STATIC AND FULL-SCALE VEHICLE CRASH TESTS OF A BREAKAWAY WOODEN UTILITY POLE

by

EDWARD R. POST, P.E.
TERRY J. WIPF, P.E.
ROBERT W. BOLTON, E.I.T.
PATRICK A. CHASTAIN, E.I.T.

Prepared for

FEDERAL HIGHWAY ADMINISTRATION
OFFICES OF RESEARCH & DEVELOPMENT
WASHINGTON, D.C. 20590

CIVIL ENGINEERING DEPARTMENT
RESEARCH REPORT NO. TRP-03-007-80

UNIVERSITY OF NEBRASKA

Engineering Research Center
College of Engineering and Technology
University of Nebraska
Lincoln, Nebraska 68588

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/RD-		

4. Title and Subtitle	5. Report Date
Feasibility Study of Breakaway Stub Concept for Wooden Utility Poles	Jan. 1982
	6. Performing Organization Code: 31V2-132
7. Author(s): Post, Edward R., Wipf, T.J., Bolton, R.W. and Chastain, P.A.	8. Performing Organization Report No.
9. Performing Organization Name and Address: Civil Engineering Department, 226 Bancroft Hall, University of Nebraska-Lincoln, Lincoln, Nebraska 68588	10. Work Unit No.
	11. Contract or Grant No.: DTFH 61-80-P-30071, DTFH 61-81-P-30116
12. Sponsoring Agency Name and Address: Federal Highway Administration, Office of Research, HRS-12, 400 7th Street, SW, Washington, D.C. 20590	13. Type of Report and Period Covered: Final Report, Dec. 1979 to Jan. 1982
	14. Sponsoring Agency Code

15. Supplementary Notes

FHWA Contract Manager: Mr. Charles F. McDevitt, P.E. (HRS-12)

16. Abstract Two full-scale static tests and three full-scale vehicle crash tests were conducted to determine the feasibility of a concept for retrofitting in-place wooden utility poles to breakaway under vehicle impacts. The breakaway concept was originally developed and tested in an earlier study by the University of Nebraska-Lincoln (UNL) on "new" 40 ft (12.2 m) Class 4 Southern Yellow Pine utility poles. This study was a continuation of the work conducted by UNL. Basically, the concept consists of two breakaway joints located 2 in (5 cm) and 8 ft (2.4 m) above ground. The breakaway joints were made by drilling a horizontal row of five 1-in. (2.5 cm) diameter holes in the direction of impact and then sawcutting the spaces between the holes.

The full-scale static tests showed that the breakaway design is structurally adequate to carry the heavy ice lateral loading conditions specified by the National Electric Safety Code (ANSI) for the midwestern state of Nebraska, but that the breakaway design is not structurally adequate to carry the unbalanced longitudinal loading conditions specified in the ANSI Code.

The full-scale vehicle crash tests showed that the breakaway stub design concept was effective in reducing the impact severity of a 2,450 lb (1,110 kg) vehicle collision at 21 mph (34 km/h) and 26 mph (42 kn/h).

In conclusion, it will be necessary to modify the breakaway design concept to bring the pole back up to its full unmodified strength in the longitudinal direction in order that it can carry the unbalanced longitudinal loading specified in the ANSI Code. It is important to point out that any modification must be done in such a manner as not to significantly change the pole breakaway characteristics.

17. Key Words	18. Distribution Statement
Breakaway Poles, Roadside Safety, Vehicle Tests	No Restrictions. This document is available through the National Technical Information Service, Springfield, VA. 22161

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

Form DOT F 1700.7 (8-69)

ABSTRACT

Key Words: roadside safety, wooden utility pole, computer simulation, full-scale vehicle crash test, cost-effectiveness

In the development of roadside safety improvement programs, many types of obstacles have been identified as being hazardous. In some cases these obstacles can be removed or relocated. The utility pole is an example of an obstacle that cannot be relocated easily. The severity of vehicle impacts with roadside obstacles can be reduced by making modifications to the obstacle in place. This study investigates the feasibility of a breakaway utility pole concept developed by the Transportation Research Program at the University of Nebraska-Lincoln.

Pendulum and full-scale vehicle crash tests were conducted to determine the feasibility of the breakaway concept as well as to provide an understanding of the mechanics involved. A computer simulation model was developed and validated with data obtained from the tests in order to assist in the evaluation of the breakaway concept. A cost-effectiveness analysis was performed using severity index and probability of injury values calculated from results of full-scale tests and the computer simulations.

Three full-scale vehicle crash tests were conducted using 40 ft. Class 4 Southern Pine utility poles. A large test vehicle (4450 lbs) was used for the first test and a small vehicle (2250 lbs) was used for the final two tests. The results of this study indicate that:

(1) the breakaway concept is effective in reducing impact severities and therefore the probability of injury

(2) the breakaway concept is cost-effective.

TABLE OF CONTENTS

		Page
I	INTRODUCTION	
	I-A UNL Breakaway Concept	1
	I-B UNL Full-Scale Vehicle Test Results	4
	I-C Study Objectives	8
II	DESIGN OF BREAKAWAY UTILITY POLE	9
	II-A Typical Design Pole	9
	II-B Design of Breakaway Joints	14
	II-C Longitudinal Moments	17
III	FULL-SCALE STATIC STRENGTH TESTS	20
	III-A Testing Apparatus	20
	III-B Test Evaluation Procedure	22
	III-C Results of Test No. 1	22
	III-D Results of Test No. 2	25
	III-E Comparison of Static Test Results	25
IV	FULL-SCALE CRASH TESTS	29
	IV-A Description of Test Site	29
	IV-B Description of Full-Scale Vehicle Testing Apparatus	29
	IV-C Breakaway Joints	32
	IV-D High-Speed Photographic Equipment and Setup	34
	IV-E Results of Full-Scale Crash Test No. 2-1	35
	IV-E-1 Comparison of Crash Test No. 2-1 and Test No. 2	44
	IV-F Results of Full-Scale Crash Test No. 2-2	46
	IV-G Results of Full-Scale Crash Test No. 4-1	49
	IV-G-1 Comparison of Test No. 4-1 and Test No. 2	57
V	SUMMARY AND CONCLUSIONS	59
	V-A Full-Scale Static Tests	59
	V-B Full-Scale Crash Tests	61

Table of Contents (continued)

	Page
REFERENCES.	65
APPENDIX A - FULL-SCALE STATIC TESTS.	66
APPENDIX B - HIGH-SPEED FILM ANALYSIS	80
APPENDIX C - VEHICLE INSTRUMENTATION.	88
APPENDIX D - DAMAGE ESTIMATES ON FULL-SCALE TEST VEHICLES	100
APPENDIX E - CONSTRUCTIVE CRITICISM BY LINCOLN ELECTRIC	104

LIST OF FIGURES

Figure		Page
1	Photographs of Typical Utility Pole Field Installation	2
2	Breakaway Stub Concept for Wooden Utility Poles	3
3	Breakaway Stub Concept Hole Pattern	5
4	Photographs of Full-Scale Test No. 2	7
5	Typical 40 ft. Class 4 Breakaway Utility Pole: Dimensions, Arrangement, Applied Loading, and Moments	11
6	Properties of Breakaway Joint	15
7	Drilling Jig (4 x 4 10 D.F. Wood Block)	18
8	Static Test Loading System	21
9	Load Diagram for Static Test No. 1	23
10	Static Test No. 1	24
11	Load Diagram for Static Test No. 2	26
12	Photographs of Static Test No. 2	27
13	Location of Full-Scale Test Site	30
14	Reverse Vehicle Two and Rail Guidance System	31
15	Photographs of Full-Scale Test Site	33
16	Vehicle Velocities for Test No. 2-1	36
17	Vehicle C.G. Decelerations for Test No. 1-2 and Test No. 2-1 . .	37
18	Sequence Photographs of Test No. 2-1: Closeup Views	38,39
19	Sequence Photographs of Test No. 2-1: Far-away Views	40
20	Documentation Photographs of Test No. 2-1	41
21	Illustrations of Critical Failure Modes of Lower Breakaway Joint and Pole Snagging on Ledge in Test No. 2-1 . . .	42
22	Vehicle Velocities for Test No. 2-2	47
23	Vehicle C.G. Decelerations for Test No. 2-2	48
24	Sequence Photographs of Test No. 2-2	50
25	Documentation Photographs of Test No. 2-2	51
26	Insulator-Conductor Connection Details	53
27	Documentation Photographs of Test 4-1.	54
28	Sequence Photographs of Test 4-1; Closeup Views.	55
29	Sequence Photographs of Test 4-1; Wideangle Views.	56

LIST OF TABLES

Table		Page
1	Results of Full-Scale Vehicle Crash Tests on UNL Breakaway Utility Poles Stub Concept (after Post)	6
2	Summary of Utility Pole Lengths (after Labra)	10
3	Design Specifications for Wood Utility Poles	12
4	Magnitude of Applied Loads	13
5	Required Dimensions of Breakaway Joints	17
6	Comparison of Ultimate Moments	28
7	Photographic Equipment	34
8	Vehicle Damage Reports For Test No. 2-1	44
9	Comparison of Results From Test No. 2-1 and Test No. 2 . . .	45
10	Comparison of Results From Test No. 4-1 and Test No. 2 . . .	58
11	Summary of Full-Scale Crash Test Results	62

I. INTRODUCTION

During the past decade, considerable attention has been given to improving roadside safety by removing or relocating point hazards in the immediate vicinity of the travelled roadway. In many cases where point hazards could not be readily removed or relocated, the hazards were made to break-away when struck by an errant vehicle. Research and accident experience have shown that breakaway sign supports and luminaire supports have been very effective in reducing the accident severity of vehicle impacts. However, not until recently has much attention been given to wooden utility poles. In a recent Transportation Research Board (TRB) report, Jones (1)* found that utility poles represented the most frequent object struck in urban single-vehicle accidents and the most frequent source of injury. Typical utility pole installations located in the immediate vicinity of the travelled roadway which would warrant attention are shown in Figure 1.

I-A. UNL Breakaway Concept

In 1978, a concept for retrofitting existing wooden utility poles in the field to breakaway under impact was proposed by Post (2) at the University of Nebraska-Lincoln (UNL); and, in 1979, a study was conducted by Post to determine the feasibility of the breakaway concept. As shown in Figure 2, the breakaway concept consisted of making two breakaway joints located 2 in. (5.1 cm) and 8 ft. (2.4 m) above the level of the ground. The breakaway failure mechanism was found to be dependent on the impact speed of the vehicle. Under low-speed vehicle impacts, only the lower breakaway joint actuated thereby allowing the pole to rotate about the conductors and slowly bringing the vehicle to a stop as illustrated in Figure 2a. However, under high-speed vehicle impacts, the vehicle knocked out the stub between the lower and upper breakaway joints thereby allowing the vehicle to pass safely under the portion of the pole above the upper breakaway joint as illustrated in Figure 2b.

---

* Reference designation number

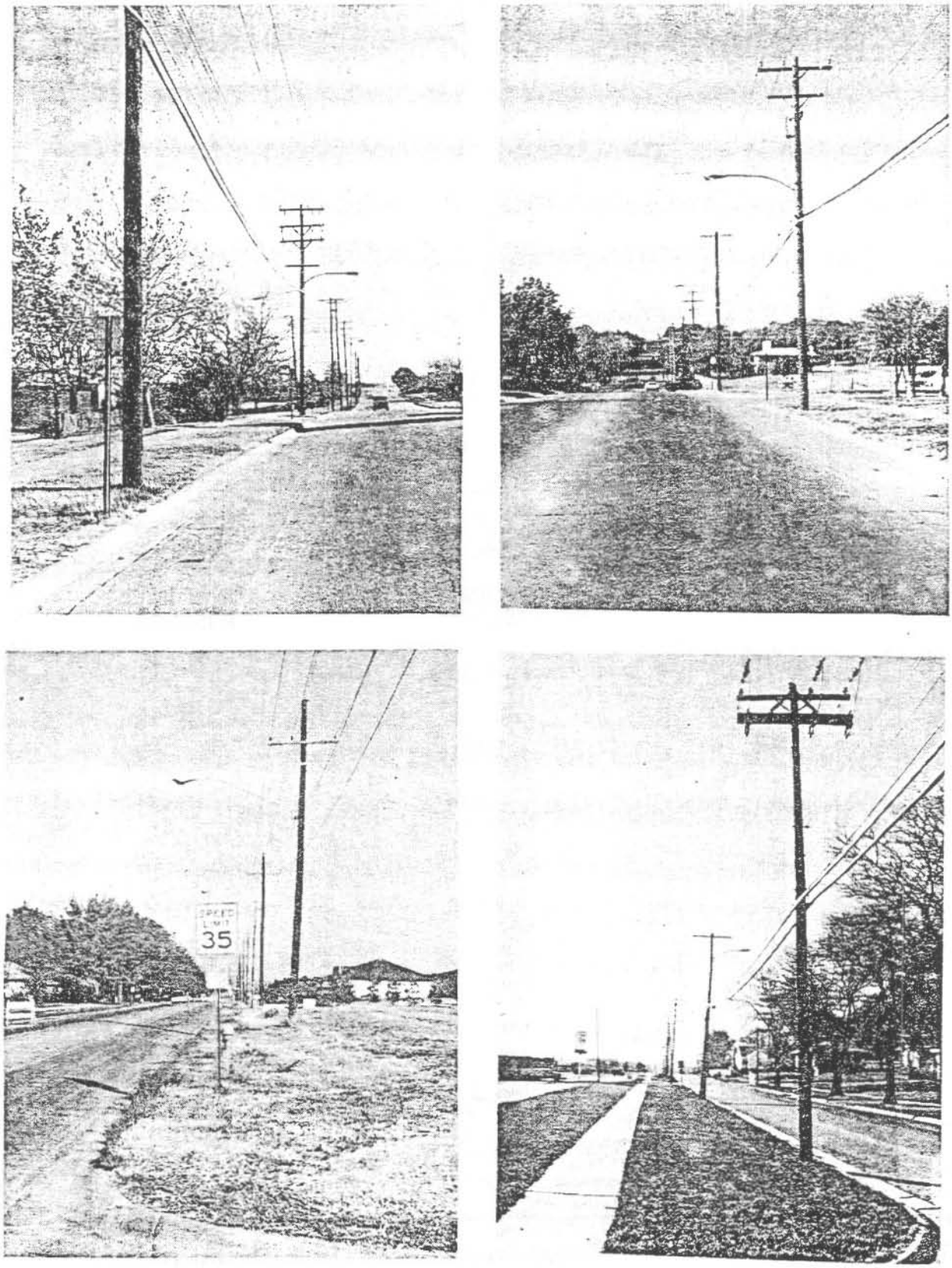


FIGURE 1. PHOTOGRAPHS OF TYPICAL UTILITY POLE FIELD INSTALLATIONS

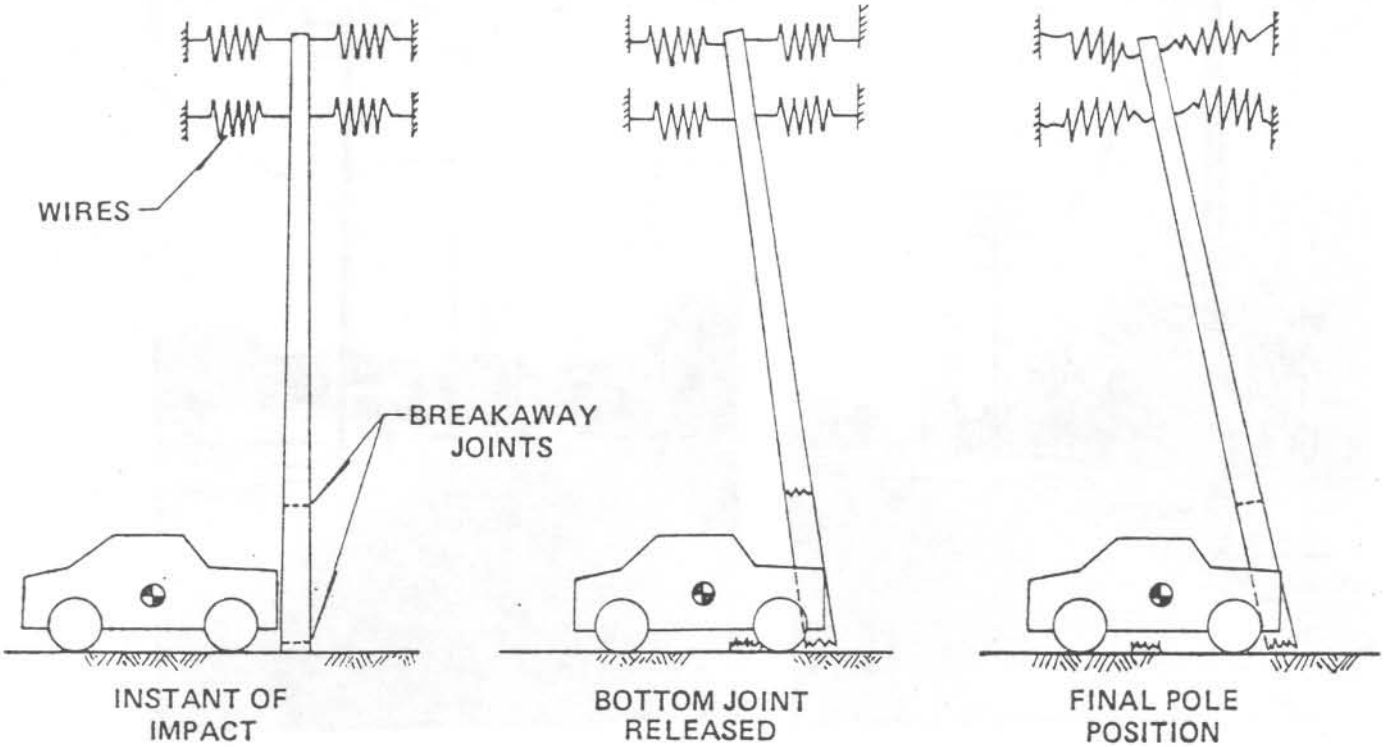


Figure 2a. Low-Speed Impact Failure Mechanism

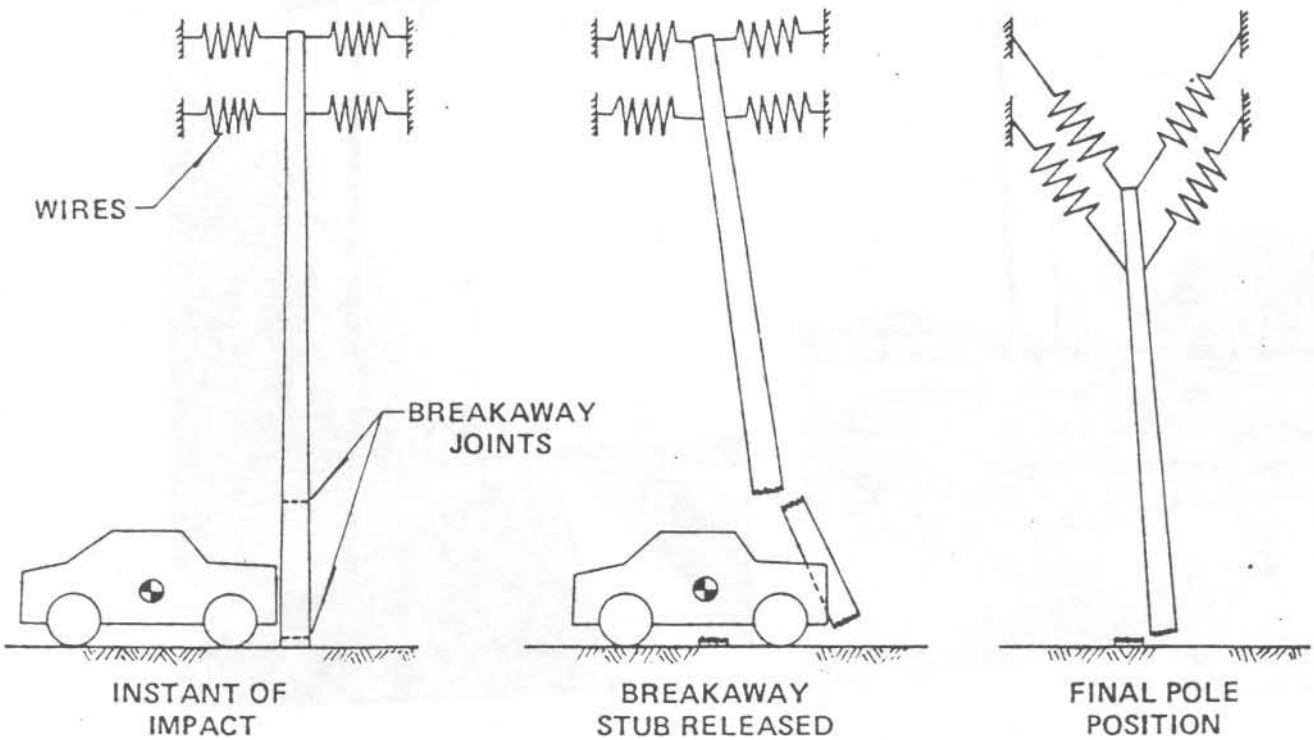


Figure 2b. High-Speed Impact Failure Mechanism

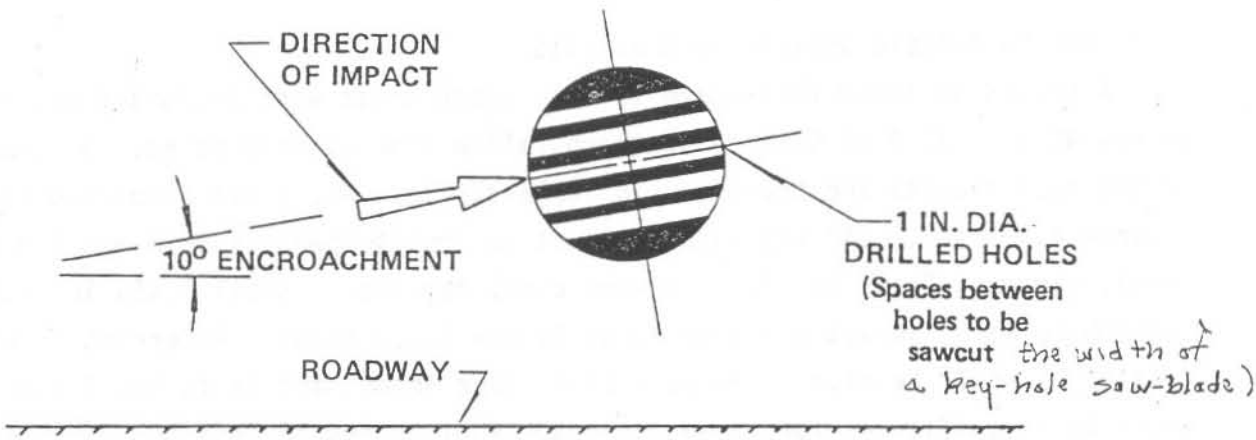
FIGURE 2 BREAKAWAY STUB CONCEPT FOR WOODEN UTILITY POLES

The breakaway joints were made by drilling a horizontal row of 1-in. (2.5 cm) diameter holes as shown in Figure 3 and then making a sawcut between the holes. A drilling jig was clamped to the pole to maintain correct alignment and spacing of the holes. The holes were drilled in the direction in which the majority of impacts would most likely occur. This pattern and direction of holes provided (a) the minimum bending strength parallel to the conductors and in the direction of impact, and (b) the maximum bending strength perpendicular to the conductors to carry the required ice and/or wind loads specified in the American National Standard Institute: National Electrical Safety Code (3).

I-B: UNL Full-Scale Vehicle Test Results

A series of three full-scale vehicle crash tests were conducted by Post (2) on new 40 ft. (12.2 m) Class 4 Southern Yellow Pine utility poles. A summary of the test results are presented in Table 1. Test No. 1 was conducted with a large 4,500 lb (2,043 kg) automobile at an impact speed of 30.8 mph (49.6 km/h); whereas, Tests No. 2 and 3 were conducted with a small 2,450 lb (1,112 kg) automobile at an impact speed of about 21 mph (33.8 km/h). Referring to Figure 2, Test No. 1 would be classified as a high-speed impact and Tests No. 2 and 3 would be classified as low-speed impacts. Photographs of Test No. 2 are shown in Figure 4.

The vehicle weight and impact speed in Test No. 2 were in conformance with the recommended test procedures in TRB Circular 191 (4), whereas the vehicle weight and impact speed in Test No. 1 did not conform. The evaluation criteria in TRB 191 indicates that a change-in-momentum of the vehicle greater than 1,000 lb-s (4,890 Ns) is considered unacceptable. It can be seen in Table 1 that the change in momentum in Test No. 2 exceeded this criteria, but the change in momentum in Test No. 1 did not exceed it. In spite of this fact, Test No. 2 was considered to be promising because (a) the vehicle was slowly brought to a stop over a distance of about 12 ft. (3.7 m), and (b) the utility pole remained attached to the conductors. Test No. 3 was conducted in an attempt to repeat the results in Test No. 2, however, the results of Test No. 3 were completely unacceptable because the lower and upper breakaway joints failed to actuate due to 6 in. (15.2 cm) of pole displacement in saturated soil.



Metric Conversion:
1 in. = 2.54 cm.

FIGURE 3
BREAKAWAY STUB CONCEPT HOLE PATTERN

Table 1. Results of Full-Scale Vehicle Crash Tests on UNL Breakaway Utility Pole Stub Concept [after Post (2)]

Condition	Test No. 1	Test No. 2	Test No. 3[a.]
Vehicle Type	1973 Buick	1974 Vega	1974 Vega
Vehicle Weight (lb)	4,600	2,450	2,450
Impact Speed (mph)	30.8	21.4	20.8
Upper B/A Joint Actuate	Yes	No	No
Lower B/A Joint Actuate	Yes	Yes	No
Type Failure Mechanism	Figure 2b	Figure 2a	--
TRB 191 Criteria			
Momentum Change (lb-sec)	1,100[b.]	1,450[c.]	2,300[c.]

a. Test results unacceptable because breakaway joint(s) failed to actuate due to large displacements of pole in saturated soil.

b. Time between incipient contact and loss of contact between vehicle and breakaway utility pole.

c. Time for free missile to travel a distance of 24 in. starting from rest with the same magnitude of vehicle deceleration.

Metric Conversion Factors

1 mph = 1.609 km/h

1 lb = 0.454 kg

1 lb-s = 4.45 Ns

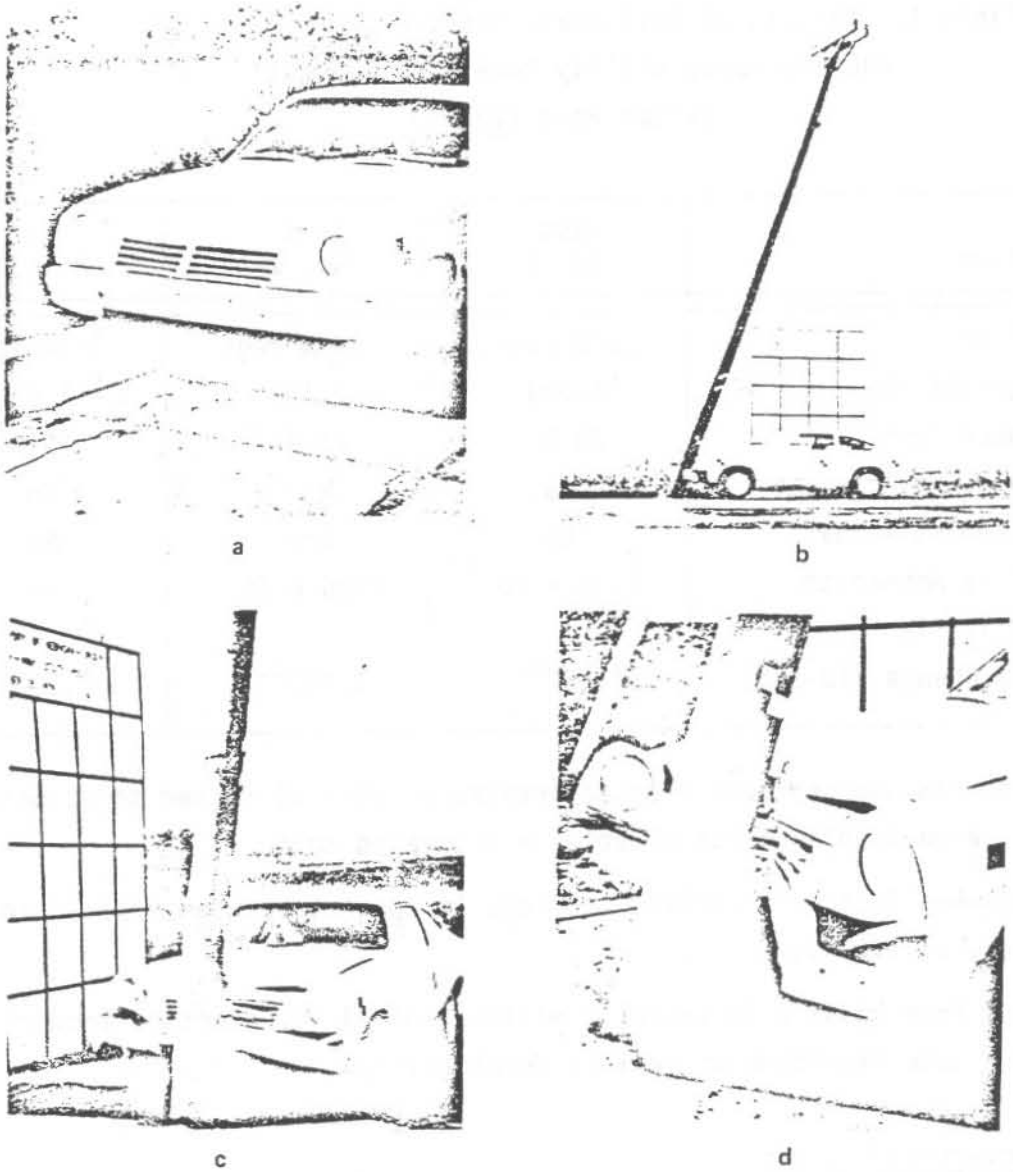


Figure 4. Photographs of Full-Scale Test No. 2

[after Post (2)]

I-C. Study Objectives

Because the breakaway utility pole concept proposed and tested by Post (2) of the University of Nebraska showed much promise as being a viable improvement alternative, the Federal Highway Administration (FHWA) provided funds to continue work on the UNL breakaway concept.

The objectives of this study were twofold. The first objective was to conduct two full-scale static bending strength tests to evaluate the performance of the breakaway UNL concept in carrying environmental loads. The second objective was to conduct three full-scale vehicle crash tests in an attempt to repeat the previous results of Test No. 2 in Table 1. Both the static tests and the crash tests were conducted on "new" 40 ft. (12.2 m) Class 4 Southern Yellow Pine utility poles.

II. DESIGN OF BREAKAWAY UTILITY POLE

The majority of utility poles in use range from 25 to 105 ft. (7.6 to 32.0 m) in height. In this study, new 40 ft. (12.2 m) Class 4 poles were used for full-scale testing. A recent survey conducted by Labra (5) of the Southwest Research Institute showed that the 40 ft. (12.2 m) Class 4 poles were the most common size pole in use. The percentage breakdown of the survey by Labra on pole lengths are shown in Table 2.

II-A. Typical Design Pole

The "typical" 40 ft. (12.2 m) utility pole and conductor arrangement used in this study and shown in Figure 5 were selected by Redding (6) of the Lincoln Electric System. The pole has 3 top conductors (type 336.4 KCM, 18/1) on a double cross-arm and 1 bottom neutral wire (2/0, 6/1) on the pole. The span length between poles was 150 ft. (45.8 m).

The loadings on the pole and conductors were in accordance with the design code specifications of the American National Standard Institute: National Electrical Safety Code [ANSI Code (3)]. The ANSI Code specifications applicable to Nebraska are summarized in Table 3. The Code requires that a utility pole in Nebraska satisfy design loadings under (a) combined heavy ice + wind, and (b) extreme wind. The position of the applied loads are shown in Figure 5, whereas, the computed magnitude of the applied loads are shown in Table 4. The equations used to calculate the applied loads were as follows:

$$P_1 = (d_1 + 2t)Lq \tag{1}$$

$$P_2 = (d_2 + 2t)Lq \tag{2}$$

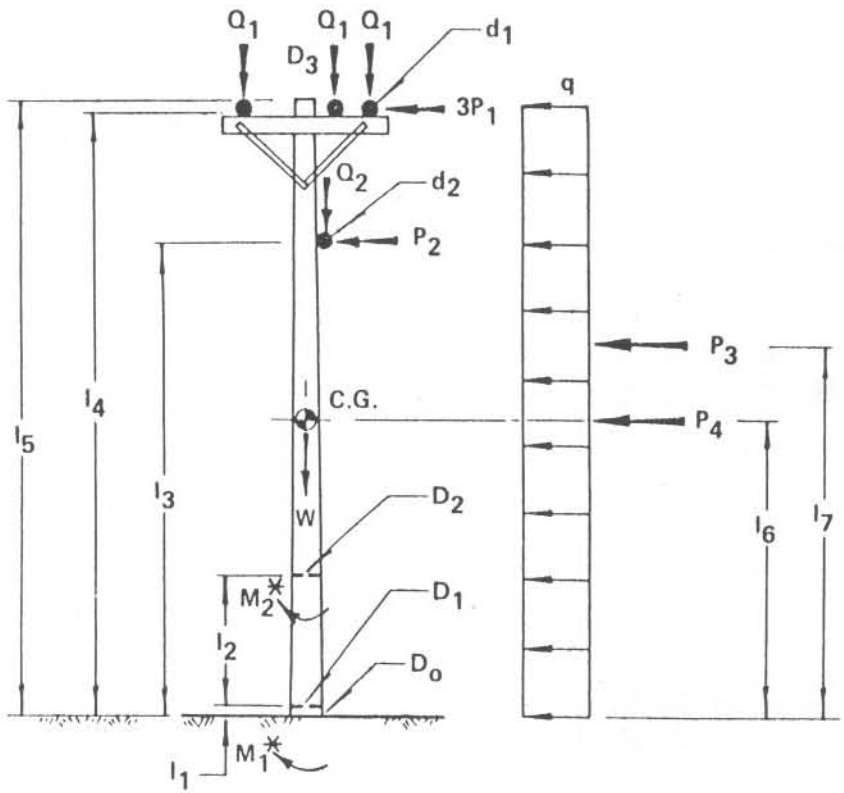
$$P_3 = \left(\frac{D_2 + D_3}{2}\right)(l_5 - l_1 - l_2)q \tag{3}$$

$$P_4 = \left(\frac{D_1 + D_3}{2}\right)(l_5 - l_1)q \tag{4}$$

$$Q_1 = W_1L + \frac{\pi}{4}\left[(d_1 + 2t)^2 - d_1^{\,2}\right]Lp \tag{5}$$

Table 2. Summary of Utility Pole Lengths
[after Labra (5)]

Pole Length (ft)	Percent in Use (%)	Cumulative Total (%)
25	0.2	0.2
30	20.7	20.9
35	21.9	41.9
40	29.6	71.5
45	16.6	88.1
50	7.6	95.7
55	0.7	96.4
60	0.6	98.3
75	0.6	98.9
80	0.5	99.4
85	0.4	99.8
90	0.1	99.9
100	Negl.	99.9
105	Negl.	99.9



* Resisting moments from applied loads

Dimensions				
Wire Diameters	a. : d_1	=	0.684	in.
	d_2	=	0.447	in.
Pole Diameters (min.)	: D_o c.	=	10.7	in.
	D_1 b.	=	10.6	in.
	D_2 b.	=	9.9	in.
	D_3	=	6.7	in.
Vertical Heights	: l_1	=	0.5	ft.
	l_2	=	6.5	ft.
	l_3	=	27.0	ft.
	l_4	=	33.0	ft.
	l_5	=	34.0	ft.
	l_6	=	17.0	ft.
	l_7	=	20.5	ft.
Average Span Length		=	150	ft.

Notes:
(a) Cross-Arm Wires (336.4 KCM, 18/1) ... 0.543 kg/m
Neutral Wire (2/0, 6/1) ... 0.272 kg/m
Wires fixed to insulators
(b) Locations of Breakaway Joints
(c) 6 ft. from butt (10% l_5 + 2)
Metric Conversion Factors
1 in. = 2.54 cm
1 ft. = 0.305 cm

Figure 5. Typical 40 Ft. Class 4 Breakaway Utility Pole: Dimensions, Conductor Arrangement, Applied Loadings and Moments

Table 3. Transverse Design Loading for Wood Utility Poles

ANSI (3)

Loading Condition	Code Section	I T E M	Specifications (Grade B)
Combined Ice + Wind Loading (Heavy)	250. B.	Radial Ice Thickness	0.50 in.
	250. B.	Horizontal Wind Pressure	4 psf
	250. B.	Ice Unit Weight	57 pcf
	252. B.2.	Pole Shape Factor	1
	261.A.2.a(1)	Designated Fiber Stress (Yellow Pine)	8,000 psi
	261.A.2b	Overload Capacity Factor	4
Extreme Wind Loading	250. C.	Horizontal Wind Pressure	16 psf
	252. B.2.	Pole Shape Factor	1
	260. C.	Overload Capacity Factor	1.0
	261.A.2.a(1)	Designated Fiber Stress (Yellow Pine)	8,000 psi

Metric Conversion Factors

1 in. = 2.54 cm

1 psi = 7.031 (10^{-2}) kg/cm^2

1 psf = 4.882 kg/m^2

1 pcf = 16.018 kg/m^3

Table 4. Magnitude of Applied Loads

Variable (Figure 5)	Applied Loads (lb)	
	Ice + Wind Loading	Extreme Loading
P_1	85	140
P_2	70	90
P_3	75	300
P_4	95	385
Q_1	165	55
Q_2	115	25

Metric Conversion Factor

1 lb = 4.45 N

$$Q_2 = W_2L + \frac{\pi}{4}\,[d_2 + 2t)^2 - d_2{}^2]\ Lp \qquad (6)$$

where

P_1 = resultant load on each cross-arm conductor

P_2 = resultant load on neutral conductor

P_3 = resultant load on portion of pole above upper breakaway joint

P_4 = resultant load on portion of pole above lower breakaway joint

Q_1 = resultant load on each cross-arm conductor

Q_2 = resultant load on neutral conduction

t = radial ice thickness

q = horizontal wind pressure

W_1 = unit weight of each cross-arm conductor

W_2 = unit weight of neutral conductor

p = unit weight of ice

L = span length between poles

d_1 = diameter of each cross-arm conductor

d_2 = diameter of neutral conductor

D_o = diameter of pole at ground level

D_1 = diameter of pole at lower breakaway joint

D_2 = diameter of pole at upper breakaway joint

l_1 = height of lower breakaway joint above ground level

l_2 = height of upper breakaway joint above lower breakaway joint (stub length)

l_3 = height of neutral conductor above ground level

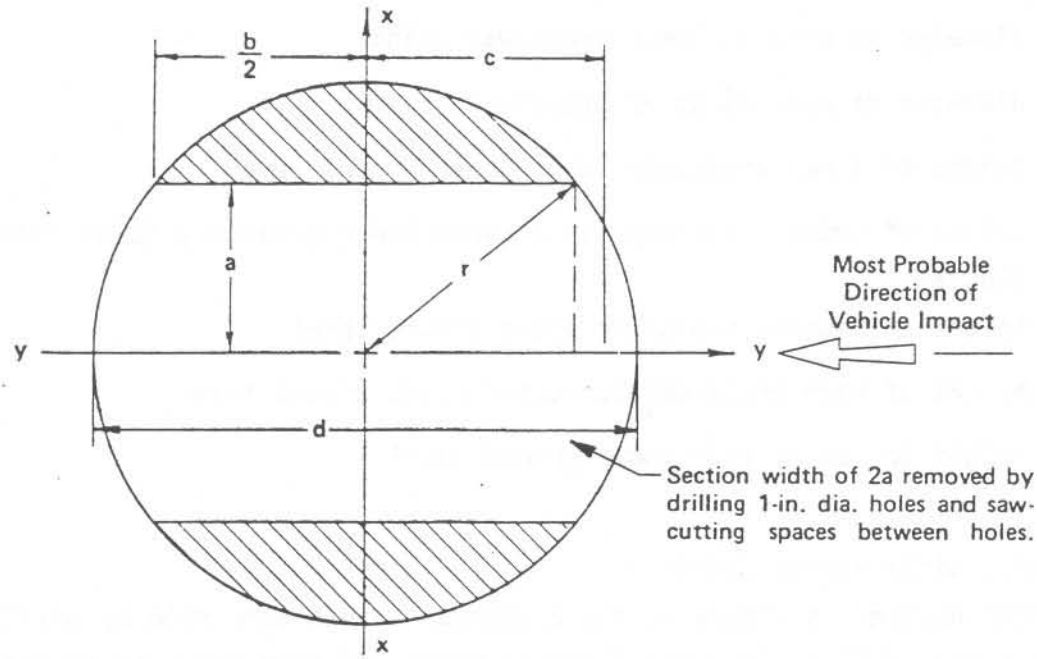
l_4 = height of each cross-arm conductor above ground level

l_5 = height to top of pole above ground level

II-B. Design of Breakaway Joints

As shown earlier in Figure 3, the breakaway joints were made by drilling a horizontal row of 1-in. (2.5 cm) diameter holes and then saw-cutting the spaces between the holes. A drilling jig was clamped to the pole to maintain correct alignment and spacing of the holes. The holes were drilled in the direction in which the majority of impacts would most likely occur. This pattern and direction of holes provided (a) the minimum bending strength parallel to the conductors and in the direction of impact, and (b) the maximum bending strength perpendicular to the conductors to carry the required ice and/or wind loads specified by the ANSI Code (3). Referring to Figure 6, the maximum bending strength of the breakaway joint occurs about the y-axis, and the minimum bending strength occurs about the x-axis. The breakaway joint is similar in shape to a wide-flange beam. Equations used to compute the properties of the breakaway joint in relation to the y-axis are shown in Figure 6.

The breakaway joint in Figure 6 was designed to resist only the bending moments due to the environmental ice and/or wind loads specified by the ANSI Code (3). No attempt was made to take into consideration axial forces, shearing forces, moments about the weak x-axis, or the vehicle impact loads. The section modulus of the breakaway joint required to comply with the ANSI Code



Properties of Breakaway Joint

$$a = \sqrt{r^2 - \frac{b^2}{4}} \qquad \text{.....(7)}$$

$$c = \frac{1}{4}(d + b) \qquad \text{.....(8)}$$

I_Y (moment of inertia) =

$$\frac{\pi}{64} d^4 - \frac{1}{12}(2c)(2a)^3 \qquad \text{.....(9)}$$

S_Y (section modulus) =

$$\frac{\pi}{32} d^3 - \frac{8}{3} c \frac{a^3}{d} \qquad \text{.....(10)}$$

A (cross-sectional area) =

$$\frac{\pi}{4} d^2 - 2a\,(2c) \qquad \text{.....(11)}$$

Figure 6. Properties of Breakaway Joint

was computed by the flexural equation given below.

$$S_y = \frac{M_y}{f_c} \tag{12}$$

where

S_y = required section modulus to comply with ANSI Code

M_y = ultimate design moment due to environmental ice and/or wind loads

f_c = ultimate bending strength

The ultimate design moments occurring at the lower and upper breakaway joints can be computed from the environmental loading conditions shown in Figure 5. Neglecting the effects of the vertical conductor loads, the equations used were as follows:

<u>Lower Breakaway Joint</u>

$$M_y = [3P_1 (l_4 - l_1) + P_2 (l_3 - l_1) + P_4 (l_6 - l_1)] (OL) \tag{13}$$

<u>Upper Breakaway Joint</u>

$$M_y = [3P_1 (l_4 - l_1 - l_2) + P_2 (l_3 - l_1 - l_2) + P_3(l_7 - l_1 - l_2)](OL) \tag{14}$$

The computed bending moment, section modulus, and width of pole to be removed for each of the lower and upper breakaway joints are shown in Table 5. Because of the larger design moment, it can be seen that the section modulus of each joint was governed by the ice + wind loading conditions. It can also be seen in Table 5 that the width of pole to be removed from each joint differs by only 1/4 in. (0.6 cm) which is insignificant if one takes into consideration the variability in pole size and strength from pole to pole. In this study, an average width of 6-3/4 in. (17.1 cm) was removed from both the lower and upper breakaway joints. This practice would simplify actual field operations and minimize the probability of using the wrong drilling jig on the wrong joint. A detailed drawing of the drilling jig used is shown in Figure 7.

The residual section modulus of the breakaway joints is approximately 60%. The residual section modulus is defined as the section modulus of the breakaway joint expressed as a percentage of non-breakaway section modulus. In other words, the residual section modulus is a measure of the strength of the pole after it is modified.

Table 5. Required Dimensions of Breakaway Joints

Breakaway Joint	Ultimate Design Moments[a.] (lb-ft)		Required Section Modulus[b.] (in^3)		Width of Pole to be Removed[c.] (in)	Residual Section Modulus[d.] (%)
	Ice + Wind Loading (OL = 4)	Extreme Wind Loading (OL = 1)	Ice + Wind Loading	Extreme Wind Loading		
Lower	46,480	22,390	70.3	33.6	6.80	60
Upper	36,170	16,770	54.3	25.2	6.55	57

a. Eqs. 13 and 14 where, OL = Overload Capacity Factor

b. Eq. 12

c. Eqs. 7, 8, and 10 (see Figure 6)

d. Section modulus of breakaway joint expressed as a percentage of non-breakaway section modulus.

Metric Conversion Factors

1 in. = 2.54 cm
1 in^3 = 16.39 cm^3
1 lb-ft = 1.36 Nm

II-C. Longitudinal Loadings

In the previous work, the moments resulting from the lateral ice + wind loads applied perpendicular to the conductors were considered critical in the design of the breakaway joints. The longitudinal moments required to support wind loads applied in the direction of the conductors were determined for comparative purposes later in the study (Section III) with the results from the full-scale static test about the weak axis of the pole.

No attempt was made in this study to take into consideration the longitudinal loadings specified in Section 252C of the ANSI Code. The loading

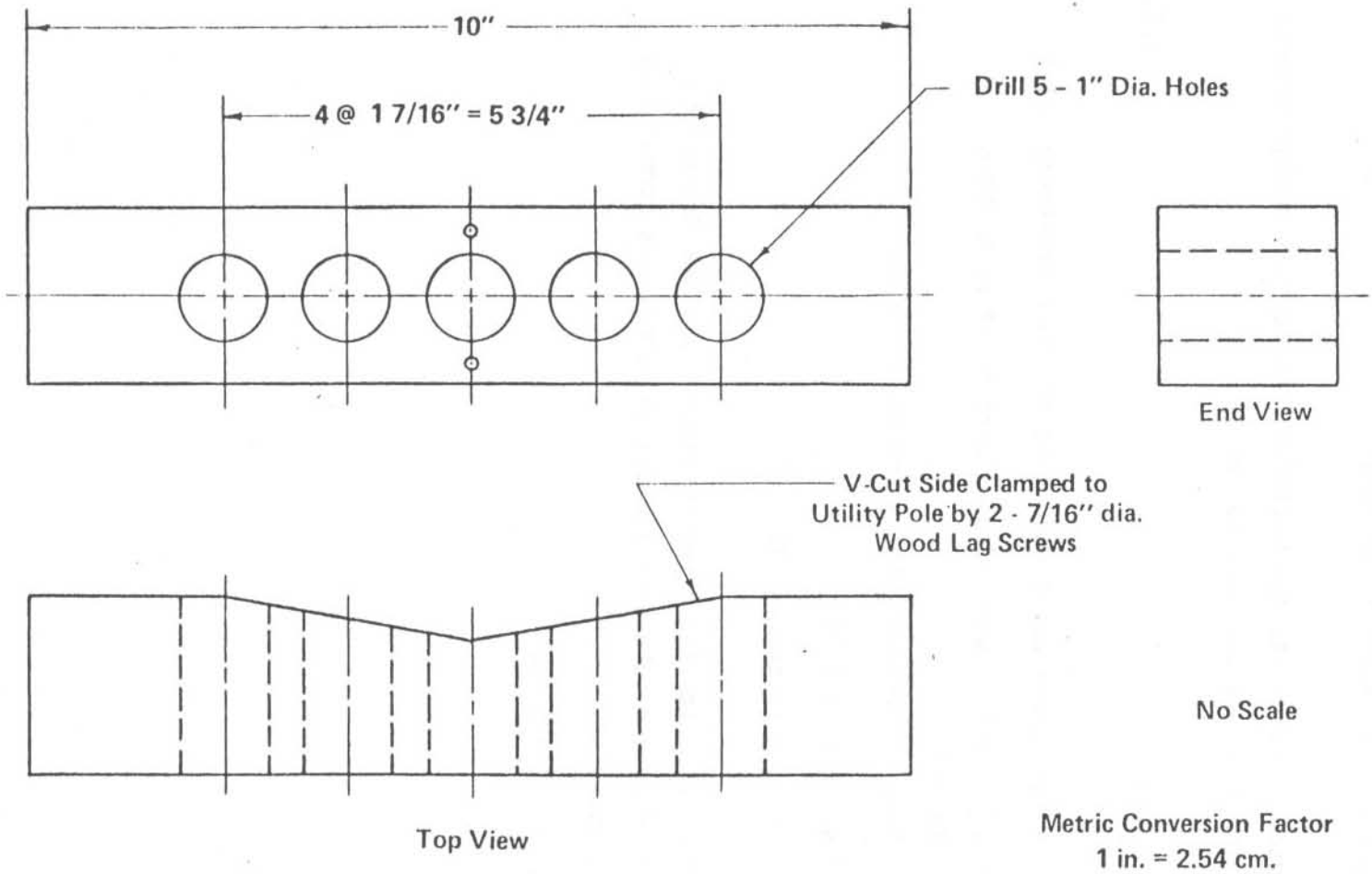


Figure 7. Drilling Jig (4x4x10 D.F. Wood Block)

conditions in the Code included such items as (a) stringing loads, and (b) unequal spans and unequal vertical loadings.

The equation used to calculate the ultimate longitudinal design moments due to an assumed wind pressure only was as follows:

$$M_x = P_4 \, (l_6 - l_1)(OL) \tag{15}$$

where

M_x = ultimate design moment about weak axis of lower breakaway joint

P_4 = resultant longitudinal wind load on portion of pole above breakaway joint

l_1 = height of lower breakaway joint above ground level

l_6 = center-of-gravity of pole

OL = overload capacity factor = 1.33

Using the extreme wind loading given in Table 4 and the dimensions of the pole given in Figure 5, the ultimate design moment was computed by use of Eq. 15 to be equal to:

M_x = 8,450 lb-ft (11,490 Nm)

III. FULL-SCALE STATIC STRENGTH TESTS

Two full-scale static tests were conducted on "new" 40 ft (12.2 m) Class 4 Southern Yellow Pine utility poles in order to evaluate the ultimate strength performance of the UNL breakaway utility pole concept. The tests were conducted by Hughes Brothers at their utility pole testing facility in Seward, Nebraska. A copy of the report prepared and submitted to the University by Hughes Brothers is presented in Appendix A.

III-A. Testing Apparatus

A sketch of the testing apparatus is shown in Figure 8. The test pole was set 6 ft (1.8 m) in the ground and backfilled and tamped with soil from the test site. Three weights were hung from the crossarm to simulate the conductor loads, Q_1, shown earlier in Figure 5; and, one weight, Q_2, was hung from the pole to simulate the neutral conductor load. The weights used were shown in Table 4. The horizontal loads acting on a utility pole under ice and/or wind loads were idealized by a single resultant load applied by a cable attached to the test pole at a height of 28 ft (8.5 m) above ground level. This height of load corresponds to the centroid of the lateral loads shown in Figure 5. The cable, in turn, was attached to a dead-load weight of 5,000 lb (2,270 kg) supported by a forklift. The loads in the cable were measured by a dynamometer.

The testing setup shown in Figure 8 was used for conducting tests about both the weak and strong bending axes of the breakaway joint shown earlier in Figure 6. This setup is obviously not correct for testing about the weak axis because the direction of the applied load should be parallel to the conductors and therefore perpendicular to the crossarm. However, engineers from Hughes Brothers felt at the time that this setup would reduce as much as possible the percentage of the failure moment caused by the conductor weight eccentricities. These eccentricities are not as easily nor as accurately obtained as are dynometer readings. Therefore, it was felt that more accurate results would be obtained if the moment contributions due to the conductor eccentric loads were

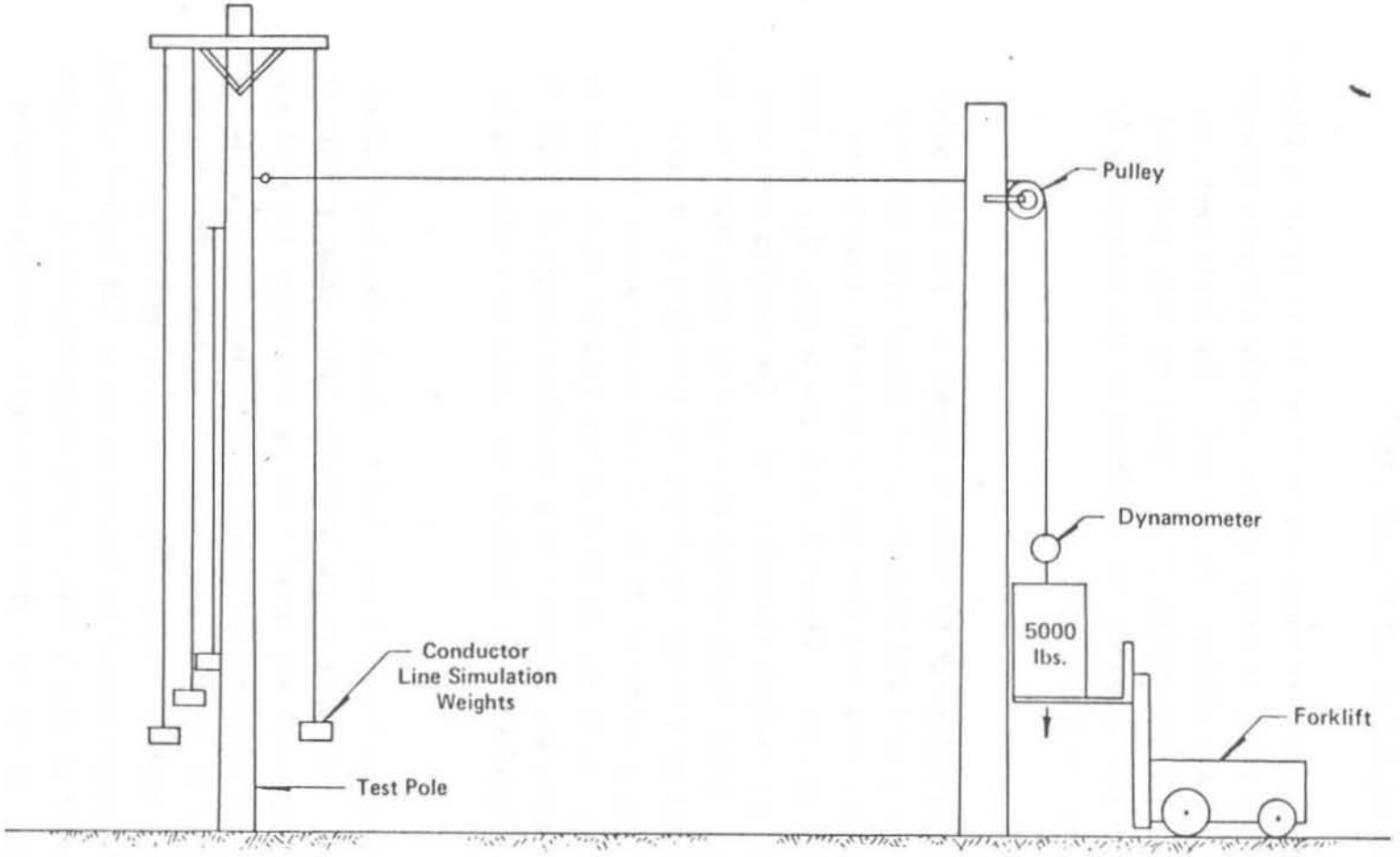


Figure 8. Static Test Loading System

held to a minimum. Due to large deflections of the test pole, it will be seen later that this attempt to minimize eccentric loading effects was unsuccessful.

III-B. Test Evaluation Procedure

The testing evaluation procedure consisted of comparing the ultimate "resisting" moments from the full-scale tests with the ultimate "design" moments computed by use of design criteria specified by the ANSI Code (3). The equation used to compute the ultimate resisting moments from the tests was as follows:

$$\begin{bmatrix} M'_x \\ M'_y \end{bmatrix} = P_T L_T + Q_1 \ (e_1 + e_2 + e_3) + Q_2 e_4 \qquad (16)$$

where

M'_x = ultimate resisting moment about weak x-axis of lower breakaway joint

M'_y = ultimate resisting moment about strong y-axis of lower breakaway joint

P_T = applied load at failure of pole

L_T = moment arm from lower breakaway joint to the position of the applied load

Q_1 = weights to simulate three individual conductor loads on crossarm

Q_2 = weight to simulate neutral conductor load

e_i = eccentricities of individual conductor loads measured from centerline of lower breakaway joint at failure of pole (i = 1 to 4)

OL = overload capacity factor

III-C. Results of Test No. 1

Test No. 1 was conducted to determine the ultimate resisting moment of the test pole about its weak bending axis (x-axis in Figure 6). Load-deflection curves at three points on the test pole are shown in Figure 9, and photographs of the test pole under various applied loads are shown in Figure 10. In Figure 9, it can be seen that the pole failed at a load of 550 lb (2,448 N) with a corresponding deflection at the top of the pole (point "A") of about 28 in. (71 cm).

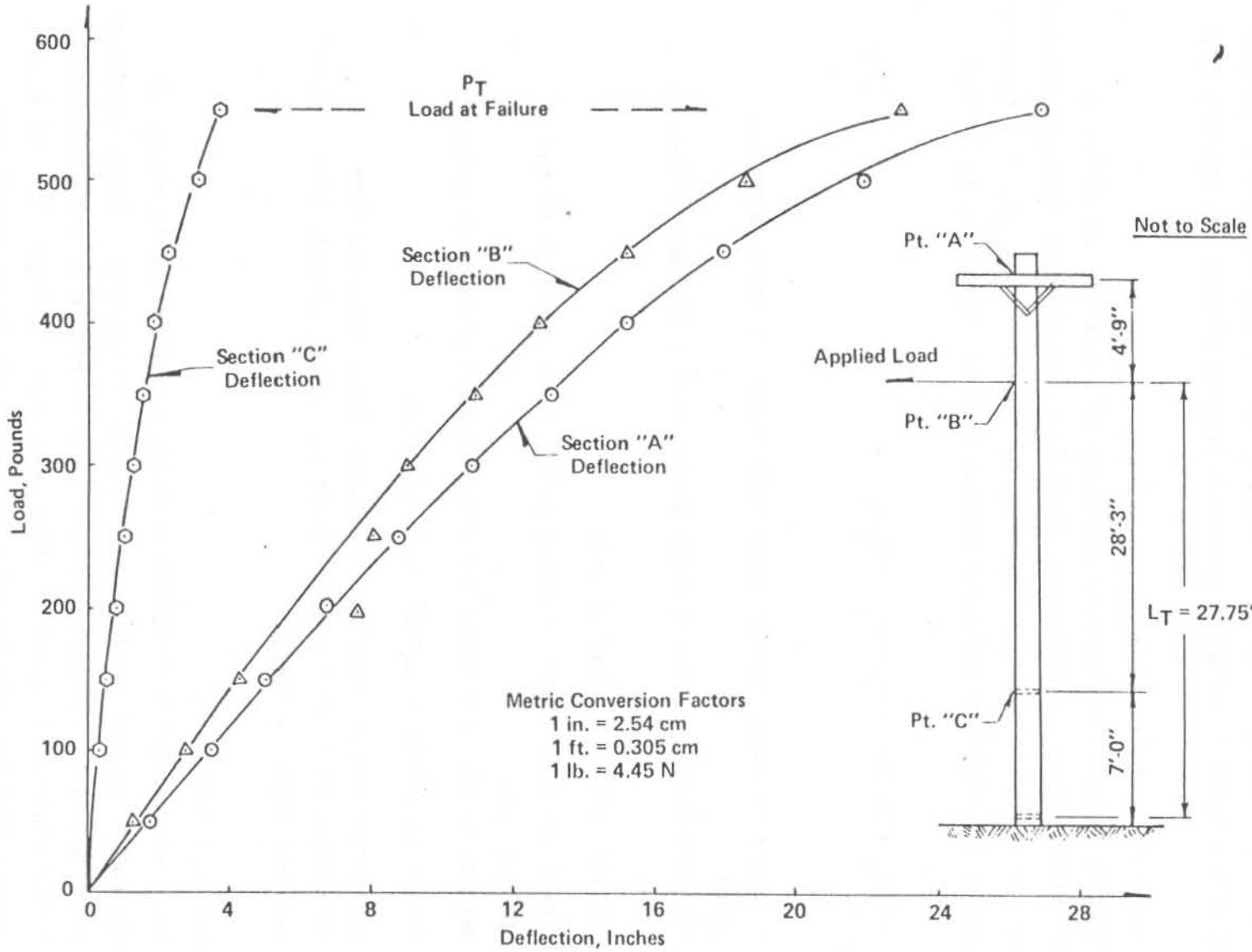
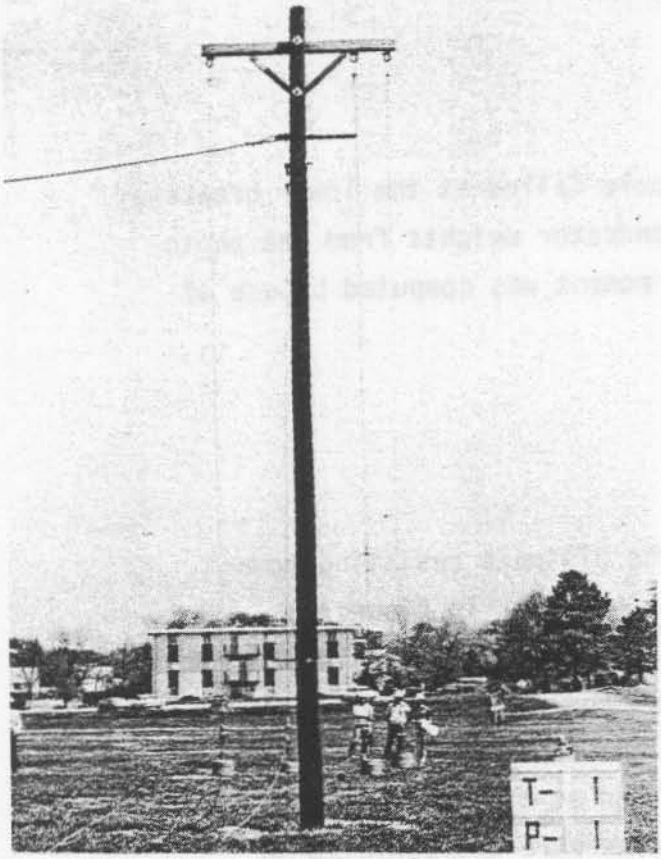
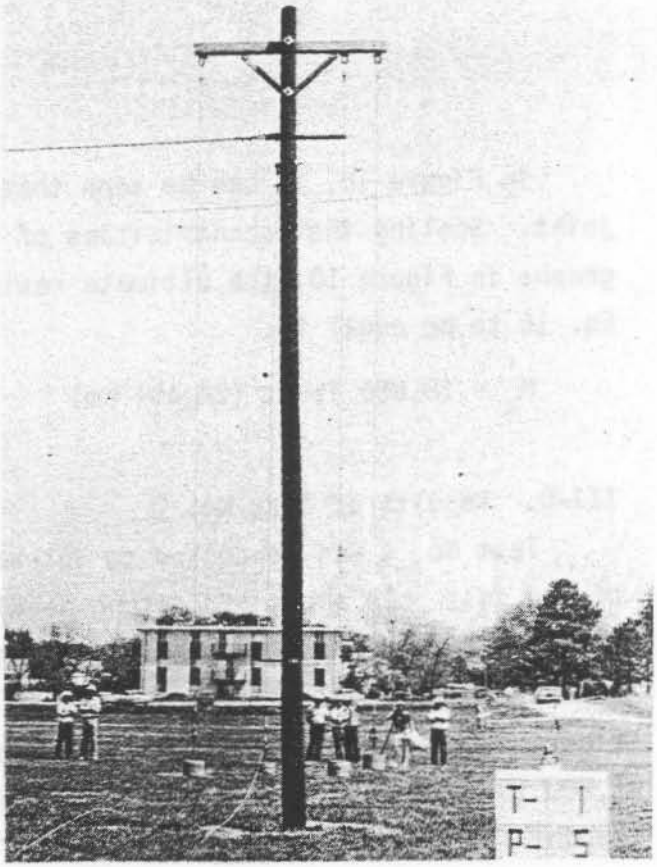


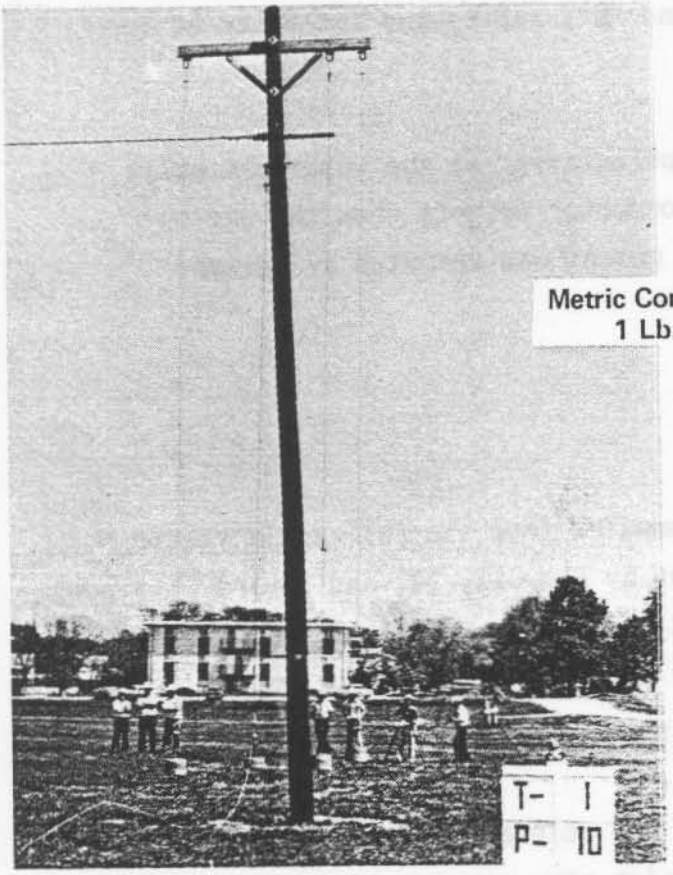
Figure 9. Load Diagram for Static Test No. 1



P = 0 Lbs.

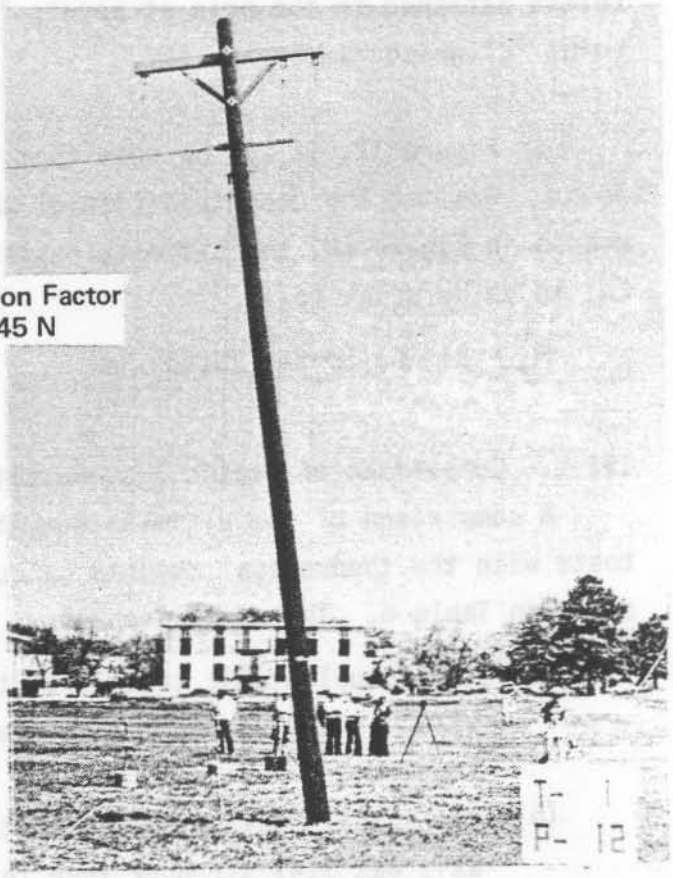


P = 200 Lbs.



P = 450 Lbs.

Metric Conversion Factor
1 Lb. = 4.45 N



P = 550 Lbs.

Figure 10. Photographs of Static Test No. 1

In Figure 10, it can be seen that the pole failed at the lower breakaway joint. Scaling the eccentricities of the conductor weights from the photographs in Figure 10, the ultimate resisting moment was computed by use of Eq. 16 to be equal to:

$$M_x' = 18{,}050 \text{ lb-ft } (24{,}494 \text{ Nm})$$

III-D. Results of Test No. 2

Test No. 2 was conducted to determine the ultimate resisting moment of the test pole about its strong bending axis (y-axis in Figure 6). Load-deflection curves at three points on the test pole are shown in Figure 11, and photographs of the test pole under various applied loads are shown in Figure 12. In Figure 11 it can be seen that the pole failed at a load of 1,800 lb (817 N) with a corresponding deflection at the top of the pole (point "A") of about 80 in. (2.0 m). The curves were extrapolated in Figure 11 because the large deflections of the pole extended beyond the rulers attached to the pole at points "A" and "B", and beyond the ruler at point "C" which had broken off.

In Figure 12, it can be seen that the pole failed at the upper breakaway joint. Scaling the eccentricities of the conductor weights from the photographs in Figure 12, the ultimate resisting moment was computed by use of Eq. 16 to be equal to:

$$M_y' = 54{,}200 \text{ lb-ft } (73{,}550 \text{ Nm})$$

III-E. Comparison of Static Test Results

A comparison of the ultimate moments computed from the full-scale static tests with the theoretical moments calculated by Eqs. 13, 14, and 15 are shown in Table 6. The comparison shows that:

(a) the actual static test strength of the pole about its strong bending axis was 17% stronger than the design strength required by the ANSI Code, and

(b) the actual static test strength of the pole about its weak bending axis was 114% stronger than the design strength required to carry wind loads.

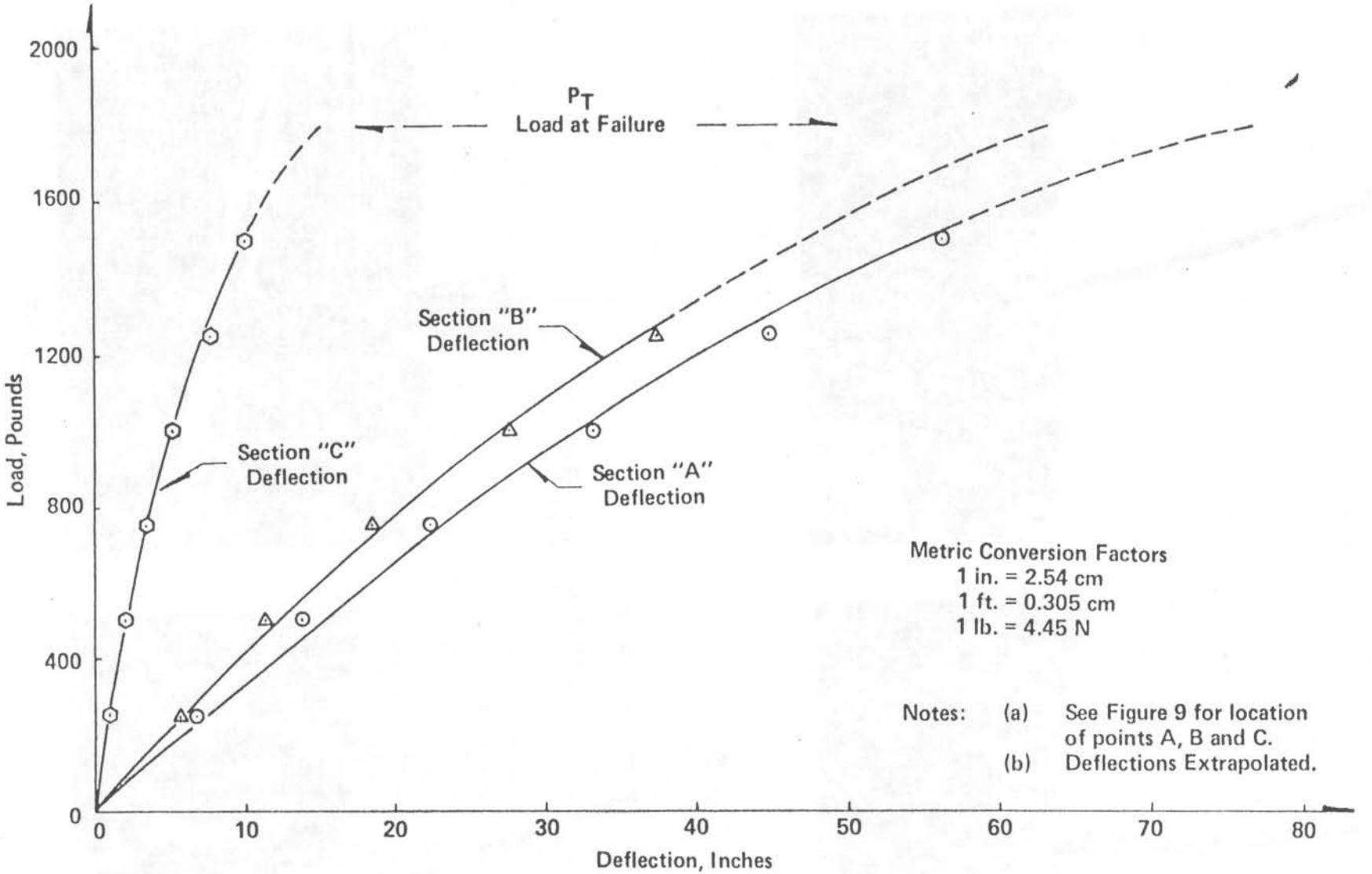
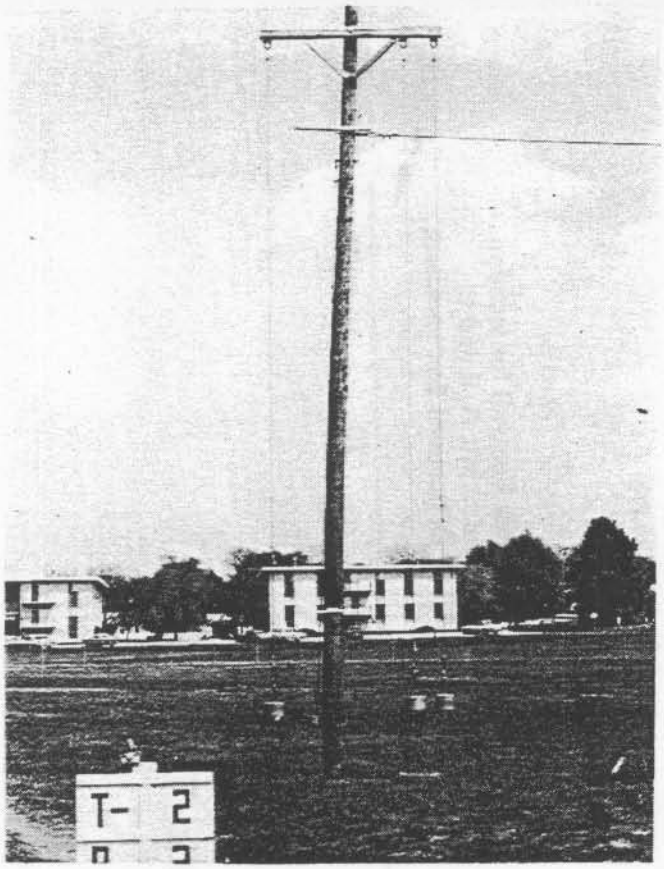
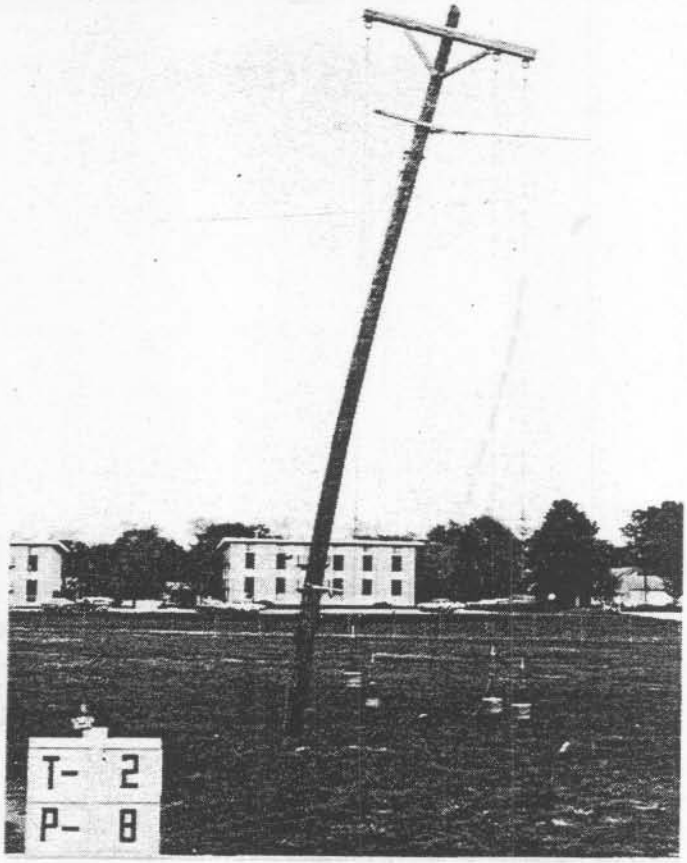


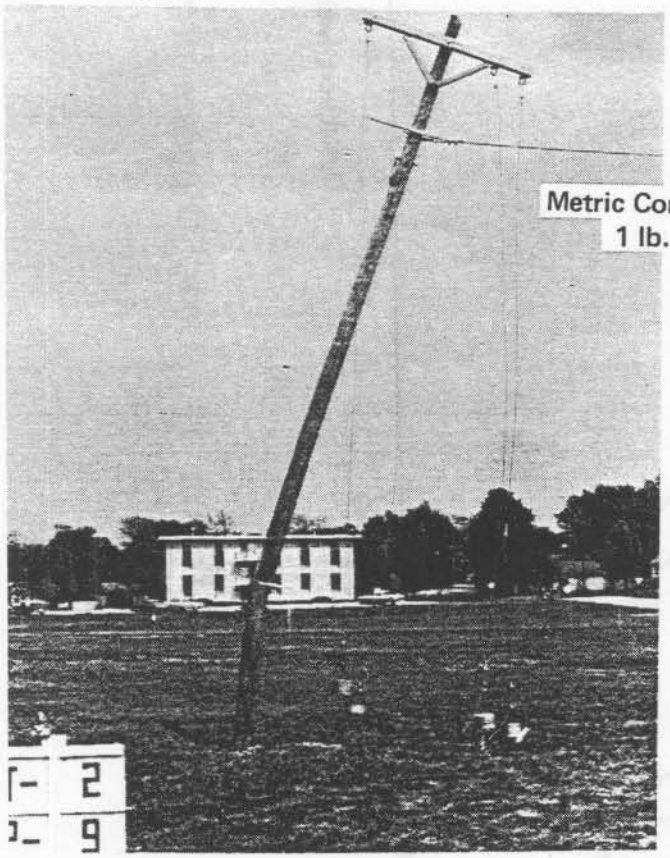
Figure 11. Load Diagram for Static Test No. 2



P = 250 Lbs.

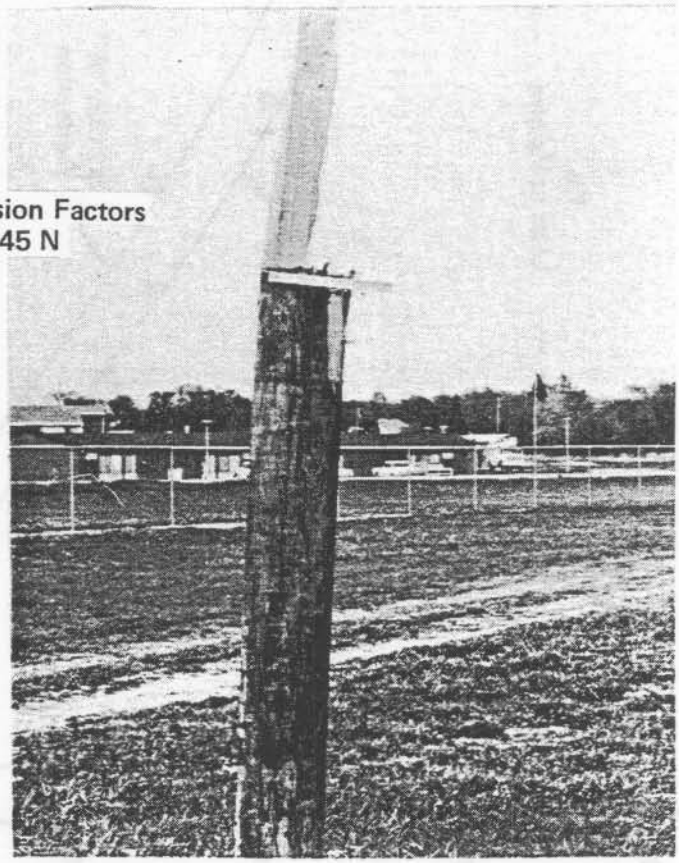


P = 1,750 Lbs.



P = 1,800 Lbs.

Metric Conversion Factors
1 lb. = 4.45 N



FAILURE

Figure 12. Photographs of Static Test No. 2

The repeatability of the two static tests results in Table 6 on new poles, and what effect pole weathering and aging will have on the strength of poles are unanswered questions at this time. To answer such questions would require more indepth testing. However, the results in Table 6 are very encouraging and show that the UNL breakaway concept is feasible.

Table 6. Comparison of Ultimate Moments

Bending Axis of Lower Breakaway Joint	Ultimate Resisting Moments (lb-ft)	Ultimate Design Moments[c.] (lb-ft)
Weak x-axis	18,050[a.]	8,450
Strong y-axis	54,200[b.]	46,840

a. Static Test No. 1

b. Static Test No. 2

c. ANSI Code (ice and/or wind loading requirements)

Metric Conversion Factors

1 lb-ft = 1.36 Nm

When conducting Static Test No. 1 about the weak axis of the breakaway utility pole, it was observed that as the pole was deflecting under load (see Figure 10) that the gap of the removed section on the compression side of the breakaway joint began to close shut. If the gap had been only as thick as a saw-blade as in the full-scale vehicle crash tests, then the resulting "transformed" section would cause the neutral axis (or plastic axis) to shift toward the new compression area, and as a result, the resisting moment capacity would greatly increase. Thus, Test No. 1 is a very conservative indication of the strength of the modified pole in the weak (x-axis) direction.

IV. FULL-SCALE CRASH TESTS

Three full-scale vehicle crash tests were conducted on new 40 ft (12.2 m) Southern Yellow Pine utility poles in an attempt to repeat the test results of Test No. 2 in the previous study conducted by Post (2) on the UNL Breakaway Utility Pole Concept. The span lengths between the breakaway pole and the end support poles were 75 ft (22.9 m) and 100 ft (30.5 m), respectively. The poles had two top conductors (type 336.4 KCM, 18/1) mounted on a double crossarm and one bottom neutral conductor (type 2/0, 6/1) attached to the pole. A positive type connector between the conductors and insulators was used in Test No. 4-1 to guard against the pole breaking away from the conductors after impact. Details of the connection are discussed in a later section. The poles and conductors were installed by the Lincoln Electric System.

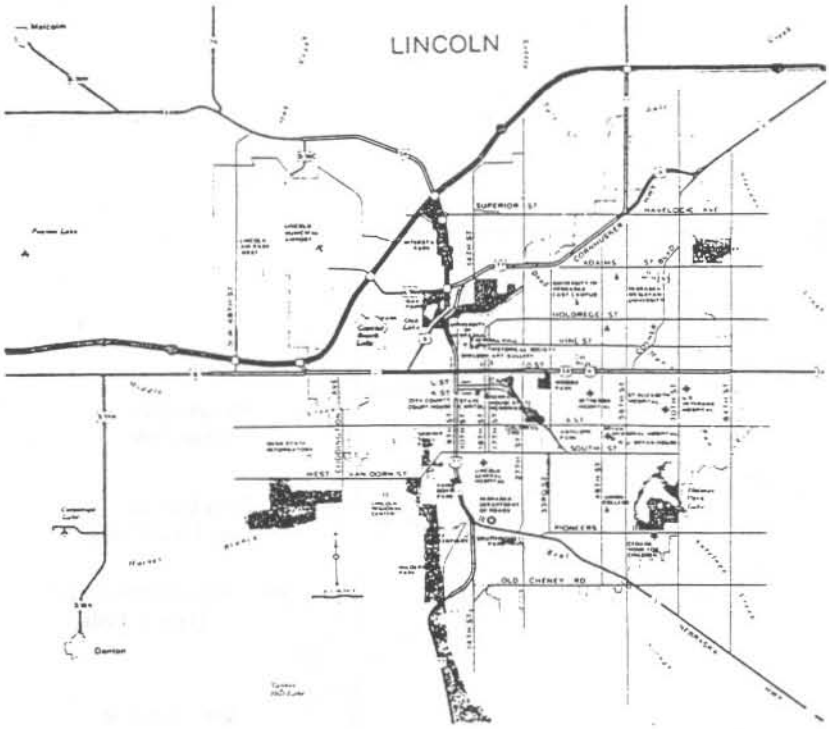
IV-A. Description of Test Site

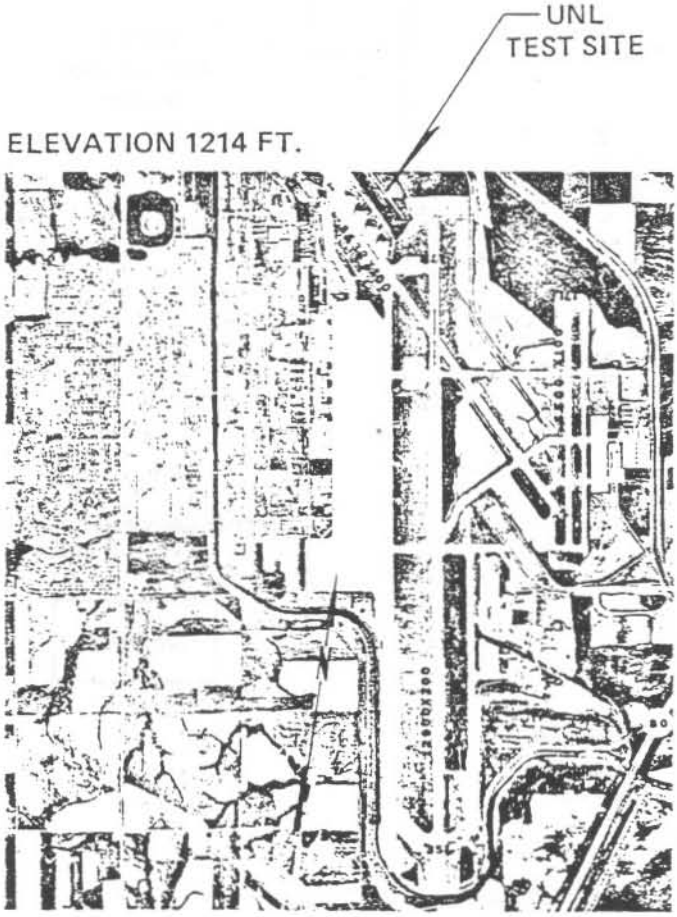
The test site was located at the Lincoln Municipal Airport which is approximately 3-1/2 mi. (5.6 km) NW of the University and the central business district. The test site, which was leased from the Lincoln Airport Authority, consists of an old abandoned concrete roadway located between the ends of runways 14 and 17R as shown in Figure 13. The roadway was 20 ft (6.1 m) wide and 1,800 ft (594 m) long. A "Notice of Proposed Construction or Alteration" was filed with the FAA because the height of the utility poles exceeded the 100 to 1 imaginary surface.

In order that the test poles be set in soil, a 3 x 3 ft (0.92 m) area of the concrete roadway slab was removed. The test pole was placed near the center of this area and backfilled and tamped with soil and gravel.

IV-B. Description of Full-Scale Vehicle Testing Apparatus

A reverse vehicle towing apparatus with a mechanical advantage of 20 to 1 was used to pull the crash test vehicles as shown in Figure 14. Because of the mechanical advantage, the distance travelled and the running speed of the test vehicles were twice those of the towing vehicle. A 1973 1/2-ton (908 kg)





Metric Conversion Factor
1 Ft. = 0.305m

FIGURE 13. LOCATION OF FULL-SCALE TEST SITE

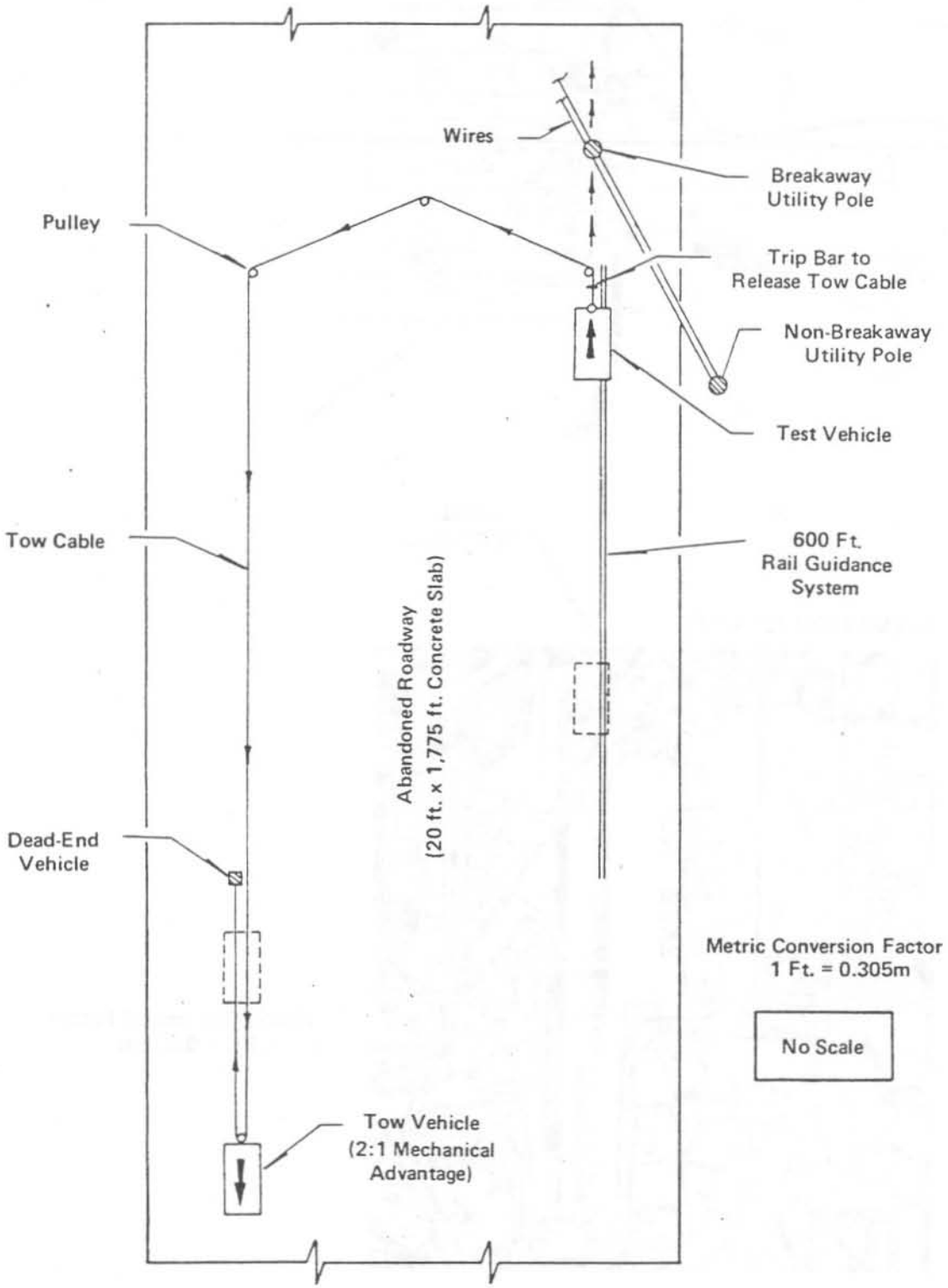


Figure 14. Reverse Vehicle Tow and Rail Guidance System

Dodge pickup truck was used as the towing vehicle. The speedometer in the pickup, which was marked at 1 mph (1.609 km/h) intervals, was accurately calibrated and used to obtain the desired impact test speed.

As shown in Figure 14, the crash test vehicles were guided along a rail system with the two tires on the right-hand side mounted inside two steel angles placed back-to-back. Photographic views of the rail guidance system are shown in Figure 15. The width between the two angles was adjustable at the slotted connections located at 20 ft (6.1 m) intervals so that the rail system can accomodate any size vehicle tire. The rail guidance system ended 20 ft (6.1 m) in advance of the breakaway utility pole so that test vehicles would be in a free-wheeling steer mode just before impact.

A 1/4-in. (0.64 cm) diameter tow cable was attached to a breakaway high-strength slotted bolt that was connected to the test vehicles. The slotted bolt will break-away and release the tow cable when it hits a trip-bar that was mounted to the roadway. As shown in Figure 14, the tow cable passes around four pulleys (one pulley on tow vehicle) and was connected to a dead-end anchor. The trip-bar to release the tow cable was mounted hear the end of the rail guidance system.

IV-C. Breakaway Joints

The design of the breakaway joints to provide the "minimum" required section modulus to carry the heavy ice and wind loadings specified in the ANSI Code (3) was discussed earlier in the section, entitled "DESIGN CRITERIA". As shown in the photographic views in Figure 15, the lower and upper breakaway joints were made by drilling a row of five 1-in. (2.5 cm) diameter holes. The spaces between the holes were then sawcut. The 4 x 4-in. (10.2 cm) wood block drilling jig, which was attached to the pole by two lag screws, was used to maintain the correct spacing and alignment of the holes.

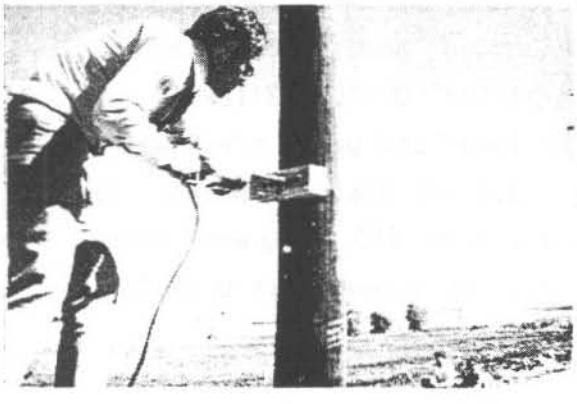
The lower breakaway joint was made at approximately 2 in. (5.1 cm) above the ground, whereas, the upper joint was made at 8 ft (2.4 m) above ground level. The location of the upper breakaway joint was determined from a dynamic

(a)

(b)

(c)

(d)



(e)

(f)

Figure 15. Photographs of Full-Scale Test Site

analysis conducted in a previous study by Post (2). In that study, the utility pole was idealized as a cantilevered lumped mass system and the vehicle as a spring mass system.

Retrofitting the utility pole to breakaway under vehicle impact by the drilling of 1-in. (2.5 cm) diameter holes was demonstrated to be a very practical method. A single sawcut was made from hole to hole with a key-hole saw. It required about 30 minutes to drill and sawcut both breakaway joints.

IV-D. High-Speed Photographic Equipment and Setup

Two high-speed cameras, described in Table 7, were used in this study. Both cameras were located perpendicular to the path of the test vehicle at a distance of 100 ft (30.5 m) from the test pole. The film was analyzed on a Vanguard Motion Analyzer, described in Table 7.

Table 7. Photographic Equipment

Equipment Description
1. LoCam model 50-003 high speed Camera. Film rate is variable to 500 fm./sec. Actual film speed = 480 fm./sec.
2. Eastman Kodak high speed Camera, type III. Film rate is variable to 3000 fm./sec. Actual film speed = 900 fm./sec.
3. Vanguard Motion Analyzer model C-11P with M16CP projection head. Frame rate is variable to 30 fm./sec. A model 534-C digitizer built at the University of Iowa to input data to a computer is also linked up.

IV-F. Results of Full-Scale Crash Test No. 2-1

Test No. 2-1 was conducted with a compact automobile weighing 2,450 lbs (1,112 kg). The impact speed of the vehicle was 23.6 mph (38.0 km/hr). Graphs of the change in vehicle velocity and vehicle deceleration versus time are shown in Figures 16 and 17, respectively. Data points on these graphs were obtained by a high-speed film analysis using the Vanguard Motion Analyzer. The method of analysis and the displacement-time data measured from the high-speed film are presented in Appendix B.

Close-up and far-away high-speed sequence photographs of Test No. 2.1 are shown in Figures 18 and 19, respectively, At first glance, it would appear from these photographs that the test was unsuccessful because after knocking out the pole stub between the lower and upper breakaway joints (a) the vehicle was abruptly stopped over a relatively short distance, and (b) the double crossarm on the pole rotated to a vertical position and then penetrated through the roof and into the front passenger compartment area of the vehicle. A careful examination of the high-speed film on the Vanguard Motion Analyzer revealed, however, that these undesirable events would not have occurred if the pole after breaking away had not snagged on a sawcut ledge of a 3 x 3 ft. (0.9 x 0.9 m) concrete section that had been removed from the roadway. The documentation photographs in Figure 20 show the pole located in the center of the section of the roadway removed. Detailed sketches of the events leading up to the problem of pole snagging are illustrated in Figure 21. A brief discussion of each event in Figure 21 follows:

Fig. 21a. Time of Event: 65 msec

Longitudinal splitting above and below lower breakaway joint as pole rotates clockwise about conductors. Top breakaway joint remains intact.

Fig. 21b. Time of Event: 80 msec

Rotating portion of pole clear of pole stump in the ground. Longitudinally split fibers begin to tear in bending.

Fig. 21c. Time of Event: 115 msec

Upper portion of rotating pole breaks free from stump of pole. Pole drops and penetrates 2 in. (5 cm) into the ground.

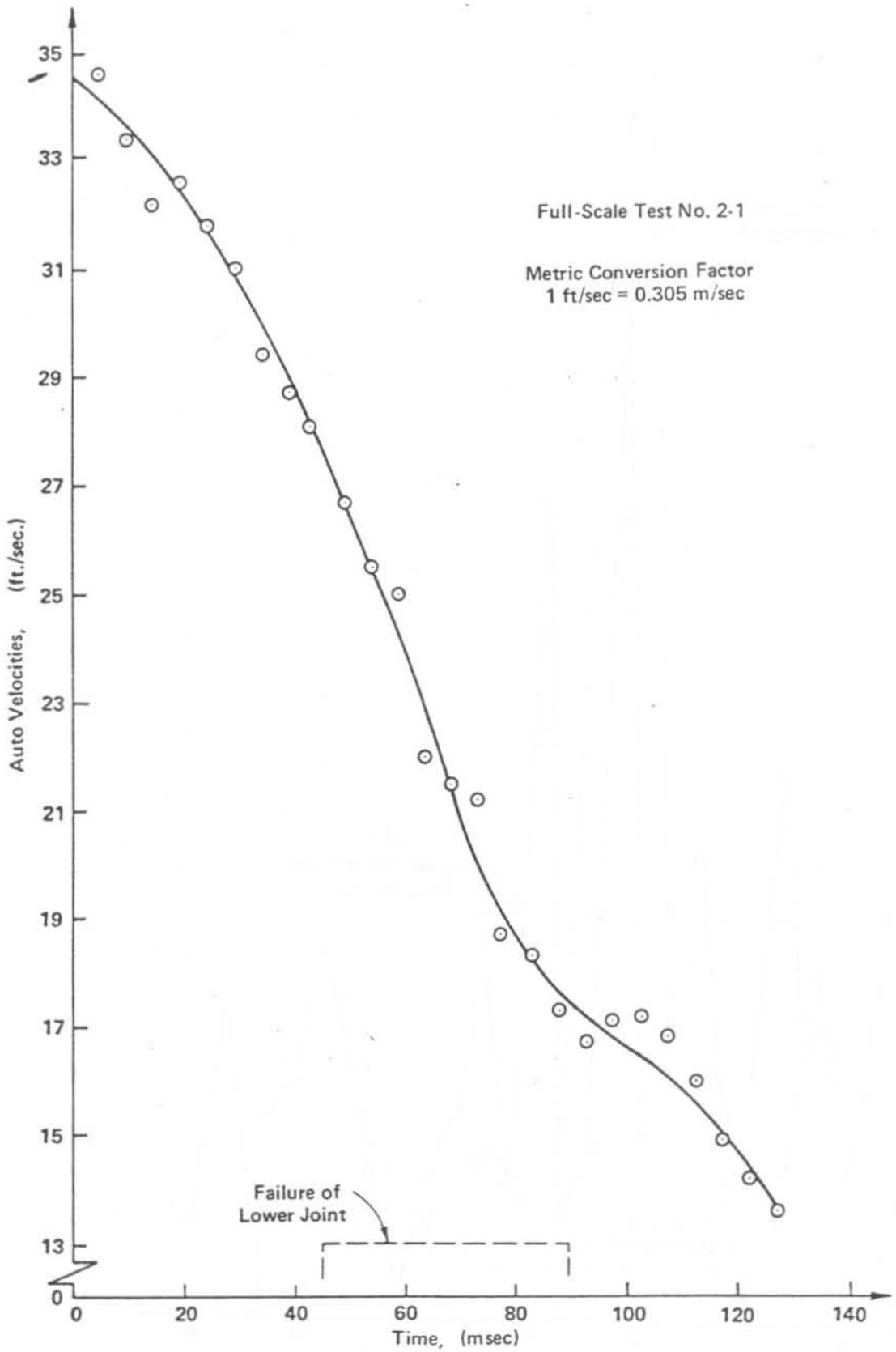


Figure 16. Vehicle Velocities for Test No. 2-1

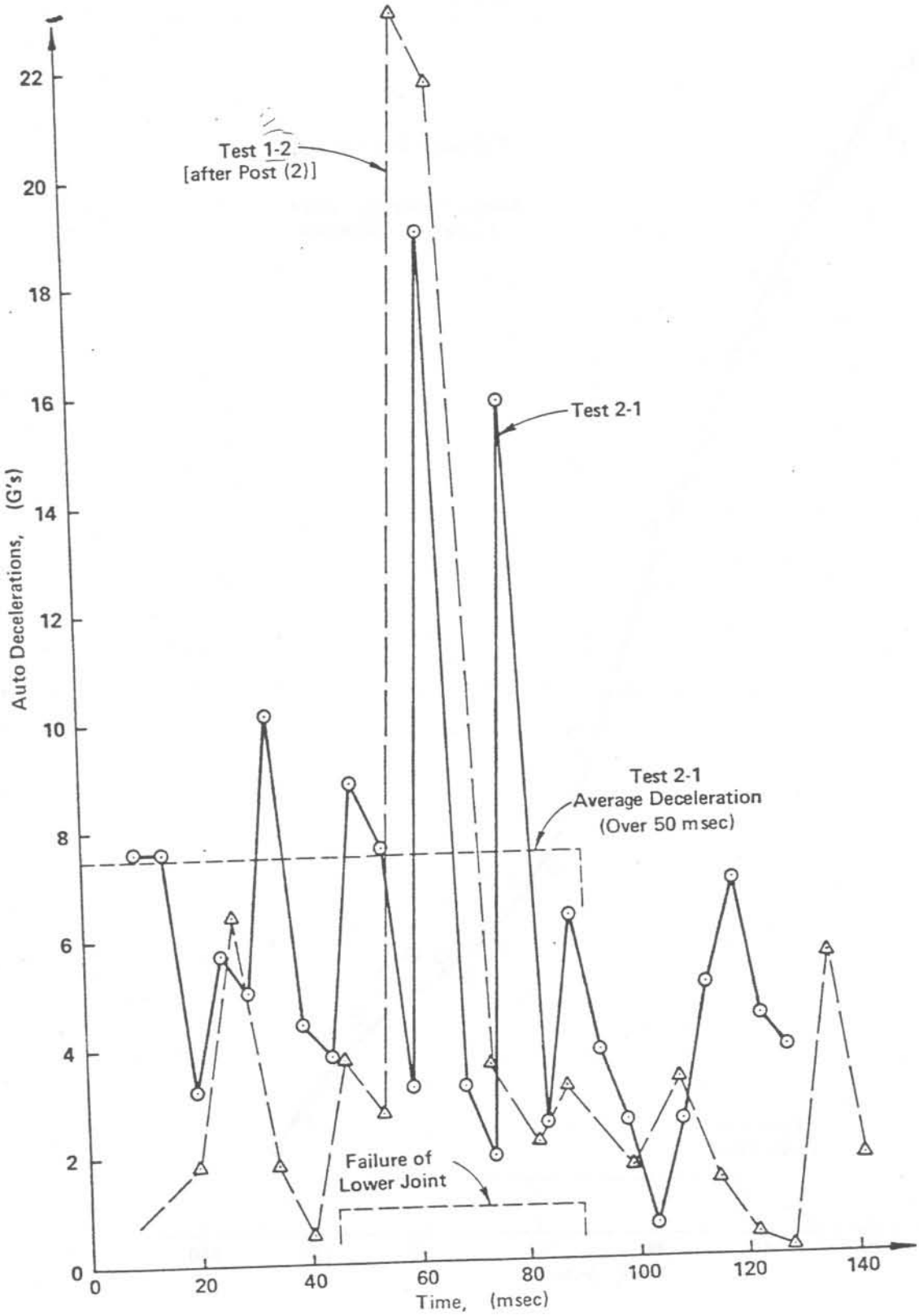
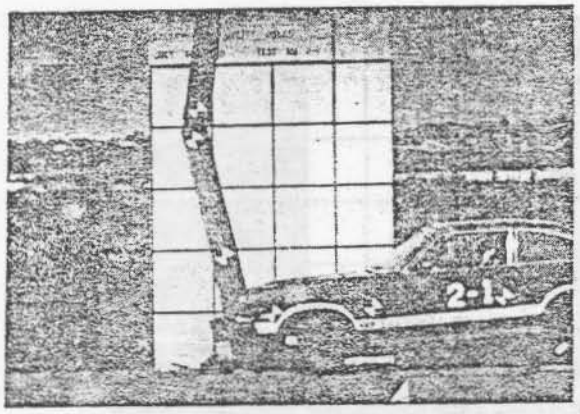
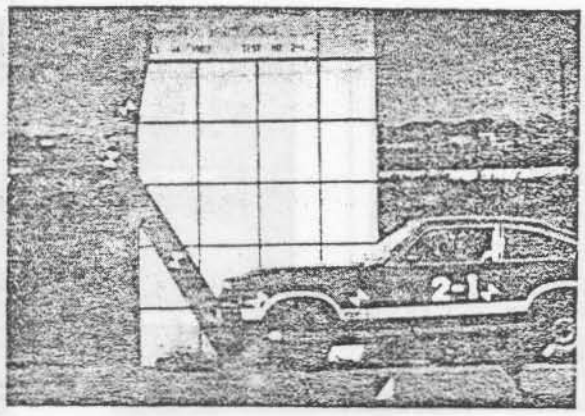


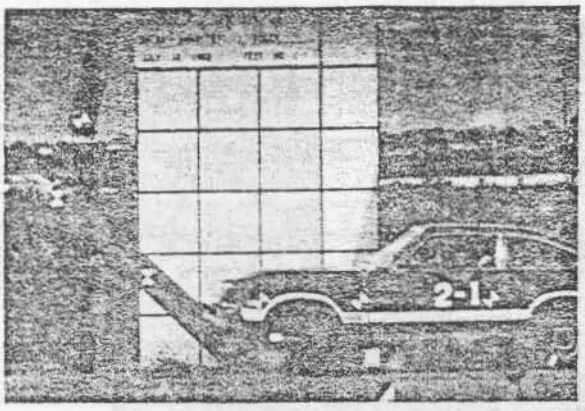
Figure 17. Vehicle C.G. Decelerations for Test Nos. 2 and 2-1



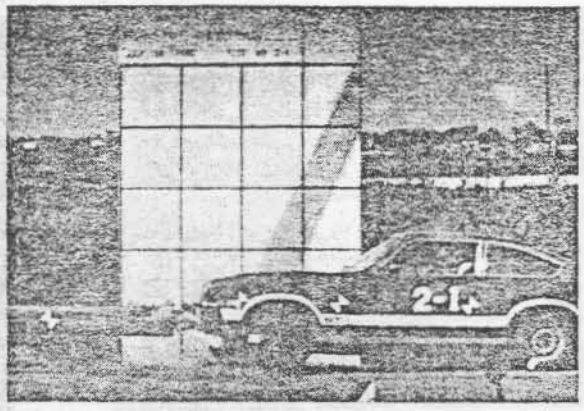
I + 200 msec



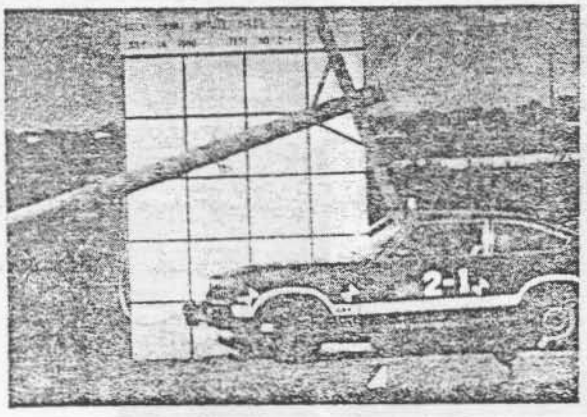
I + 277 msec



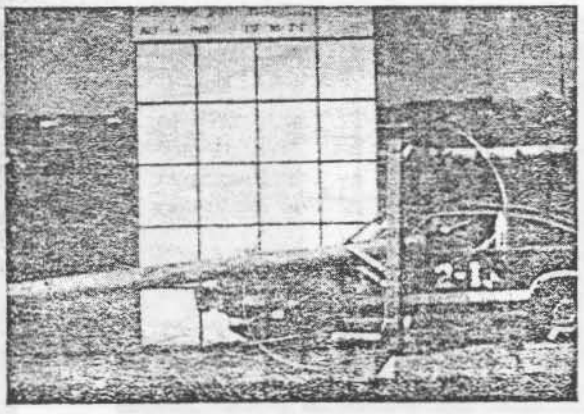
I + 342 msec



I + 525 msec

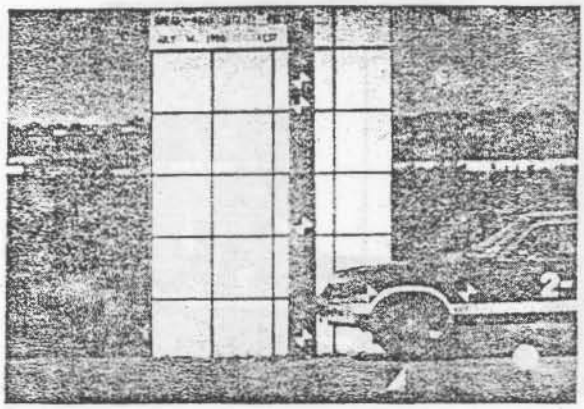


I + 2263 msec

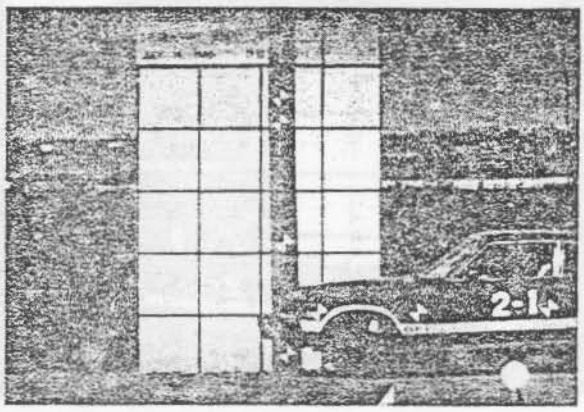


I + 3483 msec

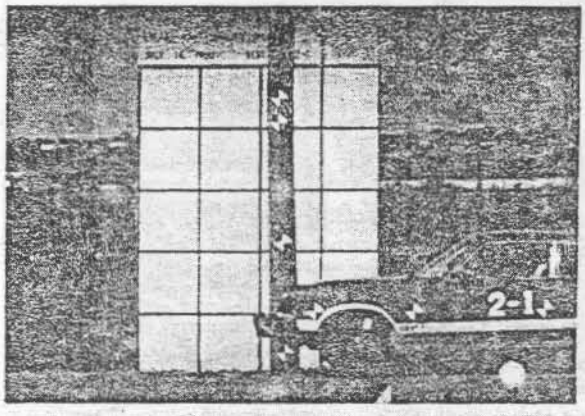
FIGURE 18. SEQUENCE PHOTOGRAPHS OF TEST 2-1: CLOSE-UP VIEWS



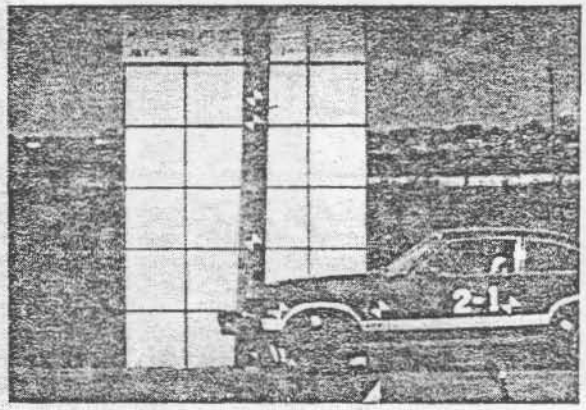
IMPACT



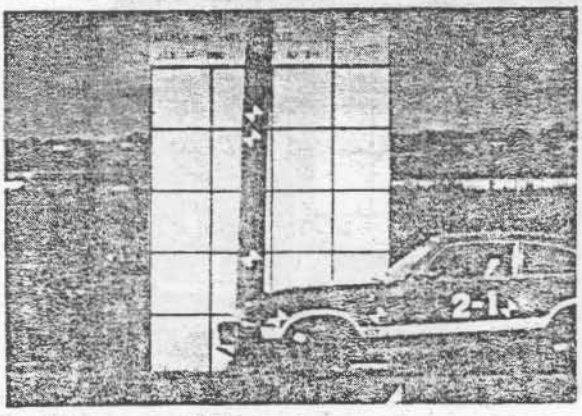
I + 40 msec



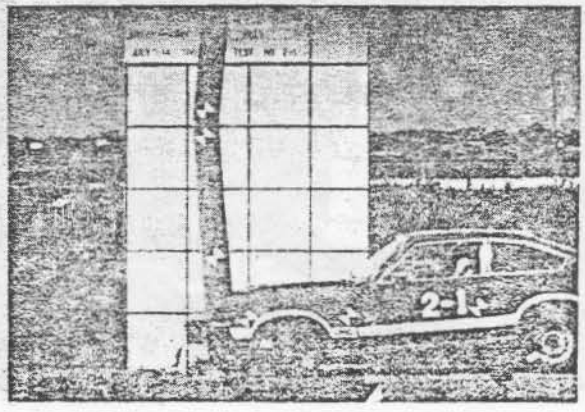
I + 43 msec



I + 76 msec

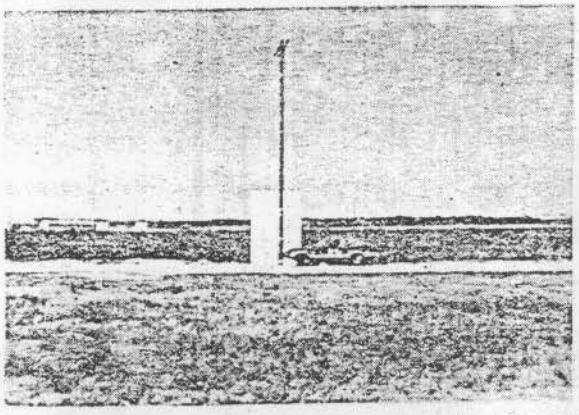


I + 124 msec

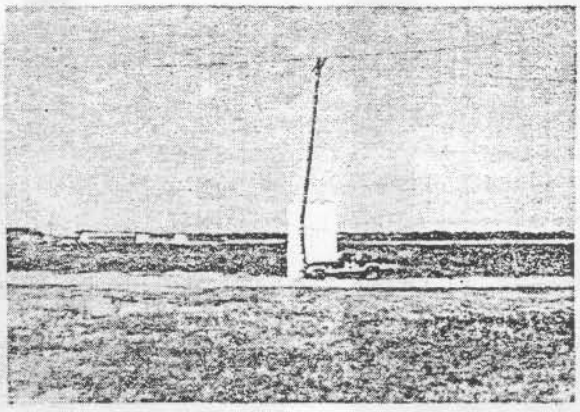


I + 160 msec

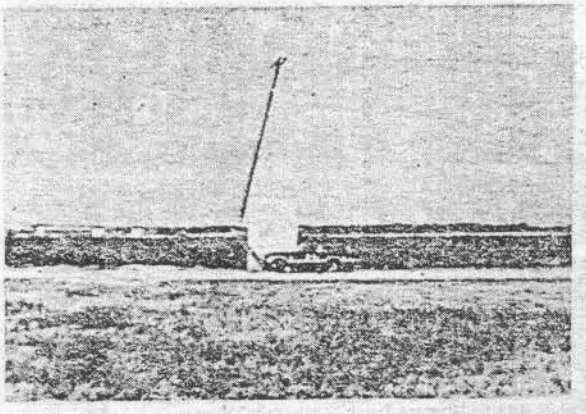
FIGURE 18. SEQUENCE PHOTOGRAPHS OF TEST 2-1: CLOSE-UP VIEWS



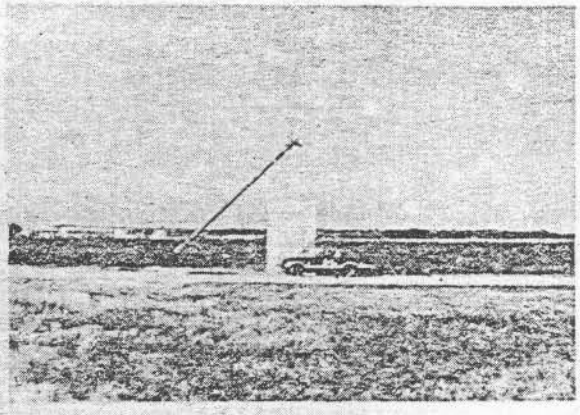
IMPACT



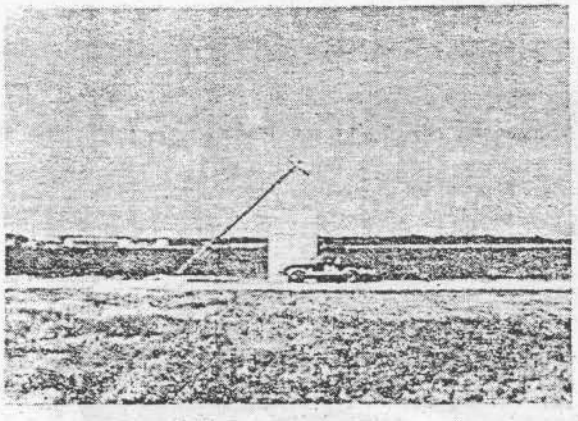
I + 153 msec



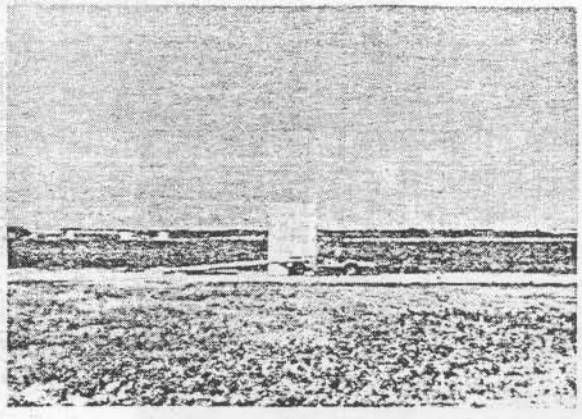
I + 281 msec



I + 1038 msec

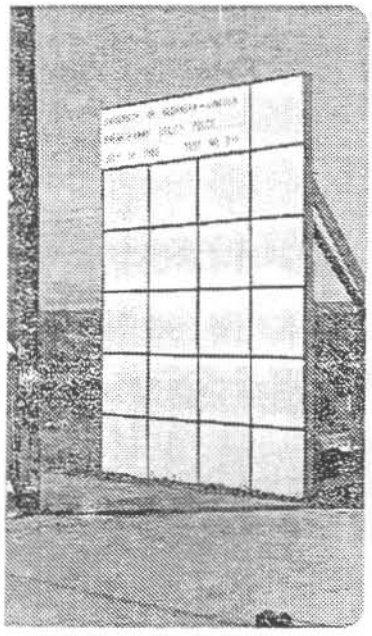


I + 1230 msec

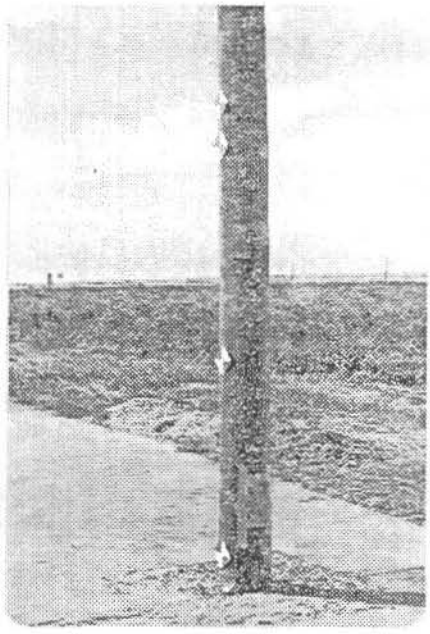


I + 2781 msec

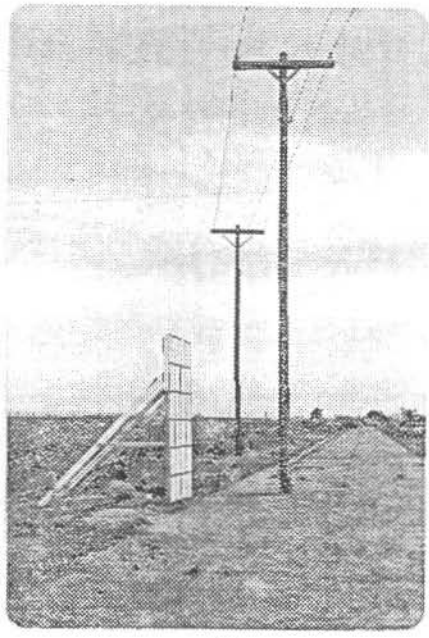
FIGURE 19. SEQUENCE PHOTOGRAPHS OF TEST 2-1: FARAWAY VIEWS



(a)

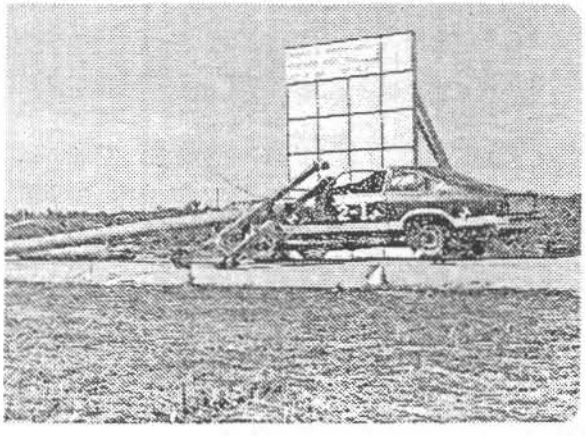


(b)

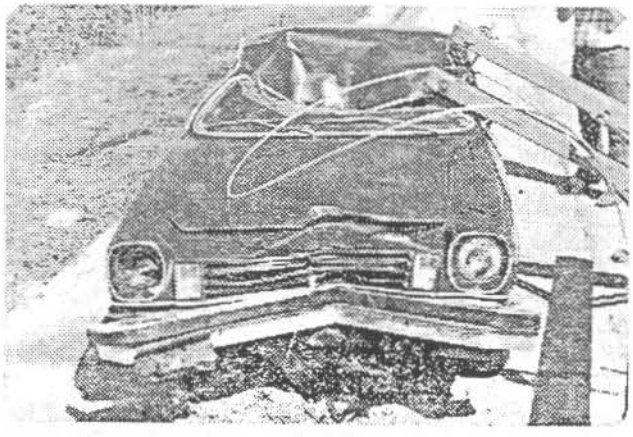


(c)

(d)



(e)



(f)

FIGURE 20. DOCUMENTATION PHOTOGRAPHS OF TEST 2-1

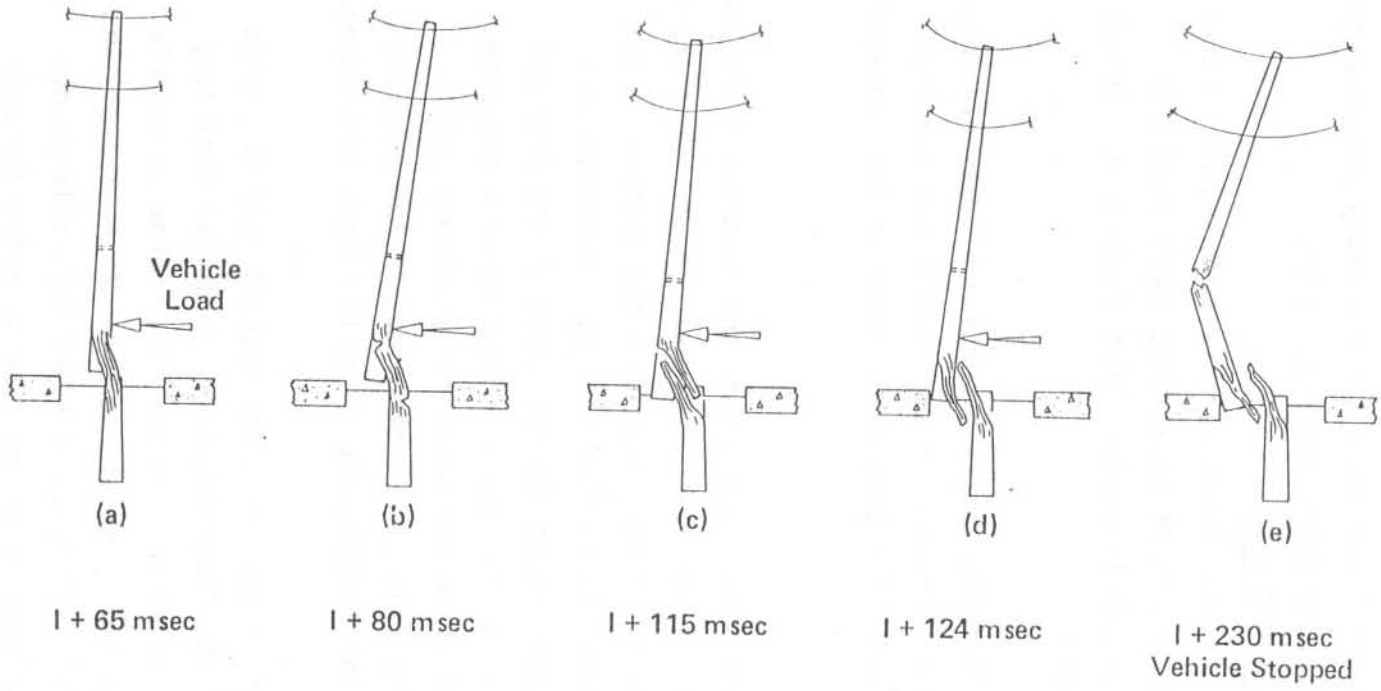


FIGURE 21. ILLUSTRATIONS OF CRITICAL FAILURE MODES OF LOWER BREAKAWAY JOINT AND POLE SNAGGING ON LEDGE IN TEST NO. 2-1.

Fig. 21d. Time of Event: 124 msec

Rotating pole snags on sawcut concrete ledge of roadway. Stub portion of pole between lower and upper breakaway joints begins to pivot counterclockwise about concrete ledge.

Fig. 21e. Time of Event: 230 msec

Top breakaway joint fails. Rotating pole stub begins to translate forward, while portion of pole above upper breakaway joint continues to rotate clockwise about conductors. Vehicle forward motion stopped.

In Figure 19, it can be seen that the rotating portion of the pole above the upper breakaway joint had separated from both the neutral and two crossarm conductors just prior to the event, I + 1039 msec, shown in the sequence photographs.

In addition to illustrating the snagging problem, the sketches in Figure 21 illustrate the failure mechanism of the lower breakaway joint. Contrary to earlier predictions by Post (2), it is now clear that the joint will not fail in transverse shearing. Instead, failure of the joint occurred as a combination of longitudinal splitting around the heartwood of the pole and then a tearing of the longitudinally split fibers in bending at a distance of about 10 to 15 in. (25 to 38 cm) above and below the breakaway joint. This type of failure mechanism allows the pole time to rotate and gain sufficient momentum in order to tear the longitudinally split fibers in bending.

Referring to Figure 16, it can be seen that the highest rate of change in vehicle velocity occurred while the lower breakaway joint was beginning to fail in the time interval range of 50 to 70 msec. The change in vehicle momentum over the time interval for a free missle to move 24 in. (61 cm) was computed to be 1,550 lb-s (6,900 Ns). It is to be noted that this change in vehicle momentum occurred far in advance of the time in which the pole snagged on the concrete ledge.

Referring to Figure 17, it can also be seen that the peak vehicle decelerations occurred while the lower breakaway joint was failing. The highest average vehicle deceleration over a time interval of 50 msec was computed to be 7.5 g's.

Documentation photographs of the damage done to the front-end, roof, and front passenger compartment area of the vehicle are shown in Figure 20. National Safety Council Damage Scale Ratings (7) and estimated repair costs are shown in Table 8. A breakdown of the vehicle damage costs in terms of parts and labor is presented in Appendix D.

Table 8. Vehicle Damage Report for Test No. 2-1

Vehicle Area Damaged	TAD Damage Rating NSC (7)	Estimated Repair Costs ($)
Front-End	FC-3	798
Roof	Not Defined	1,492
	Total	2,290

IV-E-1. Comparison of Crash Test 2-1 and Test 2

As discussed earlier, full-scale Test No. 2-1 was run as a repeat of Test No. 2 conducted in previous study by Post (2) because Test No. 2 showed much promise as a breakaway concept. Test results and documentation photographs of Test No. 2 were shown in Table 1 and Figure 4, respectively.

A comparison of the results from Test No. 2-1 and Test. No. 2 are shown in Figure 17 and Table 9. In Figure 17, it can be seen that the two vehicle deceleration graphs were similar and that the "peak" decelerations in both tests were of about the same magnitude and occurred at about the same time while the lower breakaway joint was failing. In Table 9, it can be seen that

Table 9. Comparison of Results From Test No. 2-1 and Test No. 2

Test. No.	Vehicle Weight (lb)	Vehicle Impact Speed (mph)	Average Change in Vehicle Momentum[c.] (lb-s)	Average Vehicle Deceleration[d.] (g's)	Vehicle Front-End Crushing Distance (in)
2[a.]	2,450	21.4	1,460	7.4	13
2-1[b.]	2,450	23.6	2,550	7.5	14

a. Lower breakaway joint 6 in. (15.2 cm) above ground

b. Lower breakaway joint 2 in. (5.1 cm) above ground

c. Time interval for free missile to move 24 in. (61 cm)

d. Highest average over 50 msec

Metric Conversion Factors

1 in. = 2.54 cm

1 mph = 1.609 km/h

1 lb-s = 4.45 Ns

the average deceleration and momentum change of the vehicle in Test No. 2-1 were slightly higher than in Test No. 2. A reason for the higher values in Test No. 2-1 was because the impact speed was 2 mph (3.2 km/h) higher.

In both tests, the vehicle decelerations and momentum changes were critical during failure of the lower breakaway joint. As illustrated in Figure 21, failure of the lower breakaway occurred far in advance of the time in which snagging occurred in Test No. 2-1. From a careful review of the high-speed film on the Vanguard Motion Analyzer, it can be concluded that the "overall" performance of the breakaway utility pole in Test 2-1 would have been the same as that in Test No. 2 (see Figure 4) if the snagging had not occurred. Several apparent reasons for the pole snagging in Test No. 2-1 and not snagging in Test No. 2 were because (a) the height above the ground of the

lower breakaway joint in Test No. 2-1 was about 4 in. (10 cm) lower than the height of the joint in Test No. 2, or (b) the soil around the pole in Test No. 2-1 was not compacted as well as in Test No. 2, thereby, allowing the pole to penetrate deeper into the soil, or (c) a combination of these two effects. The height of the lower breakaway joint in Test No. 2-1 was made lower to minimize any chances of snagging on the undercarriage of the vehicle.

IV-F. Results of Full-Scale Crash Test No. 2-2

Test No. 2-2 was conducted under similar conditions as Test No. 2-1 with the exception of a change in one important design element. After consultations with the FHWA ~~project~~ contract manager, the decision was made to cast a concrete collar around the test pole. The concrete collar, which is visible in the documentation photographs shown in Figure 25, was about 2 ft. (0.6 m) square and 6 in. (15 cm) deep. The concrete collar was used in an attempt to (a) eliminate the pole snagging problem encountered in Test 2-1, and (b) eliminate possible future problems of large displacements of breakaway poles in saturated soil by reducing the soil bearing pressures. In an earlier study conducted by Post (2), it can be seen in Table 1 that large pole displacements in saturated soil prevented the breakaway pole concept from working.

Test No. 2-2 was conducted with a compact automobile weighing 2,450 lbs (1,112 kg). The impact speed of the vehicle was 22.8 mph (36.7 km/h). Graphs of the change in vehicle velocity and vehicle deceleration versus time are shown in Figures 22 and 23, respectively. Data points on these graphs were obtained by a high-speed film analysis using the Vanguard Motion Analyzer (see Appendix B).

The change in vehicle momentum over the time interval for a free missile to move 24 in. (61 cm) was computed to be 1,940 lb-s (8,635 Ns). Referring to the graph in Figure 23, the average vehicle deceleration was computed to be 10.3 g's.

The unfavorable results in Test 2-2 can be attributed to the concrete collar cast around the pole. As can be seen in the documentation photographs

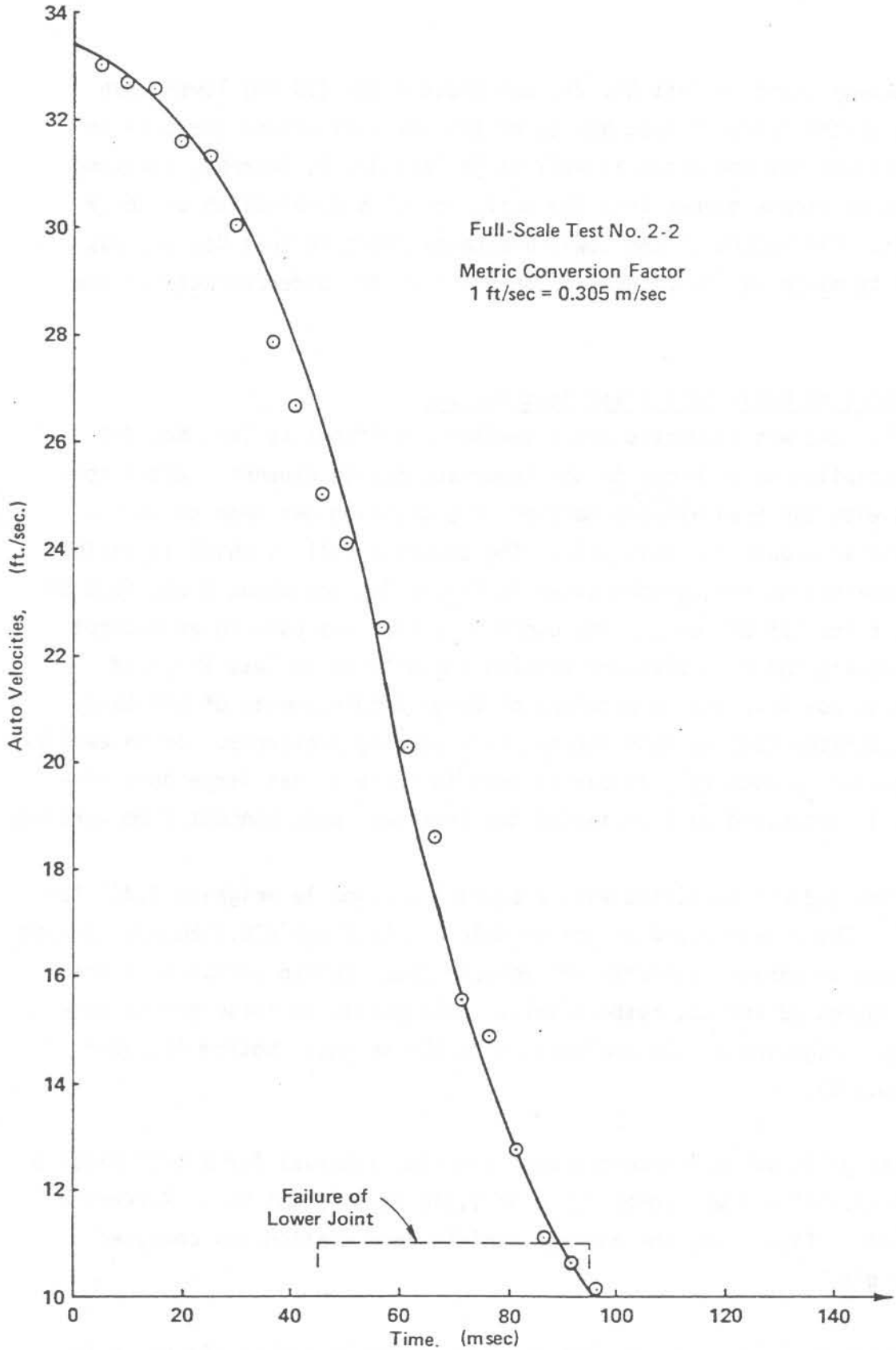


Figure 22. Vehicle Velocities for Test No. 2-2

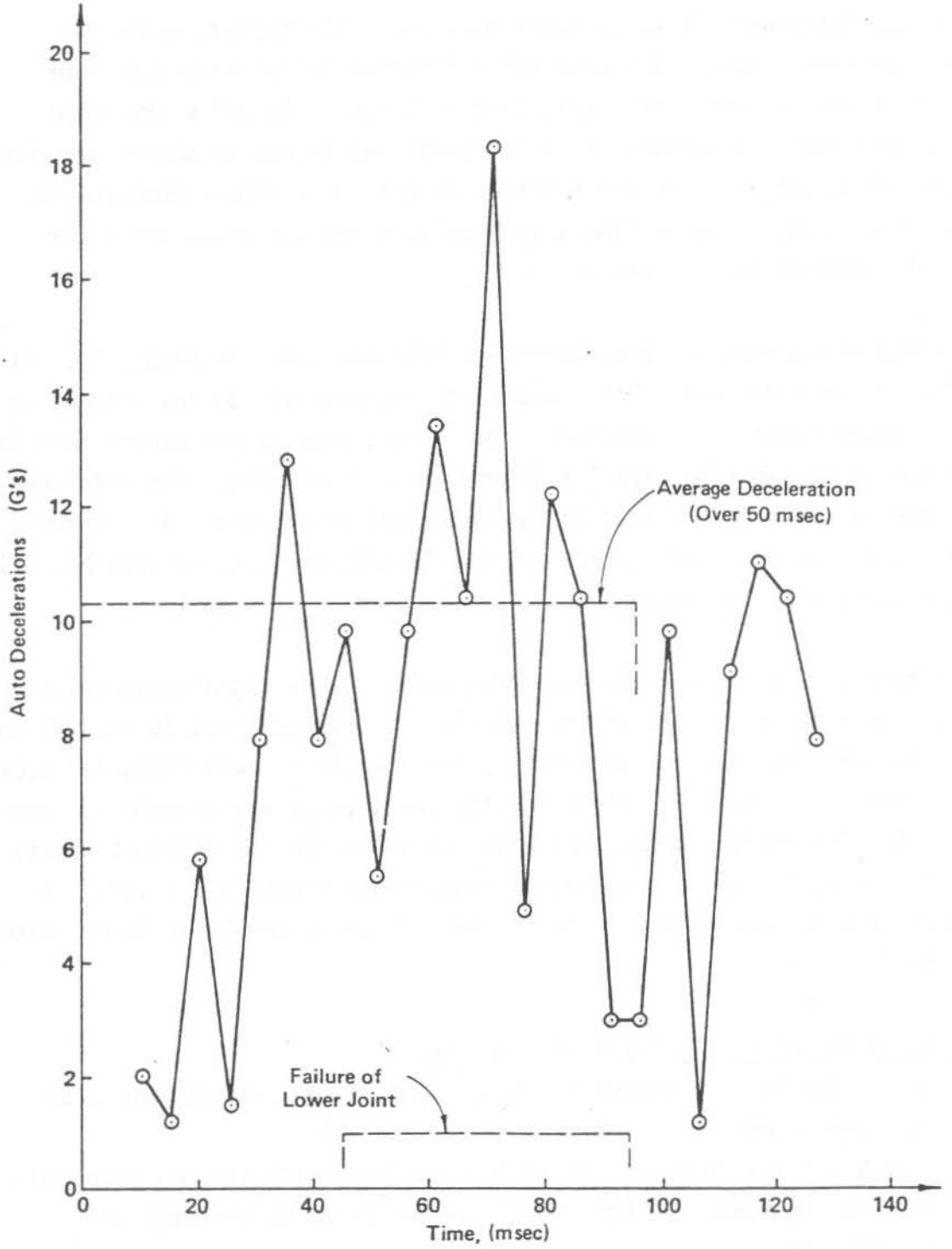


Figure 23. Vehicle C.G. Decelerations for Test No. 2-2

of Figure 25, the lower breakaway joint only partially failed, while the top joint remained intact. The pole split longitudinally above the lower joint, but it was prevented from splitting longitudinally below the joint because of the concrete collar. This "binding" resistance of the collar did not allow sufficient time for the rotating pole to gain enough momentum to fail the longitudinally split fibers in bending above and below the lower joint as illustrated by the sketches in Figure 21.

Sequence photographs of the high-speed film are shown in Figure 24. After impact, the lower breakaway joint translated approximately 10 in. (25 cm) as the pole rotated about the conductors. This joint translation can be seen in the sequence photographs between I + 44 msec to I + 105 msec. The reference lines on the backboard are spaced 24 in. (61.0 cm) on centers. The concrete collar in this test moved only about 1/4 in. (6 mm), whereas, in Test No. 2-1 the pole without a collar moved about 1 in. (2.5 cm) in the soil.

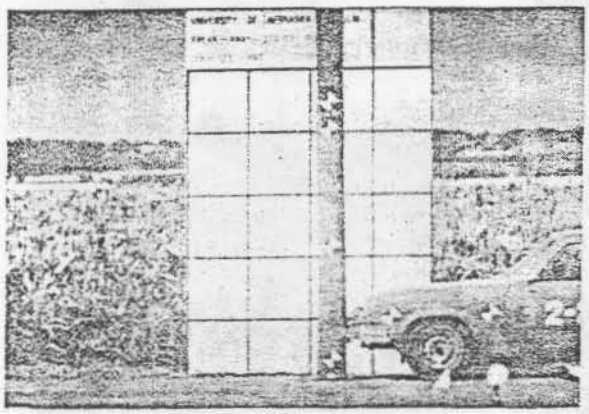
In Figure 24, it can also be seen that prior to any significant rotation of the pole that the front-end of the vehicle had crushed about 16 in. (41 cm). After partial failure of lower breakaway joint the vehicle was rebounded backward about 8 ft. (2.4 m). The final resting position of the vehicle is shown in Figure 25. The vehicle damage was rated as a FC-3 in the National Safety Council TAD Scale (7), and the estimated damage repair cost was $1,271. A breakdown of the vehicle damage costs in terms of parts and labor is presented in Appendix D.

IV-G. Results of Full-Scale Crash Test No. 4-1

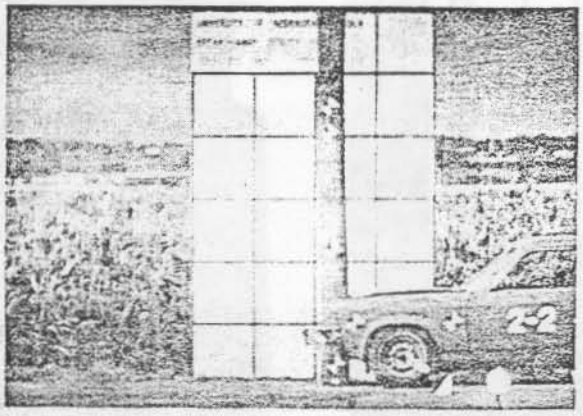
Except for the following modifications, Test No. 4-1 was set up to be run under the same conditions as Test Nos. 2-1 and 2-2.

(a) Test No. 4 was to be evaluated in accordance with the new proposed criteria in NCHRP 230 (8) as well as the existing criteria in TRB 191 (4).

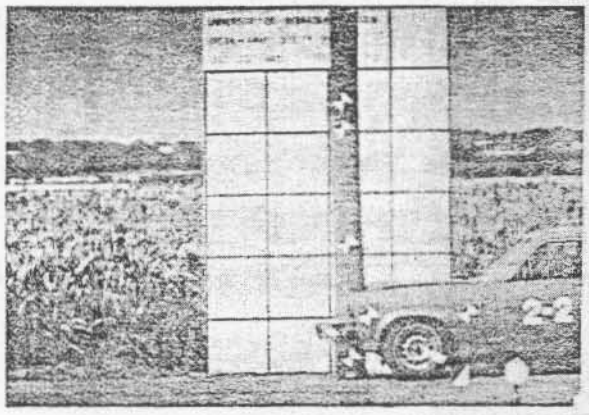
(b) A tri-axial accelerometer unit was mounted on the vehicle center-of-gravity in Test No. 4-1. (An indepth discussion on the electronic instrumentation and the data reduction analysis technique is presented in Appendix C.)



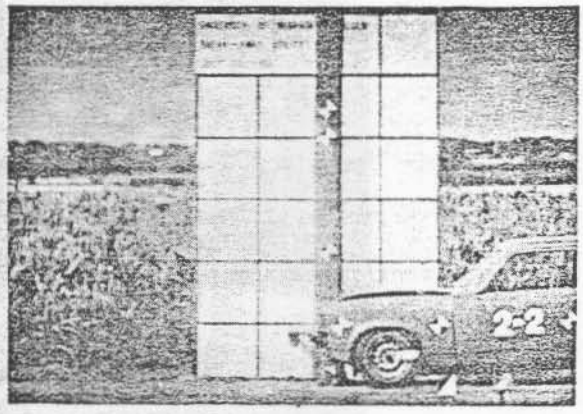
IMPACT



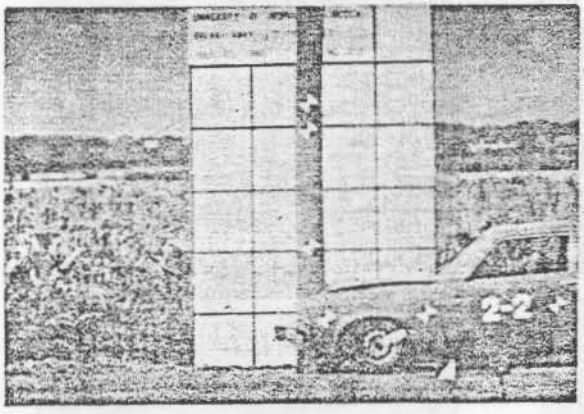
I + 42 msec



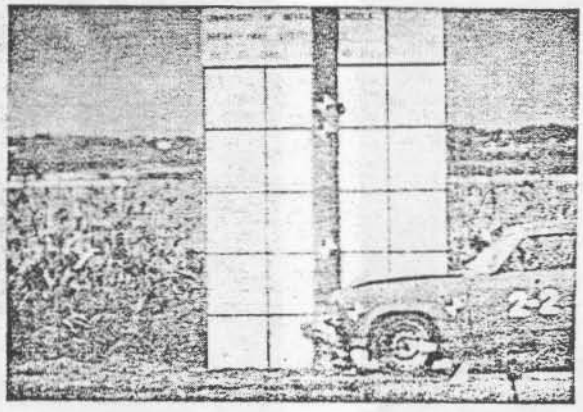
I + 44 msec



I + 73 msec

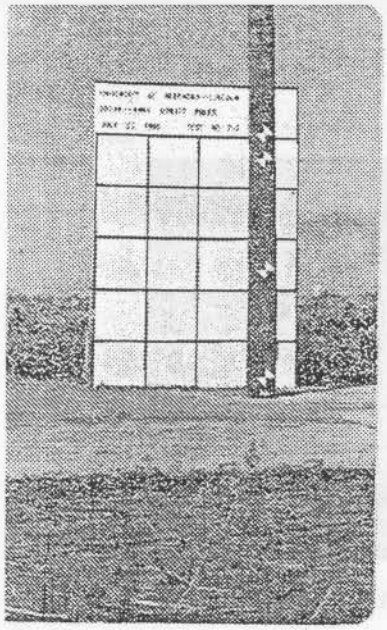


I + 105 msec

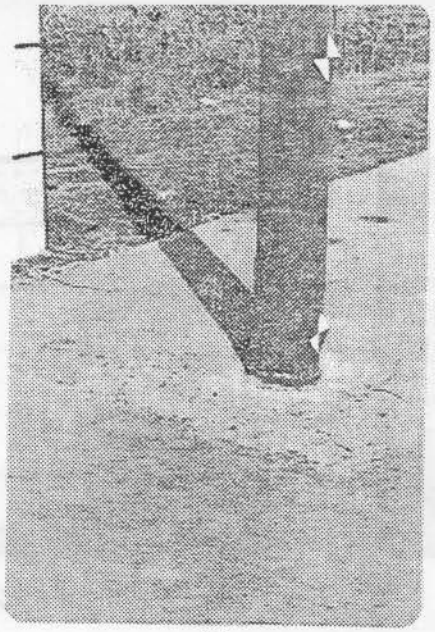


I + 291 msec

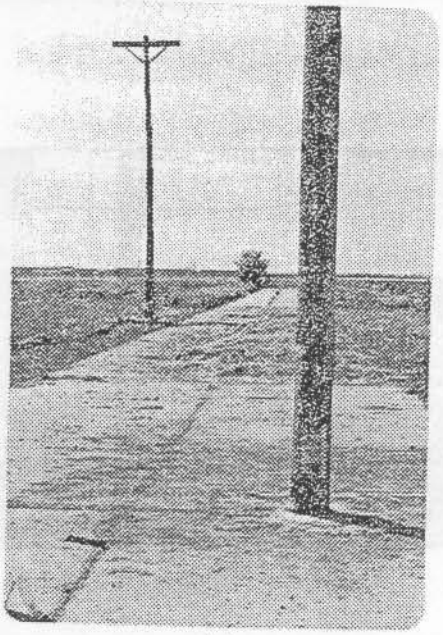
FIGURE 24. SEQUENCE PHOTOGRAPHS OF TEST 2-2.



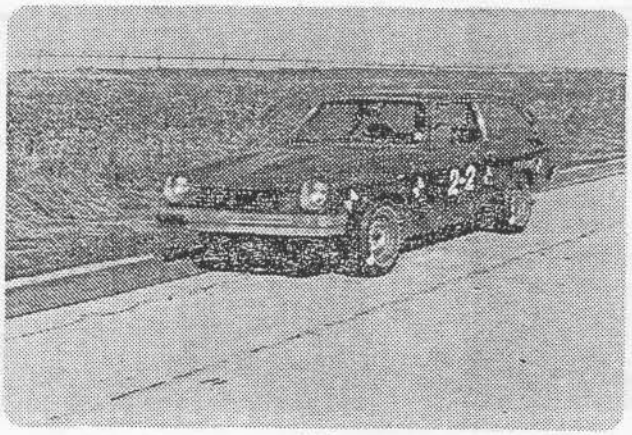
(a)



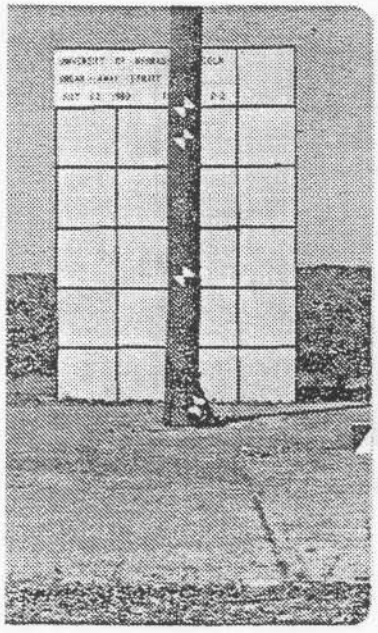
(b)



(c)



(d)



(e)

(f)

(g)

FIGURE 25. DOCUMENTATION PHOTOGRAPHS OF TEST 2-2

(c) A positive non-standard insulator-conductor connection was used in Test No. 4-1 to prevent the breakaway pole from falling down.

Before discussing the results of Test No. 4-1, a brief discussion on the insulator-conductor connection will be presented.

A non-standard conductor-insulator connection was used on the double crossarms for Test No. 4-1. The components that make up the connection are shown in Figure 26. As illustrated, the post top clamp is bolted to the top of the post insulator and the conductor is then clamped in the device. This design results in a positive type connection wherein the conductor will not separate from the insulator nor from the crossarms. The positive type connection was also used so that a more thorough analysis could be made of the breakaway joint behavior during the crash test.

Test No. 4-1 was conducted with a 1974 Chevrolet Vega weighing 2,450 lb (1,110 kg). The impact speed of the vehicle was 26 mph (42 km/h). Due to an error in reading the speedometer in the tow vehicle, the impact speed turned out to be 6 mph (10 km/h) higher than the planned speed of 20 mph.

Documentary photographs of Test No. 4-1 are shown in Figure 27. As can be seen, only the lower breakaway joint of the utility pole failed. The vehicle travelled 46 ft. (13.7 m) past the original position of the pole and stopped in a thin sand arrestor bed. The roof of the vehicle sustained minor damage as the pole dragged over the vehicle. The severity of front-end vehicle damage was rated as FC-3 in accordance with the National Safety Council TAD Scale (7). The effectiveness of the non-standard insulator-conductor connection in preventing the breakaway portion of the pole from falling is evident in Figure 27. None of the conductors were damaged in the test.

Close-up and wide-angle high speed sequence photographs of Test No. 4-1 are shown in Figures 28 and 29, respectively. Referring to Figure 28, it can be seen that the maximum flexure of the upper breakaway joint occurred at about 100 msec after impact. It is predicted that the upper breakaway joint would

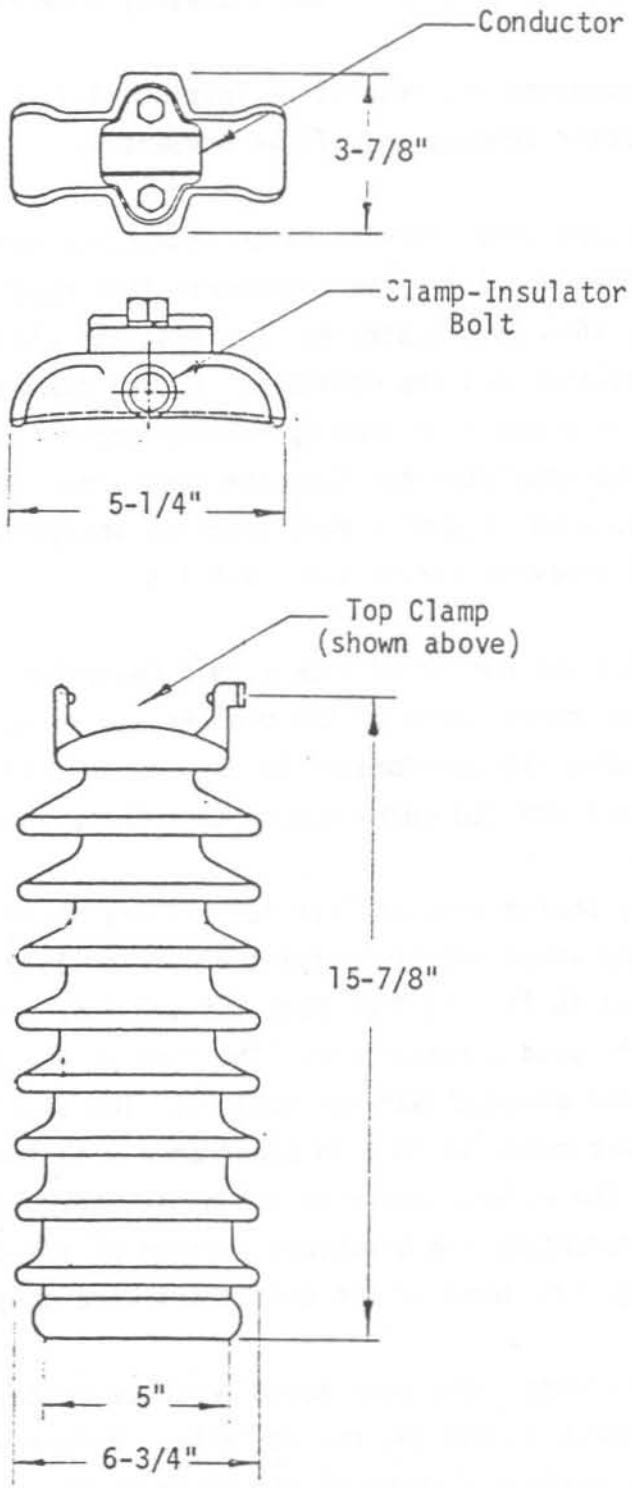
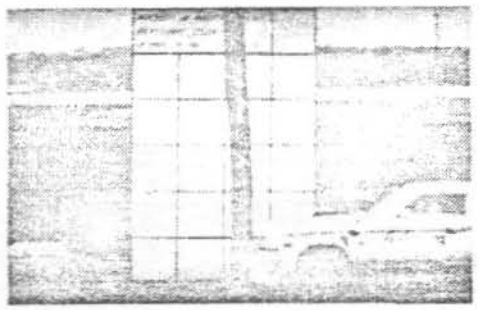
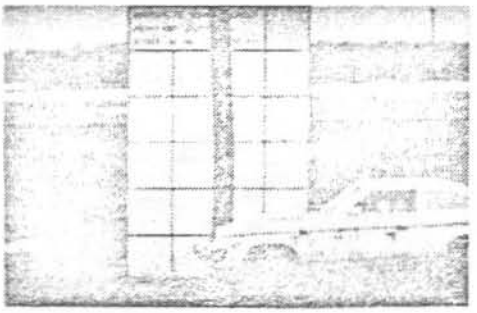


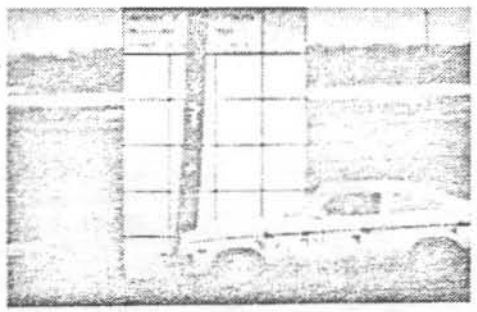
Figure 26. Non-Standard Insulator-Conductor Connection



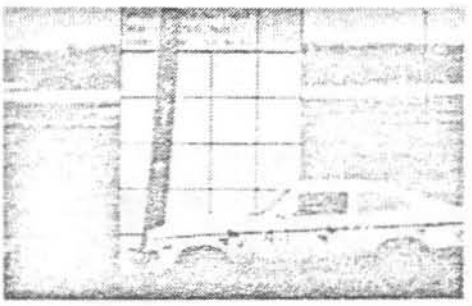
Impact



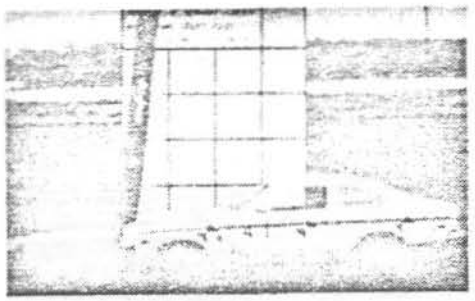
I + 50 msec



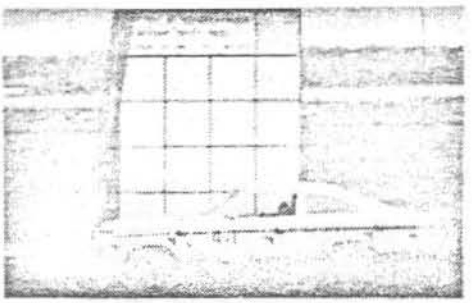
I + 100 msec



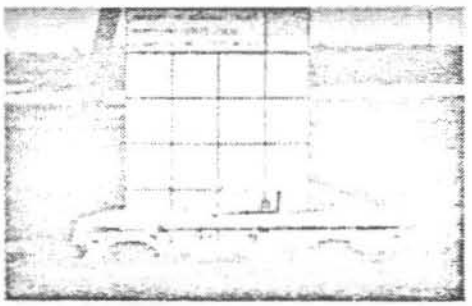
I + 150 msec



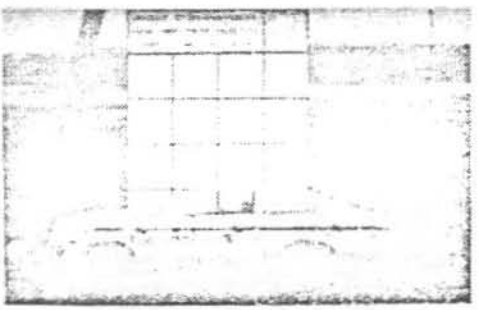
I + 200 msec



I + 250 msec

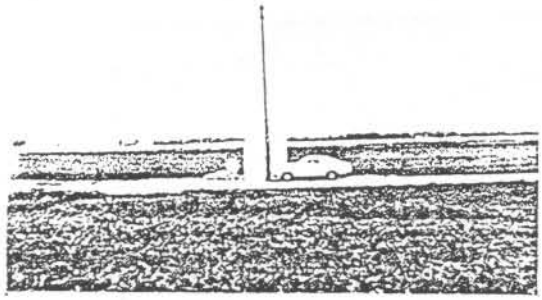


I + 300 msec

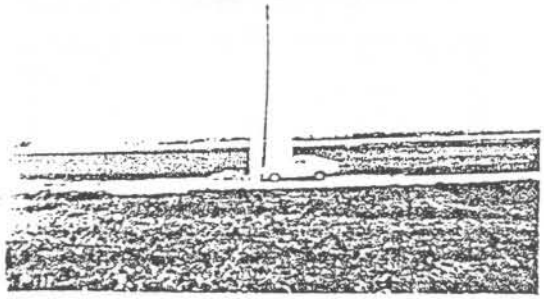


I + 350 msec

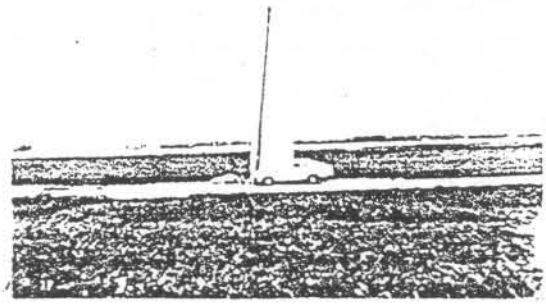
Figure 28. Sequence Photographs of Test No. 4-1: Close-Up Views



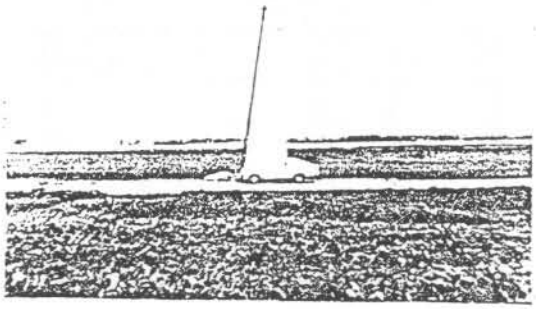
Impact



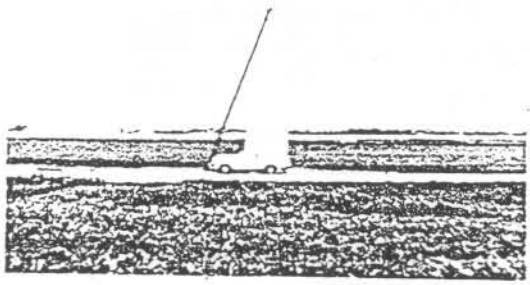
I + 100 msec



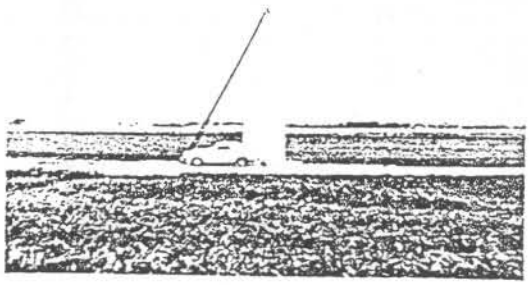
I + 150 msec



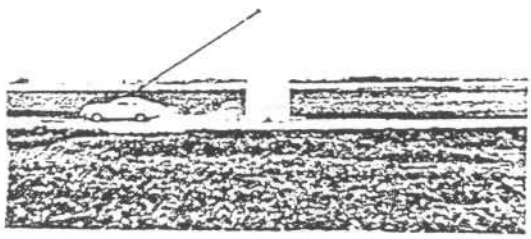
I + 250 msec



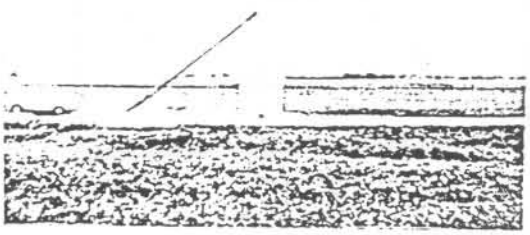
I + 400 msec



I + 450 msec



I + 1600 msec



I + 2600 msec

Figure 29. Sequence Photographs of Test No. 4-2: Far-Away Views

have failed at an impact speed of about 30 mph (48 mg/h). The wide-angle sequence photographs show the entire interaction of the vehicle and breakaway pole.

Using the criteria in TRB 191, the momentum change was computed to be 1,475 lb-s (6,565 Ns) over the time duration for a free missile to travel 24 in. (61 cm). The momentum change was greater than the 1,100 lb-s (4,890 Ns) criteria for sign and luminaire supports in TRB 191. On the other hand, the test can be considered to be acceptable by the NCHRP 230 criteria as the computed occupant/dash impact velocity of 19.3 fps (5.9 m/s) and the occupant ridedown acceleration of 1.6 g are well below the acceptable design limit values for 30 fps (9.2 m/s) and 15 g, respectively.

IV-G-1. Comparison of Test No. 4-1 and Test No. 2

As discussed earlier, full-scale Test Nos. 2-1, 2-2, and 4-1 were run as a repeat of Test No. 2 conducted in previous study by Post (2) because Test No. 2 showed much promise as a breakaway concept. Test results and documentation photographs of Test No. 2 were shown in Table 1 and Figure 4, respectively. Because the test results of Test Nos. 2-1 and 2-2 were considered inconclusive for reasons explained earlier, it was considered necessary to conduct Test No. 4-1.

A comparison of the results from Test No. 4-1 and Test No. 2 are shown in Table 10. The only apparent difference between the two tests is that the vehicle in Test No. 4-1 travelled a greater distance beyond the point of impact because if its higher speed of impact. This difference in travel distance could be misleading because in Test No. 2 there appeared to be some vehicle undercarriage snagging on the 6 in. (15 cm) stub portion of the lower breakaway joint above the roadway surface.

Both tests can be considered as a "failure" in regard to the criteria of TRB 191 because the changes in vehicle momentum were greater than 1,100 lb-s (4,900 Ns). On the other hand, both tests can be considered as "acceptable" in regard to the new proposed criteria of NCHRP 230 because the occupant/dash

Table 10. Comparison of Results From Test No. 4-1 and Test No. 2

Test No.	Vehicle Weight (lb)	Vehicle Impact Speed (mph)	Vehicle Travel Beyond Impact Point (ft)	TRB 191	NCHRP 230	
				Momentum Change (lb-s)	Occupant/Dash Impact Velocity (fps)	Occupant Ridedown Acceleration (g)
2[a.]	2,450	21.4	12	1,460	20.3	2.0
4-1[b.]	2,450	26.0	46	1,475	19.3	1.6

a. Lower breakaway joint 6 in. (15 cm) above ground

b. Lower breakaway joint 2 in. (5 cm) above ground

Metric Conversion Factors

1 in. = 2.54 cm
1 ft. = 0.305 m
1 lb. = 0.454 kg
1 mph = 1.609 km/h
1 lb-s = 4.45 Ns
1 fps = 0.305 m/s

---

impact speeds and the occupant ridedown accelerations were below the design limits of 30 fps (9 m/s) and 15 g, respectively. It is important to point out that the TRB criteria was developed for breakaway and yielding sign and luminaire type supports.

V. SUMMARY AND CONCLUSIONS

The UNL breakaway wooden utility pole stub concept proposed and full-scale vehicle crash tested by Post (2) showed that (a) the concept offered much promise in reducing the severity of utility pole accidents, and (b) the concept appeared to be a very cost-effective improvement alternative.

This study, which consisted of conducting two full-scale static bending strength tests and three full-scale vehicle crash tests on "new" 40 ft. (12.2 m) Class 4 Southern Yellow Pine utility poles, was a continuation study of the earlier study conducted by Post (2). Summary and conclusions pertinent to the two types of full-scale tests conducted in this study follows.

V-A. Full-Scale Static Tests

The objective of conducting the two full-scale static tests was to compare the "ultimate resisting" moments from the full-scale tests with the "ultimate computed design" moments. The findings of this study showed that:

(a) the full-scale static test strength of the pole about the strong bending axis of the lower breakaway joint was 17% stronger than the design strength required by the ANSI Code (3) to carry the lateral heavy ice + wind loading conditions in the midwestern states using an overload capacity factor of four.

(b) the full-scale static test strength of the pole about the weak bending axis of the lower breakaway joint was 114% stronger than the design strength required to carry the longitudinal extreme wind loading conditions acting on the projected area of the pole alone.

However, based upon comments offered by Findlay (9) of the Lincoln Electric System (LES) and the results of a single full-scale static test in the longitudinal direction, it is apparent that the breakaway pole may not be structurally adequate to carry the longitudinal loading due to unbalanced ice loads on adjacent connector spans. Unbalanced longitudinal loading conditions are specified in Section 252.C.4 of the ANSI Code (3). The comments of LES are presented in Appendix E. In Section 252.C.4, the Code states:

"Where longitudinal loads can be created by the difference in tensions in the wires in adjacent spans caused by unequal vertical loading or unequal spans, the structures should be capable of supporting this unbalanced longitudinal loading."

As LES points out, unequal vertical loading could occur when one span sheds its ice load while the adjacent spans are still ice loaded. Also, unequal span loading could occur when a breakaway pole is struck by a vehicle. The examples of LES indicate that these unbalanced longitudinal loading conditions are of such magnitude as to fail the breakaway pole.

It is imp~~rot~~ortant to point out that only two exploratory static tests were conducted on "new" poles. No attempt was made to study the decrease in pole strength with age and change in moisture content. This issue was also brought to the attention of the researchers by LES, whereby, it was pointed out that a wood member under the continuous action of bending stress for 10 years will carry only about 60% of the load attained by the same specimen loaded in a standard bending strength test of a few minutes duration. The effects of age and change in moisture content will certainly need to be investigated in future research.

In conclusion, the results of the full-scale static test conducted about the strong axis of the breakaway joint (perpendicular to the wires) showed that the breakaway design was structurally adequate to carry the heavy ice lateral loading conditions specified by the National Electric Safety Code (ANSI) for the midwestern state of Nebraska. However, the results of the static test conducted about the weak axis of the breakaway joint (longitudinally to the wires) to simulate the unbalanced loading conditions specified in ANSI were inconclusive because the spaces between the drilled holes of the breakaway joint were unintentionally chiselled-out (slotted) and not sawcut to the width of a keyhole saw-blade as was planned and done in conducting the full-scale vehicle crash tests. If the spaces between the drilled holes had been sawcut, then the transformed section modulus in bending due to compression as the sawcut closed under load would have resulted in a greatly increased section bending modulus and longitudinal load carrying capacity.

V-B. Full-Scale Crash Tests

A summary of the three full-scale vehicle crash test results conducted in this FHWA study along with the results from the three tests conducted earlier by Post (2) is presented in Table 11. All of the vehicle tests were headon center type impacts.

The TRB 191 (4) evaluation criteria specifies that an unacceptable test is one in which the vehicle change in momentum is greater than 1,100 lb-s (4,900Ns); whereas, the NCHRP 230 (8) proposed evaluation criteria specifies that an unacceptable test is one in which the occupant/dash impact velocity and the occupant ridedown acceleration are greater than 30 fps (9.2 m/s) and 15 g, respectively. It is important to point out that the TRB criteria may not provide a good measure of performance for breakaway utility poles because the criteria was designed for less massive breakaway and yielding roadside sign type supports and luminaire type supports.

The results of Test Nos. 3, 2-1, and 2-2 in Table 11 were considered to be inconclusive. In Test No. 3, the soil backfall material was saturated, and as a result, the displacement of the pole in the soil absorbed a large portion of the vehicle's kinetic energy and thereby prevented the breakaway joints from actuating. In Test No. 2-1, the test started out to be a good test but the rotating pole accidentially snagged on a sawcut concrete ledge, and as a result, the pole upon pivoting about the ledge failed the upper breakaway joint and rapidly decelerated the vehicle over a distance of about 3 ft (0.9m). In Test No. 2-2, a concrete collar was cast around the base of the pole to prevent the breakaway pole from snagging on the sawcut concrete ledge. The collar in turn prevented the fibers of the pole below the breakaway joint from stretching a sufficient distance to fail in tension.

The results of Test No. 1 are within the criteria of both TRB 191 and NCHRP 230. It is to be noted the test conditions in Test No. 1 were different than all the other tests in that, the test was run with a heavier 4,600 lb (2,090 kg) vehicle at a higher impact speed of 31 mph (50 km/h).

CONDITIONS	Study by Post			FHWA Study		
	Test No.1	Test No.2	Test No.3	Test No.2-1[g]	Test No. 2-2	Test No.4-1
Vehicle Weight (lb)	4,600	2,450	2,450	2,450	2,450	2,450
Vehicle Impact Speed (mph)	31	21	21	24	23	26
Vehicle Travel Beyond Impact (ft)[a]	50[b]	12[c]	2	3	2	45
Vehicle Damage...NSC Rating Scale	FC-2	FC-3	FC-3	FC-3	FC-3	FC-3
Pole Backfill Condition	Dry	Dry	Wet	Dry	Conc.Collar	Dry
Lower Breakaway Joint Fail	Yes	Yes	No	Yes	Partially	Yes
Upper Breakaway Joint Fail	Yes	No	No	No	No	No
Breakaway Pole Fall	Yes	No	No	Yes	No	No[d]
TRB 191 Criteria						
Vehicle Momentum Change (lb-s)	1,100(P)	1,450(F)	2,300(F)	1,550(F)	1,950(F)	1,450(F)
NCHRP 230 Proposed Criteria						
Occupant/Dash Impact Velocity(fps)	10(P)	20(P)	27(P)	25(P)	32 (U)	19(P)
Occupant Ridedown Acceleration (g)	2(P)	2(P)	4(P)	3(P)	6(P)	2(P)
Breakaway Pole Performance Evaluation[f]	Promising	Promising	Inconclusive	Inconclusive	Inconclusive	Promising

a. Includes vehicle crushing
b. Vehicle stopped by fixed barrier
c. Slight vehicle undercarriage dragging on 6 in. (15 cm) stub
d. Positive non-standard insulator-conductor connection used
f. Researchers Opinion
g. Breakaway pole snagged accidentially on sawcut concrete ledge
P=Pass U = Unacceptable

Metric Conversion Factors

1 lb = 0.454 kg
1 ft = 0.305 m
1 fps = 0.305 m/s
1 mph = 1.609 km/h
1 lb-s = 4.45 Ns

In this test, both breakaway joints actuated thereby allowing the stub portion of the pole between the joints to release. The stub slightly cracked the windshield. The breakaway pole separated from the conductors and landed on top of the vehicle. It was evident from the high-speed film that the pole would not have landed on top of the vehicle if the vehicle had not been stopped by a fixed barrier located 50 ft downstream of the point of impact.

Test No.2 was conducted with a 2,400 lb (10,680 N) vehicle at an impact speed of 21 mph (34 km/h). The results of the test were unacceptable by the TRB 191 criteria, but acceptable by the new proposed NCHRP 230 criteria. In any event, the test results are very promising because the vehicle was decelerated over a long distance of 12 ft (3.7 m). The performance of the breakaway pole in this test is, in essence, comparable to the performance of a sand inertia crash cushion. It is conceivable that the vehicle would have travelled even a greater distance if dragging on the undercarriage of the vehicle on the 6 in. (15 cm) high stub had not occurred.

Test No. 4-1 was conducted with a 2,450 lb (1,110 kg) vehicle at an impact speed of 26 mph (41 km/h). Due to an error in reading the speedometer in the tow vehicle, the impact speed was 6 mph (10 km/h) higher than planned. As in Test No. 2, the results of Test No. 4-1 were unacceptable by the TRB 191 criteria but acceptable by the NCHRP 230 criteria. The vehicle in this test travelled further than in Test No. 2 because of the higher impact speed and because there was no evidence of vehicle undercarriage dragging on the lower 2 in. (5 cm) stub. Other than distance travelled after impact, the results of Test No. 4-1 compare reasonably well with the results of Test No. 2.

In conclusion, the full-scale vehicle crash tests showed that the breakaway stub design concept is promising and effective in reducing the impact severity of a (a) 2,450 lb (1, 110 kg) vehicle collision at speeds of 21 mph (34 km/h) and 26 mph (42 km/h), and (b) 4,600 lb (2,090 kg) vehicle collision at 31 mph (50 km/h). ~~It will, however, be necessary to modify~~

REFERENCES

1. Jones, I. S., Baum, S., "Analysis of the Problem of Urban Utility-Pole Accidents", TRB 681, pp 89-94, 1978.

2. Post, E. R., McCoy, P. T., Wipf, T. J. and Bolton, R. W., "Feasibility Study of Breakaway Stub Concept for Wooden Utility Poles", University of Nebraska-Lincoln, Civil Engineering Department, Research Report No. TRP-03-005-79, in cooperation with Lincoln Electric System and Lincoln Telephone and Telegraph Company, pp 146, 1979.

3. ANSI, American National Standard Institute: National Electric Safety Code, Sections 25 and 26, 1981 edition.

4. "Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances", TRB Circular 191, Feb. 1978.

5. Labra, J. J., "Development of Safer Utility Poles", Interim Report, SWRI Project No. 03-4502, Dec. 1977.

6. Redding, D., Supervisor of Transmission and Substation, Lincoln Electric System, Project Representative on Breakaway Utility Poles.

7. "Vehicle Damage Scale for Traffic Accident Investigators", National Safety Council, TAD Project Technical Bulletin No. 1, 1968.

8. Michie, J. D., "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances", NCHRP 230, March 1981.

~~9. Findley, Bill, Constructive Criticism Offered by Lincoln Electric System on "Feasibility Study of Breakaway Stub Concept for Wooden Utility Poles", January 22, 1982.~~ Letter not title, "An analysis

9. Findlay, Bill, letter entitled "Analysis of the Feasibility Study of Breakaway Stub Concept for Wooden Utility Poles", January 21, 1982.

APPENDIX A.

FULL-SCALE STATIC TESTS

HUGHES
BROTHERS
P. O. BOX 159 • 210 NORTH 13TH STREET • SEWARD, NEBRASKA 68434 • PHONE (402) 643-2991

UNIVERSITY OF NEBRASKA - LINCOLN

SINGLE POLE TANGENT STRUCTURE

(BORED FOR SAFETY)

TESTS

SEWARD, NEBRASKA

MAY, 1980

Manufacturer of Transmission and Distribution Material for the Electric Utility Industry since 1921.

HUGHES BROTHERS
P. O. BOX 159 • 210 NORTH 13TH STREET • SEWARD, NEBRASKA 68434 • PHONE (402) 643-2991

UNIVERSITY OF NEBRASKA - LINCOLN

SINGLE POLE TANGENT STRUCTURE

(BORED FOR SAFETY)

TESTS

SEWARD, NEBRASKA

MAY, 1980

POLE CIRCUMFERENCES

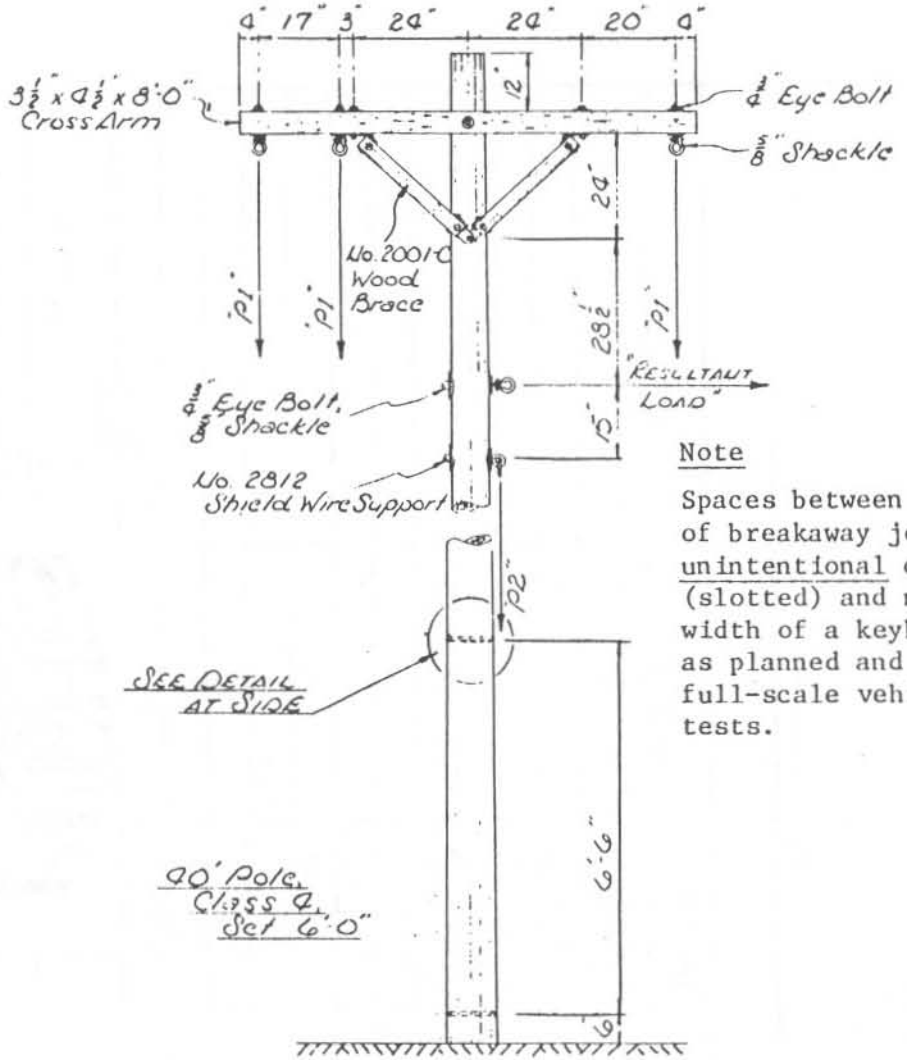
TEST NO. 1

Location	Circ. (inches)
Top	25
Crossarm	25-1/4
Resultant	27
Top Slot	31
Bottom Slot	33-1/2

TEST NO. 2

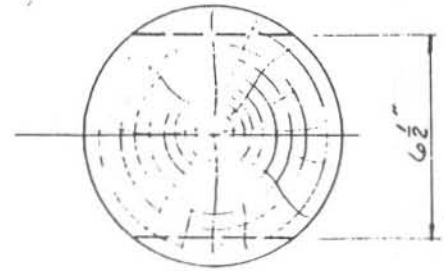
Location	Circ. (inches)
Top	22
Crossarm	22-1/4
Resultant	26
Top Slot	33
Bottom Slot	34

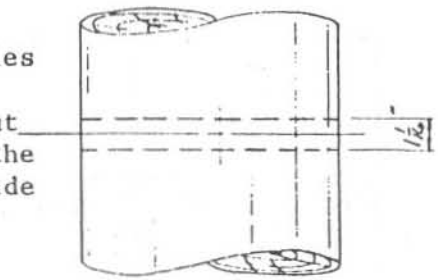
Manufacturer of Transmission and Distribution Material for the Electric Utility Industry since 1921.



Note

Spaces between drilled holes of breakaway joints were unintentional chiselled-out (slotted) and not sawcut the width of a keyhole saw-blade as planned and done in full-scale vehicle crash tests.





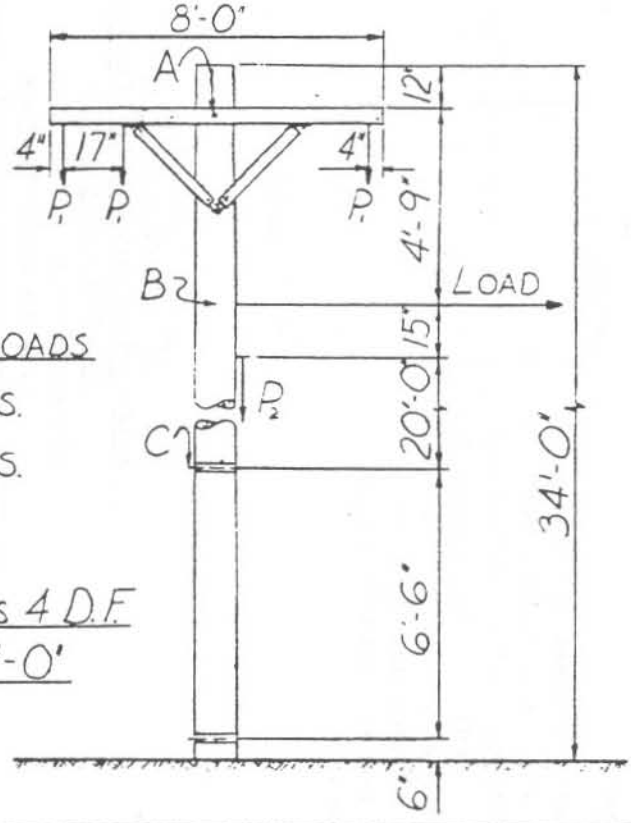
SLOT DETAIL

TEST NO. 1
TYPE B-2397-A
SINGLE POLE TANGENT STRUCTURE
BORED FOR SAFTEY
UNIVERSITY OF NEBRASKA
LINCOLN, NEBRASKA

Drawn D. POLICKY	HUGHES BROTHERS Seward, Nebraska	Date Printed JUN 11 1980
Approved		DRG. NO. B-2397-A

UNIVERSITY OF NEBRASKA - LINCOLN
SLOTTED SINGLE POLE STRUCTURE
TEST NO. 1

Date: 5-6-80



VERTICAL LOADS

P_1 = 150 lbs.

P_2 = 100 lbs.

40'-0" Class 4 D.F.
Pole Set 6'-0"

LOAD (lbs)	Deflection A	Deflection B	Deflection C	PIC. NO.	REMARKS
0	0"	0"	0"	1	
50	1 3/4"	1 1/4"	0"	2	
100	3 1/2"	2 3/4"	1/4"	3	
150	5"	4 1/4"	1/2"	4	
200	6 3/4"	7 5/8"	3/4"	5	
250	8 3/4"	8"	1"	6	
300	10 7/8"	9"	1 1/4"	7	
350	13 1/8"	11"	1 1/2"	8	
400	15 1/4"	12 3/4"	1 7/8"	9	
450	18"	15 1/4"	2 1/4"	10	
500	22"	18 5/8"	3 1/8"	11	
550	27"	23"	3 3/4"	12, 13, 14	Failure

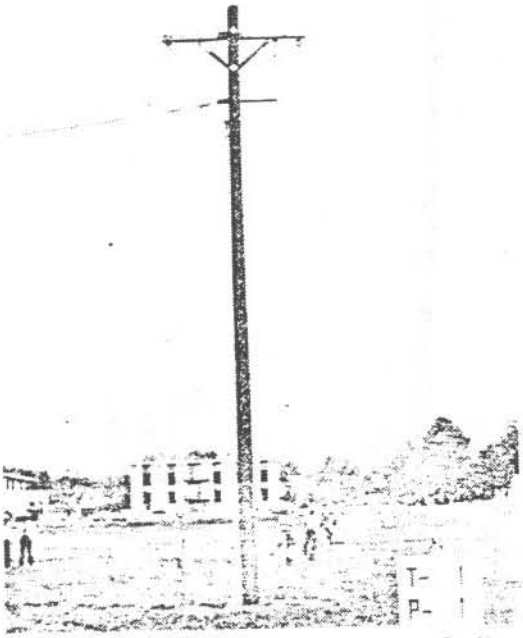
Drawn: D. JENSEN

Approved: [illegible]

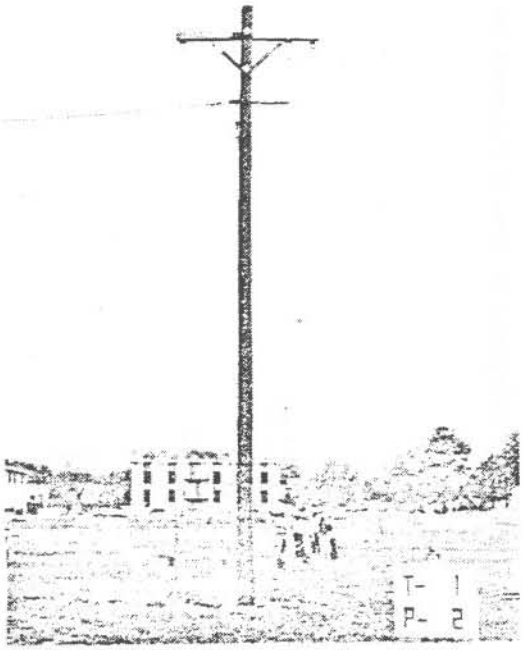
HUGHES BROTHERS
Seward, Nebraska

Date Printed: JUN 11 1980

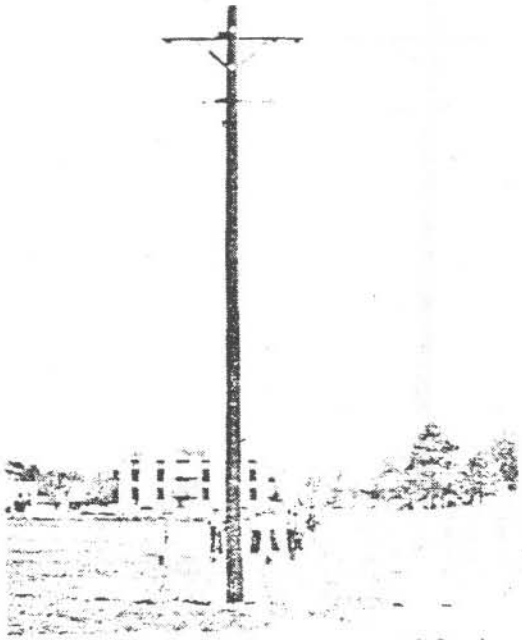
DRG. NO. A-2248-A



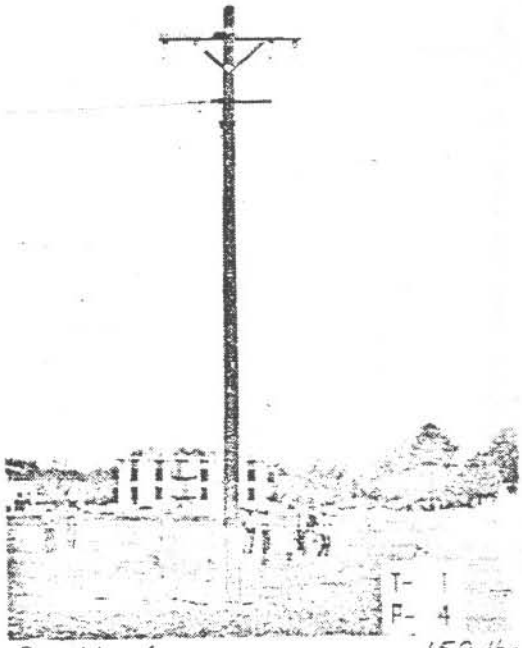
Pic. No. 1 0 lbs.



Pic. No. 2 50 lbs.



Pic. No. 3 100 lbs

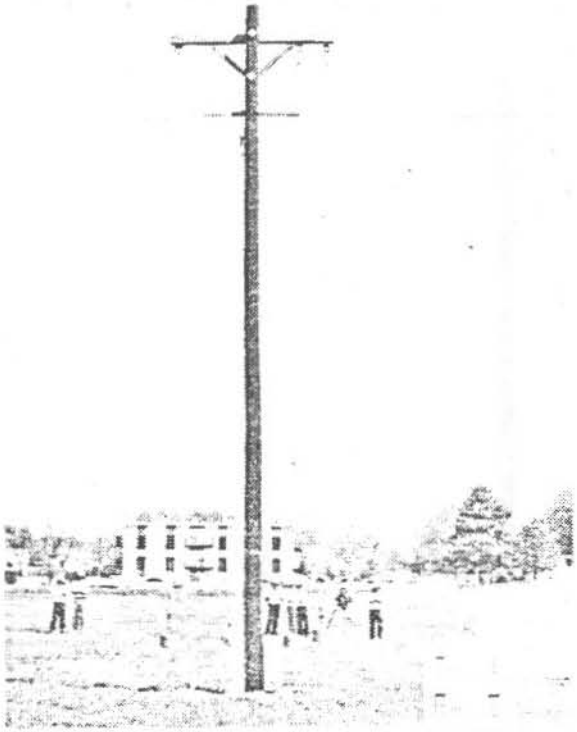


Pic. No. 4 150 lbs.

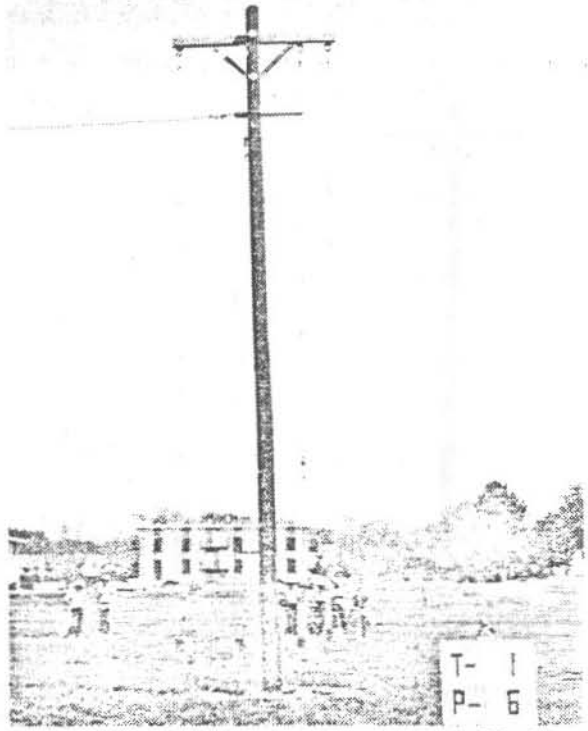
TEST No. 1

HUGHES BROTHERS

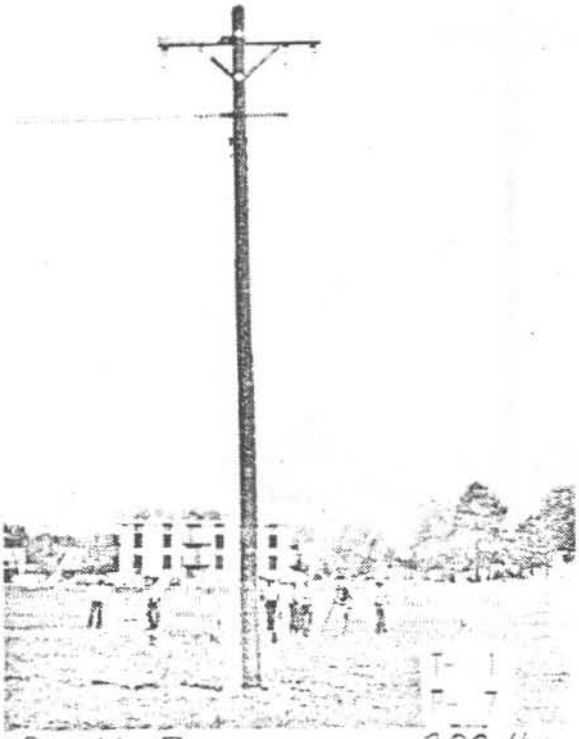
P. O. BOX 159 • 210 NORTH 13TH STREET • SEWARD, NEBRASKA 68434



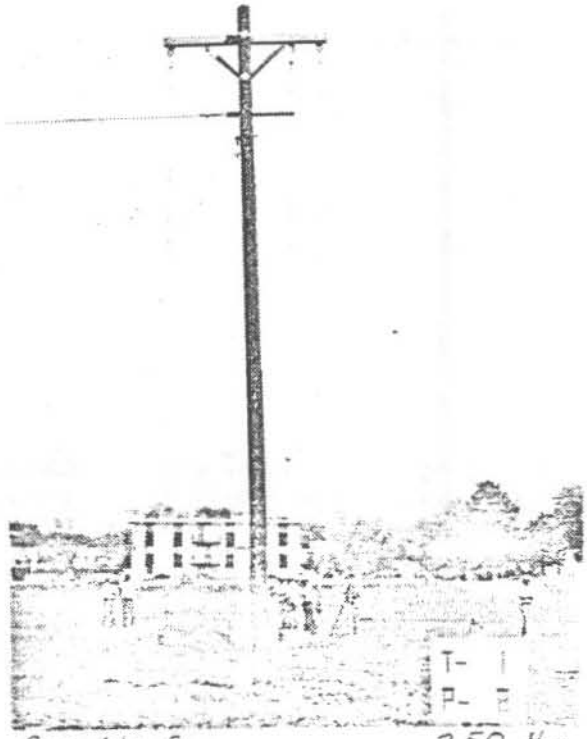
Pic. No. 5 200 lbs.



Pic. No. 6 250 lbs.



Pic. No. 7 300 lbs.

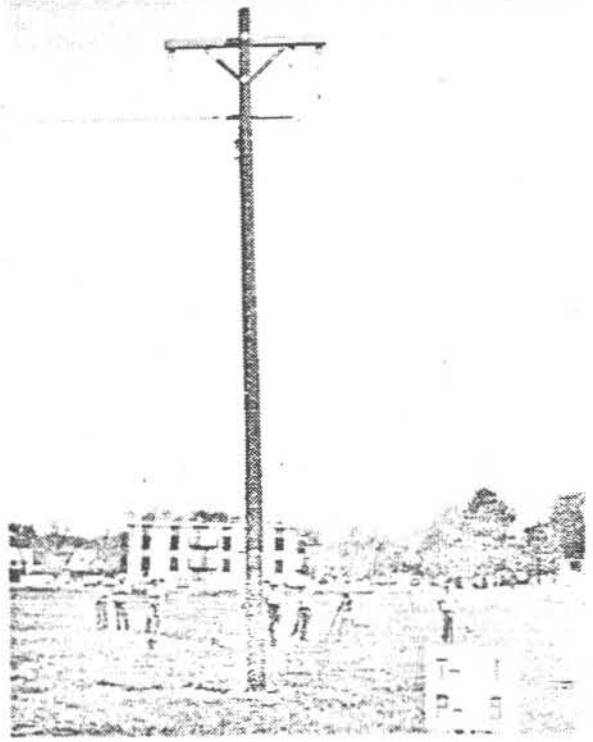


Pic. No. 8 350 lbs.

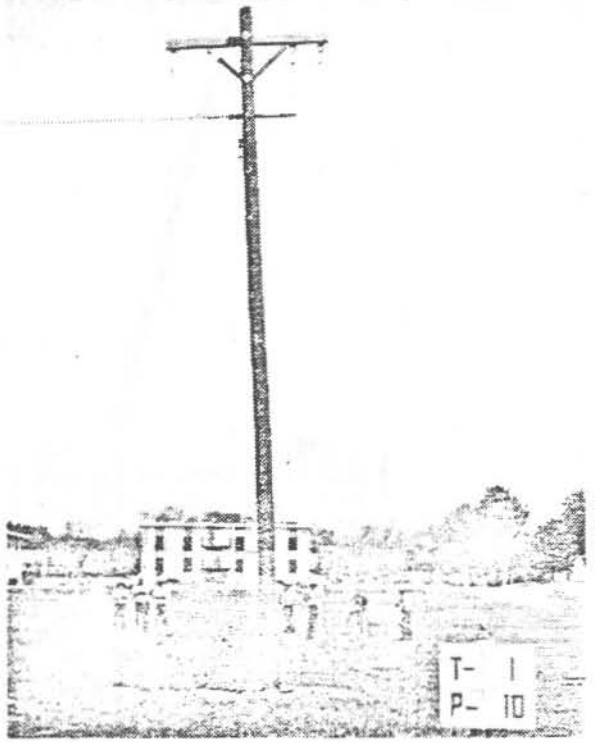
TEST NO. 1

HUGHES BROTHERS

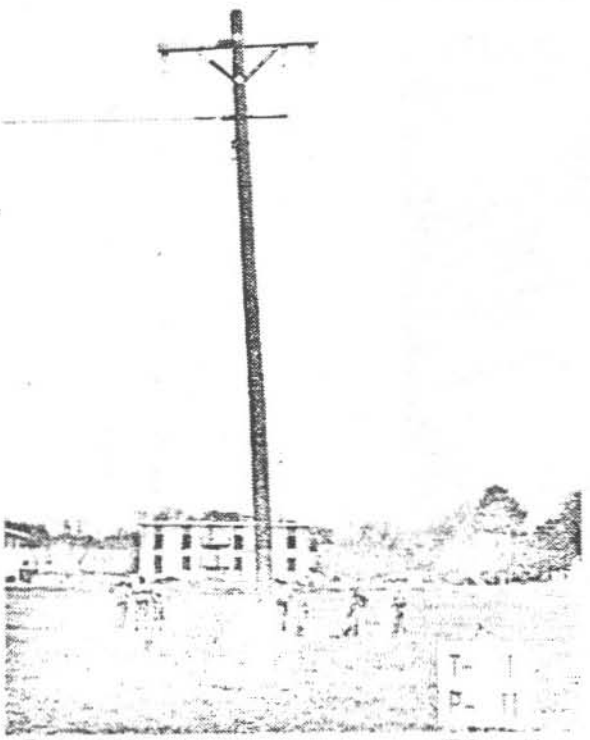
P. O. BOX 159 • 210 NORTH 13TH STREET • SEWARD, NEBRASKA 68434



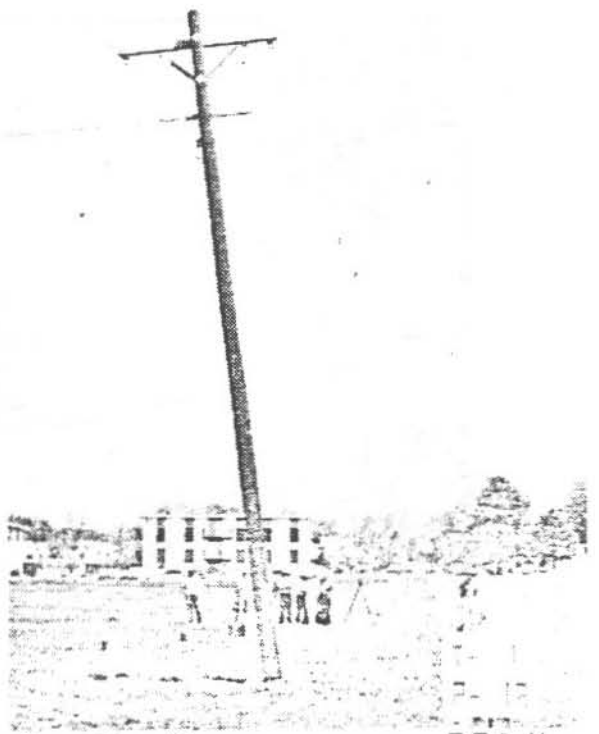
Pic. No. 9 400 lbs.



Pic. No. 10 450 lbs.



Pic. No. 11 500 lbs.

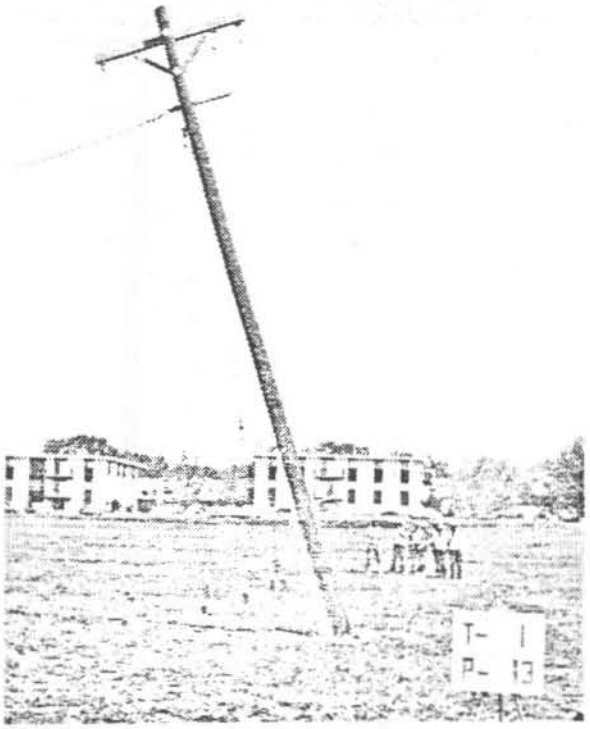


Pic. No. 12 550 lbs.

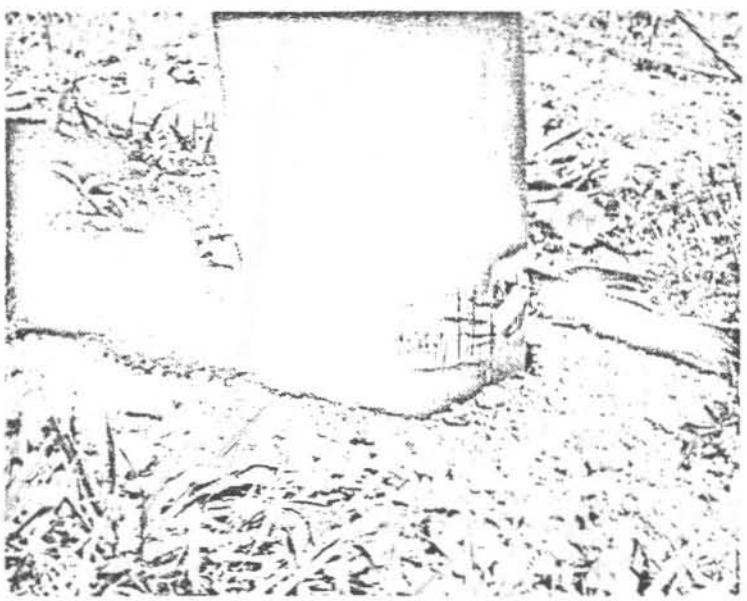
TEST No. 1

HUGHES BROTHERS

P. O. BOX 159 • 210 NORTH 13TH STREET • SEWARD, NEBRASKA 68434



PIC. NO. 13 FAILURE

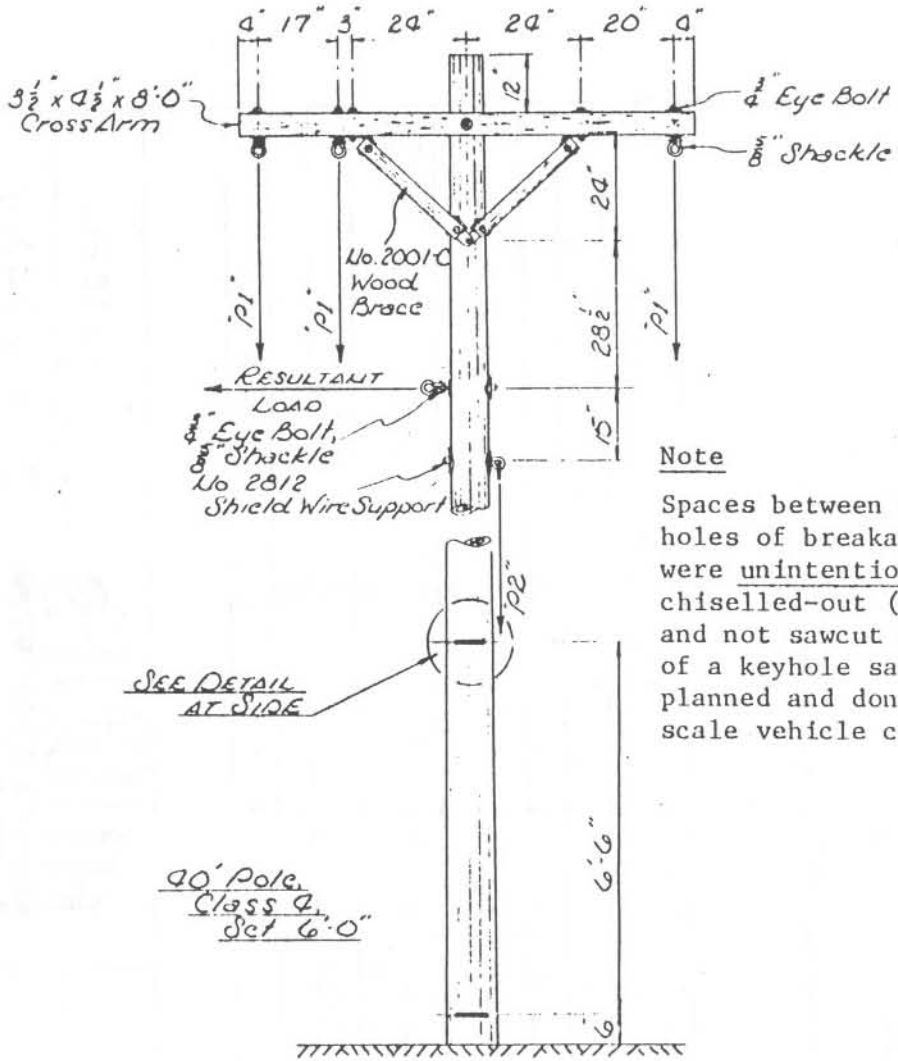


PIC. NO. 14 FAILURE

TEST NO. 1

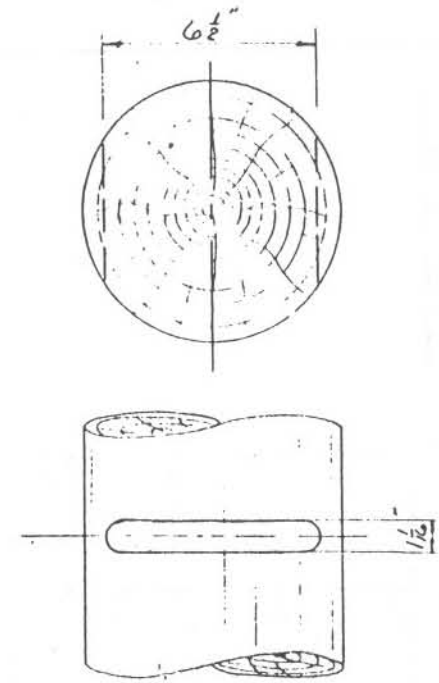
HUGHES BROTHERS

P. O. BOX 159 • 210 NORTH 13TH STREET • SEWARD, NEBRASKA 68434



Note

Spaces between drilled holes of breakaway joints were unintentional chiselled-out (slotted) and not sawcut the width of a keyhole saw-blade as planned and done in full-scale vehicle crash tests.



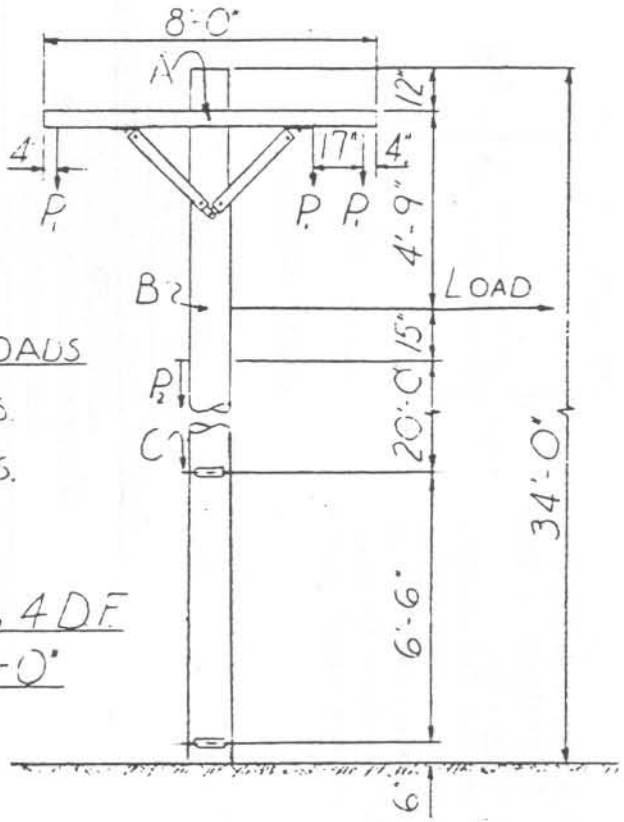
SLOT DETAIL

TEST NO. 2
TYPE B-2397-B
SINGLE POLE TANGENT STRUCTURE
BORED FOR SAFTEY
UNIVERSITY OF NEBRASKA
LINCOLN, NEBRASKA

Drawn D. POLICKY	HUGHES BROTHERS Seward, Nebraska	Date Printed JUN 12 1980
Approved		DRG. NO. B-2397-B

UNIVERSITY OF NEBRASKA - LINCOLN
SLOTTED SINGLE POLE STRUCTURE
TEST NO. 2

Date: 5-6-80



VERTICAL LOADS
P_1 = 150 lbs.
P_2 = 100 lbs.

40'-0" Class 4 DF
Pole Set 6'-0"

LOAD (lbs)	Deflection A	Deflection B	Deflection C	PIC NO	REMARKS
0	0"	0"	0"	1	
250	6 3/4"	5 5/8"	1"	2	
500	13 3/4"	11 5/8"	2"	3	
750	22 3/8"	18 1/2"	3 3/8"	4	
1000	33 1/4"	27 5/8"	5 1/4"	5	
1250	44 3/4"	37 3/8"	7 3/4"	6	
1500	56 1/4"	----	10"	7	
1750				8	
1800				9,10,11	Failure

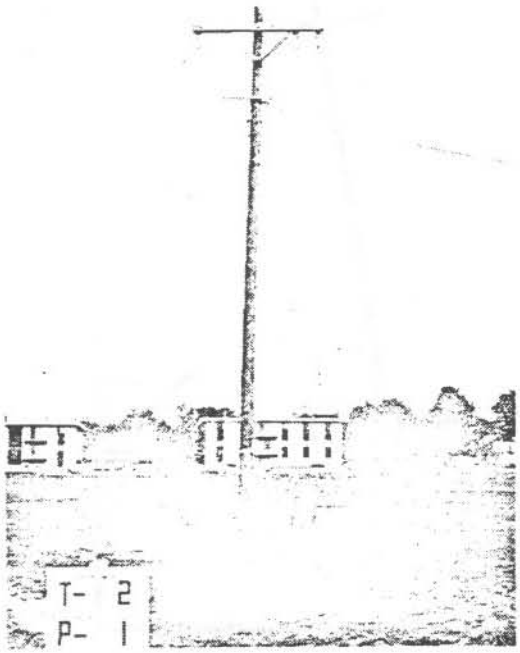
Drawn: D. Jensen

Approved: [illegible]

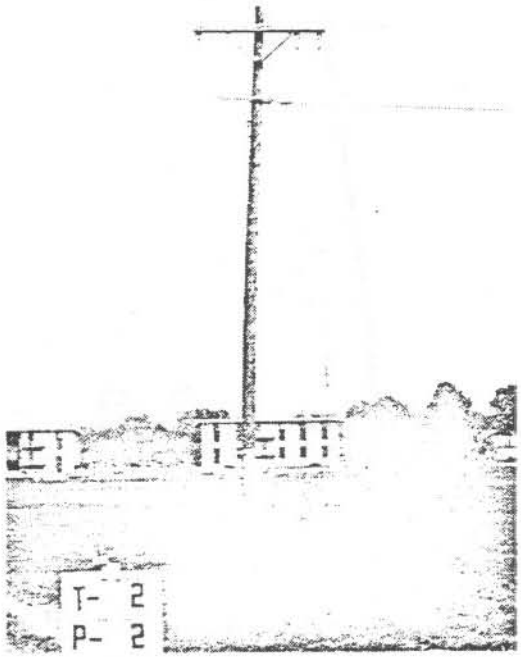
HUGHES BROTHERS
Seward, Nebraska

Date Printed: JUN 12 1980

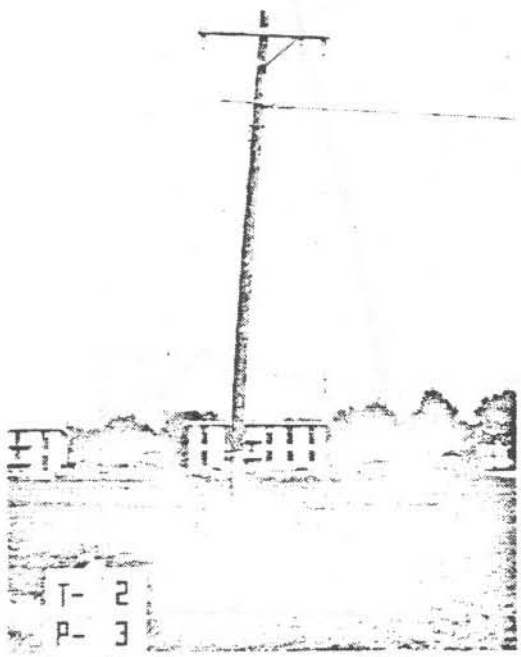
DRG. NO. A-2248-B



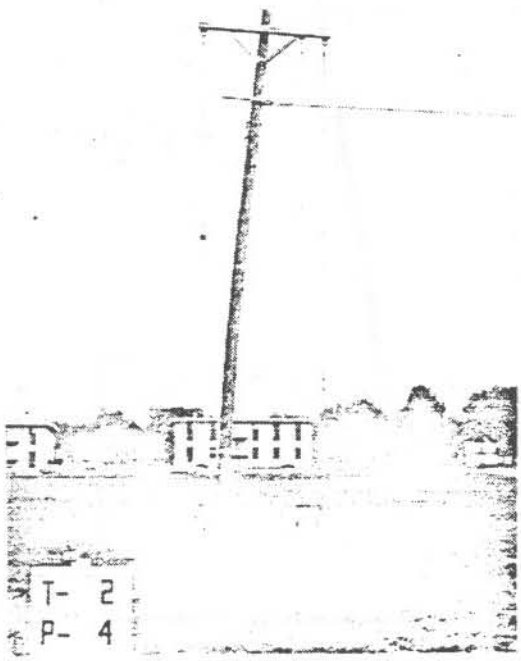
Pic. No. 1 0 lbs.



Pic. No. 2 250 lbs.



Pic. No. 3 500 lbs.

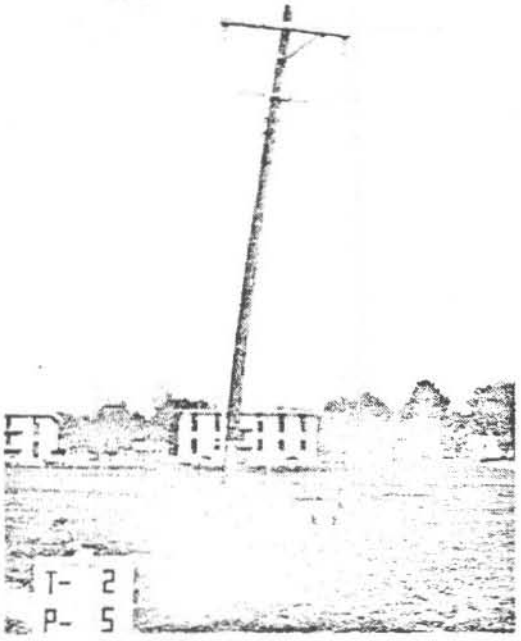


Pic. No. 4 750 lbs.

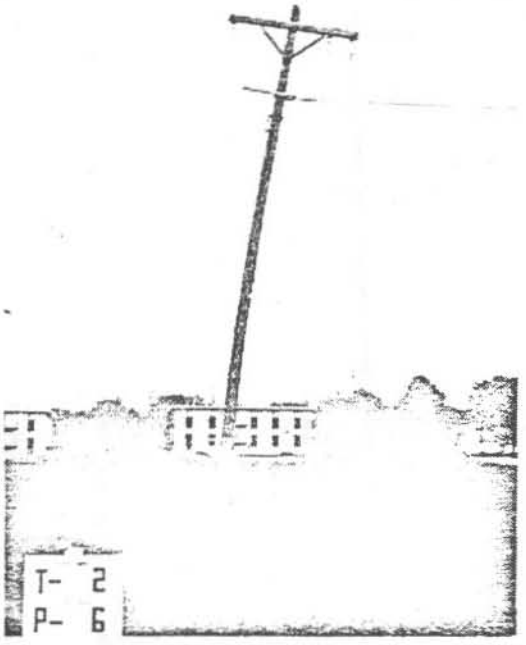
Test No. 2

HUGHES BROTHERS

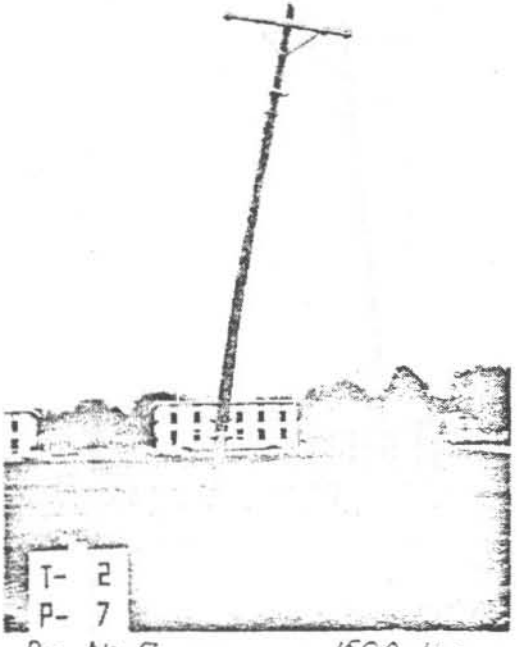
P. O. BOX 159 • 210 NORTH 13TH STREET • SEWARD, NEBRASKA 68434



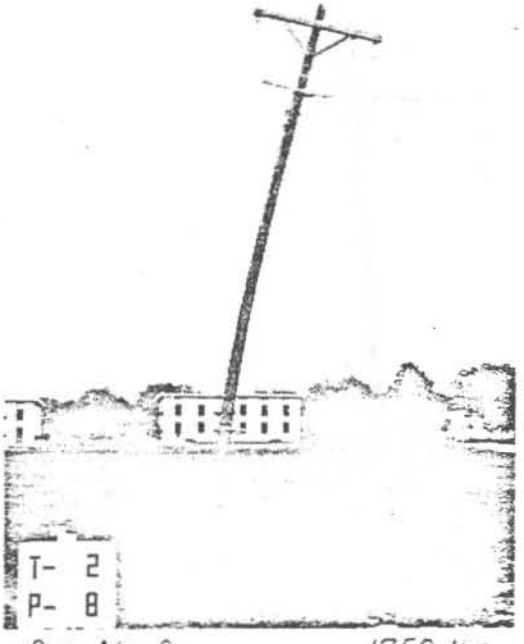
Pic. No. 5 1000 lbs.



Pic. No. 6 1250 lbs.



Pic. No. 7 1500 lbs.

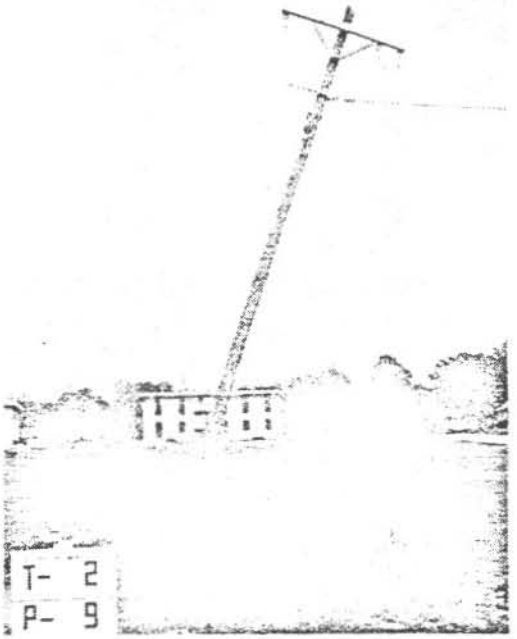


Pic. No. 8 1750 lbs.

Test No. 2

HUGHES BROTHERS

P. O. BOX 159 • 210 NORTH 13TH STREET • SEWARD, NEBRASKA 68434



PIC. NO. 9 FAILURE

P. 10 FAILURE

PIC. NO. 11 FAILURE

TEST A.

HUGHES BROTHERS

P. O. BOX 159 • 210 NORTH 13TH STREET • SEWARD, NEBRASKA 68434

APPENDIX B.

HIGH-SPEED FILM ANALYSIS

Analysis of the high-speed film was performed in largely two major steps. The first of which involved measuring the displacements of the vehicle relative to a fixed vertical or horizontal line on the backboard. The grid lines on the backboard were spaced 24 in. (70 cm) on centers. In one case, both horizontal and vertical displacement readings were recorded; however, due to the nature of the vehicle's movement which involved strictly lateral translations, the vertical measurements were not utilized. These measurements required the use of a Vanguard Motion Analyzer which allows manual measurements to 0.001 in. (0.025 mm) of image size on each individual frame. Using proper scaling factors the measurements can be converted into displacements.

The second step of analysis was to use these displacements to arrive at the vehicle decelerations. The "differencing" method of analysis was chosen due to the ease of data reduction. By means of a 100 Hz timing light exposure on the film the time covered by each frame was determined to be 0.00123 seconds.

Using this information, the velocity curve was defined by determining the vehicle displacement over a 4-frame period (0.00492 sec). These individual velocity points were then adjusted to fit a curve. Further differencing allowed a means to arrive at adjusted decelerations for use in determining the severity of impact.

An example of data measured and recorded from the high-speed film is shown for Test No. 2-1 in the pages to follow.

High-Speed Film Analysis Sheets Test: 2-1

Vehicle X	Vehicle Y	Reference X	Reference Y	Difference X	Difference Y	Actual Deflection (in.)	Comments	Time (frames)
2.794	6.974	4.421	7.645	1.627			Vehicle Impact	Impact
2.889	6.974	4.445	7.572	1.556		2.313		4
2.923	6.964	4.425	7.629	1.502		1.759		8
2.996	6.972	4.430	7.615	1.444		1.890	Upper Joint Starts to translate	12
3.062	6.977	4.446	7.547	1.384		1.955		16
3.076	6.972	4.406	7.570	1.330		1.759		20
3.141	6.917	4.414	7.628	1.273		1.857		24
3.207	6.887	4.428	7.583	1.221		1.694	Vehicle Deformation about 12"	28
3.256	6.880	4.425	7.571	1.169		1.694	Bottom Joint Begins to Shear	32
3.300	6.880	4.418	7.577	1.118		1.661		36
3.345	6.974	4.422	7.653	1.077		1.336		40
3.391	6.880	4.458	7.590	1.032		1.466		44
3.444	6.970	4.427	7.571	0.983		1.596		48
3.512	6.959	4.[illegible]	7.565	0.943		1.303		52

High-Speed Film Analysis Sheets Test: 2-1

Vehicle X	Vehicle Y	Reference X	Reference Y	Difference X	Difference Y	Actual Deflection (in.)	Comments	Time (frames)
3.[illegible]4	6.546	4.4[illegible]6	7.654	0.904		1.271		56
3.[illegible]	6.[illegible]	4.414	7.[illegible]	0.861		1.401		60
3.6[illegible]	6.8[illegible]	4.4[illegible]	7.[illegible]	0.832		0.945	Pole Begins to Drop to Ground	64
3.614	6.672	4.411	7.577	0.797		1.140		68
3.64[illegible]	6.715	4.418	7.627	0.769		0.912	Pole Completely clear of Stump	72
3.688	6.[illegible]70	4.427	7.59[illegible]	0.739		0.977		76
3.6[illegible]	6.[illegible]40	4.4[illegible]	7.567	0.708		1.010		80
3.7[illegible]4	6.[illegible]	4.410	7.567	0.676		1.042	Pole contacts Soil Starts to Plow	84
3.7[illegible]	6.[illegible]7	4.4[illegible]0	7.6[illegible]7	0.642		1.108		88
3.8[illegible]4	6.[illegible]	4.417	7.603	0.613		0.945		92
3.8[illegible]	6.8[illegible]1	4.409	7.546	0.587		0.847		96
3.871	6.[illegible]	4.4[illegible]	7.549	0.561		0.847	Pole Hits Ledge Upper Joint Actuates	100
3.852	6.[illegible]1	4.410	7.595	0.537		0.782		104
3.911	6.8[illegible]	4.414	7.600	0.513		0.782		108

High-Speed Film Analysis Sheets Test: 2-1

Vehicle X	Vehicle Y	Reference X	Reference Y	Difference X	Difference Y	Actual Deflection (in.)	Comments	Time (frames)
3.925	6.898	4.414	7.542	0.489		0.782		112
3.919	6.897	4.392	7.554	0.473		0.521		116
3.949	6.851	4.405	7.601	0.456		0.554		120
3.949	6.833	4.438	7.576	0.449		0.288		124
3.977	6.807	4.420	7.558	0.443		0.195		128
4.001	6.849	4.436	7.602	0.435		0.261		132
4.013	6.842	4.448	7.592	0.435		0.000		136
3.990	6.866	4.428	7.547	0.438		-0.098	Vehicle Stopped	140
							Pole Crossing Impact Veg a	1932

Data Reduction Sheets Test: 2-1

Time (msec.)	Displacements (inches)	Velocities (ft/sec.)	Accelerations * (ft/sec²)	Accelerations * (G's)
4.92	2.[illegible]	39.2	—	—
9.84	1.[illegible]	29.80	243.7	7.57
14.76	1.[illegible]	33.01	243.7	7.57
19.68	1.[illegible]	33.11	101.8	3.16
24.60	[illegible]	29.79	182.9	5.68
29.52	[illegible]	31.45	162.6	5.05
34.44	1.694	38.69	325.3	10.10
[illegible]	[illegible]	28.60	142.3	4.42
44.28	1.661	28.13	122.0	3.79
49.20	[illegible]	33.63	284.6	8.84
[illegible]	1.460	24.83	243.7	7.57
[illegible]	[illegible]	27.03	101.8	3.16
[illegible]	1.303	22.07	607.9	18.74
[illegible]	1.271	21.53	101.8	3.16

* After curve adjustment

Data Reduction Sheets Test: 2-1

Time (msec.)	Displacements (inches)	Velocities (ft/sec.)	Accelerations * (ft/sec²)	Accelerations * (G's)
73.80	1.101	23.13	60.9	1.89
76.72	0.945	16.07	508.1	15.78
[illegible]	1.140	18.31	81.1	2.52
[illegible]	[illegible]	15.48	203.2	6.31
[illegible]	0.977	16.55	122.0	3.79
[illegible]	1.0[illegible]	17.11	81.1	2.52
[illegible]	1.0[illegible]	17.65	20.3	0.63
[illegible]	1.1[illegible]	18.77	81.1	2.52
[illegible]	0.945	16.01	162.6	5.05
[illegible]	[illegible]	14.35	223.5	6.94
[illegible]	0.647	14.35	142.3	4.42
[illegible]	[illegible]	13.25	122.0	3.79
[illegible]	[illegible]	13.25		
[illegible]	[illegible]	13.25		

* After curve adjustment

Data Reduction Sheets Test: 2-1

Time (msec.)	Displacements (inches)	Velocities (ft/sec.)	Accelerations* (ft/sec²)	Accelerations* (G's)
142.68	0.521	8.82		
147.60	0.554	9.38		
152.52	0.224	3.86		
157.44	0.195	3.30		
162.36	0.261	4.42		
167.28	0.000	0.00		
172.20	-0.098	-1.66		

* After curve adjustment

APPENDIX C.

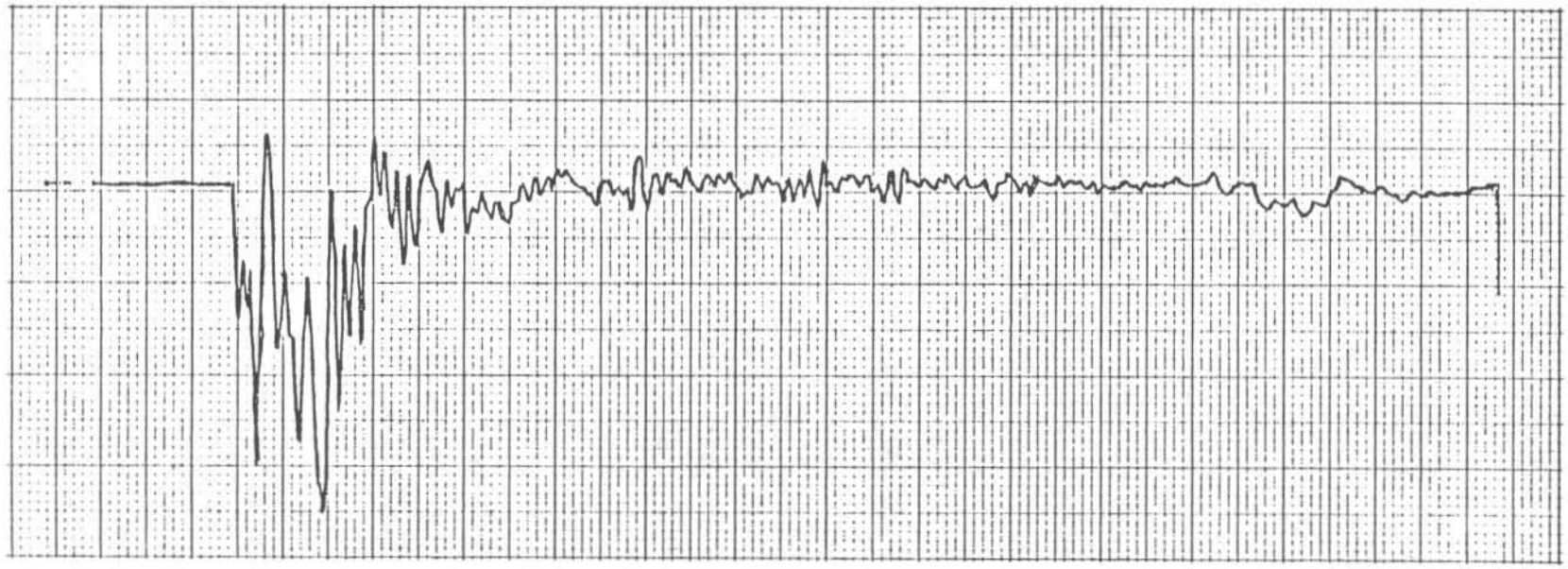
VEHICLE INSTRUMENTATION

In addition to high-speed cinematography, electronic instrumentation was used to obtain acceleration data for Test No. 4-1. Three piezoresistive accelerometers mounted in a triaxial configuration at the vehicle center-of-gravity were used to measure the vehicle accelerations along the three major axes of translation. A 1000 ft. (305 m) umbilical cable was utilized to connect the accelerometers to off-board signal conditoning equipment. Data was recorded in unfiltered analog format on an intermediate band magnetic tape recorder using FM boards.

The accelerometers used were ENDEVCO model 2264-200 piezoresistive accelerometers. The accelerometers, supplied in a half-bridge configuration, had a range of ±200 g's, and a frequency response of DC-1200 Hz. Damping was less than 0.01 of critical. Two opposed constant current sources were used for excition. A Beldon multi-conductor cable with individually shielded twisted wire pairs was used as an umbilical cable. Signal conditioning and amplification was provided by Pacific Precision model 80A signal conditoners and Pacific Precision model 60A differential amplifiers. These were laboratory type units providing filtered and unfiltered outputs with a frequency response of DC to ±100 kHz. Data was recorded in analog form on a Sangamo 3500 series magnetic tape recorder operating at 60 ips (152 cm/s) yielding a frequency response of DC-40 kHz.

The acceleration data was filtered to SAE J211b channel class 60 (100 Hz, -3dB point) requirements and digitized using a Nicolet model 2090-3 digital oscilloscope. A 12-bit word and 5000 Hz sampling rate was used. A X-Y plotter under control of the Nicolet was used to plot the data at a compatable rate.

Once the acceleration data was digitized, it was plotted to TRB 191 standards. The longitudinal accelerometer trace is presented in Appendix C. A computer program was used to read the accelerations at 1 millisecond intervals and integrate the function twice to obtain velocity and displacement histories of the event. In addition, the program calculated the required time for a 24 inch longitudinal relative displacement of the occupant to occur. At that time the velocity change of the vehicle and its subsequent ridedown accelerations (10 msec. moving average) were output from the program.



Test Number 4-1 Accelerometer Trace

Scale: 1" Horiz. = 100 milliseconds

1" Vert. = 10 g's

Test No. 2-1

(SEC)	VEHICLE ACCELERATION (G"S)		OCCUPANT VELOCITY (FT/SEC)		OCCUPANT DISPLACEMENT (IN)	
	AX	AY	VX	VY	DX	DY
.0	0.0	1.0	0.0	0.0	0.0	0.0
.001	0.0	1.0	0.0	0.0	0.0	0.0
.002	0.0	1.0	0.0	0.1	0.0	0.0
.003	0.0	1.0	0.0	0.1	0.0	0.0
.004	0.0	1.0	0.0	0.1	0.0	0.0
.005	0.0	1.0	0.0	0.2	0.0	0.0
.006	0.2	1.0	0.0	0.2	0.0	0.0
.007	0.6	1.0	0.1	0.2	0.0	0.0
.008	1.0	1.0	0.2	0.3	0.0	0.0
.009	1.5	1.0	0.4	0.3	0.0	0.0
.010	2.3	1.0	0.6	0.3	0.0	0.0
.011	3.0	1.0	0.9	0.4	0.0	0.0
.012	3.8	1.0	1.1	0.4	0.0	0.0
.013	4.6	1.0	1.3	0.4	0.0	0.0
.014	5.3	1.0	1.6	0.5	0.1	0.0
.015	6.1	1.0	1.8	0.5	0.1	0.0
.016	6.6	1.0	2.1	0.5	0.1	0.0
.017	6.9	1.0	2.3	0.5	0.1	0.1
.018	6.9	1.0	2.4	0.6	0.2	0.1
.019	6.7	1.0	2.6	0.6	0.2	0.1
.020	6.3	1.0	2.7	0.6	0.2	0.1
.021	5.9	1.0	2.8	0.7	0.3	0.1
.022	5.5	1.0	2.9	0.7	0.3	0.1
.023	5.3	1.0	3.1	0.7	0.3	0.1
.024	5.0	1.0	3.2	0.8	0.4	0.1
.025	4.8	1.0	3.4	0.8	0.4	0.1
.026	4.7	1.0	3.6	0.8	0.4	0.1
.027	4.7	1.0	3.8	0.9	0.5	0.1
.028	4.7	1.0	4.0	0.9	0.5	0.2
.029	4.8	1.0	4.1	0.9	0.6	0.2
.030	5.0	1.0	4.3	1.0	0.6	0.2
.031	5.3	1.0	4.5	1.0	0.7	0.2
.032	5.6	1.0	4.7	1.0	0.7	0.2
.033	6.0	1.0	5.0	1.1	0.8	0.2
.034	6.5	1.0	5.3	1.1	0.9	0.2
.035	6.9	1.0	5.6	1.1	0.9	0.2
.036	7.1	1.0	5.8	1.2	1.0	0.3
.037	7.2	1.0	6.1	1.2	1.1	0.3
.038	7.2	1.0	6.3	1.2	1.1	0.3
.039	7.1	1.0	6.4	1.3	1.2	0.3
.040	7.1	1.0	6.6	1.3	1.3	0.3
.041	6.8	1.0	6.7	1.3	1.4	0.3
.042	6.5	1.0	6.8	1.4	1.5	0.3
.043	6.0	1.0	7.0	1.4	1.5	0.4
.044	5.4	1.0	7.1	1.4	1.6	0.4
.045	4.9	1.0	7.2	1.4	1.7	0.4
.046	4.7	1.0	7.4	1.5	1.8	0.4
.047	4.8	1.0	7.6	1.5	1.9	0.4
.048	5.0	1.0	7.8	1.5	2.0	0.4
.049	5.4	1.0	8.1	1.6	2.1	0.5

.050	5.8	1.0	8.4	1.6	2.2	0.5
.051	6.3	1.0	8.7	1.6	2.3	0.5
.052	6.7	1.0	8.9	1.7	2.4	0.5
.053	7.1	1.0	9.2	1.7	2.5	0.5
.054	7.4	1.0	9.4	1.7	2.6	0.6
.055	7.6	1.0	9.7	1.8	2.7	0.6
.056	7.6	1.0	9.9	1.8	2.8	0.6
.057	7.5	1.0	10.0	1.8	3.0	0.6
.058	7.1	1.0	10.2	1.9	3.1	0.6
.059	6.5	1.0	10.3	1.9	3.2	0.7
.060	6.3	1.0	10.4	1.9	3.3	0.7
.061	6.4	1.0	10.7	2.0	3.5	0.7
.062	6.9	1.0	11.1	2.0	3.6	0.7
.063	7.7	1.0	11.5	2.0	3.7	0.8
.064	8.8	1.0	12.1	2.1	3.9	0.8
.065	9.7	1.0	12.6	2.1	4.0	0.8
.066	10.4	1.0	13.1	2.1	4.2	0.8
.067	10.8	1.0	13.4	2.2	4.3	0.9
.068	11.0	1.0	13.7	2.2	4.5	0.9
.069	11.0	1.0	13.8	2.2	4.7	0.9
.070	10.7	1.0	13.9	2.3	4.8	0.9
.071	10.0	1.0	14.0	2.3	5.0	1.0
.072	9.0	1.0	14.1	2.3	5.2	1.0
.073	7.6	1.0	14.2	2.3	5.3	1.0
.074	5.9	1.0	14.3	2.4	5.5	1.1
.075	4.8	1.0	14.4	2.4	5.7	1.1
.076	4.3	1.0	14.6	2.4	5.8	1.1
.077	4.4	1.0	14.8	2.5	6.0	1.1
.078	5.1	1.0	15.2	2.5	6.2	1.2
.079	6.3	1.0	15.7	2.5	6.4	1.2
.080	7.3	1.0	16.1	2.6	6.6	1.2
.081	8.1	1.0	16.5	2.6	6.8	1.3
.082	8.7	1.0	16.8	2.6	7.0	1.3
.083	9.0	1.0	17.0	2.7	7.2	1.3
.084	9.0	1.0	17.2	2.7	7.4	1.4
.085	8.9	1.0	17.2	2.7	7.6	1.4
.086	8.5	1.0	17.4	2.8	7.8	1.4
.087	8.0	1.0	17.5	2.8	8.0	1.5
.088	7.2	1.0	17.7	2.8	8.2	1.5
.089	6.3	1.0	17.9	2.9	8.4	1.5
.090	5.6	1.0	18.1	2.9	8.6	1.6
.091	5.0	1.0	18.2	2.9	8.9	1.6
.092	4.7	1.0	18.4	3.0	9.1	1.6
.093	4.5	1.0	18.5	3.0	9.3	1.7
.094	4.6	1.0	18.6	3.0	9.5	1.7
.095	4.6	1.0	18.7	3.1	9.8	1.7
.096	4.5	1.0	18.8	3.1	10.0	1.8
.097	4.3	1.0	18.9	3.1	10.2	1.8
.098	4.0	1.0	19.0	3.2	10.4	1.9
.099	3.6	1.0	19.1	3.2	10.7	1.9
.100	3.2	1.0	19.2	3.2	10.9	1.9
.101	2.9	1.0	19.2	3.2	11.1	2.0
.102	2.5	1.0	19.2	3.3	11.4	2.0
.103	2.2	1.0	19.3	3.3	11.6	2.0
.104	1.9	1.0	19.3	3.3	11.8	2.1
.105	1.7	1.0	19.3	3.4	12.0	2.1
.106	1.6	1.0	19.4	3.4	12.3	2.2
.107	1.5	1.0	19.4	3.4	12.5	2.2
.108	1.5	1.0	19.5	3.5	12.7	2.3
.109	1.6	1.0	19.6	3.5	13.0	2.3
.110	1.8	1.0	19.7	3.5	13.2	2.3
.111	2.1	1.0	19.8	3.6	13.5	2.4

2	2.4	1.0	20.0	3.6	13.7	2.4
3	2.9	1.0	20.1	3.6	13.9	2.5
4	3.3	1.0	20.3	3.7	14.2	2.5
5	3.8	1.0	20.5	3.7	14.4	2.6
6	4.2	1.0	20.7	3.7	14.7	2.6
7	4.7	1.0	20.9	3.8	14.9	2.6
8	5.1	1.0	21.1	3.8	15.2	2.7
9	5.5	1.0	21.3	3.8	15.4	2.7
0	5.7	1.0	21.5	3.9	15.7	2.8
1	5.8	1.0	21.7	3.9	15.9	2.8
2	5.9	1.0	21.9	3.9	16.2	2.9
3	5.8	1.0	22.0	4.0	16.5	2.9
4	5.7	1.0	22.1	4.0	16.7	3.0
5	5.5	1.0	22.3	4.0	17.0	3.0
6	5.3	1.0	22.4	4.1	17.3	3.1
27	5.0	1.0	22.5	4.1	17.5	3.1
28	4.7	1.0	22.7	4.1	17.8	3.2
29	4.5	1.0	22.8	4.2	18.1	3.2
30	4.2	1.0	22.9	4.2	18.3	3.3
31	4.1	1.0	23.0	4.2	18.6	3.3
32	4.0	1.0	23.1	4.2	18.9	3.4
33	3.9	1.0	23.3	4.3	19.2	3.4
34	3.8	1.0	23.4	4.3	19.5	3.5
35	3.8	1.0	23.5	4.3	19.7	3.5
36	3.7	1.0	23.6	4.4	20.0	3.6
37	3.7	1.0	23.7	4.4	20.3	3.6
38	3.7	1.0	23.8	4.4	20.6	3.7
39	3.6	1.0	24.0	4.5	20.9	3.7
40	3.6	1.0	24.1	4.5	21.2	3.8
41	3.6	1.0	24.2	4.5	21.5	3.8
42	3.6	1.0	24.3	4.6	21.8	3.9
43	3.5	1.0	24.4	4.6	22.0	3.9
44	3.5	1.0	24.5	4.6	22.3	4.0
45	3.5	1.0	24.6	4.7	22.6	4.1
46	3.5	1.0	24.7	4.7	22.9	4.1
47	3.4	1.0	24.8	4.7	23.2	4.2
148	3.4	1.0	24.9	4.8	23.5	4.2
49	3.4	1.0	25.1	4.8	23.8	4.3
150	3.4	1.0	25.2	4.8	24.1	4.3
151	3.3	1.0	25.3	4.9	24.4	4.4
152	3.3	1.0	25.4	4.9	24.7	4.5
153	3.3	1.0	25.5	4.9	25.0	4.5
154	3.3	1.0	25.6	5.0	25.3	4.6
155	3.2	1.0	25.7	5.0	25.7	4.6
156	3.2	1.0	25.8	5.0	26.0	4.7
157	3.2	1.0	25.9	5.1	26.3	4.8
158	3.2	1.0	26.0	5.1	26.6	4.8
159	3.1	1.0	26.1	5.1	26.9	4.9
160	3.1	1.0	26.2	5.1	27.2	4.9
161	3.1	1.0	26.3	5.2	27.5	5.0
162	3.1	1.0	26.4	5.2	27.8	5.1
163	3.0	1.0	26.4	5.2	28.2	5.1
164	3.0	1.0	26.5	5.3	28.5	5.2
165	3.0	1.0	26.6	5.3	28.8	5.3
166	3.0	1.0	26.7	5.3	29.1	5.3
167	2.9	1.0	26.8	5.4	29.4	5.4
168	2.9	1.0	26.9	5.4	29.8	5.4
169	2.9	1.0	27.0	5.4	30.1	5.5
170	2.9	1.0	27.1	5.5	30.4	5.6
171	2.8	1.0	27.2	5.5	30.7	5.6
172	2.8	1.0	27.3	5.5	31.1	5.7
173	2.8	1.0	27.3	5.6	31.4	5.8

est N

v

.050	8.4	1.0	8.3	1.6	1.5	0.5
.051	8.1	1.0	8.5	1.6	1.6	0.5
.052	7.9	1.0	8.7	1.7	1.7	0.5
.053	7.8	1.0	8.9	1.7	1.8	0.5
.054	7.7	1.0	9.1	1.7	2.0	0.6
.055	7.6	1.0	9.4	1.8	2.1	0.6
.056	7.6	1.0	9.7	1.8	2.2	0.6
.057	7.8	1.0	10.0	1.8	2.3	0.6
.058	8.1	1.0	10.4	1.9	2.4	0.6
.059	8.6	1.0	10.7	1.9	2.5	0.7
.060	9.2	1.0	11.1	1.9	2.7	0.7
.061	10.0	1.0	11.6	2.0	2.8	0.7
.062	10.7	1.0	12.0	2.0	2.9	0.7
.063	11.2	1.0	12.4	2.0	3.1	0.8
.064	11.5	1.0	12.8	2.1	3.2	0.8
.065	11.7	1.0	13.1	2.1	3.4	0.8
.066	11.8	1.0	13.5	2.1	3.6	0.8
.067	11.9	1.0	13.8	2.2	3.7	0.9
.068	12.2	1.0	14.2	2.2	3.9	0.9
.069	12.5	1.0	14.7	2.2	4.1	0.9
.070	12.9	1.0	15.2	2.3	4.2	0.9
.071	13.4	1.0	15.8	2.3	4.4	1.0
.072	13.7	1.0	16.3	2.3	4.6	1.0
.073	13.7	1.0	16.8	2.3	4.8	1.0
.074	13.6	1.0	17.2	2.4	5.0	1.1
.075	13.2	1.0	17.4	2.4	5.2	1.1
.076	12.7	1.0	17.6	2.4	5.4	1.1
.077	12.1	1.0	17.8	2.5	5.7	1.1
.078	11.5	1.0	18.0	2.5	5.9	1.2
.079	10.8	1.0	18.3	2.5	6.1	1.2
.080	10.1	1.0	18.6	2.6	6.3	1.2
.081	9.4	1.0	18.9	2.6	6.5	1.3
.082	9.1	1.0	19.3	2.6	6.8	1.3
.083	9.0	1.0	19.7	2.7	7.0	1.3
.084	9.1	1.0	20.1	2.7	7.2	1.4
.085	9.4	1.0	20.4	2.7	7.5	1.4
.086	10.0	1.0	20.8	2.8	7.7	1.4
.087	10.4	1.0	21.1	2.8	8.0	1.5
.088	10.6	1.0	21.4	2.8	8.2	1.5
.089	10.5	1.0	21.7	2.9	8.5	1.5
.090	10.1	1.0	21.9	2.9	8.8	1.6
.091	9.5	1.0	22.1	2.9	9.0	1.6
.092	8.6	1.0	22.2	3.0	9.3	1.6
.093	7.7	1.0	22.3	3.0	9.6	1.7
.094	6.9	1.0	22.4	3.0	9.8	1.7
.095	6.1	1.0	22.5	3.1	10.1	1.7
.096	5.3	1.0	22.6	3.1	10.4	1.8
.097	4.6	1.0	22.7	3.1	10.6	1.8
.098	4.1	1.0	22.8	3.2	10.9	1.9
.099	3.9	1.0	23.0	3.2	11.2	1.9
.100	4.0	1.0	23.2	3.2	11.5	1.9
.101	4.4	1.0	23.4	3.2	11.7	2.0
.102	5.1	1.0	23.7	3.3	12.0	2.0
.103	5.6	1.0	24.0	3.3	12.3	2.0
.104	5.9	1.0	24.3	3.3	12.6	2.1
.105	6.1	1.0	24.4	3.4	12.9	2.1
.106	6.1	1.0	24.6	3.4	13.2	2.2
.107	5.9	1.0	24.6	3.4	13.5	2.2
.108	5.7	1.0	24.7	3.5	13.8	2.3
.109	5.6	1.0	24.8	3.5	14.1	2.3
.110	5.5	1.0	25.0	3.5	14.4	2.3
.111	5.4	1.0	25.2	3.6	14.7	2.4

.112	5.3	1.0	25.4	3.6	15.0	2.4
.113	5.4	1.0	25.7	3.6	15.3	2.5
.114	5.8	1.0	26.1	3.7	15.6	2.5
.115	6.4	1.0	26.4	3.7	15.9	2.6
.116	7.2	1.0	26.7	3.7	16.2	2.6
.117	8.2	1.0	27.1	3.8	16.5	2.6
.118	9.0	1.0	27.5	3.8	16.9	2.7
.119	9.7	1.0	27.8	3.8	17.2	2.7
.120	10.2	1.0	28.2	3.9	17.5	2.8
.121	10.5	1.0	28.5	3.9	17.9	2.8
.122	10.6	1.0	28.8	3.9	18.2	2.9
.123	10.6	1.0	29.2	4.0	18.6	2.9
.124	10.6	1.0	29.5	4.0	18.9	3.0
.125	10.4	1.0	29.8	4.0	19.3	3.0
.126	10.2	1.0	30.0	4.1	19.6	3.1
.127	9.8	1.0	30.3	4.1	20.0	3.1
.128	9.5	1.0	30.6	4.1	20.4	3.2
.129	9.1	1.0	30.8	4.2	20.7	3.2
.130	8.7	1.0	31.0	4.2	21.1	3.3
.131	8.3	1.0	31.2	4.2	21.5	3.3
.132	7.9	1.0	31.5	4.2	21.9	3.4
.133	7.6	1.0	31.7	4.3	22.2	3.4
.134	7.2	1.0	31.9	4.3	22.6	3.5
.135	6.9	1.0	32.0	4.3	23.0	3.5
.136	6.5	1.0	32.2	4.4	23.4	3.6
.137	6.2	1.0	32.4	4.4	23.8	3.6
.138	5.9	1.0	32.5	4.4	24.2	3.7
.139	5.6	1.0	32.7	4.5	24.6	3.7
.140	5.3	1.0	32.8	4.5	25.0	3.8
.141	5.1	1.0	32.9	4.5	25.4	3.8
.142	4.8	1.0	33.1	4.6	25.7	3.9
.143	4.6	1.0	33.2	4.6	26.1	3.9
.144	4.4	1.0	33.3	4.6	26.5	4.0
.145	4.2	1.0	33.4	4.7	26.9	4.1
.146	4.1	1.0	33.5	4.7	27.3	4.1
.147	3.9	1.0	33.7	4.7	27.7	4.2
.148	3.8	1.0	33.8	4.8	28.2	4.2
.149	3.8	1.0	33.9	4.8	28.6	4.3
.150	3.7	1.0	34.0	4.8	29.0	4.3
.151	3.7	1.0	34.1	4.9	29.4	4.4
.152	3.6	1.0	34.2	4.9	29.8	4.5
.153	3.6	1.0	34.3	4.9	30.2	4.5
.154	3.5	1.0	34.4	5.0	30.6	4.6
.155	3.5	1.0	34.5	5.0	31.0	4.6
.156	3.4	1.0	34.6	5.0	31.4	4.7
.157	3.4	1.0	34.8	5.1	31.9	4.8
.158	3.3	1.0	34.9	5.1	32.3	4.8
.159	3.3	1.0	35.0	5.1	32.7	4.9
.160	3.2	1.0	35.0	5.1	33.1	4.9
.161	3.2	1.0	35.1	5.2	33.5	5.0
.162	3.1	1.0	35.2	5.2	34.0	5.1
.163	3.1	1.0	35.3	5.2	34.4	5.1
.164	3.0	1.0	35.4	5.3	34.8	5.2
.165	3.0	1.0	35.5	5.3	35.2	5.3
.166	2.9	1.0	35.6	5.3	35.7	5.3
.167	2.9	1.0	35.7	5.4	36.1	5.4
.168	2.8	1.0	35.8	5.4	36.5	5.4
.169	2.8	1.0	35.9	5.4	36.9	5.5
.170	2.7	1.0	35.9	5.5	37.4	5.6
.171	2.7	1.0	36.0	5.5	37.8	5.6
.172	2.6	1.0	36.1	5.5	38.2	5.7
.173	2.6	1.0	36.2	5.6	38.7	5.8

Test No. 4-1

(SEC)	VEHICLE ACCELERATION (G"S)		OCCUPANT VELOCITY (FT/SEC)		OCCUPANT DISPLACEMENT (IN)	
	AX	AY	VX	VY	DX	DY
0	0.0	0.0	0.0	0.0	0.0	0.0
001	-0.7	0.0	-0.0	0.0	-0.0	0.0
002	-1.4	0.0	-0.1	0.0	-0.0	0.0
003	-2.1	0.0	-0.2	0.0	-0.0	0.0
004	-2.8	0.0	-0.4	0.0	-0.0	0.0
005	-3.5	0.0	-0.6	0.0	-0.0	0.0
006	-3.9	0.0	-0.8	0.0	-0.0	0.0
007	-4.1	0.0	-1.0	0.0	-0.0	0.0
008	-4.1	0.0	-1.1	0.0	-0.0	0.0
009	-4.2	0.0	-1.3	0.0	-0.1	0.0
010	-4.9	0.0	-1.5	0.0	-0.1	0.0
011	-5.3	0.0	-1.7	0.0	-0.1	0.0
012	-5.6	0.0	-1.8	0.0	-0.1	0.0
013	-6.0	0.0	-2.1	0.0	-0.1	0.0
014	-6.6	0.0	-2.4	0.0	-0.2	0.0
015	-7.4	0.0	-2.8	0.0	-0.2	0.0
016	-7.9	0.0	-3.2	0.0	-0.2	0.0
017	-8.2	0.0	-3.5	0.0	-0.3	0.0
018	-8.2	0.0	-3.7	0.0	-0.3	0.0
019	-7.7	0.0	-3.8	0.0	-0.4	0.0
020	-6.8	0.0	-3.8	0.0	-0.4	0.0
021	-6.2	0.0	-3.8	0.0	-0.5	0.0
022	-5.7	0.0	-3.8	0.0	-0.5	0.0
023	-5.1	0.0	-3.8	0.0	-0.5	0.0
024	-4.3	0.0	-3.9	0.0	-0.6	0.0
025	-3.4	0.0	-4.0	0.0	-0.6	0.0
026	-2.9	0.0	-4.2	0.0	-0.7	0.0
.027	-2.9	0.0	-4.5	0.0	-0.7	0.0
028	-3.3	0.0	-4.7	0.0	-0.8	0.0
.029	-3.8	0.0	-5.0	0.0	-0.9	0.0
.030	-4.7	0.0	-5.2	0.0	-0.9	0.0
.031	-5.3	0.0	-5.4	0.0	-1.0	0.0
.032	-5.8	0.0	-5.5	0.0	-1.0	0.0
.033	-6.3	0.0	-5.8	0.0	-1.1	0.0
.034	-6.8	0.0	-6.0	0.0	-1.2	0.0
.035	-7.2	0.0	-6.3	0.0	-1.3	0.0
.036	-7.6	0.0	-6.6	0.0	-1.3	0.0
.037	-7.9	0.0	-7.0	0.0	-1.4	0.0
.038	-8.4	0.0	-7.4	0.0	-1.5	0.0
.039	-9.1	0.0	-7.8	0.0	-1.6	0.0
.040	-9.7	0.0	-8.2	0.0	-1.7	0.0
.041	-10.2	0.0	-8.6	0.0	-1.8	0.0
.042	-10.4	0.0	-8.8	0.0	-1.9	0.0
.043	-10.2	0.0	-9.1	0.0	-2.0	0.0
.044	-10.0	0.0	-9.3	0.0	-2.1	0.0
.045	-9.9	0.0	-9.5	0.0	-2.2	0.0
.046	-9.7	0.0	-9.8	0.0	-2.3	0.0
.047	-9.6	0.0	-10.1	0.0	-2.5	0.0
.048	-9.4	0.0	-10.4	0.0	-2.6	0.0
.049	-9.3	0.0	-10.8	0.0	-2.7	0.0

.050	-9.5	0.0	-11.2	0.0	-2.8	0.0
.051	-10.0	0.0	-11.7	0.0	-3.0	0.0
.052	-10.9	0.0	-12.2	0.0	-3.1	0.0
.053	-12.1	0.0	-12.8	0.0	-3.3	0.0
.054	-12.6	0.0	-13.2	0.0	-3.4	0.0
.055	-12.4	0.0	-13.5	0.0	-3.6	0.0
.056	-11.5	0.0	-13.6	0.0	-3.8	0.0
.057	-10.7	0.0	-13.6	0.0	-3.9	0.0
.058	-10.0	0.0	-13.7	0.0	-4.1	0.0
.059	-9.4	0.0	-13.9	0.0	-4.2	0.0
.060	-8.9	0.0	-14.2	0.0	-4.4	0.0
.061	-8.6	0.0	-14.5	0.0	-4.6	0.0
.062	-7.8	0.0	-14.9	0.0	-4.8	0.0
.063	-6.7	0.0	-15.1	0.0	-4.9	0.0
.064	-6.0	0.0	-15.3	0.0	-5.1	0.0
.065	-6.0	0.0	-15.4	0.0	-5.3	0.0
.066	-6.8	0.0	-15.7	0.0	-5.5	0.0
.067	-7.2	0.0	-15.9	0.0	-5.7	0.0
.068	-7.3	0.0	-16.1	0.0	-5.9	0.0
.069	-7.0	0.0	-16.2	0.0	-6.1	0.0
.070	-6.3	0.0	-16.3	0.0	-6.3	0.0
.071	-5.6	0.0	-16.4	0.0	-6.5	0.0
.072	-5.3	0.0	-16.6	0.0	-6.7	0.0
.073	-5.5	0.0	-16.8	0.0	-6.9	0.0
.074	-5.7	0.0	-17.1	0.0	-7.1	0.0
.075	-5.7	0.0	-17.3	0.0	-7.3	0.0
.076	-5.3	0.0	-17.4	0.0	-7.5	0.0
.077	-5.0	0.0	-17.6	0.0	-7.7	0.0
.078	-4.6	0.0	-17.6	0.0	-7.9	0.0
.079	-4.3	0.0	-17.7	0.0	-8.1	0.0
.080	-3.9	0.0	-17.7	0.0	-8.3	0.0
.081	-3.3	0.0	-17.6	0.0	-8.5	0.0
.082	-2.6	0.0	-17.6	0.0	-8.8	0.0
.083	-1.7	0.0	-17.5	0.0	-9.0	0.0
.084	-1.0	0.0	-17.5	0.0	-9.2	0.0
.085	-0.4	0.0	-17.5	0.0	-9.4	0.0
.086	0.2	0.0	-17.5	0.0	-9.6	0.0
.087	0.5	0.0	-17.4	0.0	-9.8	0.0
.088	0.7	0.0	-17.4	0.0	-10.0	0.0
.089	0.6	0.0	-17.5	0.0	-10.2	0.0
.090	0.4	0.0	-17.5	0.0	-10.4	0.0
.091	0.0	0.0	-17.6	0.0	-10.6	0.0
.092	-0.1	0.0	-17.6	0.0	-10.8	0.0
.093	-0.1	0.0	-17.6	0.0	-11.1	0.0
.094	-0.2	0.0	-17.6	0.0	-11.3	0.0
.095	-0.6	0.0	-17.6	0.0	-11.5	0.0
.096	-1.1	0.0	-17.7	0.0	-11.7	0.0
.097	-1.5	0.0	-17.9	0.0	-11.9	0.0
.098	-1.6	0.0	-17.9	0.0	-12.1	0.0
.099	-1.4	0.0	-17.9	0.0	-12.3	0.0
.100	-1.3	0.0	-18.0	0.0	-12.6	0.0
.101	-1.4	0.0	-18.0	0.0	-12.8	0.0
.102	-1.6	0.0	-18.1	0.0	-13.0	0.0
.103	-2.0	0.0	-18.2	0.0	-13.2	0.0
.104	-2.1	0.0	-18.2	0.0	-13.4	0.0
.105	-1.8	0.0	-18.3	0.0	-13.6	0.0
.106	-1.4	0.0	-18.3	0.0	-13.9	0.0
.107	-1.1	0.0	-18.3	0.0	-14.1	0.0
.108	-0.9	0.0	-18.2	0.0	-14.3	0.0
.109	-0.8	0.0	-18.2	0.0	-14.5	0.0
.110	-0.7	0.0	-18.2	0.0	-14.7	0.0
.111	-0.4	0.0	-18.2	0.0	-15.0	0.0

12	-0.2	0.0	-18.2	0.0	-15.2	0.0
13	0.2	0.0	-18.2	0.0	-15.4	0.0
14	0.3	0.0	-18.2	0.0	-15.6	0.0
15	0.1	0.0	-18.2	0.0	-15.8	0.0
16	-0.0	0.0	-18.3	0.0	-16.0	0.0
17	-0.3	0.0	-18.3	0.0	-16.3	0.0
18	-0.6	0.0	-18.4	0.0	-16.5	0.0
19	-0.8	0.0	-18.4	0.0	-16.7	0.0
20	-0.9	0.0	-18.5	0.0	-16.9	0.0
21	-1.0	0.0	-18.5	0.0	-17.1	0.0
22	-1.0	0.0	-18.5	0.0	-17.4	0.0
23	-1.0	0.0	-18.5	0.0	-17.6	0.0
24	-0.9	0.0	-18.5	0.0	-17.8	0.0
25	-0.8	0.0	-18.5	0.0	-18.0	0.0
26	-0.7	0.0	-18.5	0.0	-18.3	0.0
27	-0.5	0.0	-18.5	0.0	-18.5	0.0
28	-0.3	0.0	-18.5	0.0	-18.7	0.0
29	-0.2	0.0	-18.5	0.0	-18.9	0.0
30	-0.3	0.0	-18.5	0.0	-19.1	0.0
31	-0.4	0.0	-18.6	0.0	-19.4	0.0
32	-0.7	0.0	-18.6	0.0	-19.6	0.0
33	-0.9	0.0	-18.7	0.0	-19.8	0.0
34	-1.0	0.0	-18.8	0.0	-20.0	0.0
35	-1.2	0.0	-18.8	0.0	-20.3	0.0
36	-1.3	0.0	-18.9	0.0	-20.5	0.0
37	-1.4	0.0	-18.9	0.0	-20.7	0.0
38	-1.5	0.0	-19.0	0.0	-20.9	0.0
39	-1.5	0.0	-19.0	0.0	-21.2	0.0
40	-1.5	0.0	-19.0	0.0	-21.4	0.0
41	-1.4	0.0	-19.0	0.0	-21.6	0.0
42	-1.2	0.0	-19.1	0.0	-21.9	0.0
43	-1.1	0.0	-19.1	0.0	-22.1	0.0
44	-1.0	0.0	-19.1	0.0	-22.3	0.0
45	-0.9	0.0	-19.2	0.0	-22.6	0.0
46	-0.9	0.0	-19.2	0.0	-22.8	0.0
47	-0.9	0.0	-19.2	0.0	-23.0	0.0
48	-0.9	0.0	-19.3	0.0	-23.2	0.0
49	-0.9	0.0	-19.3	0.0	-23.5	0.0
50	-1.0	0.0	-19.4	0.0	-23.7	0.0
51	-1.1	0.0	-19.4	0.0	-23.9	0.0
52	-1.2	0.0	-19.5	0.0	-24.2	0.0
53	-1.3	0.0	-19.5	0.0	-24.4	0.0
54	-1.4	0.0	-19.6	0.0	-24.6	0.0
55	-1.5	0.0	-19.6	0.0	-24.9	0.0
56	-1.6	0.0	-19.7	0.0	-25.1	0.0
57	-1.6	0.0	-19.7	0.0	-25.3	0.0
58	-1.5	0.0	-19.8	0.0	-25.6	0.0
59	-1.4	0.0	-19.8	0.0	-25.8	0.0
60	-1.3	0.0	-19.8	0.0	-26.1	0.0
61	-1.1	0.0	-19.8	0.0	-26.3	0.0
62	-1.0	0.0	-19.8	0.0	-26.5	0.0
63	-0.8	0.0	-19.8	0.0	-26.8	0.0
64	-0.6	0.0	-19.8	0.0	-27.0	0.0
65	-0.4	0.0	-19.8	0.0	-27.2	0.0
66	-0.2	0.0	-19.8	0.0	-27.5	0.0
67	-0.1	0.0	-19.8	0.0	-27.7	0.0
68	-0.0	0.0	-19.8	0.0	-28.0	0.0
69	0.0	0.0	-19.8	0.0	-28.2	0.0
70	0.0	0.0	-19.8	0.0	-28.4	0.0
71	0.0	0.0	-19.8	0.0	-28.7	0.0
72	0.0	0.0	-19.8	0.0	-28.9	0.0
73	0.0	0.0	-19.8	0.0	-29.1	0.0

APPENDIX D.

DAMAGE ESTIMATES ON FULL-SCALE TEST VEHICLES

DAMAGE REPORT TEST 2-1

'-30-80 Phone No.

1, Rate Lincoln

PETE'S BODY SHOP
2035 YOLANDE
LINCOLN, NEBR., 68504
432-2617 — 432-2492

Brown

ar 1 Vega Year 74 Type State License No.

Serial No. Mileage Insurance

WORK TO BE DONE	PARTS	LABOR
resel roof with 1/2 Shelf	225 00	35 00
Repair R & left door valve		64 00
Paint as needed		112 00
Shop material & paint	50 00	
Clean up interior broken glass		32 00
R & R upholstery		40 00
		57 00

he above is a report based on our inspection and does not cover additional parts or labor which may be required after the work has opened up. Occasionally after the work has started, worn or damparts are discovered which are not evident on the first inspection. ise of this the above prices are not guaranteed, and are for immeacceptance only.

TOTAL LABOR	57 [illegible]
TOTAL PARTS	275 [illegible]
	11 00
TAX [illegible] PARTS	
TOW[illegible] and STORAGE	
TO[illegible] PORT	[illegible]

Accepted by Owner or Agent

DAMAGE REPORT TEST No. 2-2

7-30-80 Phone No.

Nebr. Lincoln

PETE'S BODY SHOP
2035 YOLANDE
LINCOLN, NEBR., 68504
432-2617 — 432-2492

Bill

ar Vega Year 75 Type Tuxter State License No.

Serial No. Mileage Insurance

WORK TO BE DONE	PARTS		LABOR	
Rt bumper, plant mounts	175	20	25	00
Header Panel	54	50	10	00
Grille	38	50	16	00
Radiator	102	00	16	00
Fan	9	50	3	00
Front Fenders	39	00	6	00
Front + align	134	00	40	00
~~[illegible]~~				
Rt Valance	25	50	[illegible]	00
Contingency	10	00	[illegible]	
~~Repair Header Panel~~				
Repair Rad Supt.			60	00
Repair unit frame section + [illegible]			[illegible]	00
Repair unit alig. lift [illegible]			6	00
Collect + [illegible]			[illegible]	00
Strip mat & paint	60	00		
Paint as needed			[illegible]	
TOTAL LABOR	[illegible]			
TOTAL PARTS	[illegible]	[illegible]		
	[illegible]	[illegible]		
TAX ON PARTS				
TOWING and STORAGE				
TOTAL REPORT	1,271	[illegible]		

The above is a report based on our inspection and does not cover additional parts or labor which may be required after the work has been opened up. Occasionally after the work has started, worn or damaged parts are discovered which are not evident on the first inspection. Because of this the above prices are not guaranteed, and are for immediate acceptance only.

Accepted by Owner or Agent

APPENDIX E

CRITIQUE

BY

LINCOLN ELECTRIC SYSTEM

NCOLN ELECTRIC SYSTEM LES
CITIZEN-OWNED

2620 FAIRFIELD STREET • P.O. BOX 80869 • LINCOLN, NEBRASKA 68521 • TELEPHONE 402-475-4211

January 22, 1982

r. Edward R. Post, P.E.
ssociate Professor of Civil Engineering
epartment of Civil Engineering
niversity of Nebraska
26 Bancroft Hall
incoln, NE 68588

ear Dr. Post:

e have received a copy of your draft report dated September 12, 1980, entitled FEASIBILITY STUDY OF BREAK-AWAY STUB CONCEPT FOR WOODEN UTILITY POLES". Bill indlay has provided us a good review of line design criteria as it applies to his break-away concept. A copy of his analysis is attached.

n light of the results of this review, it appears this break-away pole concept ould not provide LES with a safe, reliable design. Therefore, LES would not be nterested in further participation in this project.

hank you for giving us the opportunity of reviewing this project with you. If ou have any questions, please feel free to contact me.

Sincerely,

James L. Miller
Mgr., Engineering Services

rh

nclosure

c: Bill Findlay
Dave Redding
Emil Turek
Rex Martin
Walt Davis
George Selvia
Walt Canney

INTER-DEPARTMENT COMMUNICATION

DATE January 21, 1982

TO Jim Miller

FROM Bill Findlay

SUBJECT ANALYSIS OF THE FEASIBILITY STUDY OF BREAKAWAY STUB CONCEPT FOR WOODEN UTILITY POLES.

COPY Dave Redding
Emil Turek
Stan Wostrel

During the last two years the Lincoln Electric System has participated in the feasibility study of breakaway utility poles. Following are some of my comments on this study:

(1) Assumed Longitudinal Loading.

The only longitudinal loading considered in this study was that of extreme wind on the pole alone, N.E.S.C. rule 25ZC4 states "where longitudinal loads can be created by the difference in tensions in the wires in adjacent spans caused by unequal vertical loading or unequal spans, the structure shall be capable of supporting this unbalanced longitudinal loading". Unequal vertical loading happens when one span sheds its ice load while the adjacent spans are still ice loaded. A typical difference in tensions for the 336,4 KCM 18/1 ACSR for the 150' span would be 1950 pounds per conductor for the ice covered conductor at 32°, no wind, and 1330 pounds for each bare conductor at 32° with no wind. For the 2/0, 6/1 ACSR neutral a typical tension for the ice covered conductor at 32°, no wind, would be 1,110 pounds and the bare wire tension at 32°, no wind, would be 580 pounds.

This results in an unbalance in tension for the four conductors of 2,390 pounds. The unbalance in tension for any one conductor exceeds the 550 pound capability of the pole in Hughes Brothers test No. 1.

It is not an uncommon occurrence for one span to shed its ice load in the bright sun where the adjacent span is shaded and retains its ice loading.

It should be noted that the utility poles in figure 1 of the report all show additional conductors over the four conductors shown in figure 5. All of the conductors contribute to the transverse and longitudinal loading of the pole. This has not been considered in the study. In urban construction in Lincoln it would be unusual to find poles with just the four conductors on it.

(2) Design Criteria.

Section 1 introduction to the 1981 NESC is quoted here. "The purpose of these rules is the practical safeguarding of persons during the installation, operation, or maintenance of electrical supply and communication lines and their associated equipment. They contain minimum provisions necessary for the safety of employees and the public. They are not intended as a design specification or an instruction manual."

Rule 267 of the NESC specifies an overload capacity of 1.33 for longitudinal loads that has not been considered.

(3) Domino Effect.

It is estimated that a 40' class 4 pole will weigh about 1,300 lbs. with the top 26' weighing about 600 pounds, the cross arm about 32 pounds, pins and insulators 8 pounds making a total of 640 pounds that will be supported by the four conductors after the pole has been broken. Assuming each of the four conductors share the load the unbalance in tension between adjacent spans at 0°, no wind, would be about 2056 pounds.Since the breakaway poles are capable of 550 pounds there would be a domino effect with the entire pole line breaking away.

(4) Pole Deterioration.

The cutting of slots in the pole as proposed in the study exposes heartwood that has not been treated with preservative. This lack of preservative will shorten the life of the pole unless special measures are taken to try to preserve the heartwood.

(5) Fiber Stress Values.

The fiber stress values used in this study are for new poles and are primarily based on testing small clear wood specimens. Full scale testing of wood poles indicate considerable variance in pole strengths. They also indicate a decrease in strength with age. The moisture content of the wood also is a factor in strength determinations. The wood handbook published by the Forest Product Laboratory states "For example a wood member under the continuous action of bending stress for 10 years will carry only about 60% of the load required to produce failure in the same specimen loaded in a standard bending strength test of a few minutes duration". The use of new pole fiber stresses in computing the breakaway section modulus results in underestimating the required section modulus of existing poles.

(6) Column Loading.

No consideration in this study has been given to column loading on the poles. Transformers, capacitor banks and other equipment impose a column loading. A typical transformer will weigh about 400 to 600 pounds and is mounted in such a way that this load has a small eccentricity. Guying also imposes column loading with the load being determined by guy leads and size of the conductors being guyed.

In my opinion, the failure to consider longitudinal loading due to unbalanced conductor tensions has negated the conclusions of this study.

Bill Findlay

dw