3 through 7. In Table 2 changes in velocity, changes in momentum and maximum average 0.050-second accelerations are empirically determined for each test. The probability of injury estimates (%AIS_{≥1}, %AIS_{≥3} and %PI) are made in the following ways.

Method 1. %AIS_{≥1} and %AIS_{≥3}. For the tests conducted this estimate can be made using Mak's Equation for velocity change (ΔV) and momentum change (ΔM),⁽¹⁰⁾ For the hypothetical case of the same vehicle conditions on a non-breakaway pole, a third equation by Mak, depending on vehicle impact speed (V) may be used to make the AIS estimates.

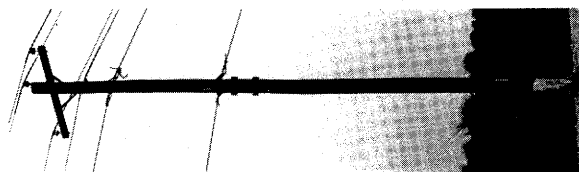
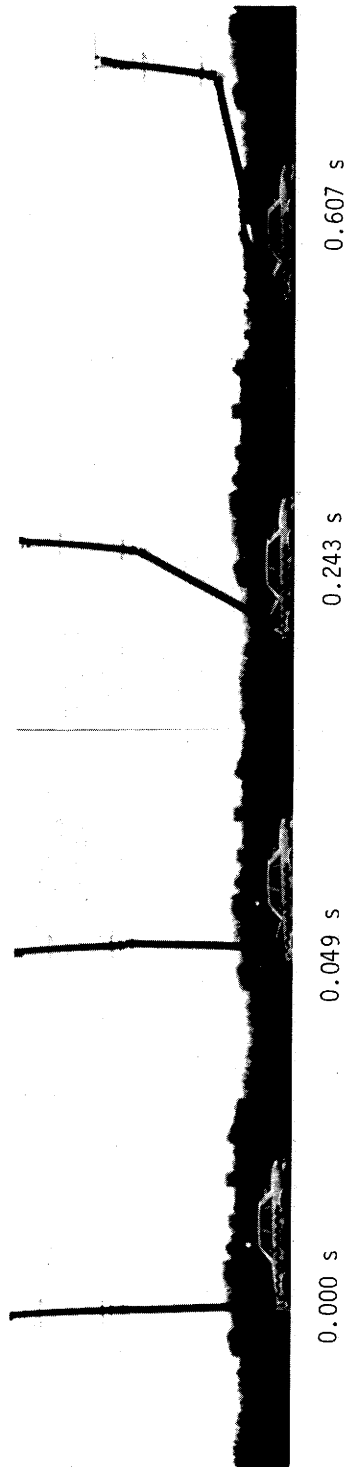
Table 1. Compliance tests for breakaway utility poles.

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 Probability of 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)	4,300-4,800 (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.

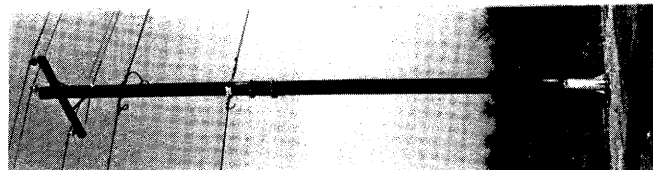
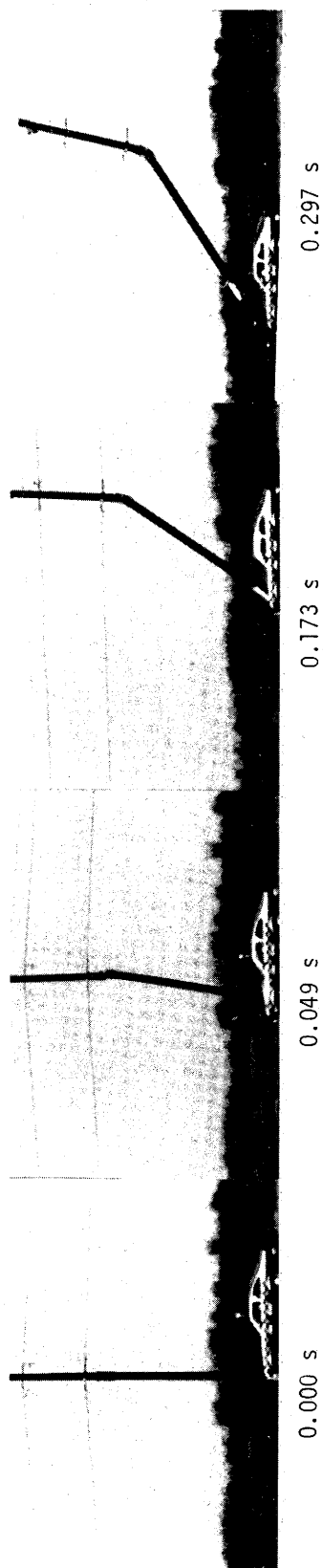


Figures 4. Summary of results for test 4859-12
(Compliance Test 2)



Test No.	4859-13	Impact Speed	40.7 mi/h (65.5 km/h)
Date	2/27/85	Change in Velocity	10.8 mi/h (17.4 km/h)
Test Article	Breakaway Wooden Utility Pole	Change in Momentum	1655 lb-s
Lower Connection	Slip Base	Vehicle Accelerations (Max. 0.050 s Avg)	
Upper Connection	Pole Band No. 2	Longitudinal	-6.7 g
Vehicle.	1980 Chevrolet Malibu	Lateral	1.4 g
Vehicle Weight		Occupant Impact Velocity	
Test Inertia	3365 lb (1528 kg)	Longitudinal.	11.9 fps (3.6 m/s)
Gross Static	3700 lb (1655 kg)	Lateral	6.3 fps (1.9 m/s)
Vehicle Damage Classification		Occupant Ridedown Accelerations	
TAD.	12FC5	Longitudinal.	-1.4 g
CDC.	12FCEN2	Lateral	1.1 g
Maximum Vehicle Crush			
Bumper Height.	18.7 in (47.5 cm)		

Figure 5. Summary of results for test 4859-13.
(Compliance Test 3)



Test No.	4859-14	Impact Speed	60.0 mi/h (96.5 km/h)
Date	3/22/85	Change in Velocity	11.0 mi/h (17.7 km/h)
Test Article	Breakaway Wooden Utility Pole	Change in Momentum	1253 lb-s
Lower Connection	Slip Base	Vehicle Accelerations (Max. 0.050 s Avg)	
Upper Connection	Pole Band No. 3	Longitudinal	-10.2 g
Vehicle.	1975 Chevrolet Vega	Lateral	-1.3 g
Vehicle Weight		Occupant Impact Velocity	
Test Inertia	2500 lb (1135 kg)	Longitudinal	15.6 fps (4.8 m/s)
Gross Static	2830 lb (1285 kg)	Lateral	No Contact
Vehicle Damage Classification		Occupant Ridedown Accelerations	
TAD.	12FR3	Longitudinal	-1.8 g
CDC.	12FREN2	Lateral	NA
Maximum Vehicle Crush			
Bumper Height.	15.0 in (38.1 cm)		

Figure 6. Summary of results for test 4859-14.
(Compliance Test 4)

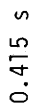
0.218 s

Figure 7. Summary of results for test 4859-5.
(Compliance Test 5)

Table 2. 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 \geq 1 %	AIS \geq 3 %	ΔM lb-s	AIS \geq 1 %	AIS \geq 3 %	g's	PI %	AIS \geq 1 %	AIS \geq 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.

Method 2. Probability of Injury, %. This estimate can be made using a relationship developed by Buth and Ivey (23). It depends on 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 a PI estimate from the same relationship.

13. Although one may see the comparison between any two injury rate levels for any test by examination of Table 2 it is somewhat easier to compare those levels using Figures 8 and 9. These bar graphs were developed for each test speed using Method 1. In Figure 8 it is seen that a significant improvement results. The great improvement, however, is shown by Figure 9. A major decrease in the AIS_{≥3} injury rate is demonstrated. This decrease, for the five compliance tests conducted, averages 91%. It is apparent from Figure 9 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. For the 40 and 60 mi/h test conditions the probability of injury greater than AIS=3 is reduced by 97%.

14. Finally, using all available test data and a computer simulation, figure 10 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

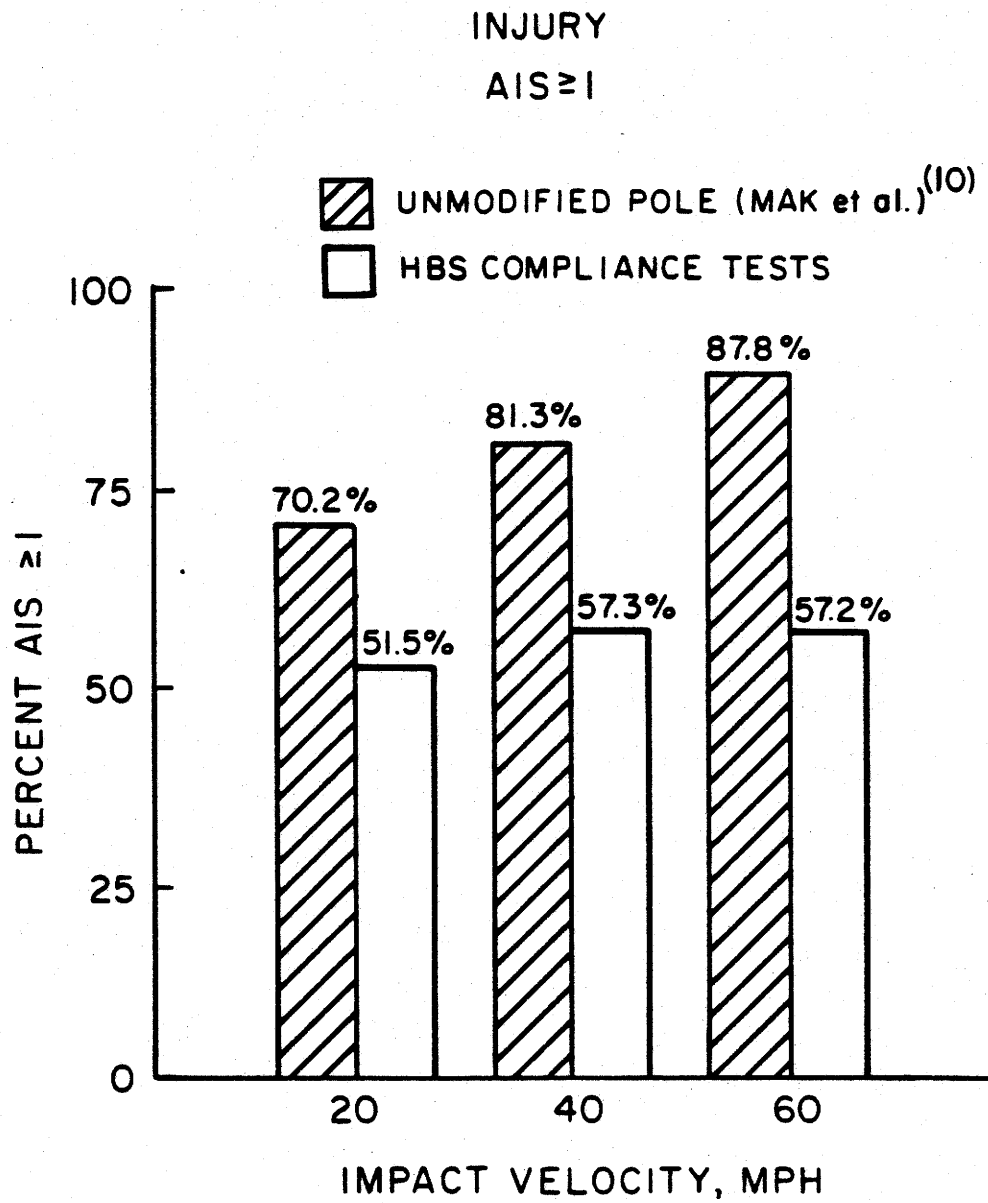


Figure 8. Comparison of injury levels from HBS compliance tests with unmodified pole injury levels (%AIS \geq 1).

SERIOUS INJURY

$\text{AIS} \geq 3$

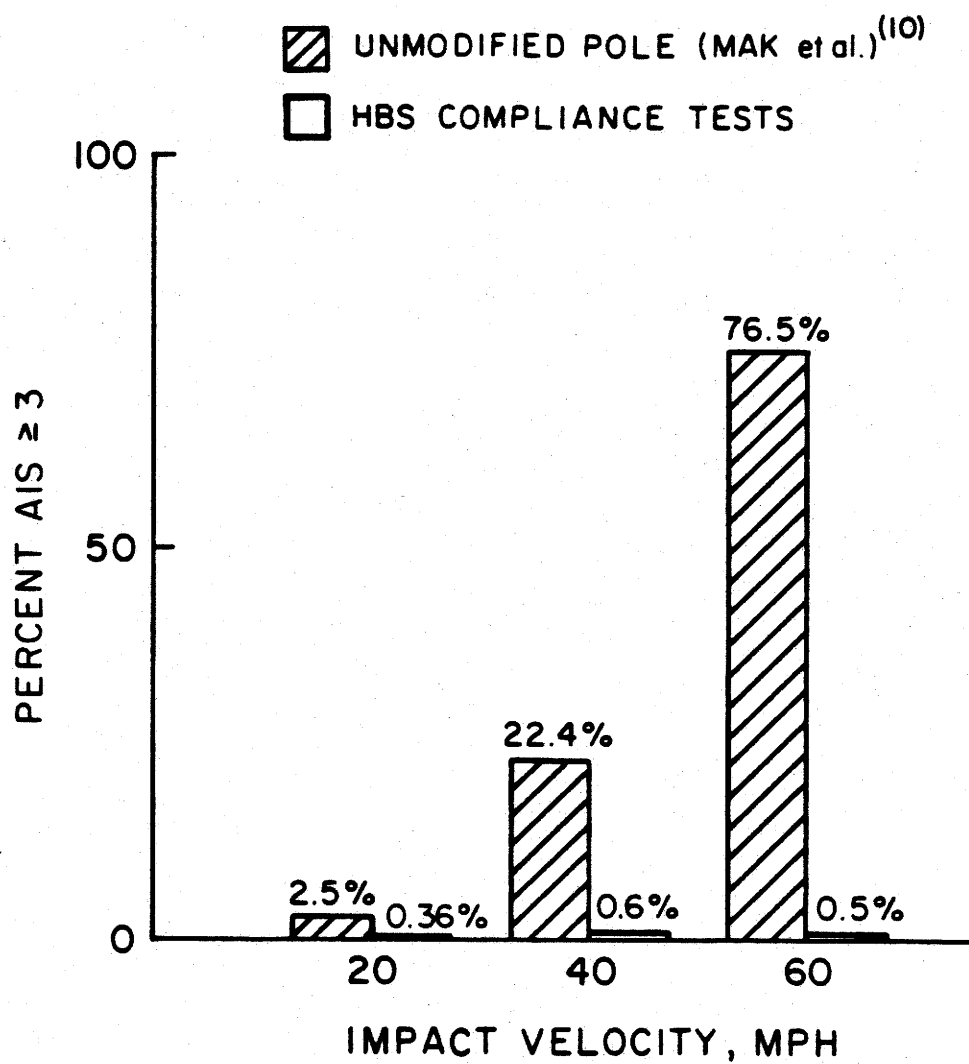


Figure 9. Comparison of injury levels from HBS compliance tests with unmodified pole injury levels ($\% \text{AIS} \geq 3$).

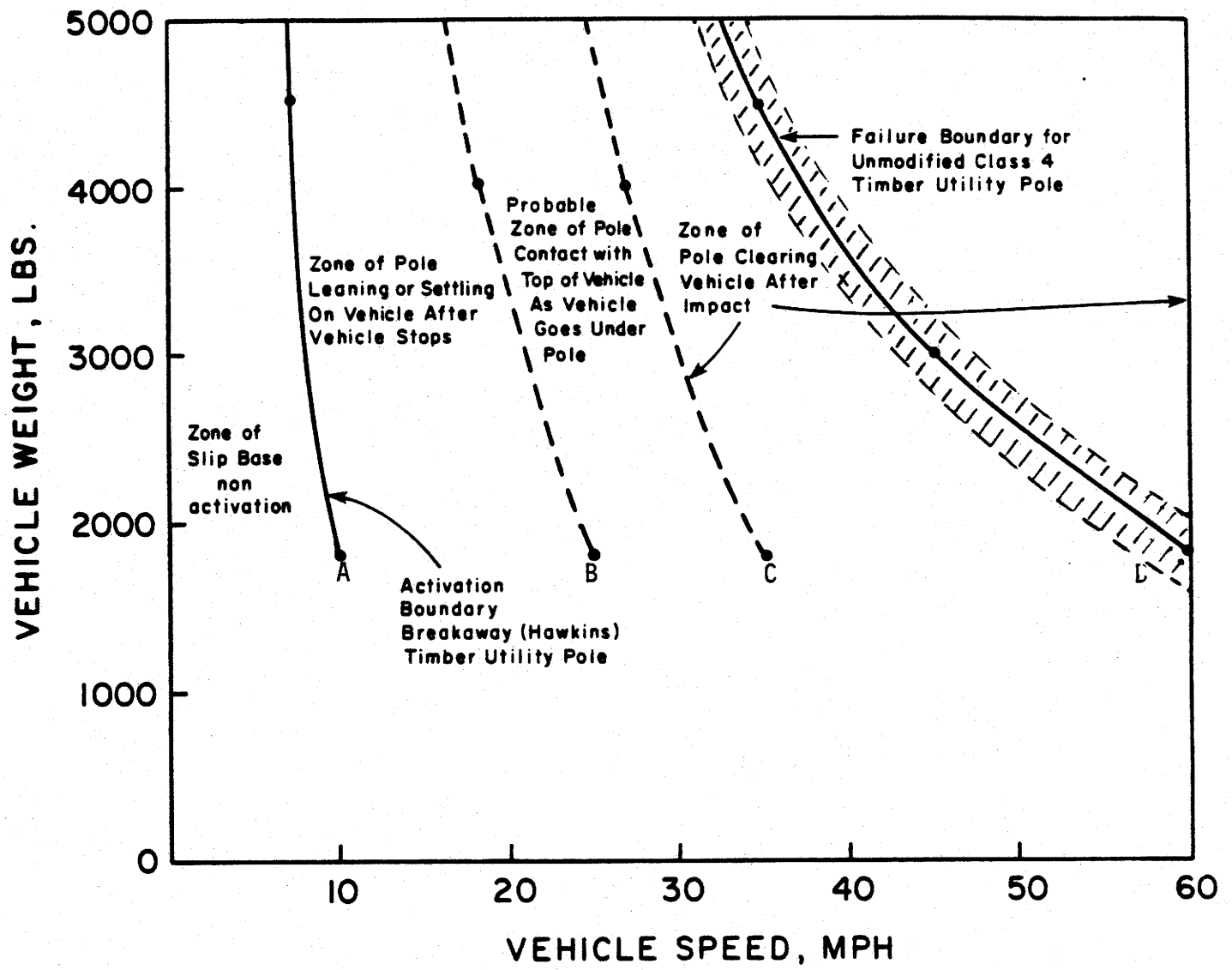


Figure 10. Zones of vehicle-pole interaction.

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 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 230

15. It should be recognized that the recommendations for Timber Utility Poles were considered extremely tentative by the writers of NCHRP 230. The development of break-away devices for these structures was in it's infancy and no one was sure it could be done. Those recommendations for "Occupant/Compartment Impact Velocity" and "Occupant Ride Down Acceleration" were based more on what the authors considered possible than on what would be preferred. In Table 8 of page 32 an acceptance factor of 1.33 was recommended. This resulted in values of ΔV of 30 fps and acceleration of 15 g's. It appears now that break-away timber utility poles can do significantly better than those values recommended in 1981. This can be seen by comparing the results of NCHRP 230 recommended tests for "Breakaway on Yielding Supports" to those values of velocity change and acceleration given above. Table 2 gives this comparison. The required tests are 60 and 61, although in

this case test 62 is substituted for 60, 62 being a more demanding test. The other test conducted was not required but is described as a possible supplementary test in Table 4, page 10. This is test No. 564, an 1800 lb. vehicle at 40 mph impacting at the center of the bumper.

16. As can be seen, the HBS results are well below the maximum values given by NCHRP 230 for Timber Utility Poles and fundamentally meet the requirements for signs and luminaire supports. They are well within the requirements for Ridedown Acceleration and with one exception meet the Occupant/Compartment Impact Velocity. That exception is test 61 where a ΔV of 15.6 fps 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 more appropriate for timber utility poles.

Table 2- NCHRP 230 Compliance Tests

NCHRP Test Designation	TTI Test Designation	Weight		Speed		ΔV		a	
		Suggested lbs.	Achieved lbs.	Suggested mph	Achieved mph	Suggested fps	Achieved fps	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

CONCLUSION

17. 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.

18. An alternate safety criteria to be applied in the evaluation of roadside structures has been developed. It can be used as the basis for the evaluation of any proposed safety improvement relative to roadside geometry and structures. It was used to develop compliance tests for breakaway utility poles but its applicability is general to the roadside environment.

19. 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. The work of Zegeer may be used to define appropriate applications, ⁽¹⁾ although Sicking and Ross have recently developed a more comprehensive benefit-cost analysis. ⁽²⁶⁾

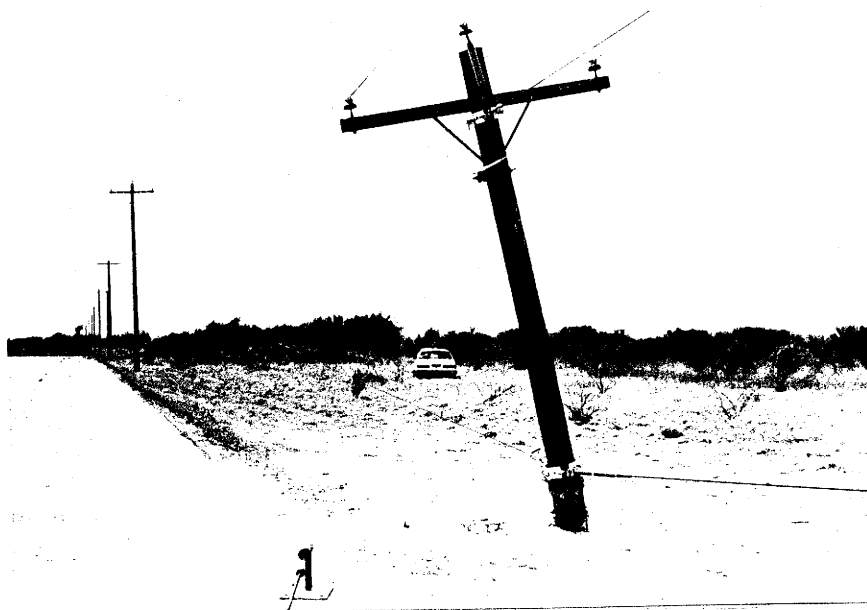
Detailed conclusions are:

- o The Hawkins Breakaway System 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. This adaption of the HBS virtually eliminates the chance of serious injury in a wide range of vehicle collisions.
- o Excellent performance has been achieved for vehicles ranging from 1,800 lbs. to 4,500 lbs. at speeds of 20 to 60 mi/h. Mak has found that there is little chance

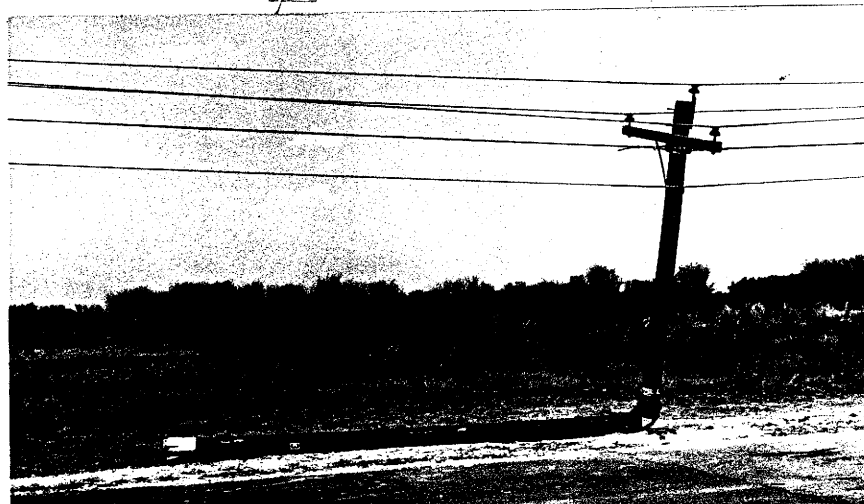
of serious injury at speeds lower than 20 mi/h, even for an unmodified pole.⁽¹⁰⁾

- o The original cost of the HBS for a single pole modification should be less than \$800.00. It is estimated that a 3 person crew with a digger/derrick and insulated aerial device can make all of the necessary repairs following an accident within a 4 hour period. Assuming a traffic congested area, energized electric power lines, and night work conditions, the manpower, material (including a new pole but excluding breakaway hardware) and equipment costs are estimated at \$875.00. Since a new pole will not always be required this cost may be somewhat high. In addition some of the breakaway hardware may need to be replaced (miscellaneous nuts and bolts and a keeper for low speed impacts plus two straps in higher speed impacts). The cost for replacement of breakaway hardware should be less than \$150.00.
- o Based on the results of the compliance tests reported here, it appears that most other types of class 4 construction could be treated in a similar manner, with similar results.

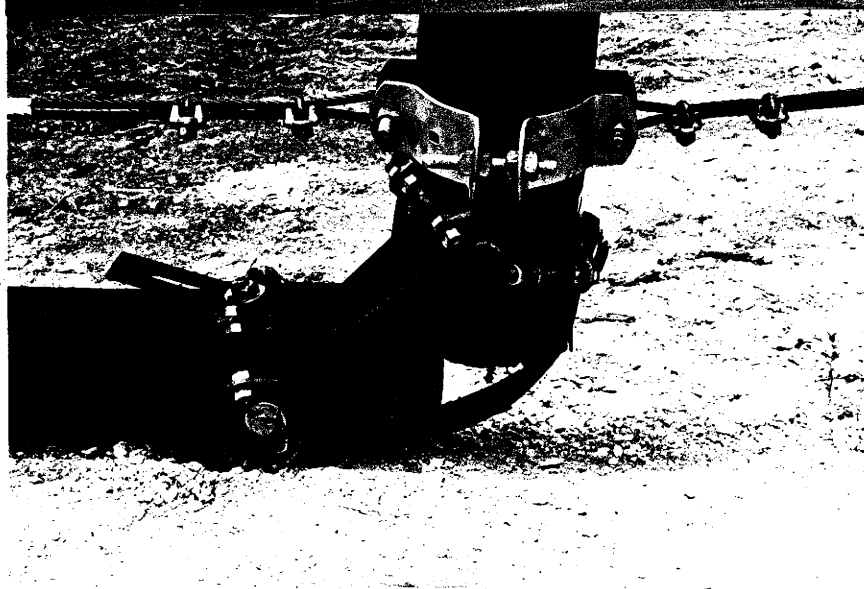
20. The Hawkins Breakaway System (HBS) is ready for implementation. Used selectively, in a benefit-cost prioritized safety improvement program it holds the potential to make a significant reduction in the 1600 deaths and 100 thousand injuries that occur annually due to collisions with timber utility poles.⁽²⁴⁾ There are also significant advantages to utility companies that will accrue as selective implementation is undertaken.⁽²⁵⁾ One major benefit is illustrated by the final Figure, Number 11. After a vehicle collision a utility maintenance crew will find a shortened pole, with conductors still intact and functioning, instead of a tangle of conductors and broken pole segments.



End view



Side View



Fully Activated
upper connection

Figure 11. An HBS modified utility pole after a high speed collision. Test 4859-3.

REFERENCES

- (1) Charles V. Zegeer and Michael J. Cynecki, "Determination of Cost-Effective Roadway Treatments for Utility Pole Accidents," TRR 970, page 52, 1984.
- (2) R. M. Olson, N. J. Rowan, and T. C. Edwards, "Breakaway Components Produce Safer Roadside Signs," Highway Research Record 174, Highway Research Board, Washington, D.C., 1967.
- (3) H. J. Hignet, "High Speed Impact Test on a 40 ft Lighting Column Filled with a Breakaway Joint," RRL Report LR 67, Crowthorne, Pabe 24, 1967.
- (4) T. C. Edwards, J. E. Martinez, W. F. McFarland, and H. E. Ross Jr., "Development of Design Criteria for Safer Luminaire Supports," NCHRP Report 77, TRB, 1969.
- (5) T. C. Edwards, "Multidirectional Slip Base for Breakaway Luminaire Supports," Research Report 75-10, Texas Transportation Institute, August 1967.
- (6) R. M. Olson, D. L. Ivey, et al, "Safety Provisions for Support Structures on Overhead Sign Bridges," Volume VI, Report No. TM-605-6, Texas Transportation Institute, March 1971.
- (7) J. J. Labra, "Development of Safe Utility Poles," SwRI Report, Project No. 03-3283, Southwest Research Institute, San Antonio, Texas, February, 1980.
- (8) G. K. Wolfe, and J. D. Michie, "Development of Breakaway Concepts for Timber Utility Poles," SwRI Report, Project No. 03-3282, Southwest Research Institute, San Antonio, Texas, February, 1973.
- (9) J. J. Labra, C. E. Kimball Jr., and C. F. McDevitt, "Development of Safer Utility Poles," TRR 942, page 42, 1983.
- (10) King K. Mak and Robert L. Mason, "Accident Analysis-Breakaway and Nonbreakaway Poles Including Sign and Light Standards Along Highways, Volume II: Technical Report," Report No. DOT-HS-805-605, NHTSA/FHWA, August, 1980.
- (11) Charles V. Zegeer and Martin R. Parker Jr., "Effect of Traffic and Roadway Features on Utility Pole Accidents," TRR 970 page 65, 1984.
- (12) The Lineman's and Calbeman's Handbook, 6th Edition, edited by H. B. Crawford and M. Lamb, McGraw-Hill, 1981.
- (13) National Electrical Safety Code, 1984 Edition, ANSI CZ-1984, American National Standards Institute.

REFERENCES (continued)

- (14) "Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances," Transportation Research Circular No. 191, TRB, February, 1978.
- (15) Jarvis D. Michie, "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances," NCHRP Report 230, March, 1981.
- (16) "Roadside Safety Design for Small Vehicles," NCHRP 22-6, Hayes E. Ross Jr., Principal Investigator, Start Date June 1, 1985.
- (17) National Transportation Policies Through the Year 2000. National Transportation Policy Study Commission, Final Report, June, 1979.
- (18) C. V. Wootan, "The Changing Vehicle Mix and its Implications," A presentation to the TexITE Winter Meeting, El Paso, Texas, February, 1980.
- (19) D. L. Ivey, "Adequacy of Current Highway Auxiliary Structures to Accommodate Major Changes in the Size of Automobiles," A paper based on a presentation to the 7th Annual North Carolina Conference on Highway Safety, originally titled "Downsizing Cars and Highway Appurtenances," November, 1980.
- (20) John G. Viner, "Implications of Small Cars on Roadside Safety," Proceedings 27th Annual Conference of the American Association for Automotive Medicine, San Antonio, Texas, October, 1983.
- (21) K. K. Mak, H. E. Ross, C. E. Buth, and L. I. Griffin, "Severity Measures for Roadside Objects and Features,:" Final Report, FHWA Contract No. DTFH61-82-C-00045, Texas Transportation Institute, Texas A&M University, College Station, Texas, April, 1985.
- (22) Donald F. Huelke, Numerous presentations and discussions at meetings of AAAM and SAE during the past 10 years.
- (23) C. E. Buth, D. L. Ivey, et al "Safer Bridge Railings," Volume 1, Summary Report, Federal Highway Administration Report No. FHWA/RD-82/072, June, 1984.
- (24) Nicholas L. Graf, James B. Boos, James A. Wentworth, "Single-Vehicle Accidents Involving Utility Poles", TRR 571, p. 36, 1976.
- (25) Don L. Ivey and James R. Morgan, "Safer Timber Utility Poles, Volume 1 , Final Report Draft, Contract DTFH61-83-C-00009, Texas Transportation Institute, June, 1985. 231 pages.
- (26) Sicking, Dean L. and H.E. Ross, Jr., "Comprehensive Benefit-Cost Warrants for Roadside Safety Appurtenances", FHWA Project No. DTFH-82K-0078, June, 1985.