TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle CHAIN LINK FENCE VEHICLE ARRESTING SYSTEM		5. Report Date July 1973 6. Performing Organization Code
7. Author(s) E. L. Marquis T. J. Hirsch G. G. Hayes		8. Performing Organization Report No. Research Report 146-10
9. Performing Organization Name and Address Texas Transportation Institute Texas A&M University College Station, Texas 77843		10. Work Unit No. 11. Contract or Grant No. Research Study 2-8-68-146 13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address Texas Highway Department 11th and Brazos Austin, Texas 78701		14. Sponsoring Agency Code

15. Supplementary Notes
Research performed in cooperation with DOT, FHWA
Research Study Title: "Studies of Field Adaptation of Impact Attenuation Systems"

16. Abstract

Three tests were conducted on a chain link fence vehicle arresting system. Each end of a chain link fence was attached to a "metal bender" energy absorber. The fence was stretched across a median type ditch 58 ft wide with 12:1 side slopes. Standard THD steel delineator posts were used to hold the fence to the ground contour. During the first test the "metal bender" tapes played out about 6 ft each and parted. The tape had bound around a center axle. A brass bushing was placed between the tape and axle and the test, a head-on, was re-run. The final two tests were conducted head-on and at an angle of 30 degrees with a line normal to the system. Both of the final tests were successful.

17. Key Words vehicle input attenuation, chain link fence, metal benders, median ditch, dragnet, barriers	18. Distribution Statement

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)

CHAIN LINK FENCE VEHICLE

ARRESTING SYSTEM

by

E. L. Marquis
Assistant Research Engineer

G. G. Hayes
Physics Research Associate

and

T. J. Hirsch
Research Engineer

Research Report 146-10
Studies of Field Adaptation of Impact
Attenuation Systems

Research Study Number 2-8-68-146

Sponsored by
The Texas Highway Department
in cooperation with
The United States Department of Transportation
Federal Highway Administration

July 1973

Texas Transportation Institute
Texas A&M University
College Station, Texas

DISCLAIMER

ACKNOWLEDGEMENTS

This study was conducted under a cooperative program between the Texas Transportation Institute and the Texas Highway Department. It was sponsored by the Texas Highway Department and the Federal Highway Administration. Laison was maintained through Mr. John F. Nixon of the Texas Highway Department and Mr. Edward V. Kristaponis of the Federal Highway Administration.

Special assistance came from Mr. Don DeCiccio and Mr. Bill Venturino of the Entwistle Corporation who manufacture the metal bender assembly. The cooperation of Mr. Marquis G. Goode, Jr., District Engineer, and Mr. William L. Stockton, Assistant District Engineer, both of District 11, Texas Highway Department, were invaluable for conducting this test. The static, dynamic and crash tests and evaluation were carried out by personnel of the Highway Safety Research Center of the Texas Transportation Institute.

ABSTRACT

Three tests were conducted on a chain link fence vehicle arresting system. Each end of a chain link fence was attached to a "metal bender" energy absorber. The fence was stretched across a median type ditch 58 ft wide with 12:1 side slopes. Standard THD steel delineator posts were used to hold the fence to the ground contour. During the first test the "metal bender" tapes played out about 6 ft each and parted. The tape had bound around a center axle. A brass bushing was placed between the tape and axle and the test, a head-on, was re-run. The final two tests were conducted head-on and at an angle of 30 degrees with a line normal to the system. Both of the final tests were successful.

Key Words: Vehicle input attenuation, chain link fence, metal benders, median ditch, dragnet, barriers.

SUMMARY

There are several features or areas along our roadways or highways which can be hazardous to vehicles when leaving the travelway at high speed. In many cases, conventional guardrails or crash cushions are not an effective or economical means of preventing vehicles from entering these hazardous areas. Some obvious areas of this type are:

1. Median areas or holes between twin bridges on divided highways.
2. "Dead Ends" or termination of roads or highways.
3. Barriers to close off entrance and exit ramps on freeways.

The chain link fence vehicle arresting system reported on here was designed specifically to prevent motorists from entering the median area or hole between twin bridges on divided highways. At the present time, guardrails or no protective device is used in these areas. Guardrail, if used, will generally be inadequate to prevent a high speed vehicle from entering this hazardous area because the vehicle will be impacting it almost head-on. The device, reported here, is composed of a chain link fence mounted on standard steel delineator posts. Each end of the fence is attached to a "metal bender" energy absorber mounted on a standard wooden guardrail post. Similar devices of this type have been used at automobile drag race tracks under the trade name of "Dragnet". The Texas Highway Department has a barrier at the Bolivar Ferry Landing near Galveston which uses the metal benders as an energy absorber.

Several tests have been conducted on similar installations in which the net between the metal benders was straight and level. District 11 of the

Texas Highway Department had a potential installation in which the net connecting the two metal benders would traverse a median ditch with 12:1 side slopes. Officials of this district were concerned about the interaction of an errant vehicle and a dragnet system spanning a ditch section of this configuration.

A test site was developed at the TTI Proving Grounds, and the dragnet system was installed. A head-on test was conducted, and the metal bender tapes failed to perform as intended. The manufacturer had modified the design of the system to simplify and improve the installation of the metal bender units. A hole was placed in the center of the metal bender of sufficient size to fit over a standard 7 in. guardrail post. The closure of the case provided an axle for the coil of tape to spin around. No bushing or bearing had been provided between this axle and the coil of metal tape. During the tsst, the tape tightened around the axle and locked up, resulting in tape breakage. Brass bushings were provided for the metal benders. The re-testing with brass bushings, verified that the median configuration could be successfully protected by a dragnet system. As a result of the first test, it was found that the fence support post could be made "breakaway" to improve the fence-vehicle entrapment performance.

IMPLEMENTATION STATEMENT

Wide medians offer distinct safety advantages to the motorists. They provide safe separation of opposing traffic, adequate recovery area, and emergency parking. However, the open area between adjacent structures often present a hazard which is difficult to eliminate.

On wide medians where decking the area between twin structures is not practical, the use of the chain link fence Vehicle Arresting System appears to have great potential to attenuate a vehicle with little damage and no injury to the occupants at a competitive cost.

Prior to the installation of a dragnet on a 72' median on US 59 in District 11, Lufkin, Texas, Two tests were conducted at the Texas Transportation Institute. A 4400-pound vehicle was impacted with a chain link fence Vehicle Arresting System on a typical median with 12:1 cross slopes. Impacts headon and at an angle of 30° at speeds of 57 and 60 mph, respectively, resulted in less than 2 G's average deceleration.

A 6-minute narrated 16 mm color film on the testing and field installation of this System may be obtained by addressing your request as follows:

R. L. Lewis, Chairman
Research and Development Committee
Texas Highway Department-File D-8
11th and Brazos
Austin, Texas 78701
(Phone 512/475-2971)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

There are several features or areas along our roadways or highways which can be hazardous to vehicles when leaving the travelway at high speed. In many cases, conventional guardrails or crash cushions are not an effective or economical means of preventing vehicles from entering these hazardous areas. Some obvious areas of this type are:

1. Median areas or holes between twin bridges on divided highways.
2. "Dead Ends" or termination of roads or highways.
3. Barriers to close off entrance and exit ramps on freeways.

The chain link fence vehicle arresting system reported on here was designed specifically to prevent motorists from entering the median area or hole between twin bridges on divided highways. At the present time, guardrail or no protective device is used in these areas. Guardrail, if used, will generally be inadequate to prevent a high speed vehicle from entering this hazardous area because the vehicle will be impacting it almost head-on. The device reported on here is composed of a chain link fence mounted on standard 2 lb per ft steel delineator post. Each end of the fence is attached to a "metal bender" energy absorber mounted on a standard wooden guardrail post (see Figure 1). The metal benders are manufactured by Van Zelm Associates, a subsidiary of Entwistle Company in Hudson, Massachusetts. Similar devices of this type have been used at automobile drag race tracks under the trade name of "Dragnet". The Texas Highway Department has a barrier at the Bolivar Ferry Landing near Galveston which uses the metal benders as an energy absorber.

Several tests have been conducted on similar installations (1*, 3) in which the net between the metal benders was straight and level. District 11 of the Texas Highway Department had a potential installation in which the net connecting the two metal benders would traverse a median ditch with 12:1 side slopes (Figure 1). Officials of this district were concerned about the interaction of an errant vehicle and a dragnet system spanning a ditch section of this configuration.

A test site with 12:1 side slopes was developed at the TTI Proving Grounds to similate field conditions and the dragnet system was installed. A head-on test was conducted, and the metal bender tapes failed to perform as intended. The manufacturer had modified the design of the system to simplify and improve the installation of the metal bender units. A hole was placed in the center of the metal bender of sufficient size to fit over the top of a standard 7 in. guardrail post. The closure of the case provided an axle for the coil of tape to spin around. No bushing or bearing had been provided between this axle and the coil of metal tape, consequently during the test, the tape tightened around the axle and locked up, resulting in tape breakage. The manufacturer was contacted who provided brass bushings for all metal benders in stock, new tapes and some financial support for re-testing. The re-testing with brass bushings, placed as shown in Figure 11, verified that the median configuration could be successfully protected by a dragnet system. As a result of the first re-test, it was found that the fence support post could be made "breakaway" to improve the fence-vehicle entrapment performance. For the final test, the posts were cut 4 in. above ground line and a simple bolted lap splice used as a breakaway feature.

---

* Numbers in parentheses refer to corresponding numbers in the Reference.

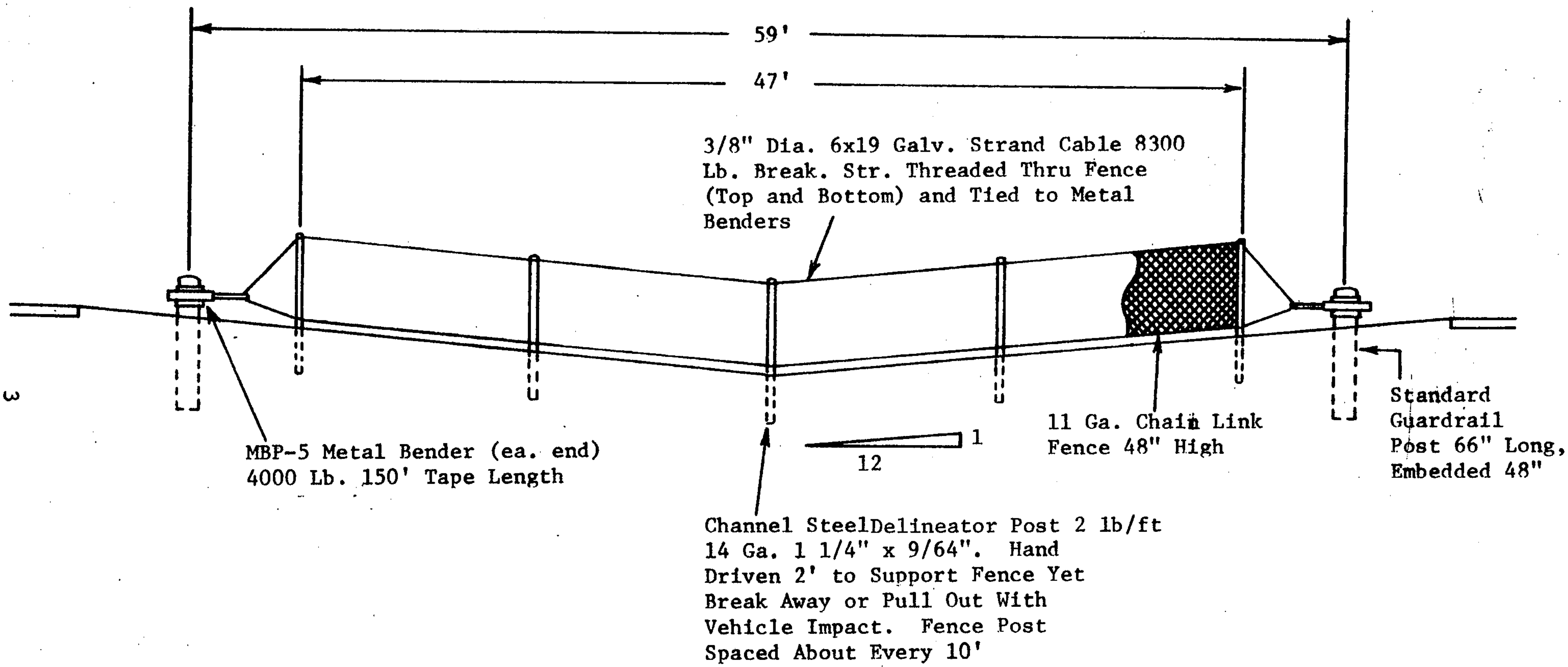


FIGURE 1 ELEVATION OF MEDIAN INSTALLATION

Description of Arresting System

The basic arresting system consists of a chain link fence attached through cables at each end to energy absorbing devices. These devices, called "metal benders," are cases containing a coil of metal tape which emerges from the case after bending back and forth around a series of stainless steel pins. The ends of the tapes are attached with cables to the net. As a vehicle engages the fence (or net), the end tapes are pulled out through the series of pins and exert a stopping force that is dependent on the size of the tape.

Figures 1, 2, and 3 show the system tested here. In this test series, the design resistance of each metal bender was 4000 lb. Previous tests of a similar system indicated that reasonable accurate predictions can be made of the amount of tape required and the stopping distance for a vehicle of known weight and impact speed (1). The equations, based on simple geometry, are given in the Appendix along with further details on the arresting system.

The net itself consisted of 11 gage chain-link fence, 48 in. high, with the 3/8 in. galvanized restraining cables threaded through the top and bottom. The net was supported in an upright position by five 2 lb per ft THD Standard delineator posts driven 2 ft into the ground. The posts were cut and lap spliced with brass screws to provide a "breakaway" feature. The net was attached to the back side of the posts with aluminum wire ties.

The metal benders themselves were mounted on 7 in. diameter wooden guardrail posts embedded 48 in. in 12 in. diameter concrete footings. The metal bender case with its contained coil of tape fits around the post and rests on a collar which allows the case to turn in the direction of the applied force. Other metal benders, tape tensions, and net arrangements can be designed to fit the intended site. Figure 4 shows the site layout on US 59 where it crosses loop 224 near Nacogdoches, Texas.

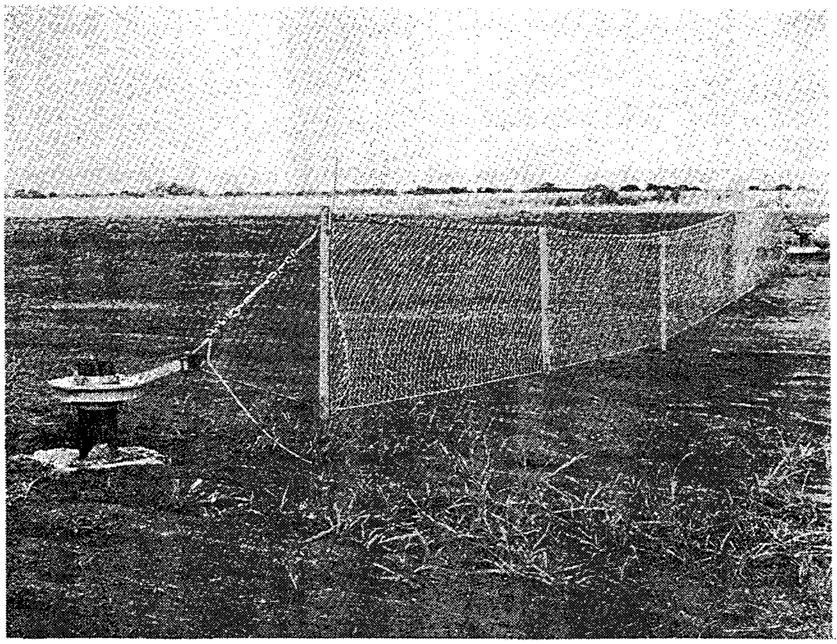


FIGURE 2. OBLIQUE VIEW OF DRAGNET INSTALLATION.

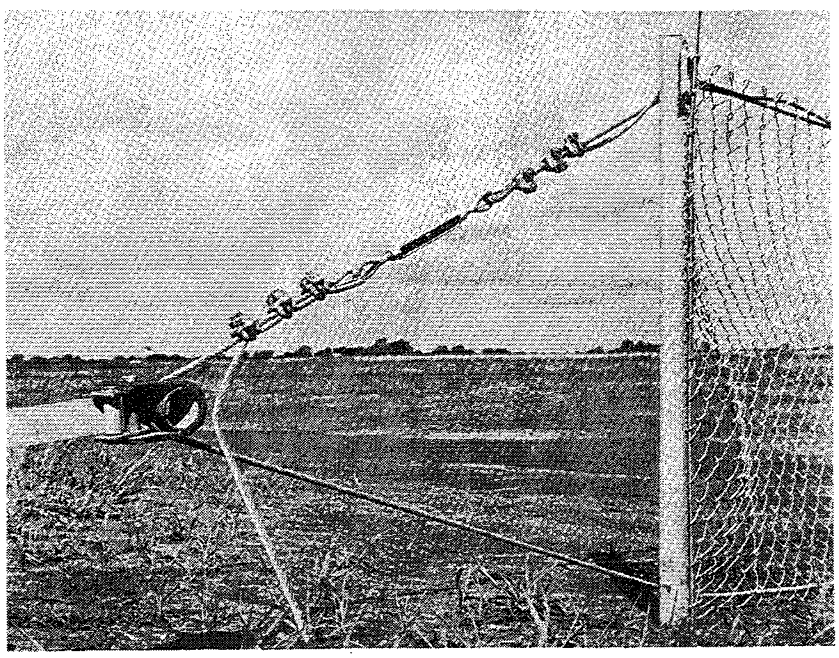


FIGURE 3. TRANSITION AREA FROM METAL TAPE TO NET.

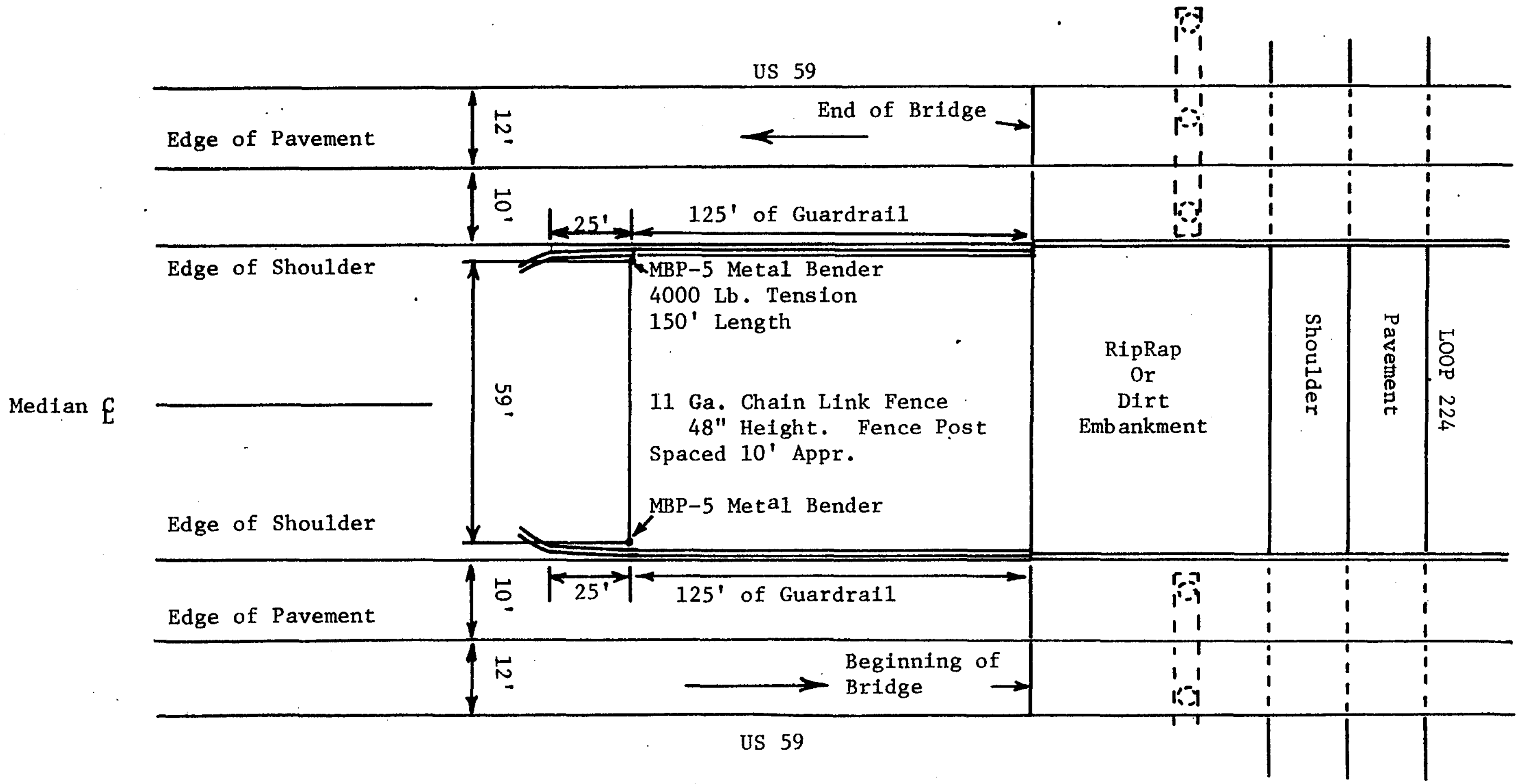


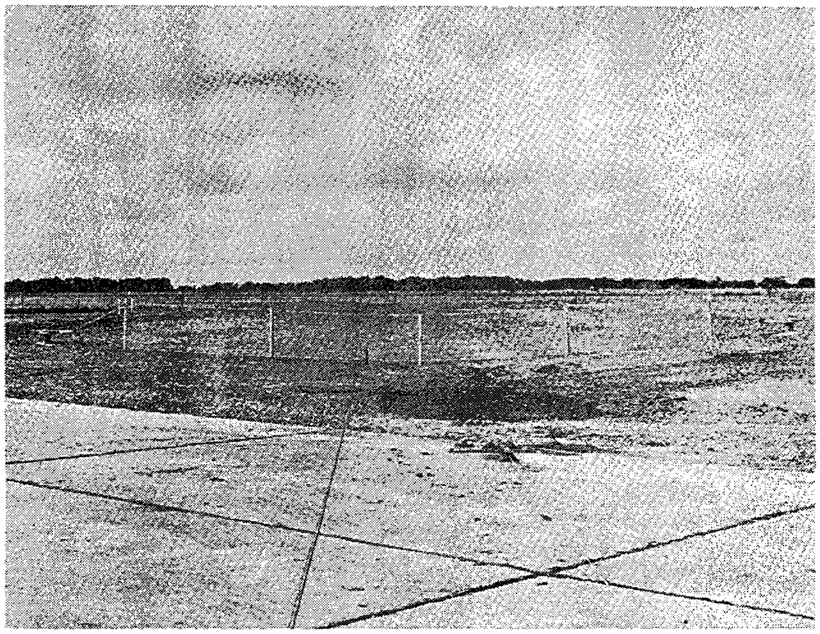
FIGURE 4 PROPOSED MEDIAN INSTALLATION OF DRAGNET TO PROTECT VEHICLE FROM RUNNING DOWN EMBANKMENT

Vehicle and Instrumentation

The vehicle used in all three full-scale tests was a 1965 Pontiac Sedan shown in Figure 5. The test weight of 4400 lb included the anthropometric dummy which was secured in the driver's seat with a lap belt anchored through a load cell which indicated lap belt force.

Lontigudinal and lateral accelerometers were mounted on each longitudinal frame member to sense vehicle accelerations. A flash bulb and an event mark on the electronic data were actuated by a tape-switch on the front bumper. This allows the electronic data with the high speed film to be synchronized. All electronic data were transmitted by telemetry to a ground station where the data were recorded on magnetic tape and displayed in analog form on a strip-chart.

In addition to documentary motion pictures, the tests were recorded on high-speed films which include timing marks. This film was analyzed to give time displacement data for the vehicle. Two data cameras were oriented perpendicular to the vehicle's path and had overlapping fields of view. The sequential photographs in the Description of Tests section were made from these high-speed motion pictures.



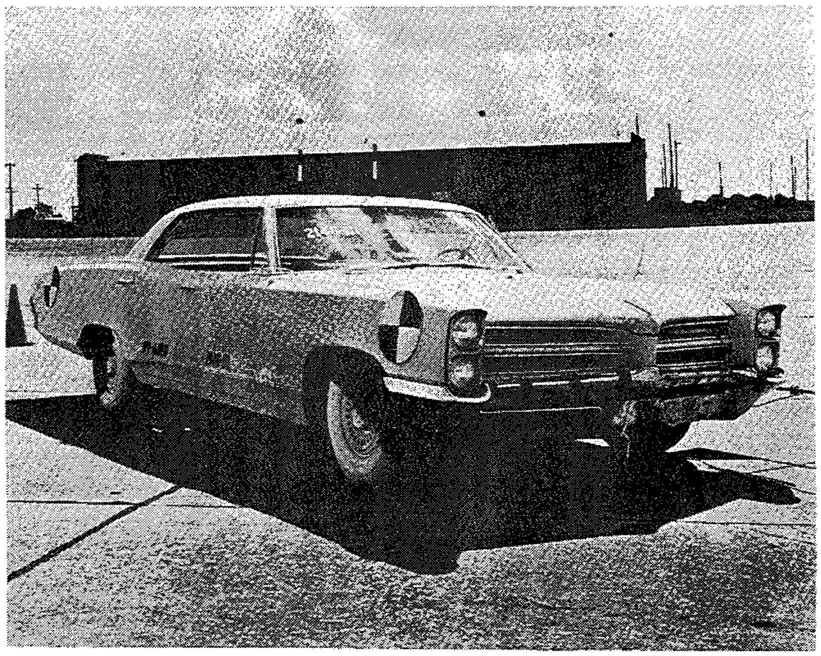


FIGURE 5. TOP PHOTO: OVERALL VIEW OF INSTALLATION LOOKING DOWN MEDIAN IN DIRECTION OF TRAVEL.
BOTTOM PHOTO: VEHICLE USED IN ALL THREE TESTS.

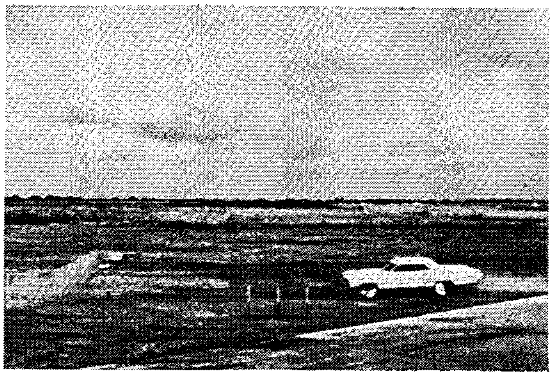
DESCRIPTION OF TESTS

Test 2146 - D1

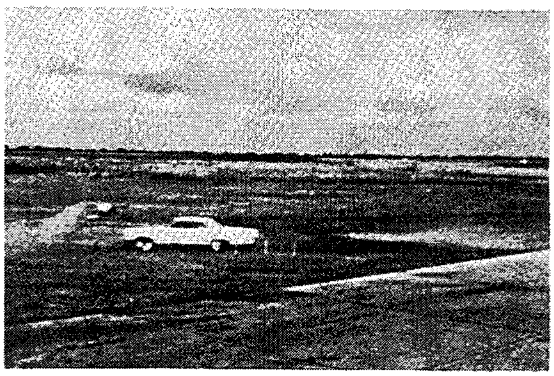
This was a head-on impact in the center of the net at 62.9 mph. The tapes coiled inside the metal bender cases tightened on the inner case wall (or core) and locked-up with the result that the net broke free. The tape on the left parted at the connection to the cables after 6 ft of tape was pulled from the metal bender, while the tape on the right played out about 6 ft and then parted near the metal bender. At this time the vehicle had traveled 21.1 ft and had slowed from 63 to 55 mph. The average deceleration to this point was 1.4 g's. The test data for all tests are summarized in Table 1, and Figures 6 and 7 show sequential photographs of the first test. Figure 8 shows the vehicle, and Figures 9 and 10 show metal benders after the test.

Static Tests

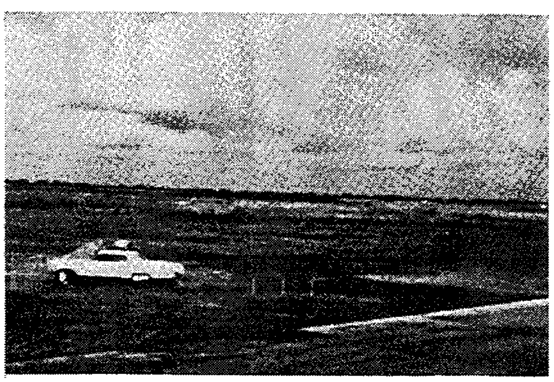
It was evident from the results of Test D1 that the metal-bender tapes must be coiled around a core that is free to turn. Consequently, a brass bushing, as shown in Figure 11, was added for this purpose, and "static" tests of the metal bender were conducted. These "static" tests were conducted using a small crane to pull the tape at very slow speeds (about 1 fps). A load cell was placed in line with the tape and crane to measure the pull out force during the tests. About 50 ft of tape was pulled during each test. The loads on the tape were relatively constant at 3,950 lb (rated capacity of MPB-5 metal bender was 4000 lb).



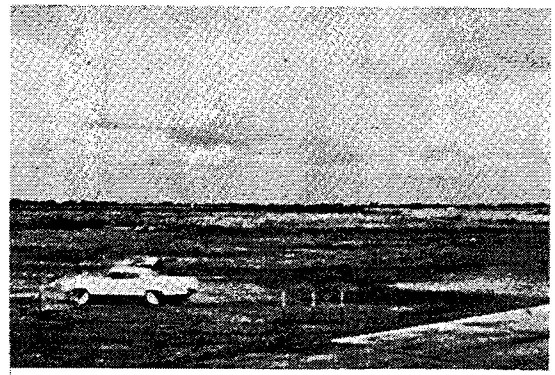
t = -0.441 sec.



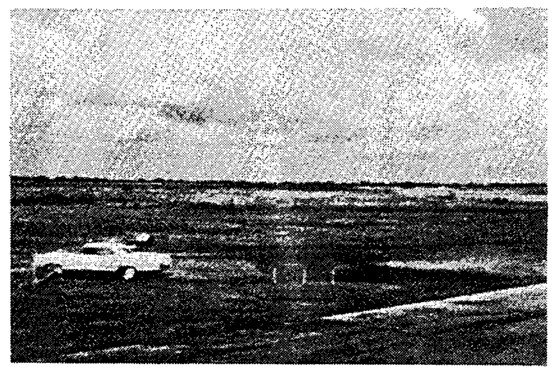
t = -0.121 sec.



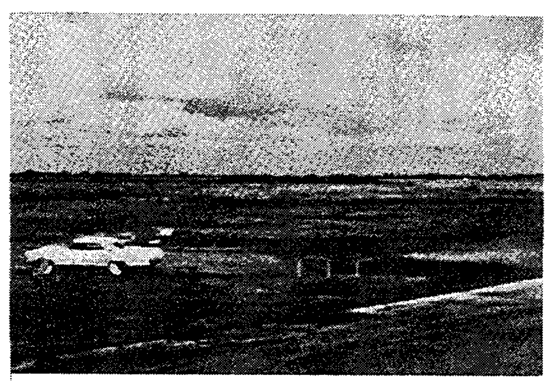
t = 0.017 sec.



t = 0.044 sec.

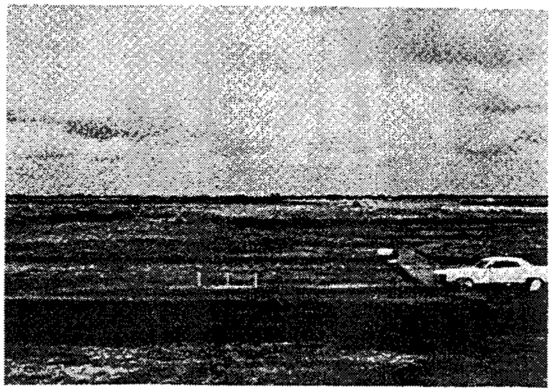


t = 0.071 sec.

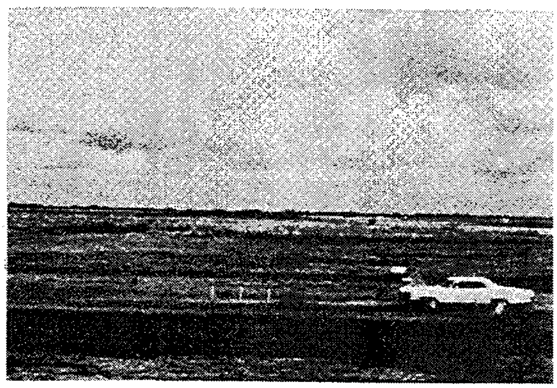


t = 0.127 sec.

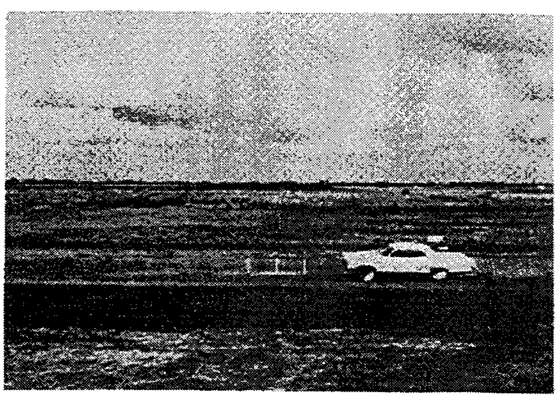
FIGURE 6. SEQUENTIAL PHOTOGRAPHS OF TEST D1 FROM CAMERA 1.



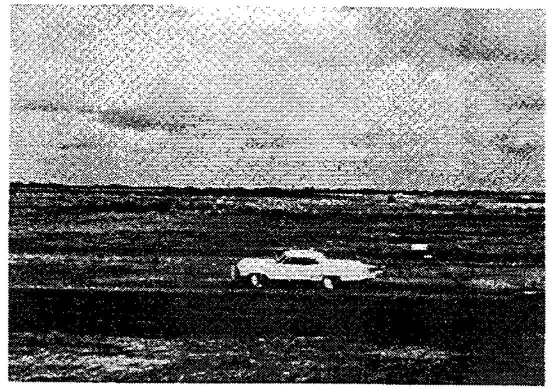
t = 0 sec.



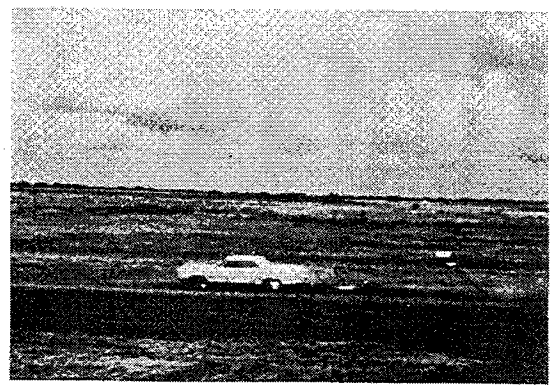
t = 0.083 sec.



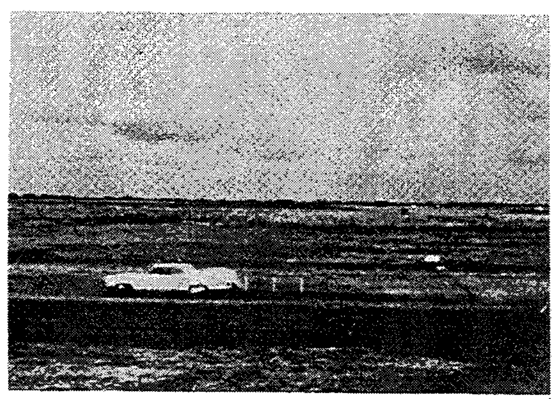
t = 0.251 sec.



t = 0.415 sec.



t = 0.565 sec.



t = 0.681 sec.

FIGURE 7. SEQUENTIAL PHOTOGRAPHS OF TEST D1 FROM CAMERA 2.

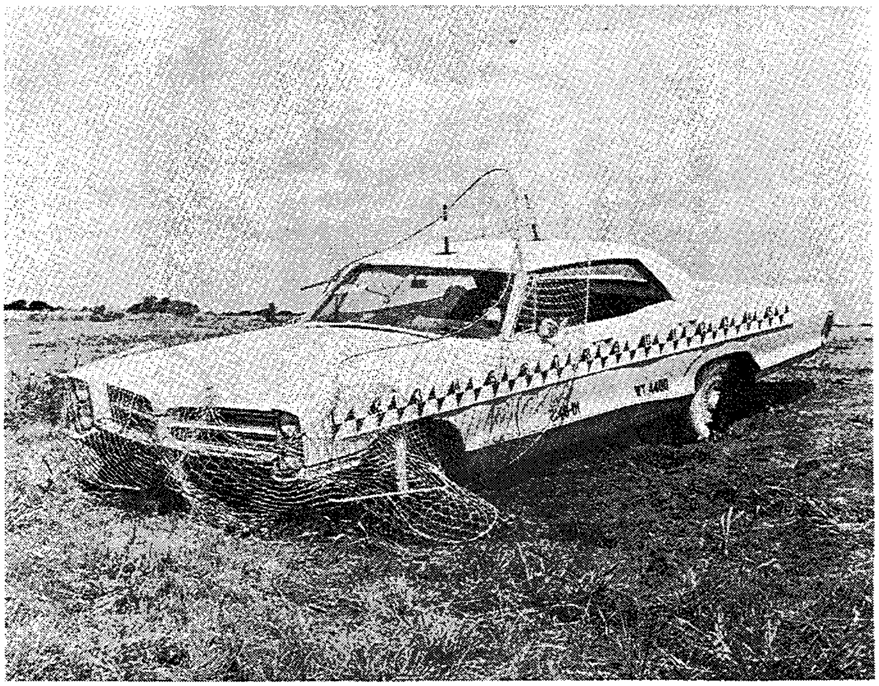


FIGURE 8. VEHICLE AFTER TEST D1 IN WHICH BOTH TAPES FAILED.

FIGURE 9. TAPE PULLED OUT IN TEST D1 BEFORE FAILURE (LEFT SIDE OF NET).

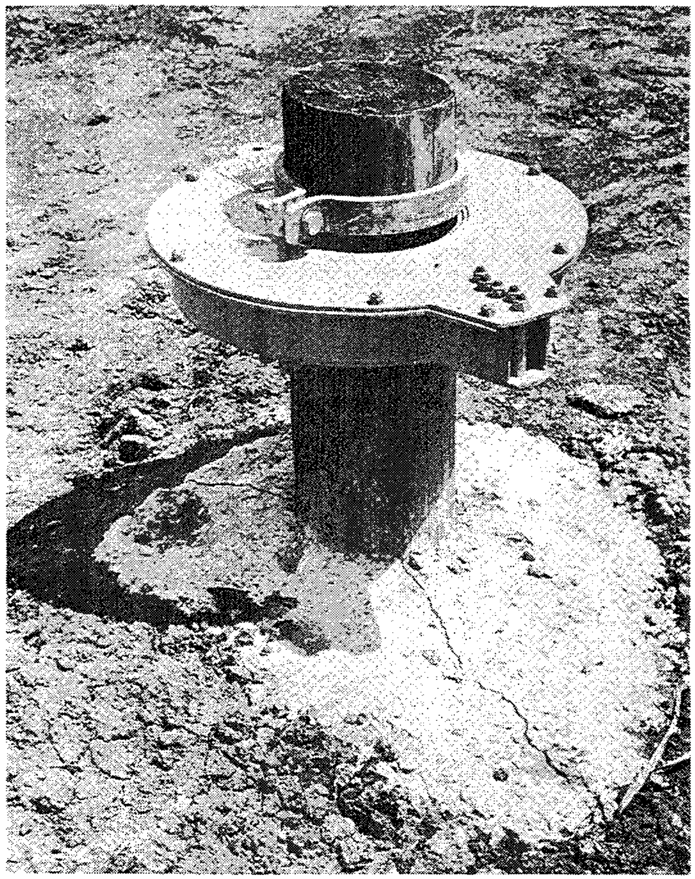
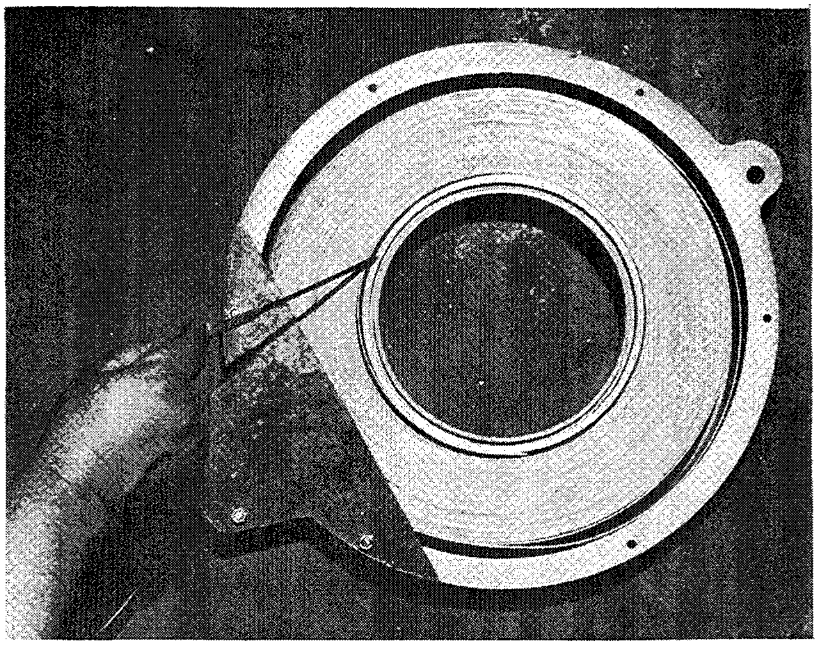


FIGURE 10 . METAL BENDER AFTER TEST D1. NOTE CRACK IN POURED CONCRETE FOOTING (RIGHT SIDE OF NET) .



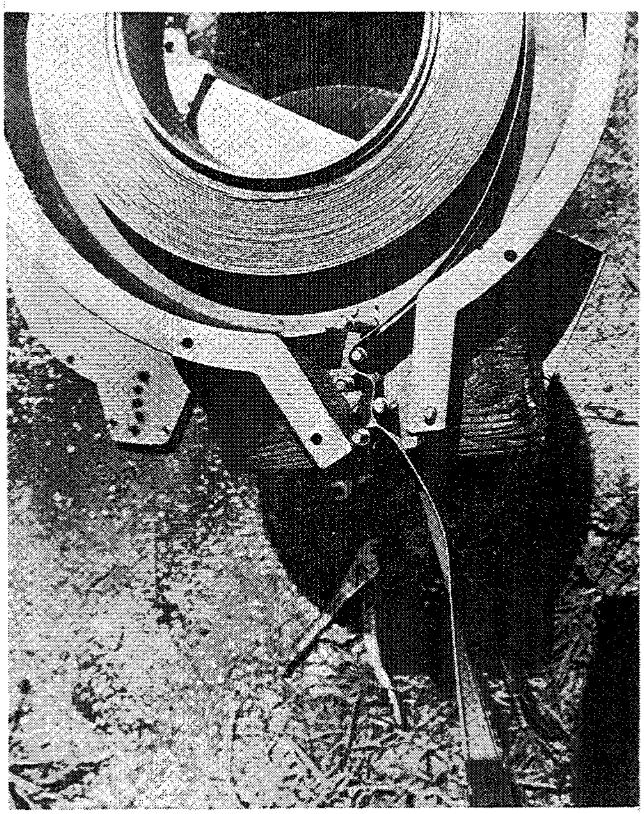


FIGURE 11. TOP PHOTO SHOWS BUSHING ADDED INSIDE COIL OF RESERVE TAPE. BOTTOM PHOTO, TAKEN AFTER THE DYNAMIC TEST, SHOWS METAL BENDER WITH TOP REMOVED. NOTE THE TAPE-BENDING ACTION OF THE FIVE PINS IN CENTER OF PHOTO.

Dynamic Test of Metal Bender with Bushing

After the "static" tests, a new tape was installed in one metal bender which was attached to an iron pipe, and the running end of the tape was attached through 200 ft of 1 in. cable to a 5 ton truck as shown in Figure 12. The truck was driven past the metal bender and reached the end of the cable traveling at about 25 mph. The truck's momentum pulled out 67 ft of tape, and no tendency to bind was observed. At this stage, it was felt that the "dragnet" was ready for further full-scale testing.

Test 2146 - D2

This test was intended as a re-run of Test D1. The center, head-on impact speed was 57.1 mph. The vehicle stopped 60 ft after impact and again the center support post was bent over allowing the vehicle to pass over it, while the net broke away from the other posts. Sequential photographs are shown in Figures 13 and 14. The net entrapped the front of the vehicle quite low as shown in Figure 20. The center post bending away from the vehicle may have caused this.

The left-hand tape pulled out 37 ft while the right-hand tape pulled out 39 ft. This represents about 300 Kip-ft of work, assuming 4000 lb force on each tape, as compared to 480 Kip-ft of kinetic energy in the vehicle at impact. The stopping distance predicted by the equations in Technical Memorandum 505-4 was 85 ft, which is 25 ft more than observed. However, the theory does not include friction with the ground or other sources of energy loss. The predicted peak deceleration was 1.7 g's, as compared to 2.0 g's from the accelerometers. The decelerations were near to the accelerometers' lower limits, and thus the accelerometer data are only approximate.

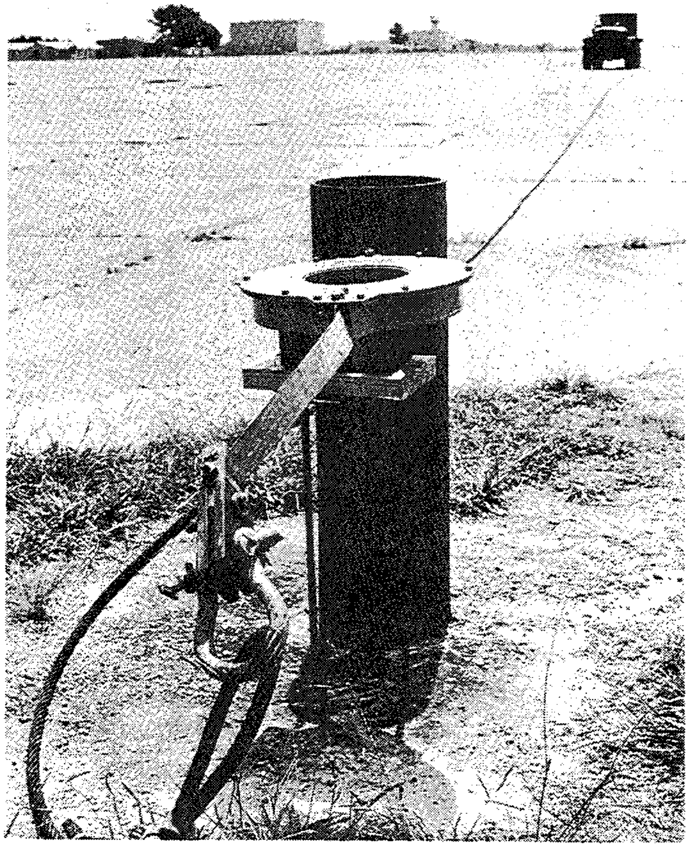
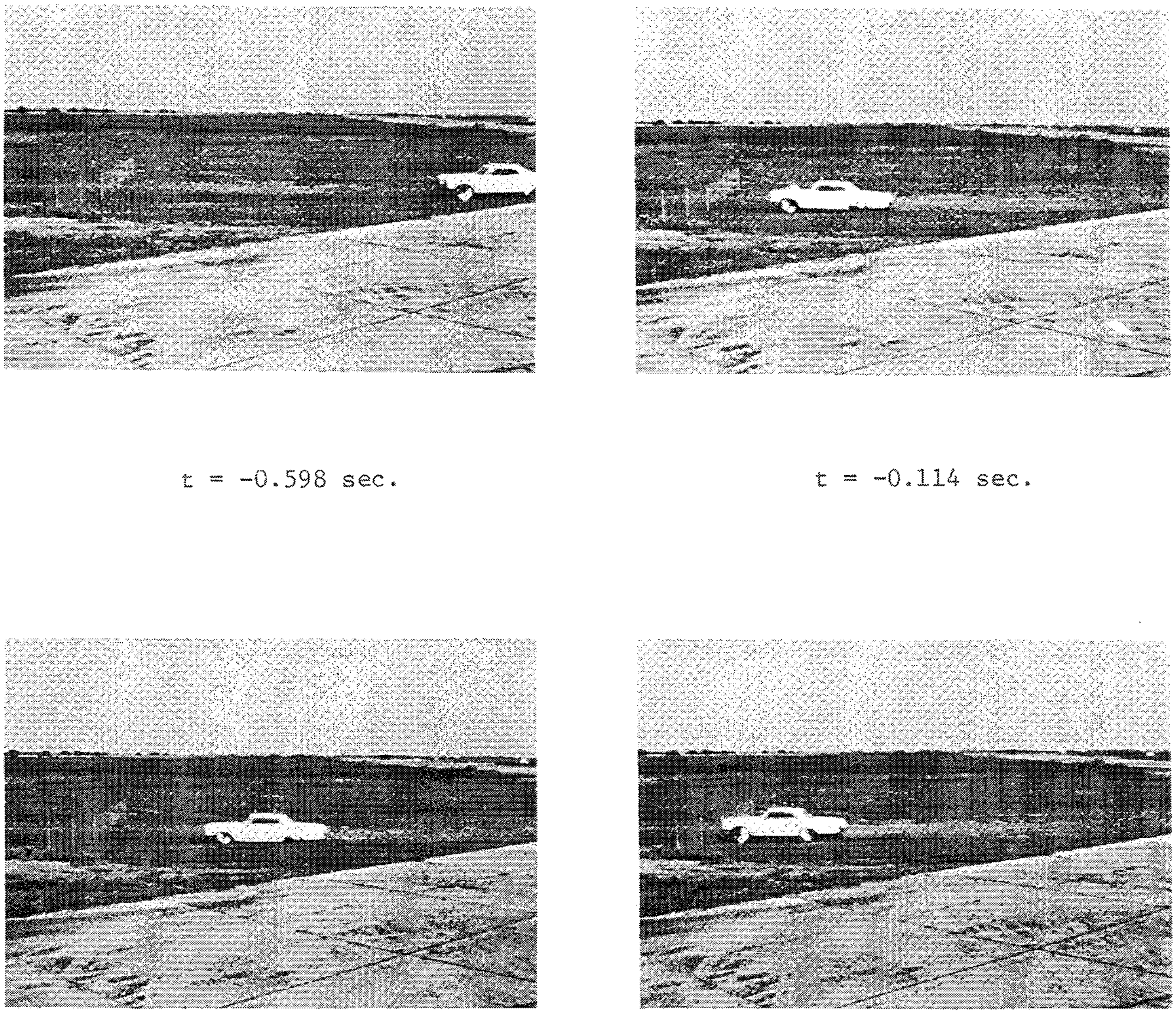


FIGURE 12. DYNAMIC TEST SETUP. TRUCK IN BACKGROUND PASSES BESIDE METAL BENDER AND "BOTTOMS OUT" ON CABLE.



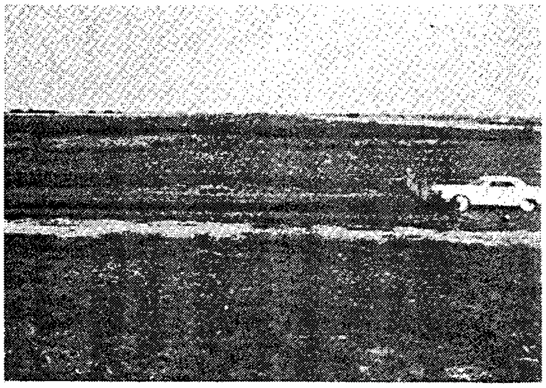
t = -0.598 sec.

t = -0.114 sec.

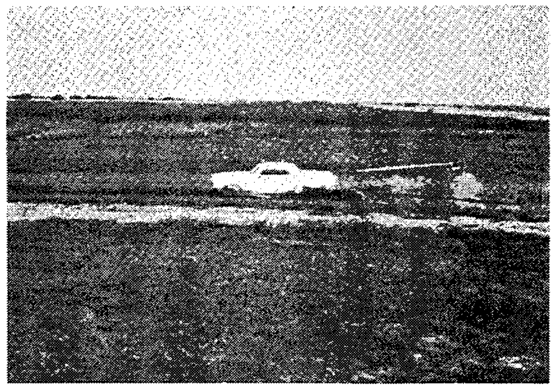
t = -0.196 sec.

t = 0 sec.

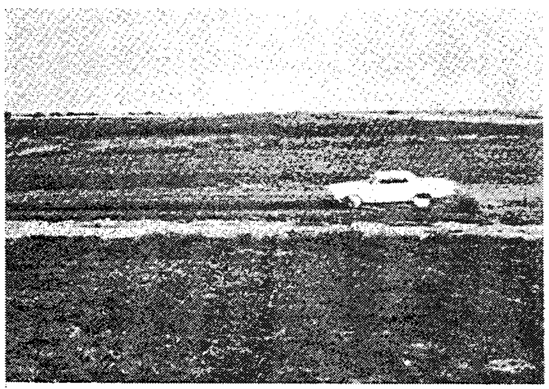
FIGURE 13. SEQUENTIAL PHOTOGRAPHS OF TEST D2 FROM CAMERA 1.



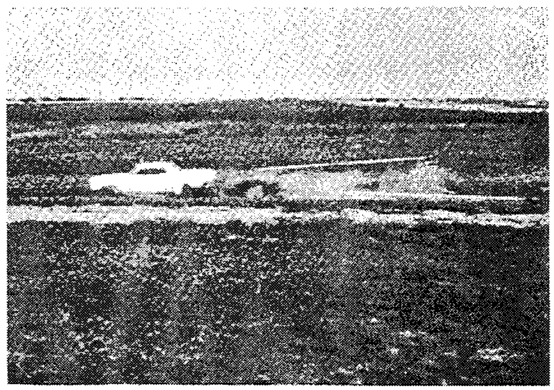
t = 0 sec.



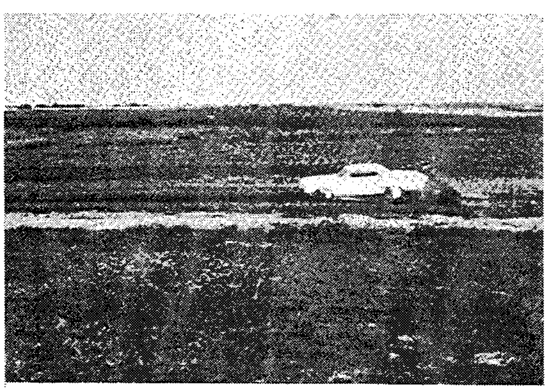
t = 0.0296 sec.



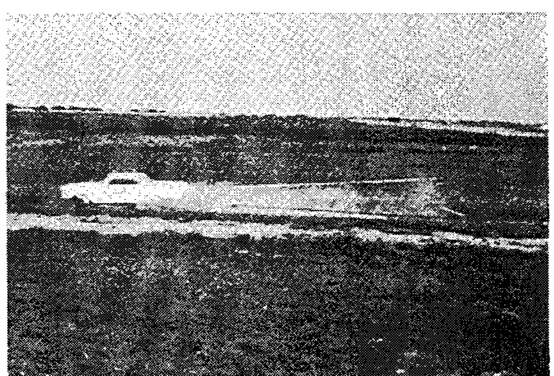
t = 0.186 sec.



t = 0.916 sec.



t = 0.267 sec.



t = 1.786 sec.

FIGURE 14. SEQUENTIAL PHOTOGRAPHS OF TEST D2 FROM CAMERA 2.

The vehicle, which stopped while traveling in a straight line, did not exhibit any unstable behavior and was not damaged. The deceleration forces were well below the accepted tolerance levels for properly restrained or unrestrained humans(2).

Test 2146 - D3

In Test D3, the vehicle was directed into the center of the net an angle of 30 degrees with the perpendicular to the net. The wire mesh was reused, and the deformation due to the previous test can be seen in Figure 16. The impact speed was 60.1 mph, giving an initial kinetic energy of 530 Kip-ft. The vehicle swerved slightly to the left as it went into the simulated median and the left front bumper struck the guidance cable anchor just prior to impact with the net. This put a large peak on the accelerometer data from the left frame member (and a lesser one on the data from the other side) which masked the initial reaction with the net. The vehicle was stopped in a relatively straight line in 65 ft with 34 ft of tape expended on the left and 52 ft on the right. Again, the predicted stopping distance of 92 ft was higher than observed, but the effects of striking the anchor post, friction with the ground, and going uphill after impact were not included in the estimate. Sequential photographs are shown in Figures 17 and 18.

In this test, the center net-support post was made breakaway by cutting it in two about 4 in. above the ground and fastening the two parts together with a lap splice secured by 3/16 in. brass screws (or bolts). The base after the test is shown in Figure 19, while the post bent around the front of the

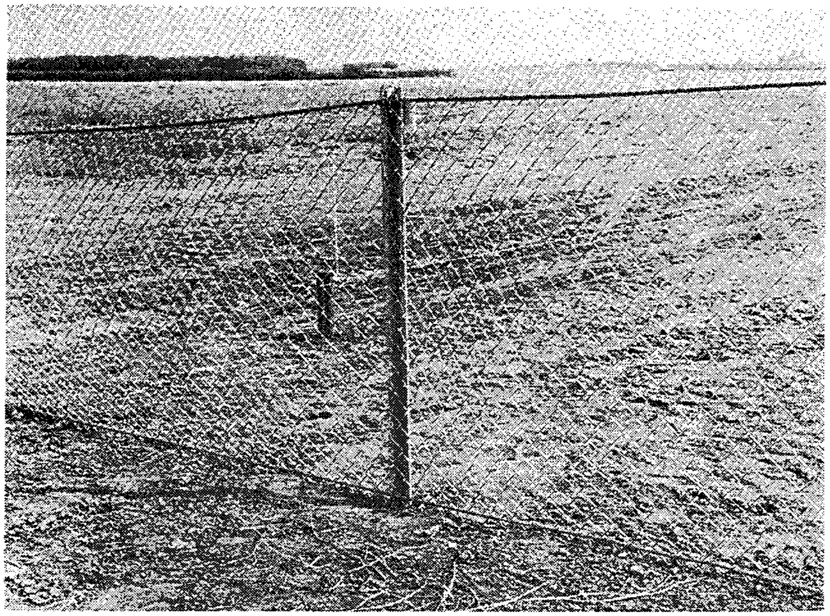


FIGURE 15. DETAIL OF NET-CABLE-POST ARRANGEMENT.

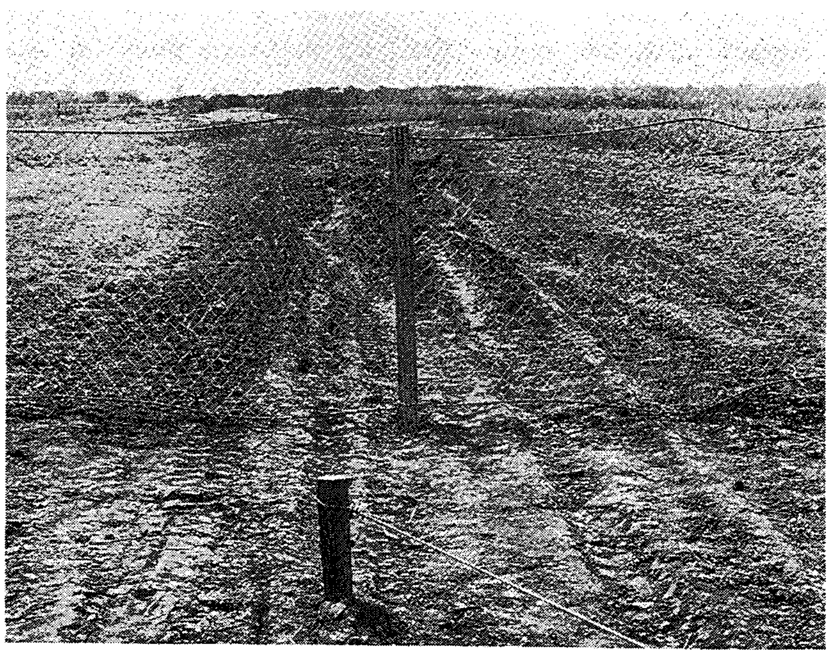
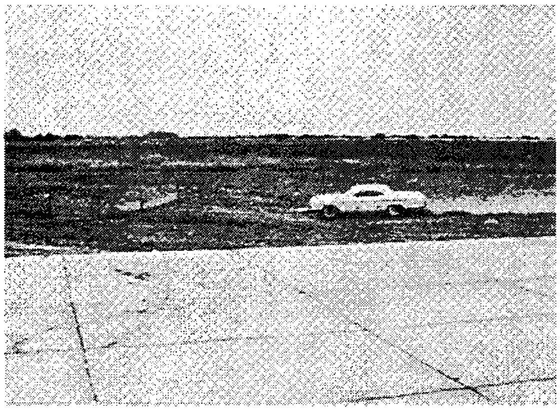
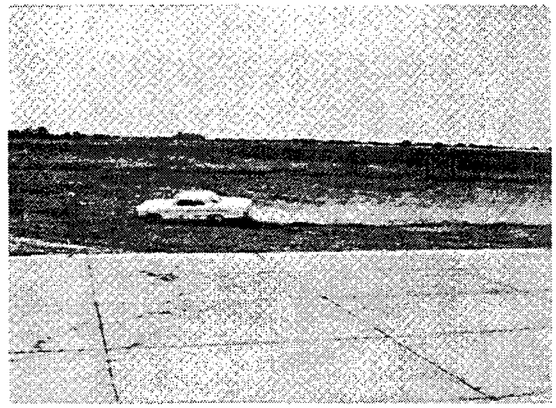


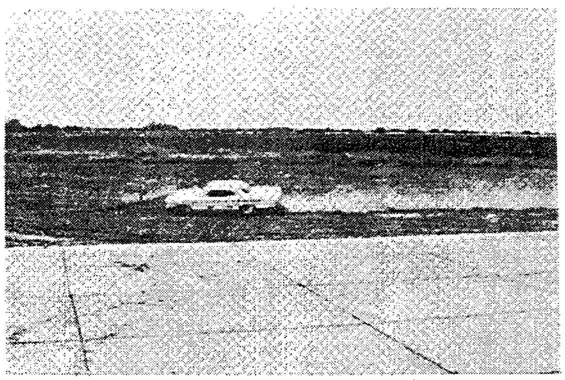
FIGURE 16. NET BEFORE TEST D3. NOTE DEFORMED NET FROM TEST D2, AND GUIDE CABLE ANCHOR IN FOREGROUND.



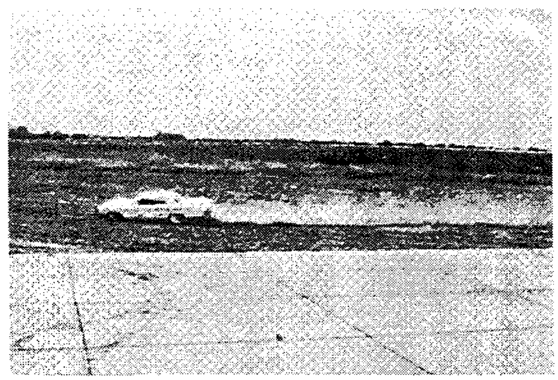
t = -0.396 sec.



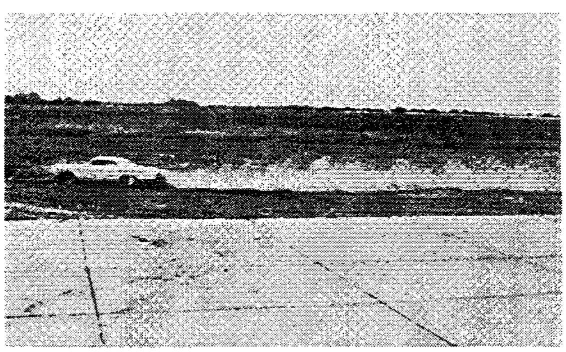
t = -0.036 sec.



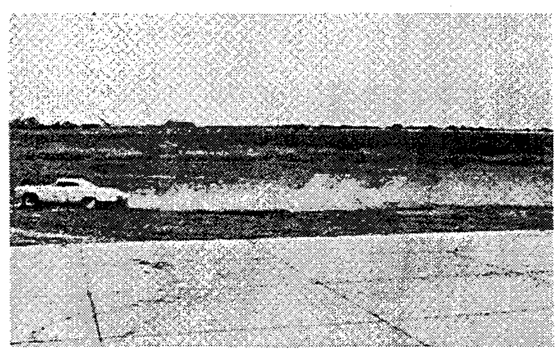
t = -0.138 sec.



t = 0 sec.

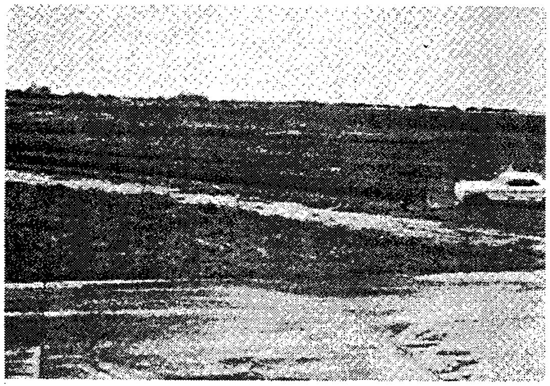


t = -0.119 sec.

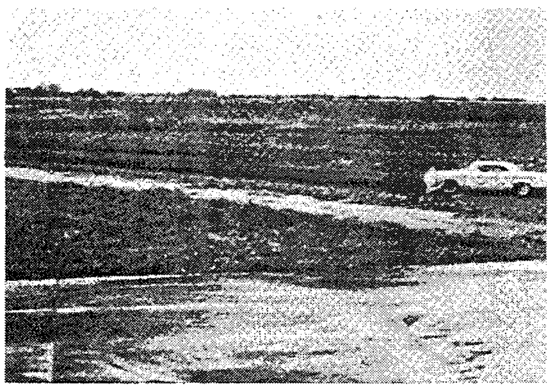


t = 0.19 sec.

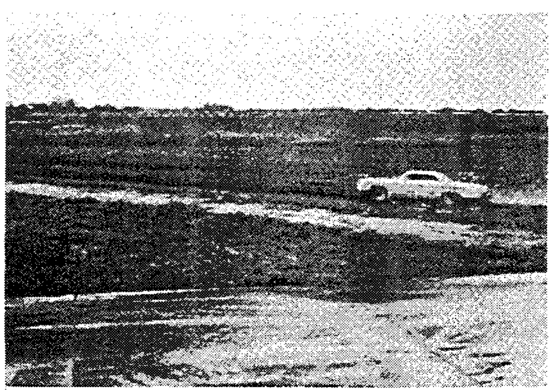
FIGURE 17. SEQUENTIAL PHOTOGRAPHS OF TEST D3 FROM CAMERA 1.



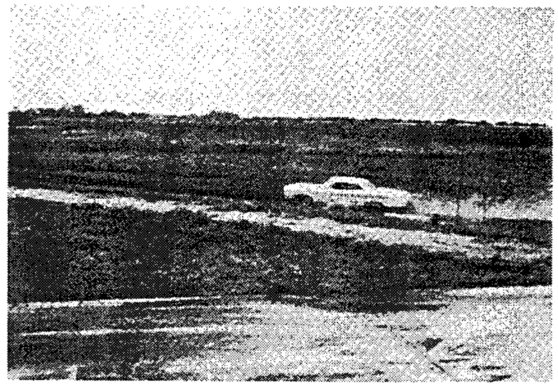
t = 0 sec.



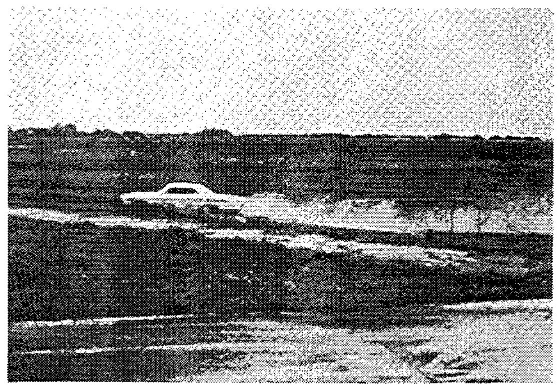
t = 0.105 sec.



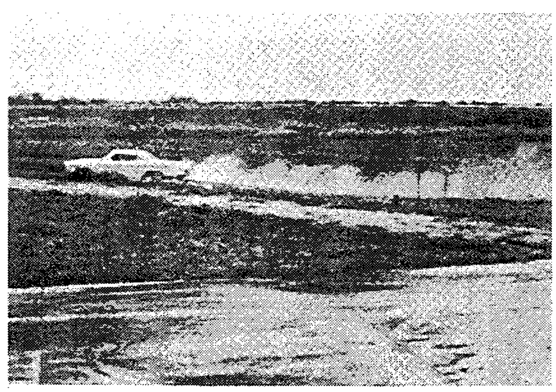
t = 0.257



t = 0.408 sec.



t = 0.711 sec.



t = 0.910 sec.

FIGURE 18. SEQUENTIAL PHOTOGRAPHS OF TEST D3 FROM CAMERA 2.

car as shown in Figure 20. Note that the net more securely entrapped the nose of the vehicle and the bent breakaway support seems to serve as a guide in shaping the "pocket". The other posts could have been (and should be) made to breakaway for non-centric impacts.

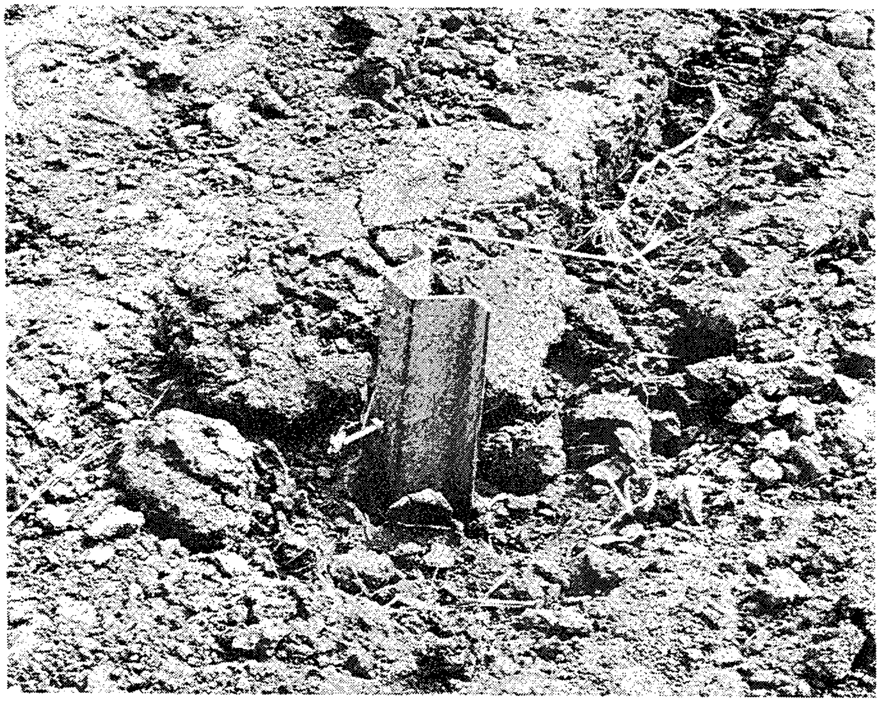


FIGURE 19. CENTER NET SUPPORT-POST BASE AFTER TEST D3. POST WAS CUT TO PROVIDE BREAKAWAY CAPABILITY AFTER TEST D2.

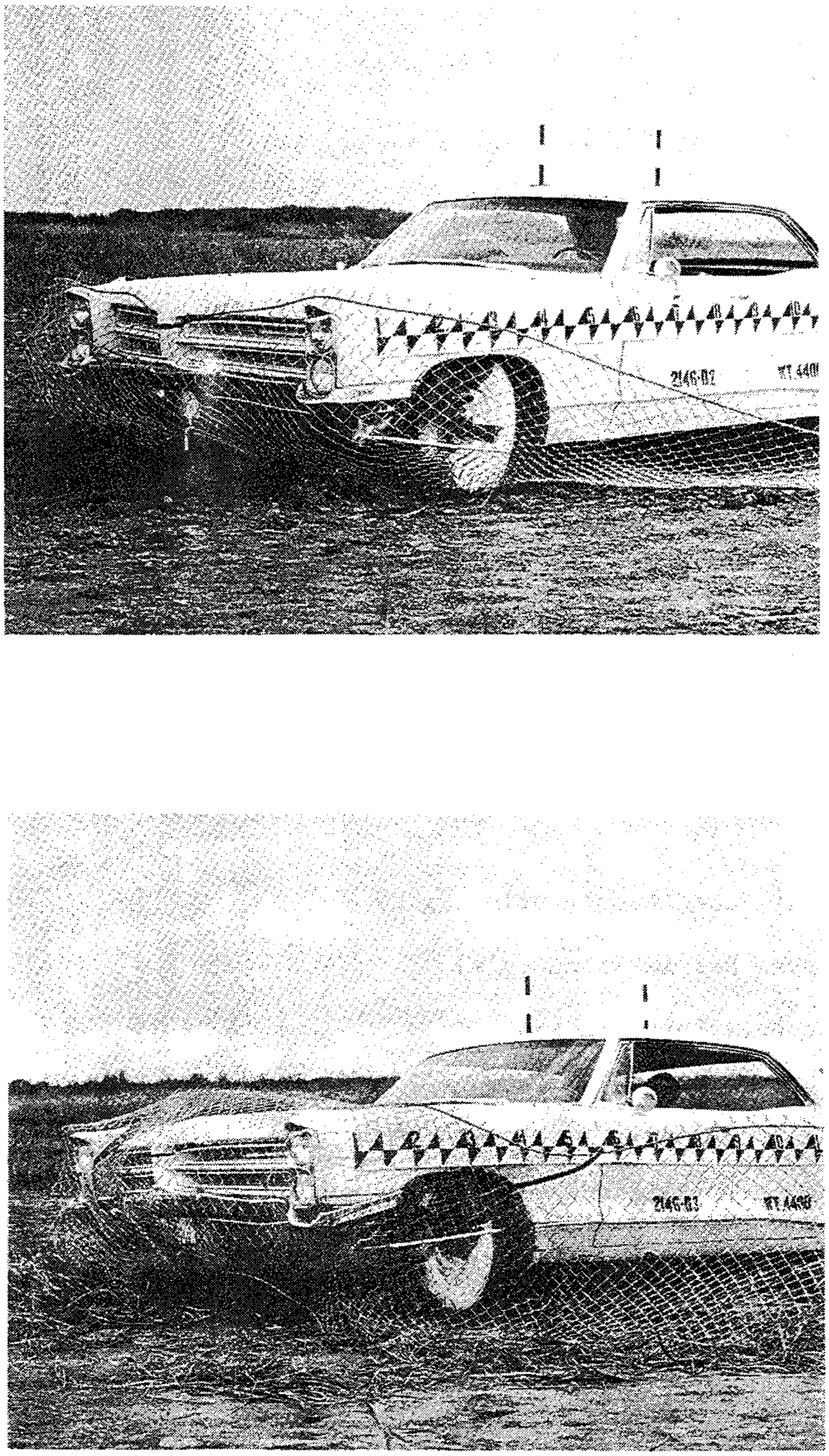


FIGURE 20. ENTRAPMENT OF VEHICLE IN TESTS D2 (TOP) AND D3 (BOTTOM). NOTE IN BOTTOM PHOTO THE BREAK AWAY POST BETWEEN THE VEHICLE AND NET.

TABLE 1 TEST DATA

Vehicle: 1965 Pontiac 4-door sedan, 4400 pounds

Test Designation	D1	D2	D3
Angle (deg)	0	0	30
Film Data			
Initial Speed (fps)	92.2	83.8	88.1
(mph)	62.9	57.1	60.1
Final Speed (fps)	80.8*	0	0
(mph)	55.1*	0	0
Maximum Forward Travel (ft)	21.1*	59.8	69.4
Time to Max. Forward Travel (sec)	0.26*	1.31	1.49
Average Deceleration (g's)≠	1.4*	2.0	1.8
Electronic Data			
Peak Longitudinal Deceleration (g's)	3.1	2.0	--**
Peak Lateral Deceleration (g's)	2.8	6.3	--**
Peak Seat Belt Force (lbs)	148	220	150
Physical Measurements			
Tape Runout (ft) Right	6.0*	39.3	52.0
Left	6.0*	36.7	34.0
Stopping Distance (ft)	N.A.	59.8	69.4

NOTE: Time-displacement data from the films, and a time-event record are included in the Appendix.

* At time metal tapes failed

** Collision with guide cable anchor masks interaction with net.

≠ $a = \frac{V_o^2 - V_f^3}{2gs}$

Discussion of Results

This particular dragnet system performed as intended after the bushings had been added to the metal benders to keep the coil of reserve tape from binding. The 4400 lb car was stopped in a straight line from approximate 60 mph with tolerable decelerations with no noticeable damage in both the head-on and 30-degree centric impacts.

The stopping distance predictions based on previously developed equations were longer than observed, assuming 4000 lb of tension from each metal bender. The stopping distance in the head-on test was 60 ft as opposed to 85 ft predicted, and in the angled test was 69 ft compared to 92 ft predicted.

From analysis of the first test, in which the system failed and allowed the vehicle to go free, an estimate of the vehicle deceleration due to vehicle-ground interaction can be made. Observing the film data over a period after the tapes broke indicates a deceleration of about 0.15 g's. Since the vehicle traveled 60 ft in Test D2 and 65 ft in Test D3, this could account for 40 and 43 Kip-ft of energy, respectively. The initial kinetic energy of the vehicle was 480 Kip-ft in the head-on test, and 530 Kip-ft in the angled test. Assuming that the energy yet unaccounted for was expended in the metal benders, the equivalent tape tensions can be computed by dividing the initial energy minus the energy lost due to rolling by the total tape pullout distance. In the head-on test, 76 ft of tape was expended, while in the 30-degree test, 86 ft was used. This gives equivalent tape tensions of 5.8 and 5.7 Kips, respectively. (In Test D3 some energy was lost in the collision with the guide cable anchor). Less than one ft per second of speed change would account for enough energy to make the two equivalent tape tensions equal at 5.8 Kips). It is concluded that in both the head-on and angled test configuration, dynamic tape tension forces of about 5.8 Kips will give accurate predictions. Friction between the bushing and core, and other dynamic effects could account for these observations. There are also other sources of discrepancies, such as stretch in the net and the assumption in the equations that the vehicle has no width, but these sources do not contribute errors of significant magnitude. Until further dynamic tests are conducted on these modified metal benders with the integral tapes and bushings, it would seem that a dynamic load factor of 1.45 would be appropriate for use on these metal benders with centerhole when estimating vehicle decelerations. For estimating vehicle stopping distance, it would be conservative to use the 4000 lb rated tape tension for these metal benders.

In Test D3, the break-away net support post seemed to permit better entrapment of the vehicle compared to Test D2. Therefore, it seems desirable to convert all posts to the breakaway type since non-centric impacts are likely in the field. These posts can be made breakaway by cutting, overlapping, and fastening with brass screws near the ground.

COST ANALYSIS

An estimated cost per installation based on data obtained in June 1972 is presented in Table 2. The figures assume that the using agency will install the system with their own personnel.

TABLE 2

ESTIMATED COST OF DRAGNET INSTALLATION

(Material prices current as of June 1972)

Initial Cost			
Metal Bender energy absorber (4000 # rated) complete with tape (150 ft)	2 ea @ $525.00	=	$1,050
Chain link fence, 11 gage, 48 in. high	50 lf @ $.60	=	30
Misc hardward, cable and posts		=	120
Labor for installation	16 hrs @ $7.50	=	120
Contingencies		=	180
Total Initial cost			$1,500
Repair after Impact			
Chain link fence		=	$ 30
2 tapes @ $170 each		=	340
Labor		=	120
Total Repair Cost		=	$ 490

Note: All material prices are subject to price increases by the manufacturer.

CONCLUSIONS

The dragnet installation using the Van Zelm metal benders as shown herein, is suitable for certain highway applications. The results of these tests show that the system may be installed in V ditch medians with slide slopes of 12:1 ratio, such as may be found in a wide median. Certain precautions are necessary to insure optimum performance of an installation. These include:

1. Bushings must be placed between the axle of the metal bender case and the tape coil so that the coil is free to turn as the tape unwinds from the metal bender. See Figure 11.

2. The posts supporting the chain link fence or other net fencing should be made breakaway (Figure 1), and the ties holding the fence to the posts should be single strand aluminum wire spaced at approximately 12 in. o.c.

3. The posts supporting the metal benders should be similar to standard guardrail posts so that they will breakaway under direct vehicle impact if their location is such that they might be struck by a vehicle.

4. Until more accurate dynamic load data are determined for this configuration of metal bender, the minimum tape length and minimum site dimensions should be determined using the rated tape force without the dynamic load factor being applied.

5. On the other hand, the average decelerations should be estimated by computing the stopping distance using a dynamic load factor of 1.45.

The redesign of the metal bender so that it may be mounted on a post is a definite improvement from an installation and maintenance point of view. However, there are apparent side effects, such as additional dynamic energy which was not absorbed in earlier configurations. Additional research is desirable to determine more precisely the dynamic force and properties of this type assembly.

References

1. Hirsch, T. J., Hayes, Gordon G., and Ivey, D. L., "Dragnet Vehicle Arresting System," Technical Memorandum 505-4, Texas Transportation Institutê, February, 1969.

2. Damon, Albert, Stoudt, Howard W., and McFarland, Ross A., "The Human Body in Equipment Design," Harvard University Press, Cambridge, Massachusetts, 1966.

3. "Dragnet, Vehicle Safety Barrier System," The Entwistle Company, Boston, Massachusetts.

APPENDIX A

Design Data

(From Reference 1)

EQUATIONS FOR ANALYSIS OF CHAIN LINK FENCE VEHICLE ARRESTING SYSTEM HEAD-ON CENTRIC VEHICLE COLLISION

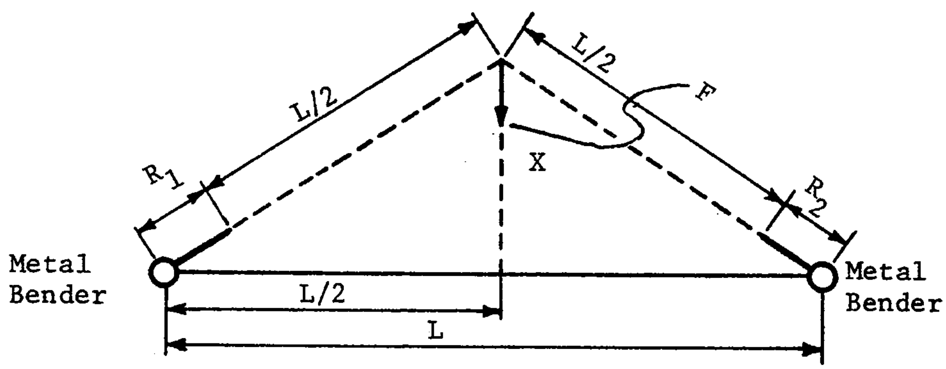


Figure A1

L = length of net, ft.

T = metal bender tape tension force, lb.

R = R_1 = R_2 = run out of metal bender tape (assuming all energy is absorbed by tape), ft.

X = travel distance of vehicle after engaging net, ft.

X_{max} = stopping distance, ft.

F = stopping force component on vehicle, lb.

W = weight of vehicle, lb.

V = initial velocity of vehicle, ft/sec.

g = acceleration due to gravity, 32.2 ft/sec^2.

Relatively simple equations will now be developed which will aid in selecting a desirable metal bending tape tension force (T) and length (R_{max}) in order to stop a given vehicle of weight (W) and speed (V).

For these tape tension forces, we can compute the minimum required length of tape (R), the stopping distance required (X_{max}), the maximum and average g forces on the vehicle as follows:

$$\text{Kinetic Energy of Vehicle} = \frac{WV^2}{2g}$$

Assuming all energy is absorbed by the metal tapes, the kinetic energy absorbed = 2TR

Due to symmetry $R = R_1 = R_2$

so

$$2TR_{max} = \frac{WV^2}{2g}$$

The maximum tape run out is then

(1) $$R_{max} = \frac{WV^2}{4Tg} \quad \text{and} \quad R_{max} = R_{1max} = R_{2max}$$

From Figure A1,

(2a) $$X = \sqrt{\left(R + \frac{L}{2}\right)^2 - \left(\frac{L}{2}\right)^2}$$

(2b) $$X_{max} = \sqrt{R_{max}^2 + R_{max} L}$$ or Where X_{max} is the stopping distance required for head-on collision.

The stopping force component on the vehicle is,

(3a) $$F = 2T \left(\frac{X}{R + \frac{L}{2}} \right)$$

(3b) $$F_{max} = 2T \left(\frac{X_{max}}{R_{max} + \frac{L}{2}} \right)$$

Maximum vehicle stopping force for head-on collision.

The maximum G force on the vehicle is,

(4) $$G_{max} = \frac{F_{max}}{W}$$

The average G force on the vehicle would be,

(5) $$G_{avg} = \frac{V^2}{2gX_{max}}$$

A graph of F vs. X would be as shown below

$$F = 2T \left(\frac{X}{R + \frac{L}{2}} \right)$$

From Equation 2,

$$R = \frac{1}{2} \sqrt{L^2 + 4X^2} - \frac{L}{2}$$

so

(6) $$F = 2T \left(\frac{1}{\sqrt{\left(\frac{L}{2X}\right)^2 + 1}} \right)$$

Table A1 has been developed as a design aid for a system being impacted at the center and at right angles for various design speeds and lengths of openings.

The preceeding analysis was based on the special case of the arresting system being impacted by a vehicle in the center and at right angles (head-on) to the chain link fence. When the vehicle impacts the system at an angle the mathematics are more complicated. This development follows.

TABLE A1

STOPPING DISTANCES AND DECELERATIONS FOR TAPE TENSIONS OF 4000 LB

Vehicle Weight lb	Velocity mph	Kinetic Energy 1-k	L=30 ft		L=40 ft		L=50 ft		L=60 ft		L=70 ft		L=80 ft	
			X_{max} ft	Gav	X_{max}	Gav	X_{max}	Gav	X_{max}	Gav	X_{max}	Gav	X_{max}	Gav
2000	30	60.1	16.8	1.8	18.9	1.6	20.2	1.5	22.5	1.3	24.1	1.2	25.6	1.2
4500	30	135.3	28.2	1.1	31.0	0.9	33.6	0.8	36.1	0.8	38.3	0.7	40.5	0.7
2000	40	106.9	24.1	2.2	26.7	2.0	29.1	1.8	31.3	1.7	33.4	1.6	35.3	1.5
4500	40	240.5	42.5	1.3	45.9	1.2	49.1	1.1	52.0	1.0	54.9	0.9	57.5	0.9
2000	50	167.0	32.6	2.5	35.6	2.3	38.5	2.2	41.1	2.0	43.6	1.9	45.9	1.8
4500	50	375.8	60.1	1.4	63.9	1.3	67.5	1.2	70.9	1.2	74.1	1.1	77.2	1.1
2000	60	240.1	42.4	2.8	45.9	2.6	49.0	2.5	52.0	2.3	54.8	2.2	57.5	2.1
4500	60	541.1	81.3	1.5	85.3	1.4	89.2	1.3	92.9	1.3	96.5	1.2	99.9	1.2
2000	70	327.3	53.9	3.0	57.5	2.8	61.0	2.7	64.3	2.5	67.4	2.4	70.3	2.3
4500	70	736.6	106.0	1.5	110.3	1.5	114.4	1.4	118.3	1.4	122.2	1.3	125.9	1.3
2000	80	426.9	66.7	3.2	70.6	3.0	74.3	2.9	77.8	2.7	81.1	2.6	84.4	2.5
4500	80	962.0	134.4	1.6	138.8	1.5	143.1	1.5	147.2	1.5	151.3	1.4	155.2	1.4

Idealized analysis of **Chain Link Fence Vehicle Arresting** System for centric vehicle collisions at any angle Θ.

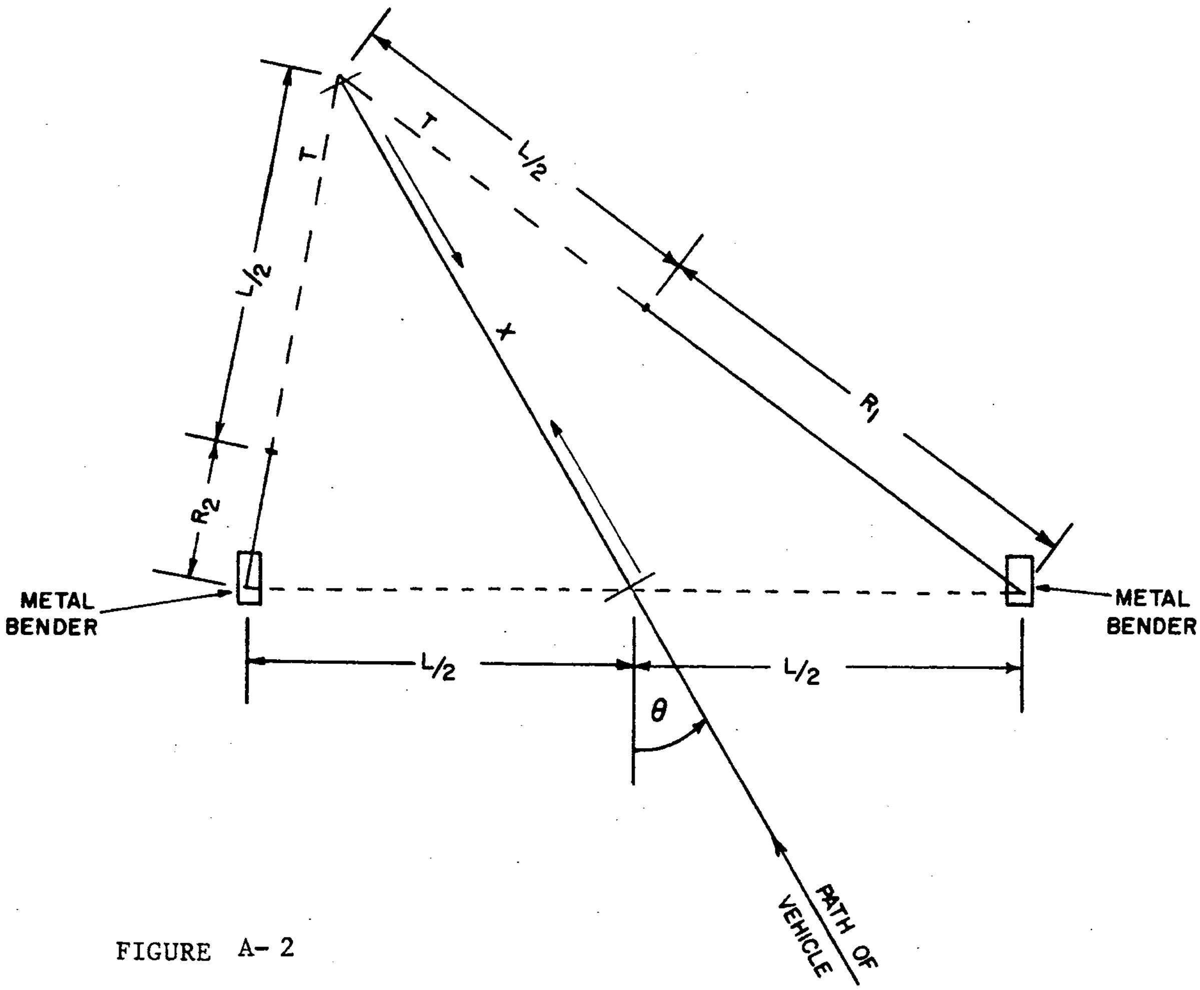


FIGURE A- 2

L = Initial length of net <u>and</u> tape between Metal Benders, ft.

T = Metal Bender tape tension, Kip.

R_1 and R_2 = Metal Bender tape runouts, ft.

X = Travel of vehicle along original path after contacting the net, ft.

Xmax = Stopping distance after contacting net, ft.

F_x = Stopping force componet along X, Kip.

W = Weight of vehicle, Kip.

V = Speed of vehicle at impact, ft/sec.

g = Acceleration due to gravity, 32.2 ft/sec^2.

θ = Impact angle, degrees.

Note: It is assumed that $R_2 = 0$ for $X \leq L \sin \theta$. (Derived from Law of Sines.)

Referring to Figure A2, the Pythagorean Theorem gives:

$$\left(R_1 + \frac{L}{2}\right)^2 = \left(\frac{L}{2} + X\sin\theta\right)^2 + \left(X\cos\theta\right)^2$$

This reduces to:

$$R_1 = \left(\frac{L^2}{4} + X^2 + LX\sin\theta\right)^{1/2} - \frac{L}{2} \tag{7}$$

Similarly,

$$R_2 = \left(\frac{L^2}{4} + X^2 - LX\sin\theta\right)^{1/2} - \frac{L}{2} \qquad \text{(for } X > L\sin\theta\text{)} \tag{8}$$

$$R_2 = 0 \qquad \text{(for } X \leq L\sin\theta\text{)}$$

Equations 7 and 8 can be solved for X in terms of R_1 or R_2:

$$X = \left(\frac{L^2}{4}\sin^2\theta + R_1{}^2 + LR_1\right)^{1/2} - \frac{L}{2}\sin\theta \tag{9}$$

or

$$X = \left(\frac{L^2}{4}\sin^2\theta + R_2{}^2 + LR_2\right)^{1/2} + \frac{L}{2}\sin\theta \qquad \text{(for } X > L\sin\theta\text{)}$$

The vehicle kinetic energy is related to the theoretical total strap pullout by:

$$KE = \frac{WV^2}{2g} = T\,(R_{1_{max}} + R_{2_{max}}) \qquad \text{(when } \theta \text{ not equal to zero)} \tag{10}$$

The component of Metal Bender stopping force along X due to R_1 is:

$$(11) \qquad F_{R_1} = T\left(\frac{X + \frac{L}{2}\sin\theta}{R_1 + \frac{L}{2}}\right) = T\left(\frac{X + \frac{L}{2}\sin\theta}{\sqrt{\frac{L^2}{4} + X^2 + L X \sin\theta}}\right)$$

Similarly,

$$(12) \qquad F_{R_2} = T\left(\frac{X - \frac{L}{2}\sin\theta}{R_2 + \frac{L}{2}}\right) = T\left(\frac{X - \frac{L}{2}\sin\theta}{\sqrt{\frac{L^2}{4} + X^2 - L X \sin\theta}}\right)$$

The total stopping force along X is: (for $X > L \sin\theta$),

$$(13) \qquad F_T = F_{R_1} + F_{R_2} = T\left(\frac{X + \frac{L}{2}\sin\theta}{\sqrt{\frac{L^2}{4} + X^2 + LX\sin\theta}} + \frac{X - \frac{L}{2}\sin\theta}{\sqrt{\frac{L^2}{4} + X^2 - LX\sin\theta}}\right)$$

$$(14) \qquad F_T = F_{R_1} = T\left(\frac{X + \frac{L}{2}\sin\theta}{\sqrt{\frac{L^2}{4} + X^2 + L X \sin\theta}}\right) \qquad \text{(for } X \leqslant L \sin\theta\text{)}$$

If all the vehicle's kinetic energy is absorbed by the Metal Bender tape pullout, then

$$KE = \frac{WV^2}{2g} = \int_0^{X_{max}} F_T \, dx$$

$$= T\int_0^{X_{max}} \left(\frac{X + \frac{L}{2}\sin\theta}{\sqrt{\frac{L^2}{4} + X^2 + L X \sin\theta}}\right) dx + T\int_{L\sin\theta}^{X_{max}} \left(\frac{X - \frac{L}{2}\sin\theta}{\sqrt{\frac{L^2}{4} + X^2 - L X \sin\theta}}\right) dx$$

(for $X > L \sin\theta$)

Let $\left(\frac{L^2}{4} + X^2 + L\,X\sin\theta\right) = u$, and $\left(\frac{L^2}{4} + X^2 - L\,X\sin\theta\right) = v$

Then $du = (2X + L\sin\theta)dx$, and $dv = (2X - L\sin\theta)dx$

Therefore,

$$KE = \frac{WV^2}{2g} = \frac{T}{2}\int_{u_i}^{u_f} u^{-1/2}\,du + \frac{T}{2}\int_{v_i}^{v_f} v^{-1/2}\,dv$$

$$= \frac{T}{2}\left(2u^{1/2} + 2v^{1/2}\right)_{\text{initial}}^{\text{final}}$$

$$= T\left(\sqrt{\frac{L^2}{4} + X^2 + L\,X\sin\theta}\,\Bigg|_0^{X_{max}} + \sqrt{\frac{L^2}{4} + X^2 - L\,X\sin\theta}\,\Bigg|_{L\sin\theta}^{X_{max}}\right)$$

$$= T\left(\sqrt{\frac{L^2}{4} + X_{max}^2 + L\,X_{max}\sin\theta} + \sqrt{\frac{L^2}{4} + X_{max}^2 - L\,X_{max}\sin\theta} - \frac{L}{2} - \frac{L}{2}\right)$$

Or,

(15) $$KE = \frac{WV^2}{2g} = T\left(\sqrt{\frac{L^2}{4} + X_{max}^2 + L\,X_{max}\sin\theta} + \sqrt{\frac{L^2}{4} + X_{max}^2 - L\,X_{max}\sin\theta} - L\right)$$

(for $X_{max} > L\sin\theta$)

(16) $$\frac{WV^2}{2g} = T\left(\sqrt{\frac{L^2}{4} + X_{max}^2 + L\,X_{max}\sin\theta} - \frac{L}{2}\right)$$

(for $X_{max} \leqslant L\sin\theta$)

Note that the expression for total energy obtained by integration of $F_T dx$ (Equation 15) is equal to $T(R_1 + R_2)$ using Equations 7 and 8.

APPENDIX B

Metal Bender - Net Connection Details

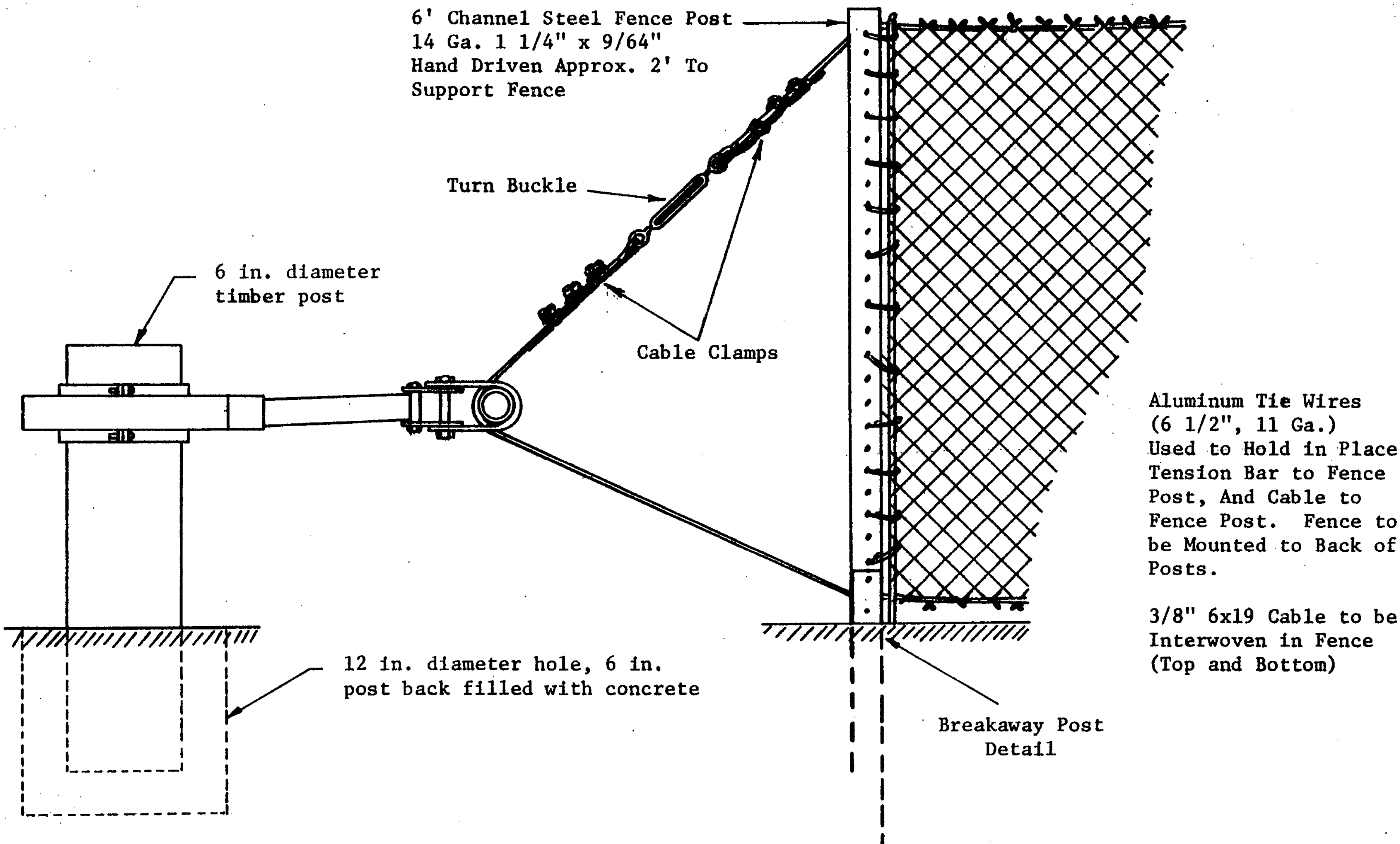


FIGURE B-1 METAL BENDER - NET TRANSITION

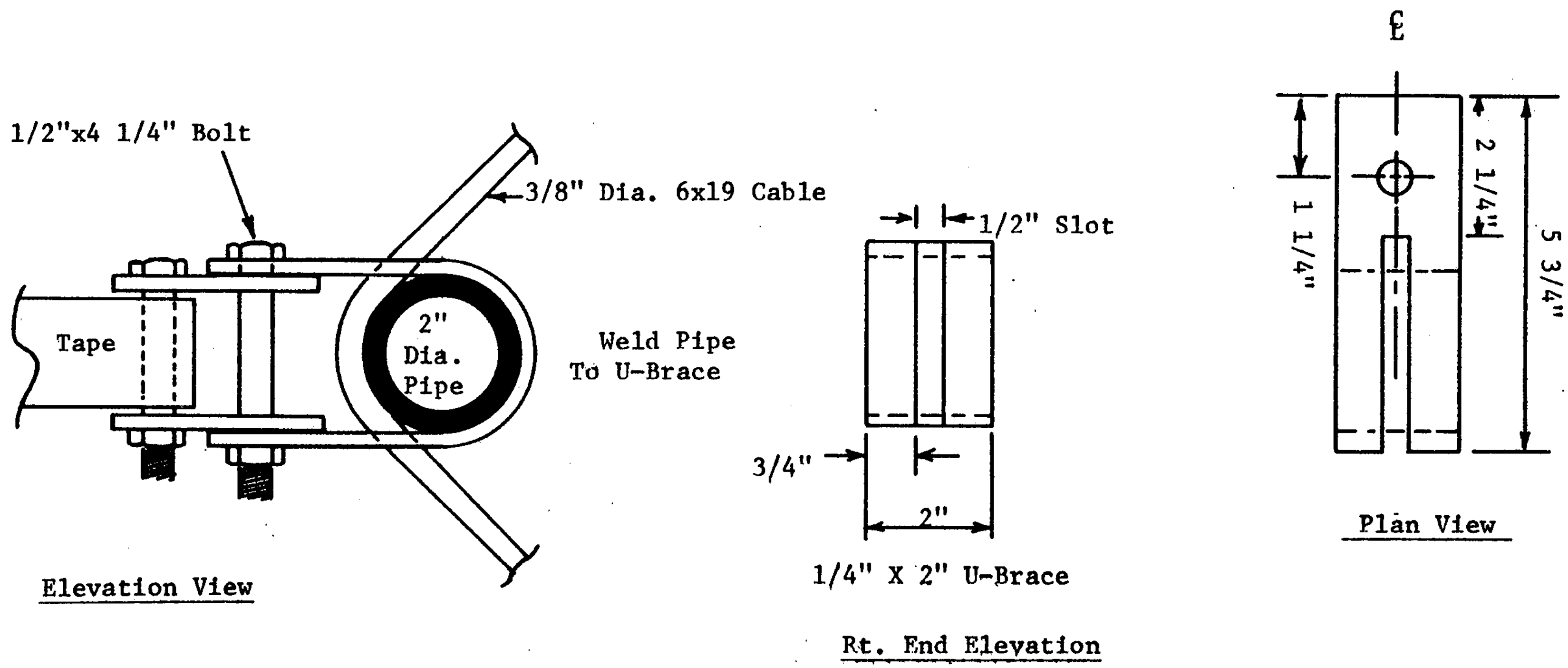


FIGURE B-2 DETAIL OF CONNECTION FROM TAPE TO NET CABLES

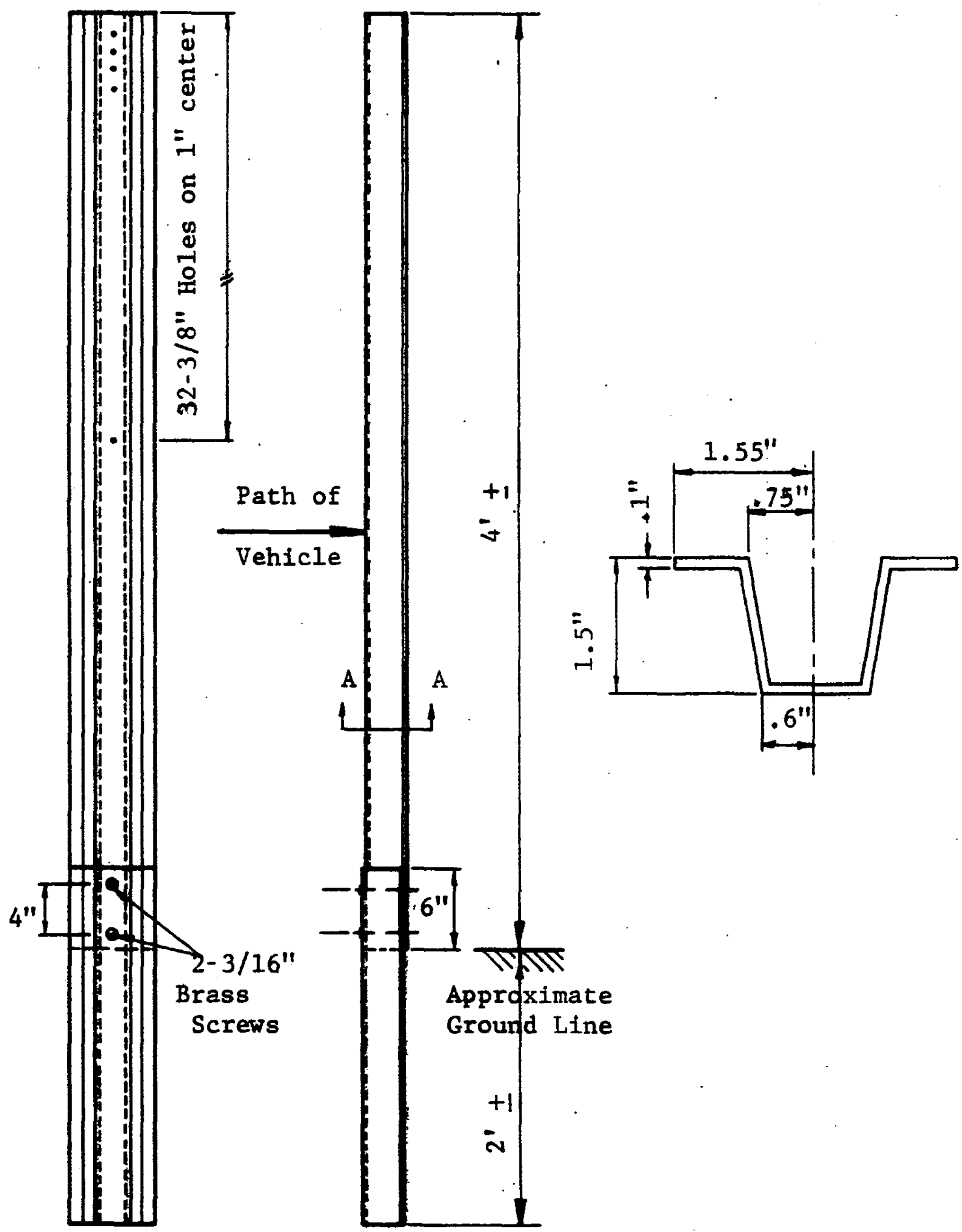


FIGURE B-3 - DETAIL OF BREAKAWAY DELINEATOR POST

APPENDIX C

Time-Displacement Data from High Speed Films

TABLE C-1

TEST 2146 D-1

DATA FROM HIGH SPEED FILM

	TIME (sec)	DISPLACEMENT (ft)	
	-0.064	-5.90	
	-0.054	-4.95	
	-0.044	-4.00	
V_i =	-0.034	-3.18	
92.2 fps or	-0.025	-2.35	
62.9 mph	-0.015	-1.35	
	-0.010	-0.94	
	-0.005	-0.50	
	0	0	Impact
	0.025	2.23	
	0.050	4.37	
	0.101	8.67	
	0.151	12.81	
	0.201	16.95	
	0.251	21.08	Tapes on both sides break
V_f =	0.259	21.69	
80.8 fps or	0.302	25.11	
55.1 mph	0.352	29.15	
	0.427	35.30	
	0.503	41.34	
	0.578	47.38	

TABLE C-1 (cont'd)

TIME (sec)	DISPLACEMENT (ft)
0.653	52.93
0.729	58.57
0.804	64.31
0.879	70.71
0.955	76.09
	Out of View

TABLE C-2

TEST 2146 D-2

DATA FROM HIGH SPEED FILM

V_i = 83.8 fps or 57.1 mph

TIME (sec)	DISPLACEMENT (ft)	
-0.066	-5.53	
-0.059	-5.04	
-0.052	-4.36	
-0.044	-3.69	
-0.037	-3.13	
-0.030	-2.65	
-0.023	-1.99	
-0.016	-1.32	
-0.008	-0.63	
0	0	Impact
0.012	0.95	
0.025	2.22	
0.037	3.13	
0.050	4.14	
0.062	5.34	
0.087	7.46	
0.111	9.51	
0.136	11.50	
0.160	13.57	

TABLE C-2 (cont'd)

TIME (sec)	DISPLACEMENT (ft)
0.185	15.48
0.210	17.72
0.234	19.46
0.259	21.19
0.283	23.12
0.308	24.89
0.332	26.64
0.357	28.43
0.381	30.16
0.406	31.64
0.430	33.15
0.454	34.33
0.479	36.12
0.503	37.45
0.528	38.25
0.552	39.67
0.576	42.01
0.601	42.92
0.625	43.18
0.650	44.39
0.674	45.90
0.698	47.52
0.722	49.10
0.746	49.55
0.771	49.66
0.795	50.56

TABLE C-2 (cont'd)

TIME (sec)	DISPLACEMENT (ft)	
0.831	51.98	
0.867	53.25	
0.903	54.32	
0.939	55.25	
0.975	56.34	
1.011	56.97	
1.047	57.69	
1.083	58.23	
1.119	58.72	
1.168	59.13	
1.216	59.46	
1.265	59.66	
1.313	59.81	Maximum Penetration
1.362	59.77	
1.410	59.50	
1.459	59.52	
1.507	59.31	
1.556	59.12	
1.604	59.10	
1.653	59.01	
1.701	58.83	Vehicle Stopped

TABLE C-3

TEST 2146 D-3

DATA FROM HIGH SPEED FILM

	TIME (sec)	DISPLACEMENT (ft)	
	-0.141	-12.39	
	-0.133	-11.88	
	-0.126	-11.13	
	-0.119	-10.47	
	-0.112	-9.88	
	-0.104	-9.20	
	-0.097	-8.52	
	-0.090	-8.00	
	-0.083	-7.21	
	-0.075	-6.73	
V_i = 88.1 fps or 60.1 mph (for -0.066 to -0.005)	-0.066	-5.82	Left Front Bumper Hits Cable Post
	-0.063	-5.56	
	-0.056	-4.95	
	-0.049	-4.31	
	-0.041	-3.65	
	-0.034	-2.94	
	-0.027	-2.36	
	-0.019	-1.61	
	-0.012	-1.08	
	-0.005	-0.46	
	0	0	Impact

TABLE C-3 (cont'd)

TIME (sec)	DISPLACEMENT (ft)
0.015	1.47
0.029	2.58
0.044	3.89
0.059	5.18
0.074	6.49
0.088	7.69
0.103	8.94
0.118	10.21
0.132	11.50
0.147	12.65
0.162	13.74
0.176	15.17
0.201	16.86
0.225	18.96
0.250	20.87
0.275	22.86
0.299	24.89
0.324	26.65
0.395	31.88
0.420	33.63
0.444	35.34
0.468	37.03
0.493	38.62
0.517	40.34
0.541	41.61
0.566	43.03

TABLE C-3 (cont'd)

TIME (sec)	DISPLACEMENT (ft)	
0.590	44.48	
0.615	45.81	
0.639	47.07	
0.663	48.26	
0.688	49.50	
0.712	50.84	
0.761	53.08	
0.785	54.20	
0.810	55.29	
0.834	56.29	
0.859	57.28	
0.883	58.21	
0.907	59.13	
0.932	60.01	
0.956	60.84	
1.005	62.32	
1.054	63.79	
1.102	64.92	
1.176	66.50	
1.249	67.60	
1.322	68.41	
1.395	69.08	
1.468	69.36	
1.493	69.44	Maximum Penetration
1.517	69.20	Vehicle Stopped

APPENDIX D

Time-Event Record From High Speed Films

TABLE D-1

TEST 2146 D-1

TABLE OF EVENTS

Event	Time (sec)
Flash (car first enters ditch)	-0.726
Car heading down ditch towards dragnet, front end lower than back, pitch of vehicle 5°[(a)]	-0.441
Pitch of vehicle 3°[(a)]	-0.270
Dummy is leaning against back of seat, vehicle pitch 2°[(a)]	-0.127
Car first impacts dragnet	0
Front end of car bending fence post and fencing	0.017
Fencing bent around front hood, dummy still leaning back	0.044
Fencing pulling away from posts	0.071
Car a little more than halfway past original position of posts	0.083
Dummy still leaning back in seat, fence bent around bumper and hood	0.171
Car completely past posts	0.243
Tape breaks on right side of dragnet	0.248
Tape breaks on left side of dragnet	0.251
Car going down ditch with fencing wrapped around it	0.415
Dummy still leaning back	0.565

TABLE D-1 (cont'd)

Event	Time (sec)
Dummy leaning forward, fencing has gone further up around car	0.681
Dummy leaning further forward, Vehicle goes out of view	0.867

****

(a)

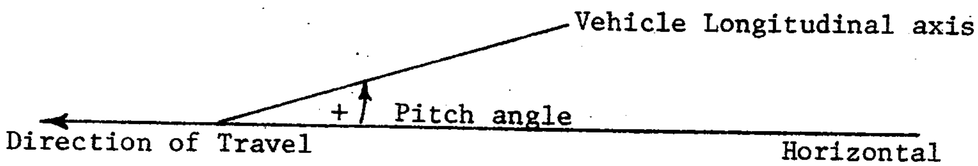


TABLE D-2

TEST 2146 D-2

TABLE OF EVENTS

Event	Time (sec)
Car first enters ditch	-0.813
Car heading down ditch towards dragnet, dummy leaning back	-0.598
Car still heading down ditch, vehicle pitch 3.7°	-0.402
Dummy still leaning back	-0.196
Impact, vehicle pitch, -0.3°	0
Center post of dragnet bending	0.010
Fencing has encircled car front, not much tape (if any) pulled out yet	0.050
Fencing has pulled away from posts on vehicle's left; tape probably starting to come out now	0.091
Car is past original position of fence posts	0.185
Dummy hits steering wheel	0.222
Left front wheel has stopped moving, vehicle pitch 3°	0.296
End of forward motion	1.313
Vehicle stopped	1.701

TABLE D-3

TEST 2146 D-3

TABLE OF EVENTS

Event	Time (sec)
Dummy is leaning back against seat	-0.718
Car still heading down ditch with dummy leaning against seat	-0.337
Car seems to be rolling to its left	-0.211
Car leaning farther to left	-0.112
Left front bumper hits guide post	-0.066
Impact, pitch, 3.3°	0
Fencing surrounding front end of car, front end rising	0.066
Car now rolling to its right, dummy is also falling to his right	0.137
Car rolling back towards the left, dummy now falling forward	0.298
Dummy might hit steering wheel here	0.526
Car levels out	0.819
Forward motion ceases	1.493
Vehicle stopped	1.517