TECHNICAL MEMORANDUM 505-4

Texas Transportation Institute
Texas A&M Research Foundation

DRAGNET VEHICLE ARRESTING SYSTEM

A Tentative Progress Memorandum on Contract No. CPR-11-5851

U. S. Department of Transportation
Federal Highway Administration
Bureau of Public Roads

by

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Crash tests and evaluations were conducted under the Office of Research and Development, Structures and Applied Mechanics Division's, Research Program on Structural Systems in Support of Highway Safety (4S Program). The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the Bureau of Public Roads.

Note: For the reader who is interested in gaining a general idea of the value of this particular arresting system and not in the details necessary to document the technical aspects of this study, the authors recommend reading pages 2 and 5 and scanning the photographs in this report.

February 28, 1969

INTRODUCTION

Six crash tests of a "dragnet" vehicle arresting system were conducted by the Texas Transportation Institute under a contract with the Bureau of Public Roads as part of their program on Structural Systems in Support of Highway Safety. This "dragnet" system uses Metal Bender energy absorbing devices developed by Van Zelm Associates, Inc., of 1475 Elmwood Avenue, Providence, Rhode Island. Descriptions include photographs of the vehicle and arresting system before, during and after each individual test.

DESCRIPTION OF ARRESTING SYSTEM

This system consists of a net made of steel cables attached at each end to Metal Bender energy absorbing devices as shown in Figure A1. The Metal Benders, which are supported on rigid steel posts, are steel boxes containing a series of rollers around which the metal tape is bent back and forth as it is pulled through the case. Each end of the net is attached to one end of the metal tape extending from a Metal Bender. The Metal Benders are designed so that a specified force will be necessary to pull the metal tape through the case. This force is relatively independent of velocity and environmental conditions and depends on the size of the tape used. By varying tape size a number of different tape forces are available.

Supplementary construction and installation data on this system were provided by Van Zelm Associates, Inc.* and are presented in Appendix A. Photographs of the arresting system used in these tests are shown in Figures 2 and 3.

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* Jackson, M. and Montanaro, L., "Arresting System for Snagging a Vehicle Leaving the Roadway Near Fixed Highway Obstacles," Van Zelm Associates, Inc., A Division of Entwistle Mfg. Corp., May 8, 1967.

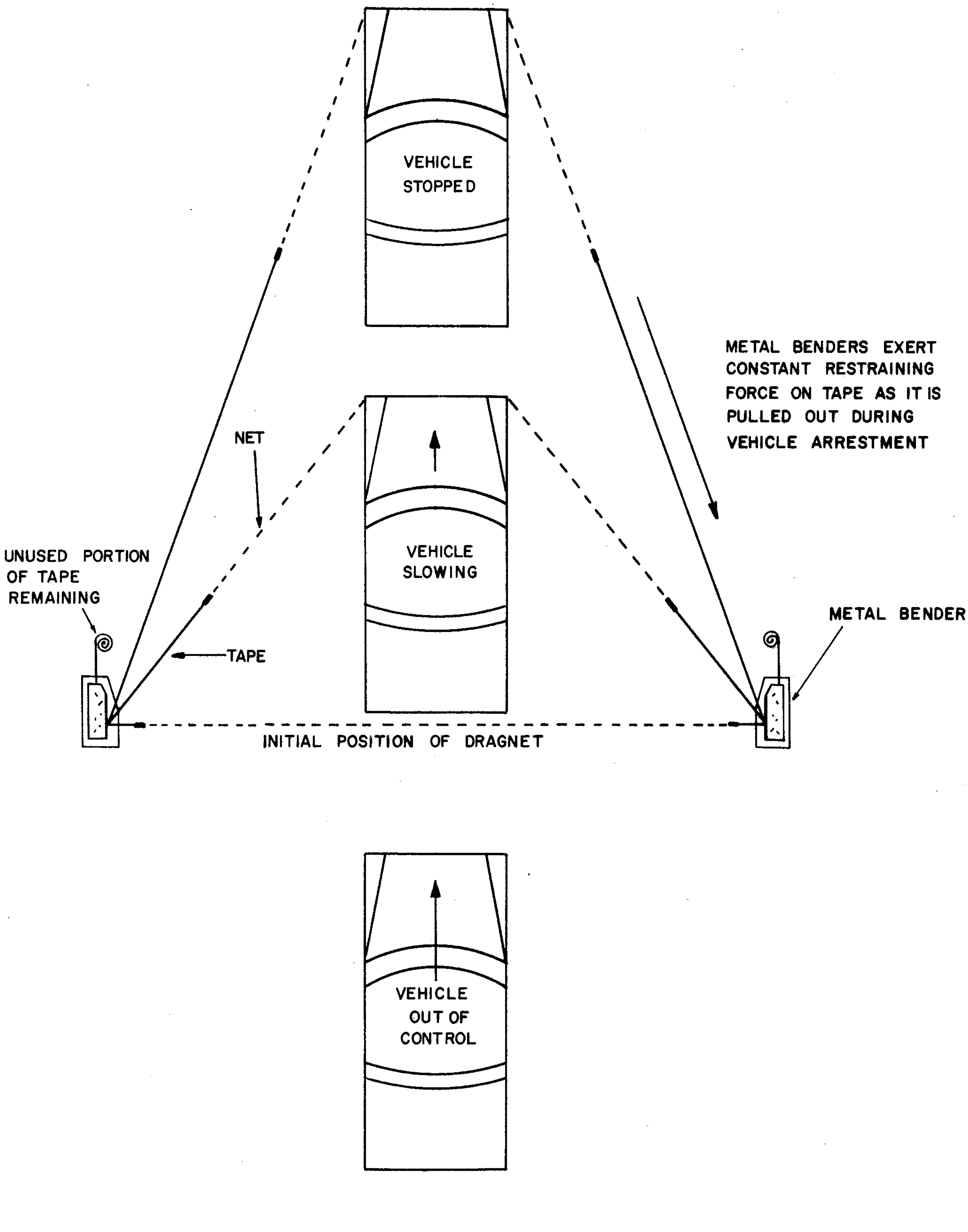


FIGURE 1, IDEALIZED FUNCTION OF DRAGNET ARRESTING SYSTEM

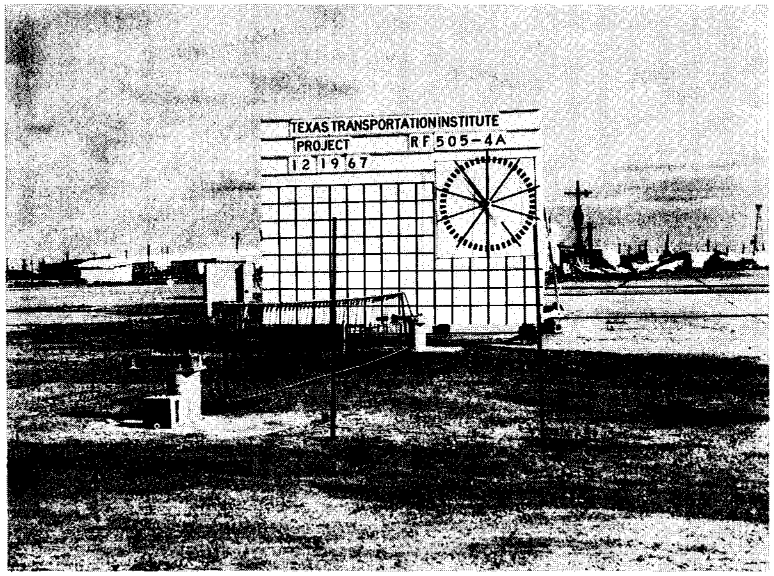


Figure 2, Dragnet Arresting System
Before Test 505-4A.

Figure 3, Metal Bender with 25,000 lb. Tape
Attached to Net.

CONCLUSIONS

The Van Zelm dragnet vehicle arresting system performed basically as designed in all tests. The performance of the system was very good in four of the six tests. In Test 4D the dragnet was engaged too low on the front of the vehicle, which resulted in the vehicle's rear end vaulting the net after most of the longitudinal deceleration had occurred. In Test 4F the performance of the dragnet system was ideal until one of the tapes ran out. Had this tape been long enough to continue applying load until the vehicle was completely stopped, the performance probably would have been excellent. Deceleration levels were reduced to a small fraction of those which would be expected in rigid barrier impacts. Increasing design tape load results in shortening the stopping distance, increasing the deceleration level and increasing vehicle damage. For any given application of the dragnet system, the longer the allowable stopping distance, the more desirable are the deceleration characteristics of the system because a smaller tape load can be used.

The height of the net was shown to be an important factor in the performance of the system. The net should be positioned so that it completely entraps the front of the entering vehicle. If it is too low, a less desirable performance may be expected, as was found in Test 4D. Good performance was found when the lower main cable of the net was positioned four inches above the ground.

No permanent damage was sustained by the dragnet system during any of these tests. All major components were reusable except for the expendable metal tapes. The system can be applied to a variety of situations by varying the Metal Bender tape tension, the tape length, and the geometry of the installation. A variety of Metal Bender tape tensions are available, some of which are given in Appendix A.

This series of tests has shown that reasonably accurate predictions of vehicle stopping distance and deceleration levels can be obtained using the equations developed in Appendix B.

RECOMMENDATIONS

The "dragnet" vehicle arresting system is an effective, practical, and economical system for safely stopping vehicles which are out of control at certain highway sites. Some obvious sites for its employment are:

1. Protecting highway medians at bridge overpasses,
2. As a barrier at "dead ends" of highways or roads,
3. As a "dead-end" barrier at ferry landings or as a barrier to close off entrance and exit ramps of freeways,
4. As a barrier to protect certain rigid obstacles in highway rights-of-way.

It is recommended that the height of the arresting net be increased to approximately 4 ft. The net used in the tests was 3 ft. high, and in several tests (notably Test 4D) failed to completely entrap the vehicle's front end. It is desirable that the upper net cable clear the top of the car hood in order to more securely entrap the vehicle.

The lowest Metal Bender tension force which is compatible with the available stopping distance should be selected. In general, Metal Bender tension forces of 12,500 lb. or less are recommended. The behavior of these "dragnet" systems can be predicted very well with the mathematical analysis presented in Appendix B.

It is the opinion of the authors that with Metal Bender tension forces of 8,000 lbs. or less, acceptable stopping characteristics would be achieved with the Metal Benders mounted flush with the ground, thus removing the hazard of the protruding anchor post or pier. Metal Benders of 4,000 lbs. or less can be mounted on single 6 to 8 inch diameter timber posts embedded 3 ft. or more in the ground unless the ground is extremely soft. The top of the timber post should not extend over 20 inches above the ground. These single timber posts would normally not be a significant hazard if struck by a vehicle.

TEST PROGRAM

Six vehicle crash tests of the "dragnet" arresting system were conducted during the period of December 19, 1967 to November 21, 1968. A summary of this testing program is given by Table 1. Both compact and full-size vehicles were directed into the system. Tests 4A through 4D employed Metal Benders with 25,000 pound tape loads. These tape loads were reduced to 12,500 pounds for Tests 4E and 4F.

Each test was recorded using high-speed motion picture cameras. This film was analyzed to give detailed time-displacement data. Lower speed motion picture cameras were placed at selected points to provide a qualitative record of the test in progress. Still photographs of the vehicle before and after each test and photographs of various details of the arresting system were obtained.

Accelerometer transducers were attached to the frames of the vehicles to determine deceleration levels during each test. Deceleration traces are presented in Appendix C. Maximum decelerations under specified filtering techniques were determined from these accelerometer traces, while average decelerations were calculated on the basis of initial speed and stopping distance.

An Alderson articulated anthropometric dummy weighing 161 pounds was used to simulate a human driver in each test. A seat belt securing the dummy was equipped with strain guages which permitted the measurement of seat belt force. Variation in this seat belt force during the progress of each test is presented in Appendix C.

TABLE 1

Summary of Test Program

On Van Zelm "Dragnet" Arresting System

Test No.	4A	4B	4C	4D	4E	4F
Angle of Attack	Head-On	Head-On	30^{o}	30^{o}	Head-On	30^{o}
Tape Arresting Load (Kips)	25.0	25.0	25.0	25.0	12.5	12.5
Vehicle Weight (lbs.)	1460	4300	1620	4520	3760	3880
Vehicle Speed (mph) (fps)	42 61.8	60 87.4	48 69.7	54 78.7	56 82.6	62 91.9
Vehicle Kinetic Energy (Kip-ft)	87.1	513.	123.	437.	401.	512.

TEST 4A

A Renault Dauphine weighing 1460 pounds was directed head-on into the dragnet at a speed of 42 mph. The tape force for each Metal Bender was 25,000 pounds. All components of the system performed as designed and the vehicle was stopped after penetrating 10.2 feet. Stopping distance is defined as the distance the center of gravity of the vehicle travels after the car contacts the net. The Metal Bender strap pullout accounted for 63% of the vehicle's initial kinetic energy of 87.1 kip-ft. The remaining energy was expended in stretching the net, crushing the vehicle (see Figure 5), and increasing the vehicle's potential energy due to raising the center of gravity. The amount expended in increasing gravitational potential energy was only about one kip-ft.

The damage to the front of the vehicle was severe. The maximum longitudinal deceleration, shown in Figure C1, was 16 g's. The average deceleration was 5.8 g's over .25 seconds.

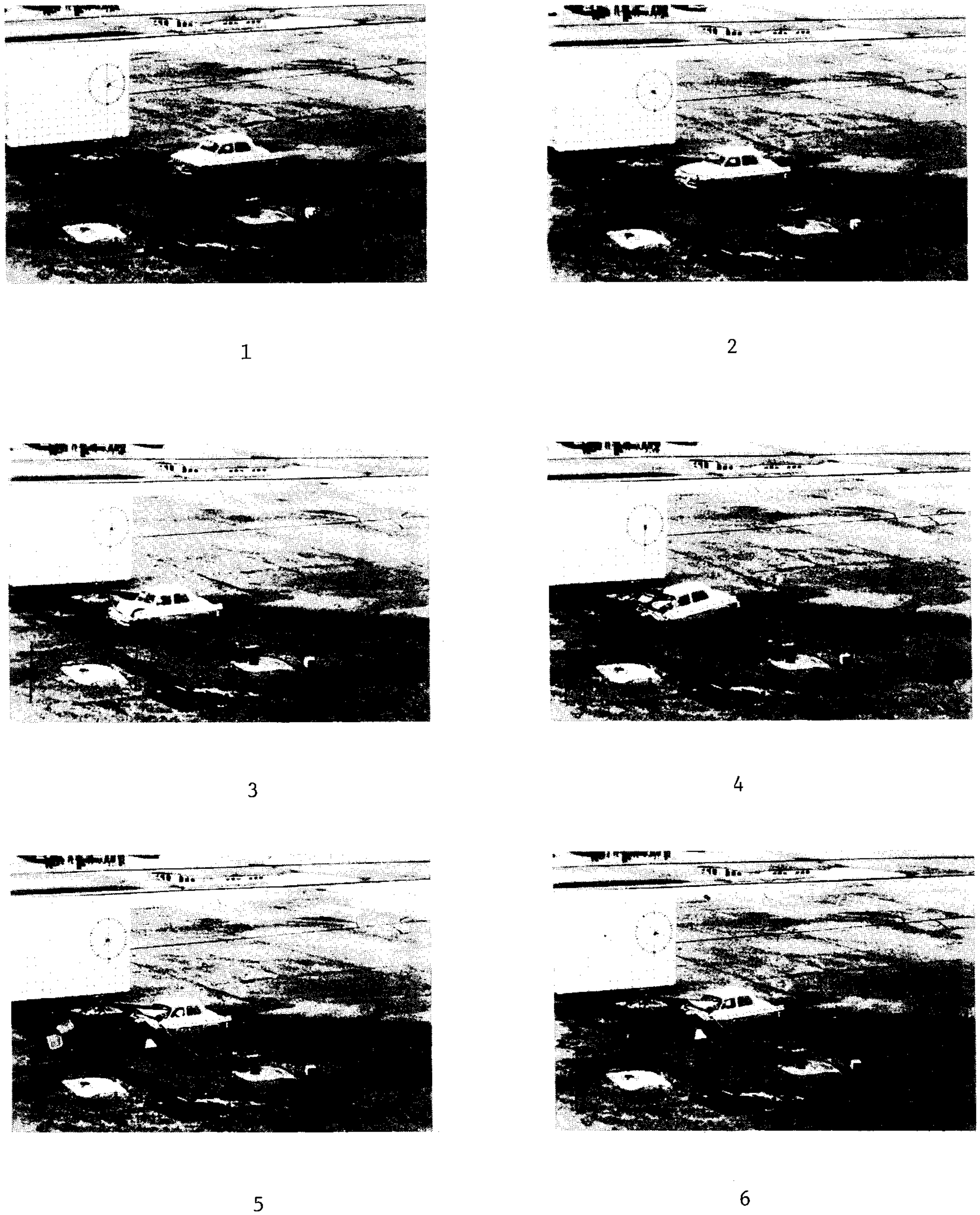


Figure 4, Sequential Photographs of Test 505-4A

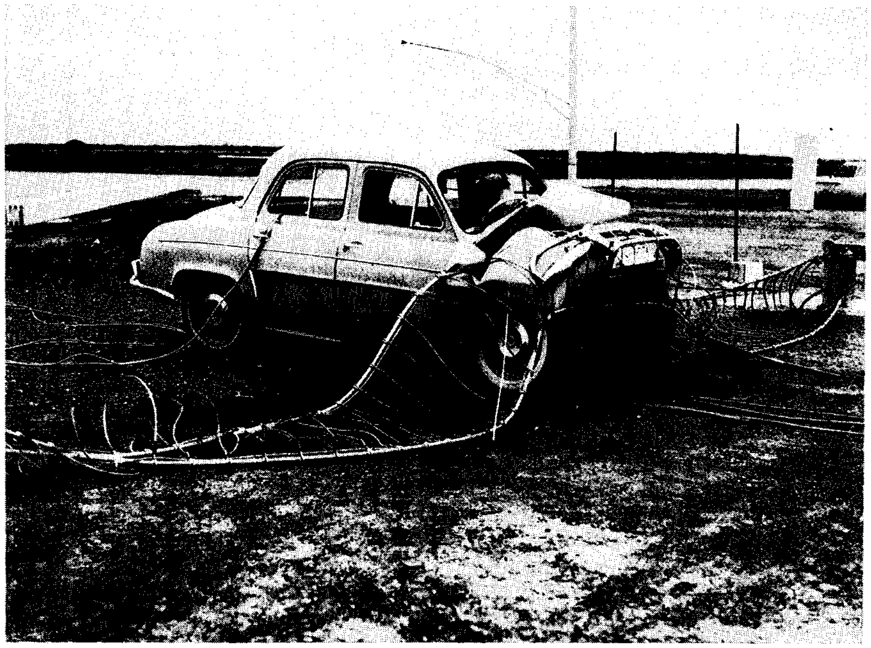


Figure 5, Vehicle and Dragnet after Test 505-4A.

TEST 4B

A 4300 pound Mercury sedan traveling 60 mph was directed head-on into the arresting system. The dragnet, which was equipped with 25,000 pound tape tension Metal Benders performed as designed. The vehicle was brought to a stop in 19.4 feet and tape pullout expended 58% of the vehicle's energy. The front of the vehicle was pulled down to the ground which caused some frictional energy losses. The change in potential energy due to the elevation of the center of gravity was estimated to be about 17 kip-ft, or 3.3% of the initial energy.

The damage to the front of the vehicle, shown in Figure 9, includes a downward bending of the front of the vehicle's frame. This was due to the net applying pressure to the lower portion of the vehicle's front end. The maximum significant deceleration, shown by Figure C3, was 16 g's, and the average deceleration was 6.1 g's.

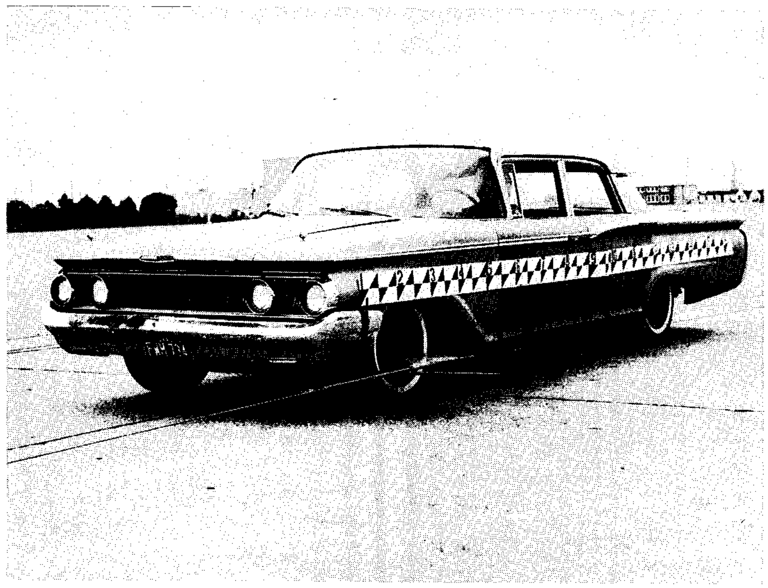


Figure 6 , Vehicle Before Test 505-4B.

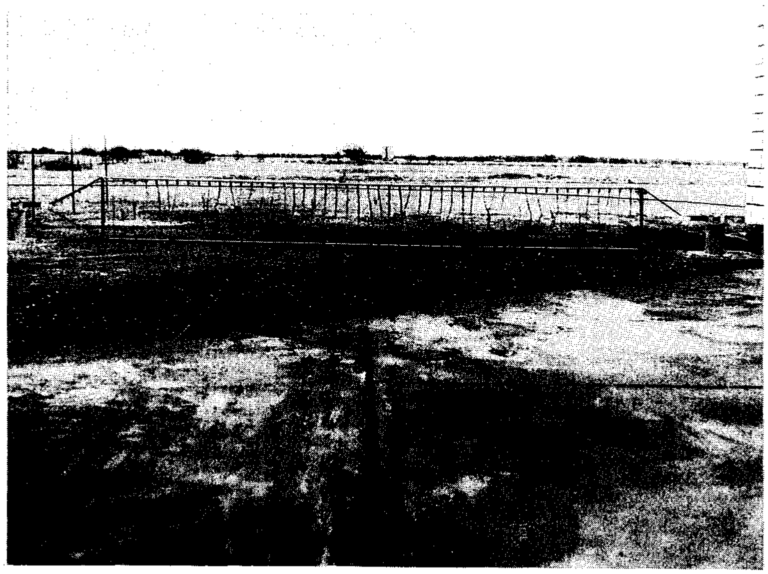
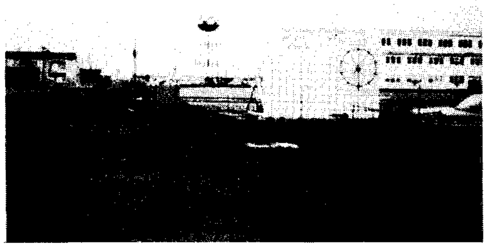


Figure 7 , Arresting System Before Test 505-4B.
(Looking Along Path of Vehicle)



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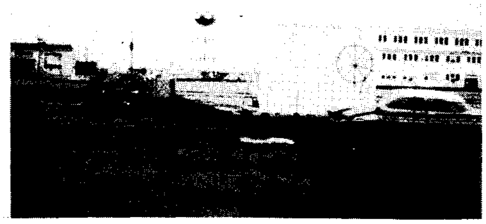

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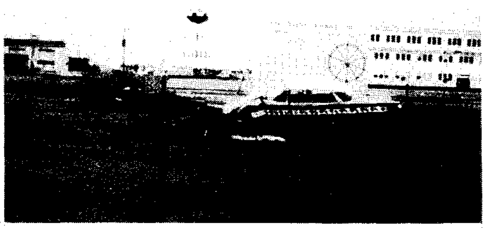

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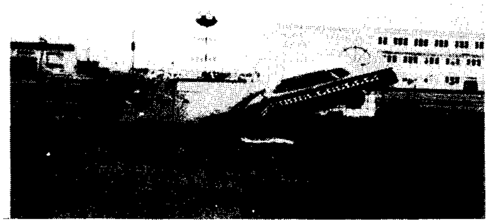

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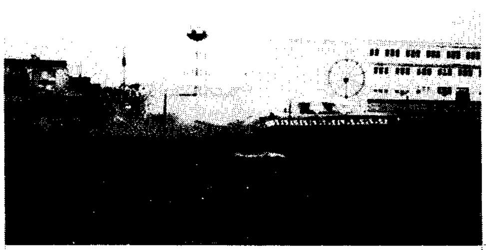

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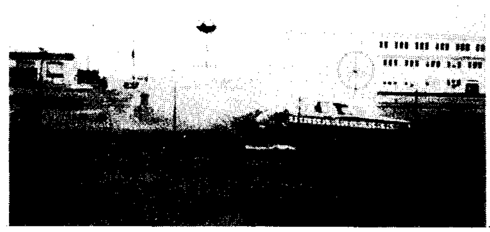

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Figure 8, Sequential Photographs of Test 505-4B.

Figure 9 , Vehicle After Test 505-4B.

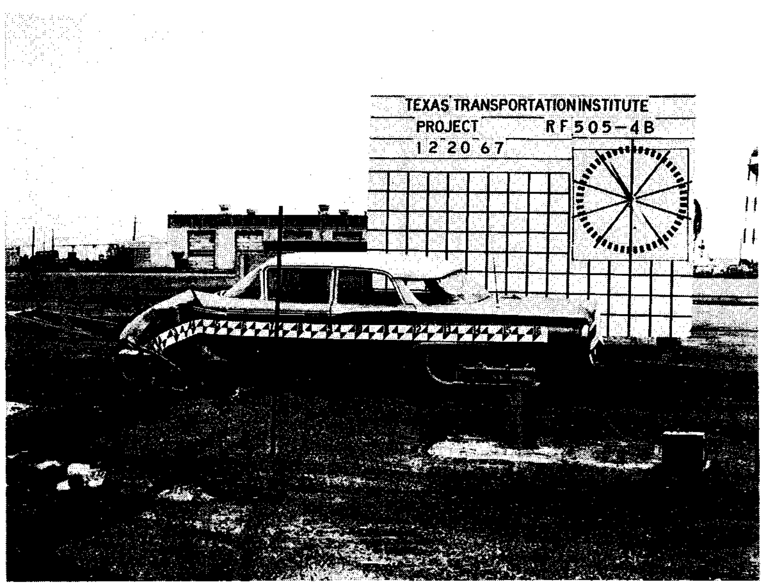


Figure 10, Vehicle and Left Metal Bender
After Test 505-4B.

TEST 4C

A 1620 pound Volkswagen traveling at 48 mph entered the arresting system at an angle of 30° with a perpendicular to the net. All subsequent angle tests will be defined on this basis. The vehicle was stopped in 13.8 feet, and pulled a total of 3.4 feet of tape out of the 25,000 pound Metal Benders. This tape pullout consumed 70% of the vehicle's kinetic energy. The estimated energy necessary to impart a horizontal rotation, or spin, to the vehicle and to elevate its center of gravity was about 3 kip-ft. These energy levels are defined at the time during the test when the tapes stop pulling out of the benders. The average deceleration level was 5.5 g's while the maximum deceleration, shown by Figure C5 is about 13 g's. The vehicle damage shown in Figure 12 was moderate.

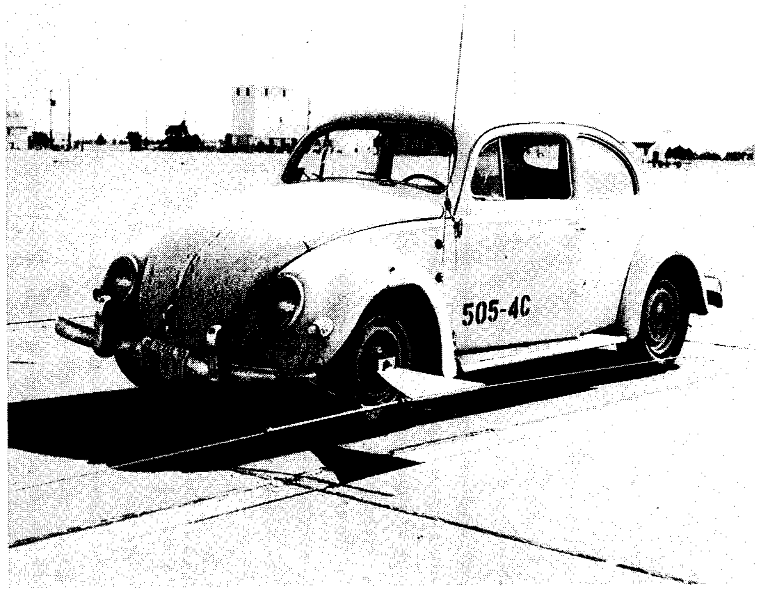


Figure 11, Vehicle Before Test 505-4C

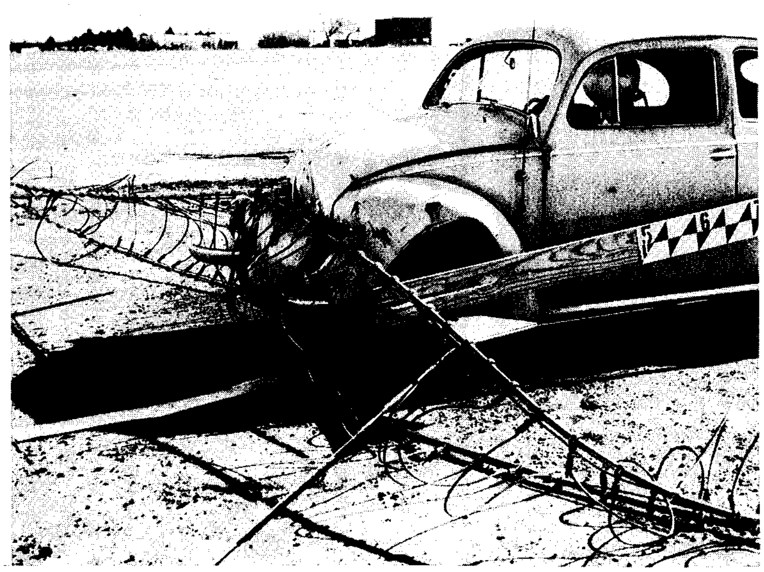


Figure 12, Vehicle After Test 505-4C

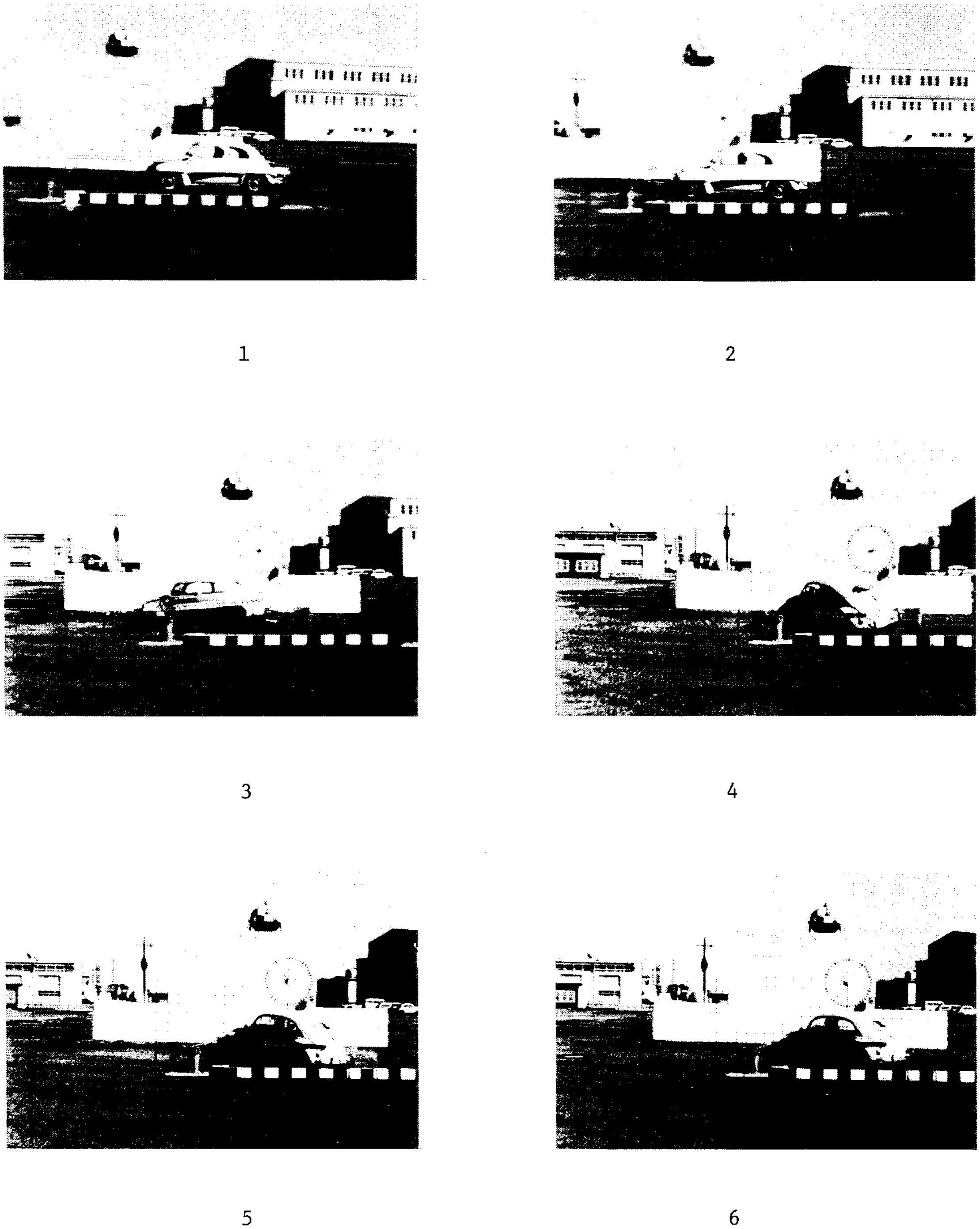


Figure 13, Sequential Photographs of Test 505-4C.

TEST 4D

In Test 4D a 4520 pound Oldsmobile sedan, traveling 54 mph, impacted the net on an initial trajectory of 30°. The high-speed films show a maximum travel of 23.5 feet after impact. The 25,000 pound Metal Benders allowed 8.6 feet of metal tape to be pulled through, accounting for 50% of the initial kinetic energy. When the maximum tape pullout had occurred, the vehicle was estimated to have 36 kip-ft of rotational energy and 11 kip-ft of gravitational potential energy. The net entrapped only the lower portion of the front of the vehicle. As the front pulled down below the vehicle center of gravity, the unbalanced inertia force resulted in the vehicle's rotation about the restrained point (see Figure 17). The vehicle was completely off the ground and the rear end went over and outside of the restraining net after the tapes had stopped pulling out. When the vehicle fell back to the ground, it came very close to rolling. The average and maximum significant longitudinal decelerations were 4.1 and 8 g's respectively. Figure C7 shows the accelerometer trace used to determine this maximum deceleration.

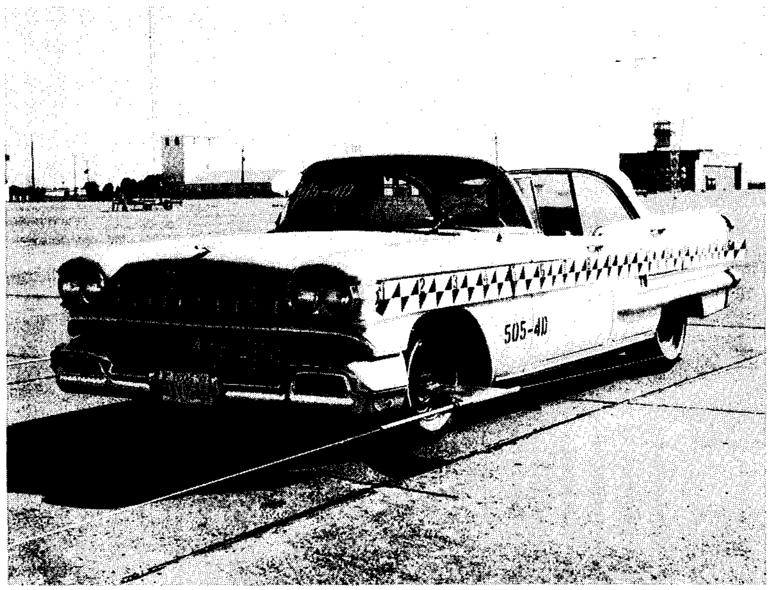


Figure 14, Vehicle Before Test 505-4D.

Figure 15, Vehicle and Right Metal Bender
After Test 505-4D.

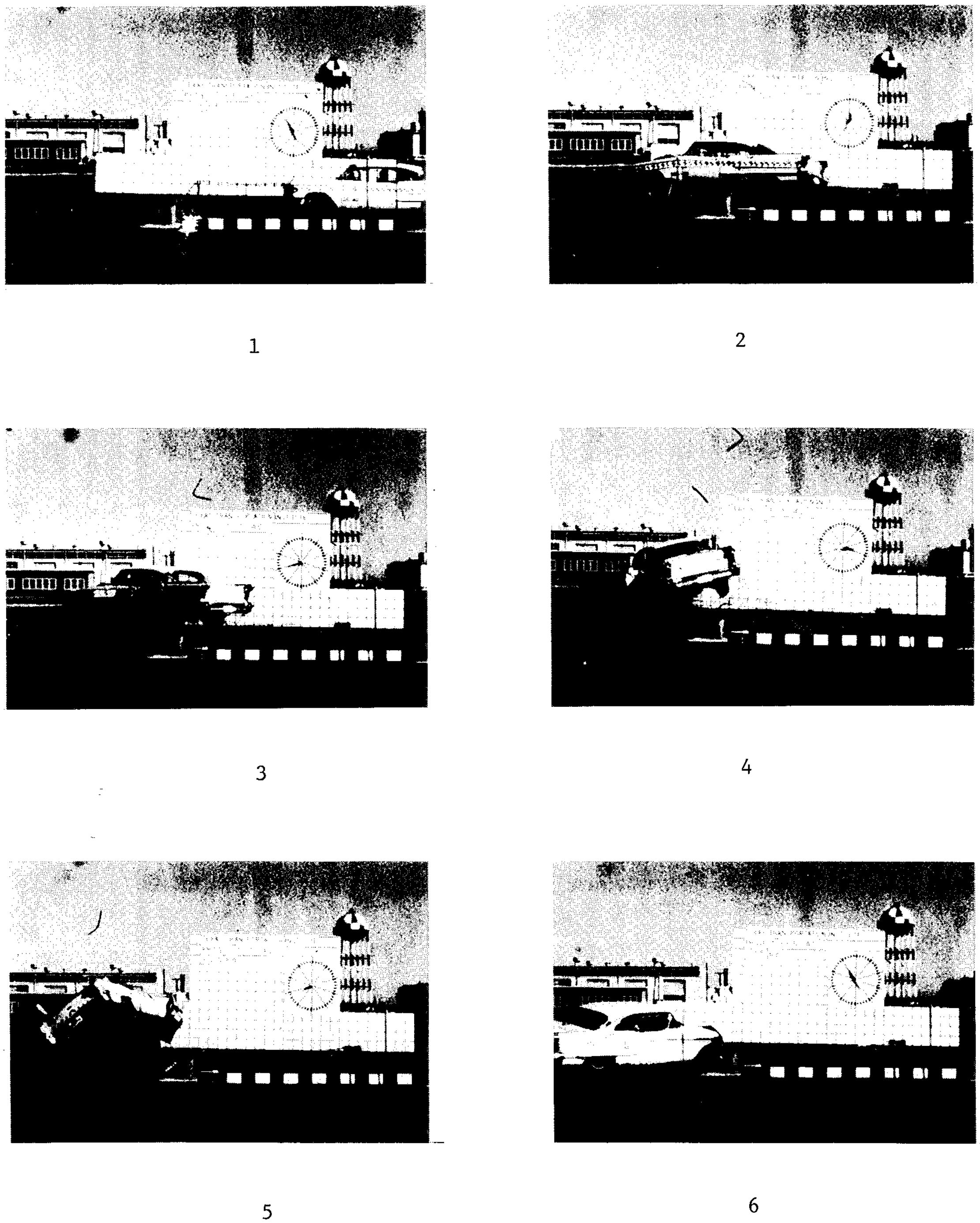
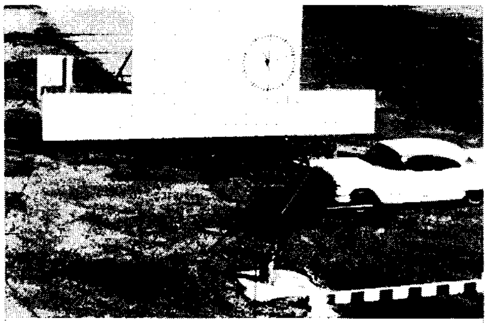
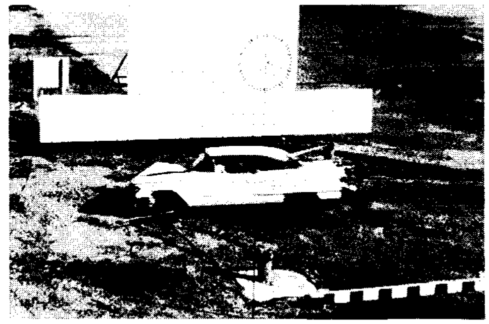


Figure 16, Sequential Photographs of Test 505-4D.





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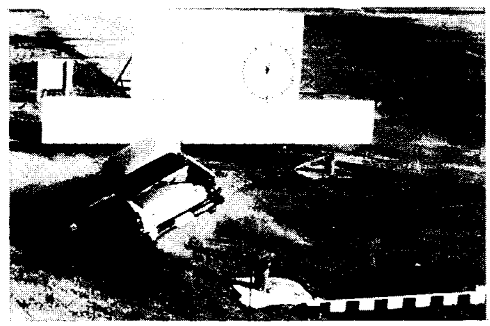

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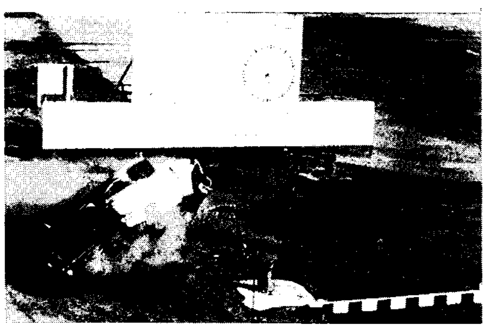

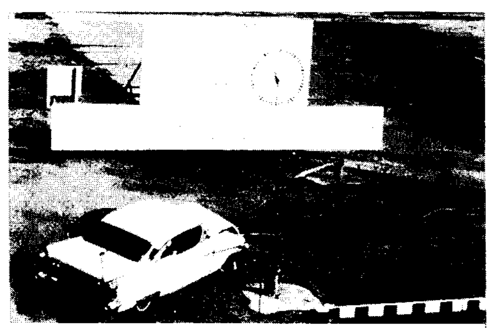

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Figure 17, Sequential Photographs of Test 505-4D Showing Behavior of Net During Arrestment.

TEST 4E

This test was similar to Test 4B in that a heavy car, a 3760 lb. Dodge sedan, was directed head-on into the dragnet at a velocity of 56 mph. However, in this and the following test the Metal Bender tape load was decreased to 12,500 lbs. and the net was raised about 4 inches off the ground to better entrap the front of the vehicles.

The vehicle was stopped in 26.3 feet and pulled out a total of 30.7 feet of tape, which is equivalent to 384 kip-ft, or 96% of the vehicle's kinetic energy. The vehicle had no significant rotational energy at maximum penetration, but had gained about 7 kip-ft of gravitational potential energy.

The vehicle damage was minor, as would be expected since the maximum deceleration was only 7.0 g's, and the average deceleration was 4.0 g's.

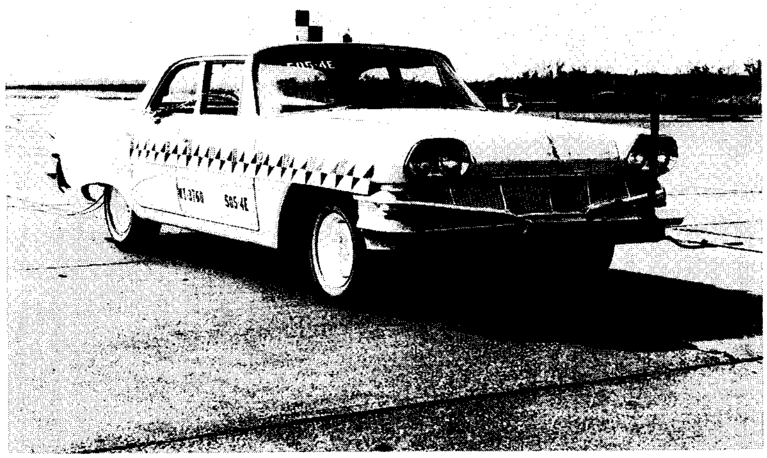


Figure 18, Vehicle Before Test 505-4E.

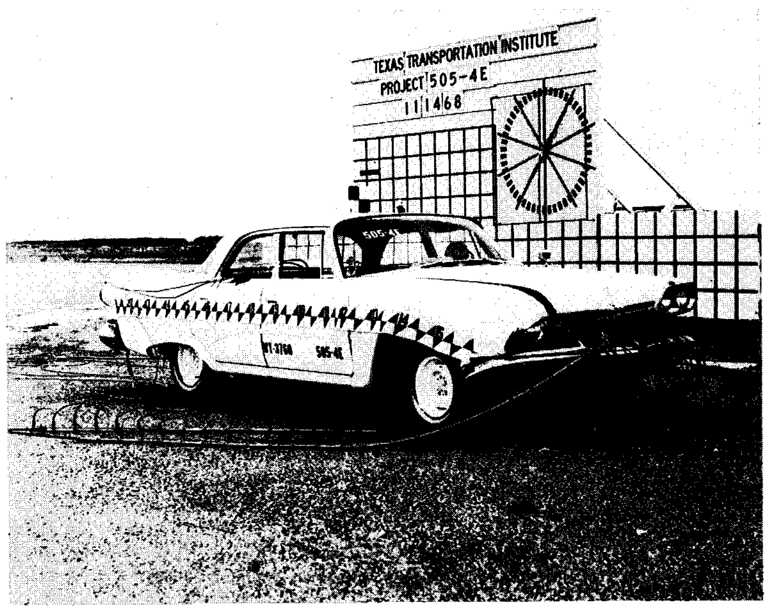


Figure 19, Vehicle After Test 505-4E.

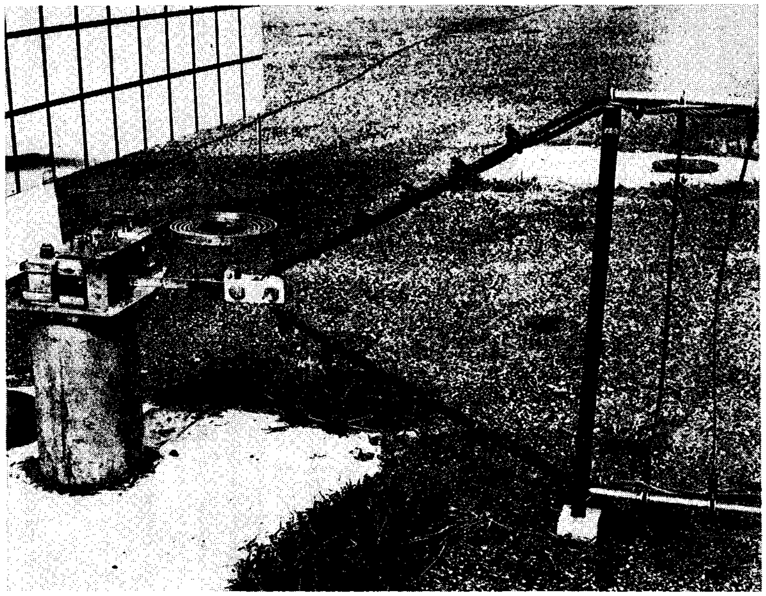
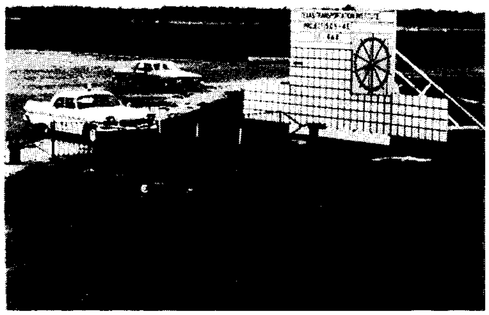


Figure 20, 12,500 Pound Metal Bender Before Test 505-4E.
(Note smaller metal tape)

Figure 21, Dummy Used In All Tests
To Simulate Human Driver.



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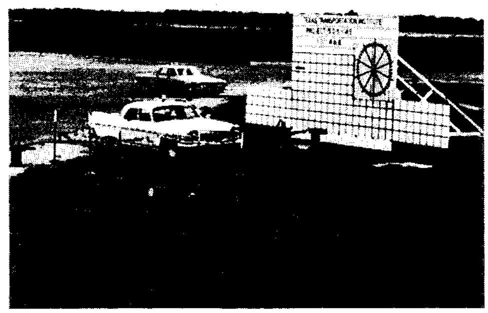

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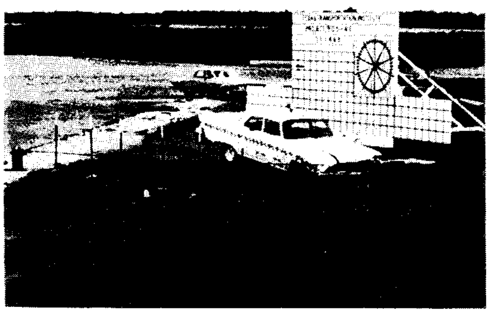

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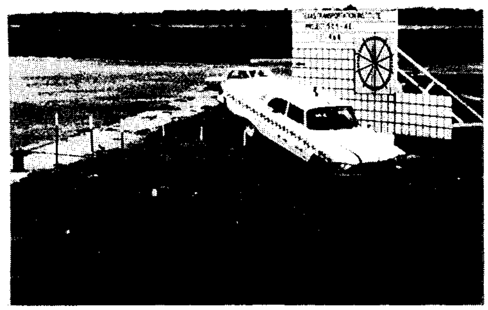

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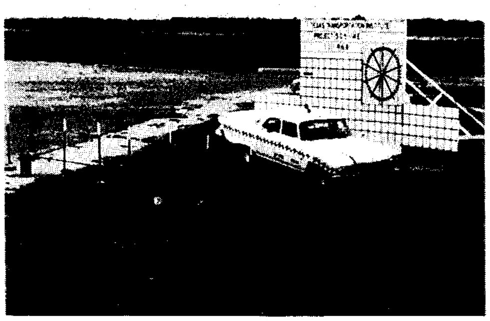

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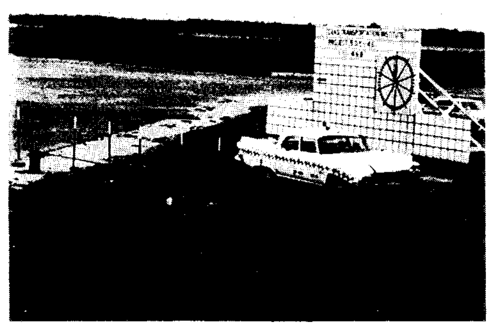

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Figure 22, Sequential Photographs of Test 505-4E.

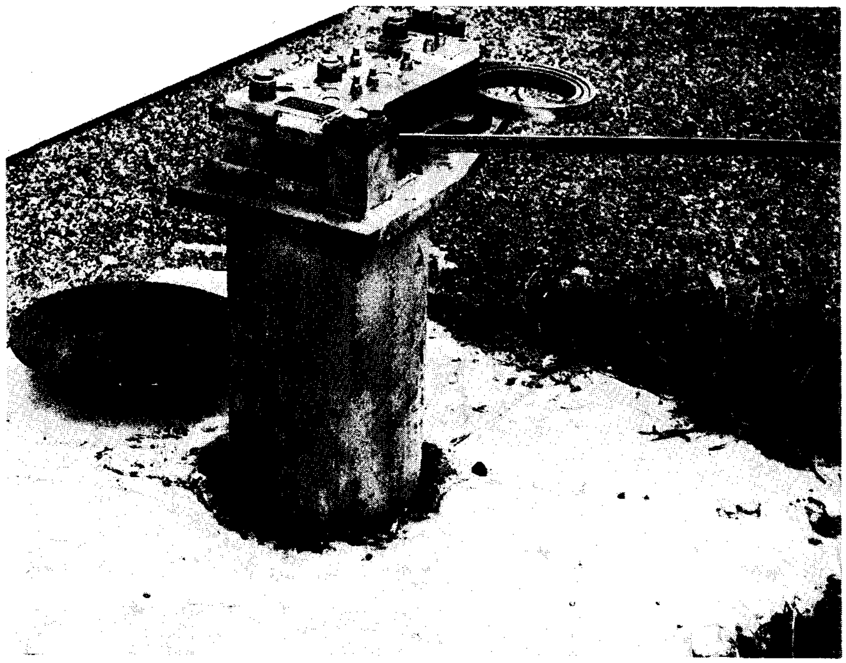

Figure 23, Metal Bender After Test 505-4E. (Approximately the same amount of tape remained on each bender)

TEST 4F

As the final test in this series a 3880 pound Ford sedan traveling 62 mph collided with the dragnet at an impact angle of 30°. As in the previous test, 12,500 pound Metal Bender tapes were used.

The tape on the right side was expended and pulled free of the Metal Bender before the vehicle had been brought to a stop. The system performed as designed up to the point of tape pullout. The net, which was still attached to one Metal Bender, caused the car to spin through an angle of about 120 degrees after pulling out the right tape before coming to rest.

The total tape pullout when the right tape pulled free was 32.9 feet, which accounts for 89% of the kinetic energy lost up to that point. The high-speed films indicate that the vehicle had lost about 91% of its initial energy at this point and that the speed was down to about 17 mph.

The total tape pullout of 38.5 feet at full stop accounts for 94% of the vehicle's initial energy. Comparisons of actual and theoretical values are made up to the point of tape expenditure.

The deceleration levels of 5.0 g's (maximum) and 2.4 g's (average) are tolerable to restrained humans.*

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

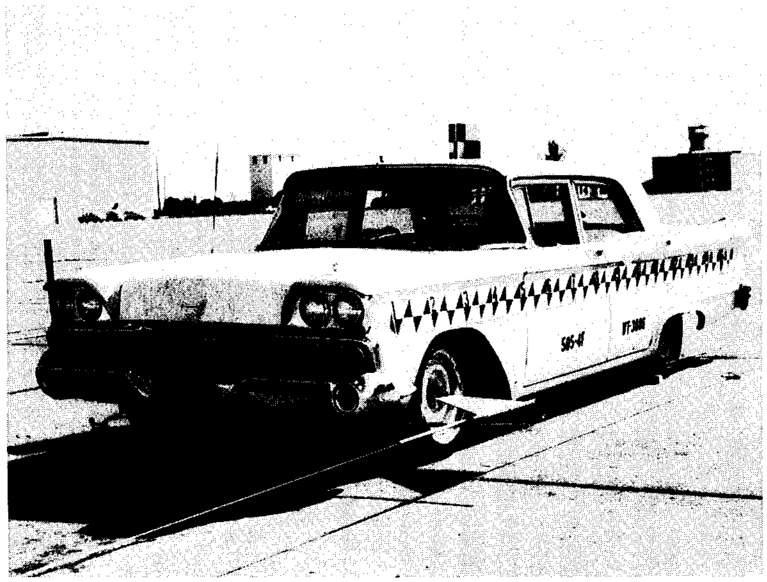

Figure 24, Vehicle Before Test 505-4F.

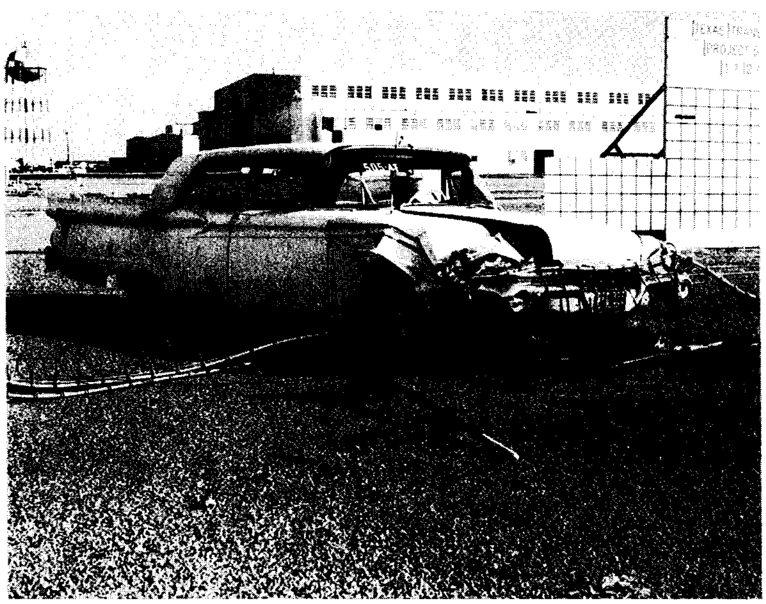

Figure 25, Vehicle After Test 505-4F.

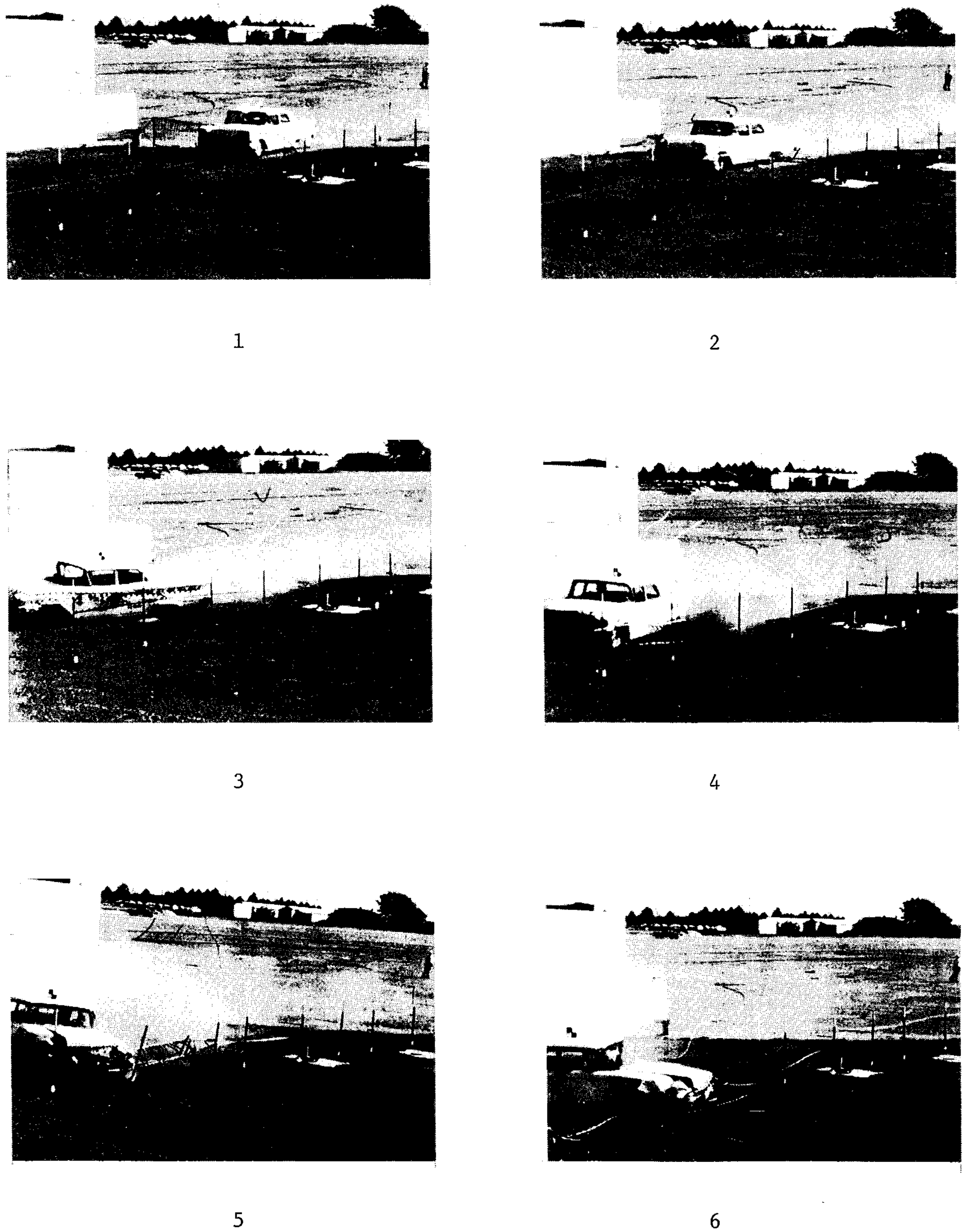

Figure 26, Sequential Photographs of Test 505-4F.

DISCUSSION

The complete test series which was conducted on the Van Zelm dragnet is summarized by Table 2. The vehicles used ranged in weight from 1460 lbs to 4520 lbs. All test vehicles impacted the dragnet at its center. Tests 4A, 4B, and 4E were head-on tests, while Tests 4C, 4D, and 4F were 30° angle tests. This means that the initial trajectory of the vehicle made an angle of 30° with a perpendicular to the original position of the dragnet. Tapes producing a 25 kip pull were used in Tests 4A through 4D, while in Tests 4E and 4F this tape force was reduced to 12.5 kips.

The energy absorbed by the Metal Benders ranged from 50% to 70% of the vehicle's initial kinetic energy for the first four tests which used the 25 kip tape loads. In Tests 4E and 4F the percent of energy absorbed by the Metal Benders ranged from 89% to 96%. Inspection of Table 3 will show several reasons for this difference. At the end of Metal Bender tape pullout, which corresponds approximately to zero longitudinal velocity, significant amounts of energy may remain in the form of gravitational potential energy and rotational kinetic energy. In most impacts there is some gravitational potential energy gain due to the tendency of the net to pull the vehicle down in front and for the rear end to rise. This results in an increase in the elevation of the vehicle's center of gravity. The total vehicle weight times this increase in elevation, E_p, is designated the gravitational potential energy at the end of tape travel. In the case of angle tests, there may be present a significant amount of horizontal rotational energy, E_{RV}, which is equal to one-half the product of the vehicle mass moment of inertia (about the vertical axis through the vehicle's center of gravity) times the square of the vehicle's angular

TEST NO.	4A	4B	4C	4D	4E	4F
Angle of Impact	Head-On	Head-On	30°	30°	Head-On	30°
Vehicle Weight (lbs)	1460	4300	1620	4520	3760	3880
Vehicle Velocity (mph)	42	60	48	54	56	62
Metal Bender Tape Load (kip)	25.0	25.0	25.0	25.0	12.5	12.5
Vehicle Deformation (ft)	1.8	1.0	0.9	1.5	0.3	0.5
Vehicle Stopping Distance (ft)	10.2	19.4	13.8	23.5	26.3	29.5*
Total Metal Bender Tape Pullout (ft)	2.2	11.8	3.4	8.6	30.7	32.9*
Energy Absorbed by Metal Bender (kip-ft)	54.8 (63%)	296 (58%)	86 (70%)	214 (50%)	384 (96%)	411 * (89%)
Max. Significant Deceleration (g's) (Electromechanical curves)	16	16	13	8	7.0	5.0
Avg. Deceleration (g's) (Film - $V^2/2gX_{max}$)	5.8	6.1	5.5	4.1	4.0	2.4*
<u>REMARKS</u>						
Dragnet Performance						
Vehicle Damage						
Dragnet Damage						
Deceleration Level						

* Up to point tape expended.

TABLE 2. SUMMARY OF TEST RESULTS

TABLE 3

TEST NO.	4A	4B	4C	4D	4E	4F*
E_{KI}	87	513	123	437	401	512
E_{MB}	55	296	86	214	384	481
E_P	1	17	2	11	7	0
E_{RV}	0	0	1	34	0	0
E_{RL}	0	0	0	2	0	0
E_M	31	200	34	176	10	31

E_{KI} = Initial vehicle kinetic energy

E_{MB} = Energy expended in Metal Bender tape pullout

E_P = Gravitational potential energy at end of tape travel

E_{RV} = Horizontal rotational energy (around vertical axis) at end of tape travel

E_{RL} = Transverse rotational energy (around longitudinal axis) at end of tape travel

E_M = Miscellaneous energy expenditure (cable stretch, vehicle deformation, contact with ground, etc.)

$$E_M = E_{KI} - (E_{MB} + E_P + E_{RV} + E_{RL})$$

* Note the fact that these energy levels are up to the point of tape pullout only.

velocity about this axis. Also present may be transverse rotational energy, E_{RL}, which is defined in the same way as the horizontal rotational energy except that the mass moment of inertia and angular velocity is about the longitudinal vehicle axis. Other energy expenditures, E_M, may be accounted for by the axial strain energy which goes into the cable and tapes, the vehicle deformation, and frictional losses such as contact of rigid portions of the vehicle with the ground. This last energy expenditure was prevalent in Test 4B. It can be concluded, at least within the range of tape forces tested, that the lower the tape force the greater the percentage of energy dissipated in the Metal Benders. If the extreme example of a tape with infinite load capacity is considered,almost all of the kinetic energy of the vehicle would be expended in vehicle deformation, rolling, etc.

A convenient way of indicating the relative desirability of dragnet arrestments is to compare the deceleration levels determined by these tests with the decelerations that would be encountered during a collision with a rigid barrier. The Attenuation Index is defined as the ratio of decelerations during an attenuated arrestment (for example by dragnet) with those estimated decelerations during a rigid barrier impact.* Both maximum and average Attenuation Indices (AI_{max} and AI_{avg}), which compare maximum and average deceleration levels, are presented in Table 4.

Tests 4E and 4F, using 12,500 pound Metal Benders, have smaller Attenuation Indices than the first four tests. This is the obvious result of cutting the stopping force in half. This reduction in stopping force significantly reduces the vehicle damage. The relatively large

* Emori, Richard I., "Analytical Approach to Automobile Collisions," SAE Paper 680016, Engineering Congress, Detroit, January 8, 1968.

TABLE 4 . COMPARISON OF VAN ZELM "DRAGNET" PERFORMANCE

WITH RIGID BARRIER IMPACT

Test No.	A	B	C	D	E	F
Metal Bender Tape Load (Kip)	25.0	25.0	25.0	25.0	12.5	12.5
Vehicle Weight (lb.)	1460	4300	1620	4520	3760	3880
Vehicle Velocity (mph)	42	60	48	54	56	62
*Maximum Deceleration (G_{max})						
Dragnet	16	16	13	8	7.0	5.0
Rigid Barrier	37.8	54.0	43.2	48.6	50.4	55.8
**Average Deceleration (G_{avg})						
Dragnet	5.8	6.1	5.5	4.1	4.0	2.4
Rigid Barrier	24.1	34.4	27.6	31.0	32.1	35.6
Attenuation Index						
$AI_{max} = \frac{G_{max}\ \text{Dragnet}}{G_{max}\ \text{Rigid}}$	0.42	0.30	0.30	0.17	0.14	0.09
$AI_{avg} = \frac{G_{avg}\ \text{Dragnet}}{G_{avg}\ \text{Rigid}}$	0.24	0.18	0.20	0.13	0.12	0.07

*G_{max} Dragnet is from frame accelerometer data.

G_{max} Rigid = 0.9 (vehicle velocity in mph)***

**G_{avg} Dragnet = $\frac{V^2}{2gX_{max}}$ from film data.

G_{avg} Rigid = 0.574 (Vehicle velocity in mph)***

***Emori, Richard I., "Analytical Approach to Automobile Collisions," SAE Paper 680016, Engineering Congress, Detroit, January 8, 1968.

energy differences between tape energy and initial kinetic energy in Tests 4A through 4D are the result of large energy expenditures on vehicle deformation.

In Appendix B is a theoretical treatment which algebraically relates vehicle weight, velocity, tape force and stopping distance. The error induced by considering the vehicle to have no finite width is approximately compensated for by the fact that after impact the "spreaders" at the ends of the net buckle, increasing the effective length of the net. Due to the fact that the main net cables loop over and under the front of the vehicles, and that the vehicles are deformed differently, some inaccuracy is expected, especially in arrestments with short stopping distances. It is also assumed in the calculations that the vehicle continues along its original path during arrestment, which is only a rough approximation in angled or non-centric hits.

Figure 27 is a plot of dragnet force on the vehicles against distance traveled after contact. The data used for this plot is taken from the theoretical calculations in Appendix B. A comparison of the calculated energy expenditures is shown in Table 5. The theoretical Metal Bender energy expenditures are obtained using the equations presented in Appendix B. As expected, the theory shows the greatest percent error for Test 4A, which had the shortest stopping distance and greatest relative deformation.

From the theoretical treatment a plot of total Metal Bender tape pullout against X_{max}, the theoretical stopping distance, was made for head-on 30° angled impacts. Neglecting other energy dissipation modes, the initial vehicle kinetic energy divided by the Metal Bender tape

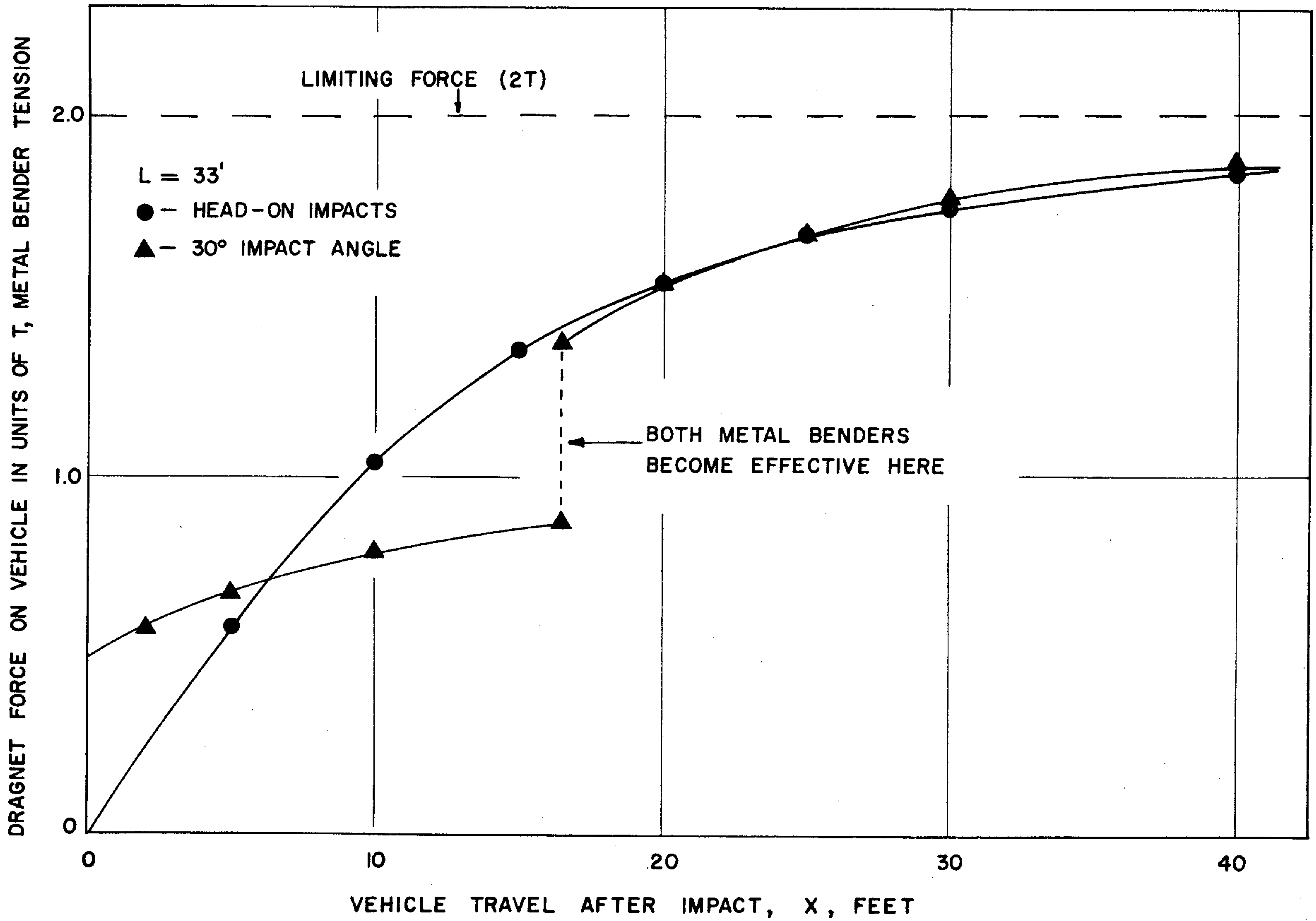

FIGURE 27, THEORETICAL STOPPING FORCE — DISPLACEMENT CURVES FOR CENTRIC IMPACTS

TABLE 5

Comparison of Vehicle Kinetic Energies
with Calculated Energy Expenditures
(in Kip-ft)

Test No.	4A	4B	4C	4D	4E	4F
Initial Kinetic Energy of Vehicle	87.1	513	123	437	401	464*
Energy Expended by Metal Benders (from measured tape pullout)	54.8	296	85.5	214	384	411*
Energy from area under Force-Displacement curve in Figure 27. (Stopping distance from high speed films)	140	450	105	440	365	330*

* To expenditure of tape in right hand Metal Bender.

tension should equal the total tape pullout. By taking the initial velocity, determined from the high-speed films, and calculating initial kinetic energy, and by knowing the Metal Bender tape tensions, we can calculate the theoretical total tape pullout. Using this value and Figure 28, we can determine theoretical stopping distance. The theoretical stopping distances so determined are compared with actual stopping distances from the high-speed film data in Table 6. In this comparison, the measured stopping distance is the measured stopping distance of the vehicle's center of gravity minus the vehicle's deformation. (This is the distance traveled by the vehicle's front end after contacting the net.)

Again the percentage difference between actual and theoretical values is greater for short stopping distances (high Metal Bender tensions). An examination of the high-speed films indicates that in Test 4C the combination of the low, narrow front end of the vehicle and the collapse of the end net spreaders, which occurred in every test, delays application of the main stopping force until the vehicle has traveled about four feet beyond initial contact. This is a considerable portion of the total stopping distance, and explains the large difference between measured and calculated stopping distance. For this vehicle's initial energy, the calculated total tape pullout is 4.9 feet. This compares favorably with the actual measured tape pullout of 3.4 feet. The theoretical calculations are applied to an example design problem in Appendix B.

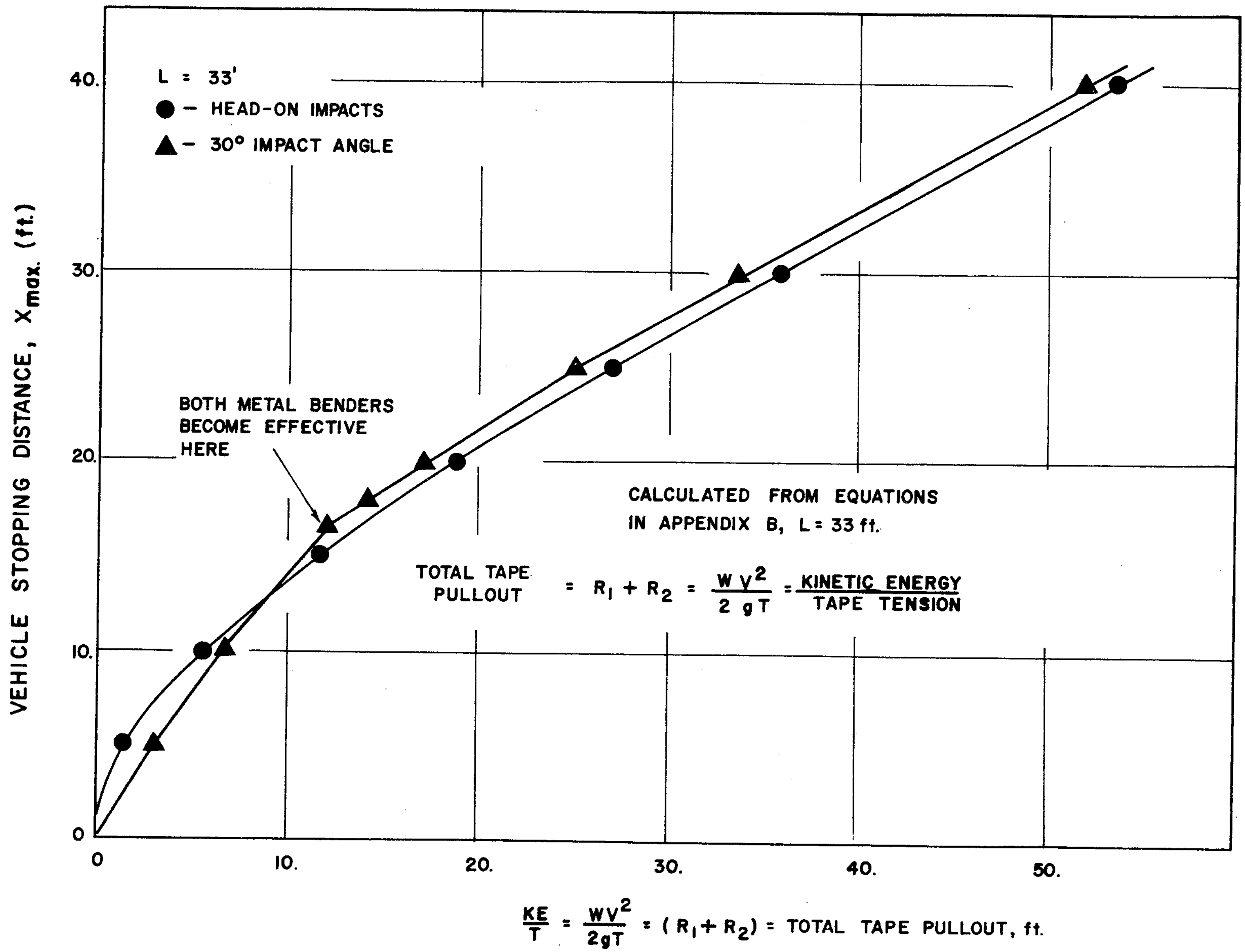

FIGURE 28, STOPPING DISTANCE VS. TOTAL TAPE PULLOUT

TABLE 6

Comparison of Computed Stopping Distances with Measured Stopping Distances

Test No.	4A	4B	4C	4D	4E	4F
$(X_{max})_M$ (ft) **	8.4	18.4	12.9	22.0	26.0	29.0*
$(X_{max})_C$ (ft) ***	7.8	21.0	7.6	20.2	27.7	29.5*
$\left[(X_{max})_C - (X_{max})_M \right]$ (ft)	-0.6	+2.6	-5.3	-1.8	+1.7	+0.5*

* Calculated up to point metal tape was expended.

** Measured stopping distance from film minus vehicle deformation.

*** Calculated stopping distance from initial vehicle velocity and theoretical treatment in appendix.

A P P E N D I X   A

Design and Installation

Data

VAN ZELM *Associates* INC.

DEVELOPMENT ENGINEERS

1475 ELMWOOD AVENUE
PROVIDENCE, RHODE ISLAND 02907
TEL. (401) 781-3500

May 13, 1968
Serial Number S-305

Mr. T. J. Hirsch
Head, Structural Research Department
Texas A&M University
College of Engineering
College Station, Texas 77843

Dear Mr. Hirsch:

This letter supplements the previous information transmitted to you by our letter of April 29, 1968 and answers your telephone request of May 1.

Van Zelm has several Metal Bender Units which have been developed and tested and are adaptable for highway use. These units, with their pertinent physical and operational characteristics are presented below.

Torture Chamber Mod. No.	Tape Size	Tape Load	Tape Nominal Runout	Max. Runout Possible
Std.Dragnet-MBP-1	1-1/4X.050	2500#	200 Ft.	500 Ft.
" " -MBP-2	2" X .050	2000# or 4000#	400 Ft.	1000 Ft.
Texas A&M Config.	2" X 3/8	25,000#	12.3 Ft.	18.7 Ft.
" " "	1-1/2"X3/8	18,500#	18.7 Ft.	18.7 Ft.
" " "	1 X 3/8	12,500#	18.7 Ft.	18.7 Ft.*

Units may be combined to produce a desired tape load which falls between the loads produced by the basic units. For example two 4000 lb. units may be combined to produce an 8000 lb. load or a 4000 lb. unit and a 2500 lb. unit a 6500 lb. load.

Also attached is one copy of Van Zelm drawing 1E-2909 detailing the dragnet test installation at T.T.I.

Very truly yours,

L. Montanaro

L. Montanaro

LM:lt

* The tapes used in Tests 4E and 4F were 25 feet in length.

SUBSIDIARY OF ENTWISTLE MANUFACTURING CORPORATION

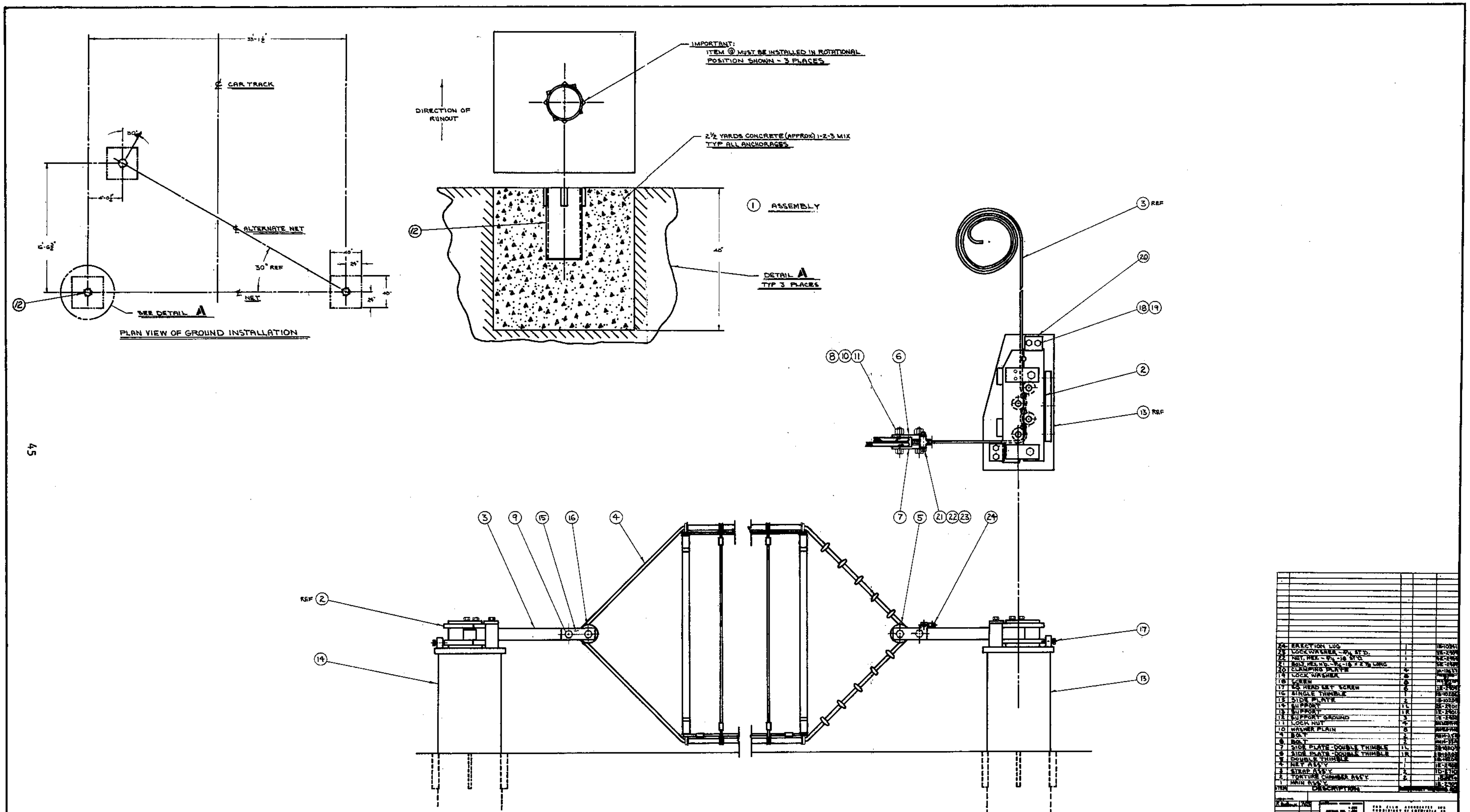
IMPORTANT:
ITEM ⑫ MUST BE INSTALLED IN ROTATIONAL POSITION SHOWN - 3 PLACES
DIRECTION OF RUNOUT
2½ YARDS CONCRETE (APPROX) 1-2-3 MIX TYP ALL ANCHORAGES
① ASSEMBLY
DETAIL A
TYP 3 PLACES
℄ CAR TRACK
℄ ALTERNATE NET
30° REF
℄ NET
SEE DETAIL A
PLAN VIEW OF GROUND INSTALLATION
IE-290

Figure A1

APPENDIX B

Theory and Design

Example

EQUATIONS FOR ANALYSIS OF VAN ZELM METAL BENDER DRAGNET SYSTEM

HEAD-ON CENTRIC VEHICLE COLLISION

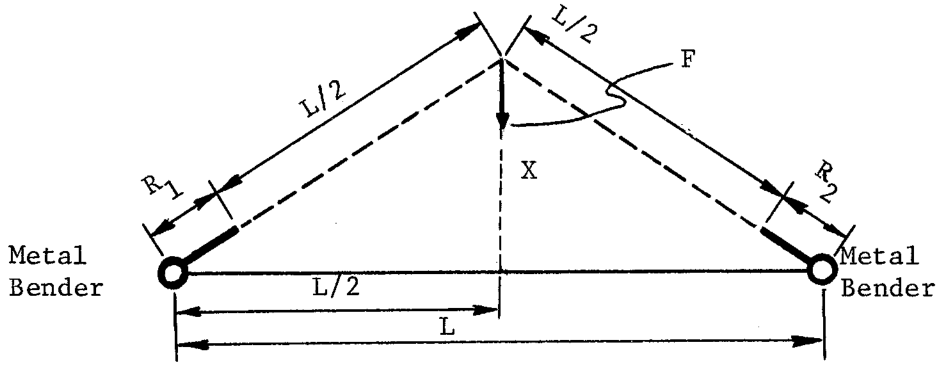

Figure B1

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).

Van Zelm now has available metal tapes and metal benders (sometimes called "torture chambers") which provide tape tension forces (T) of 2,500 lb., 4,000 lb., 12,500 lb., 18,750 lb., and 25,000 lb. Two of the 4,000 lb. metal benders can be stacked on top of each other to provide a tape tension force of 8,000 lb.

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 metal tape will yield the energy absorbed by metal bender tape = 2TR

Because of symmetry $R = R_1 = R_2$

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

The maximum tape run out is then

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

since system is symmetrical in this case.

From Figure B1,

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

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

The stopping force component on the vehicle is,

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

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

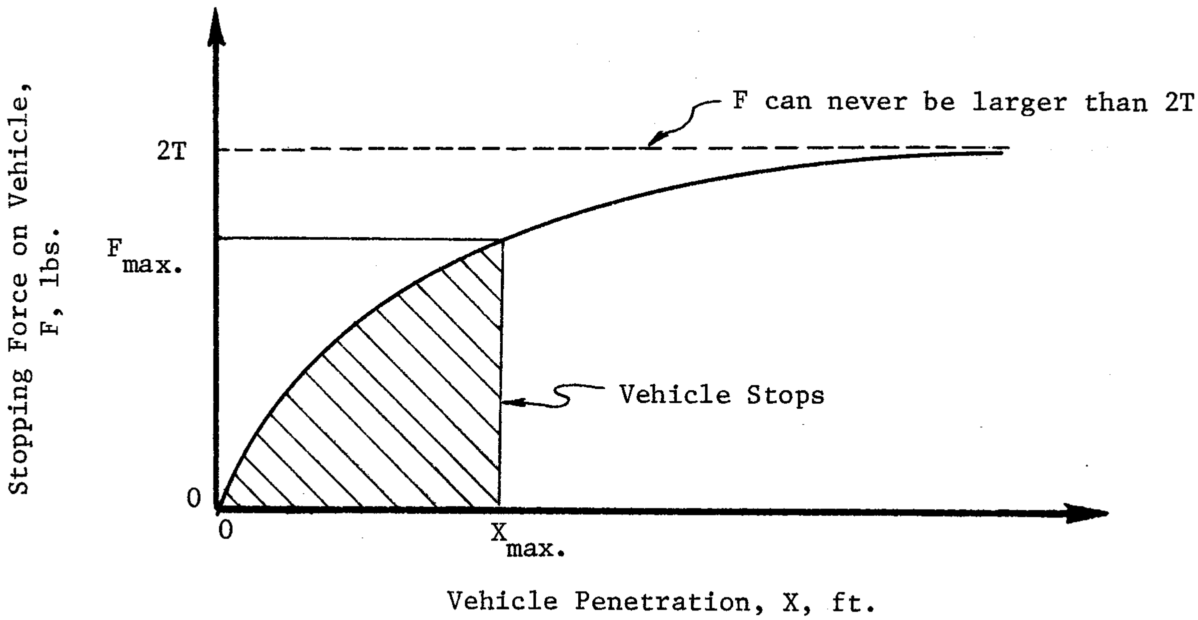

Figure B2, Idealized Vehicle Stopping Force vs. Stopping Distance

The preceding analysis applied to the special case of the "Dragnet" system being struck by a vehicle head-on and in the center. When the vehicle strikes the "Dragnet" at an angle, the mathematics becomes a little more complicated. An analysis of this problem will now be presented.

Idealized analysis of Van Zelm Metal Bender Dragnet Arresting System for centric vehicle collisions at any angle Θ.

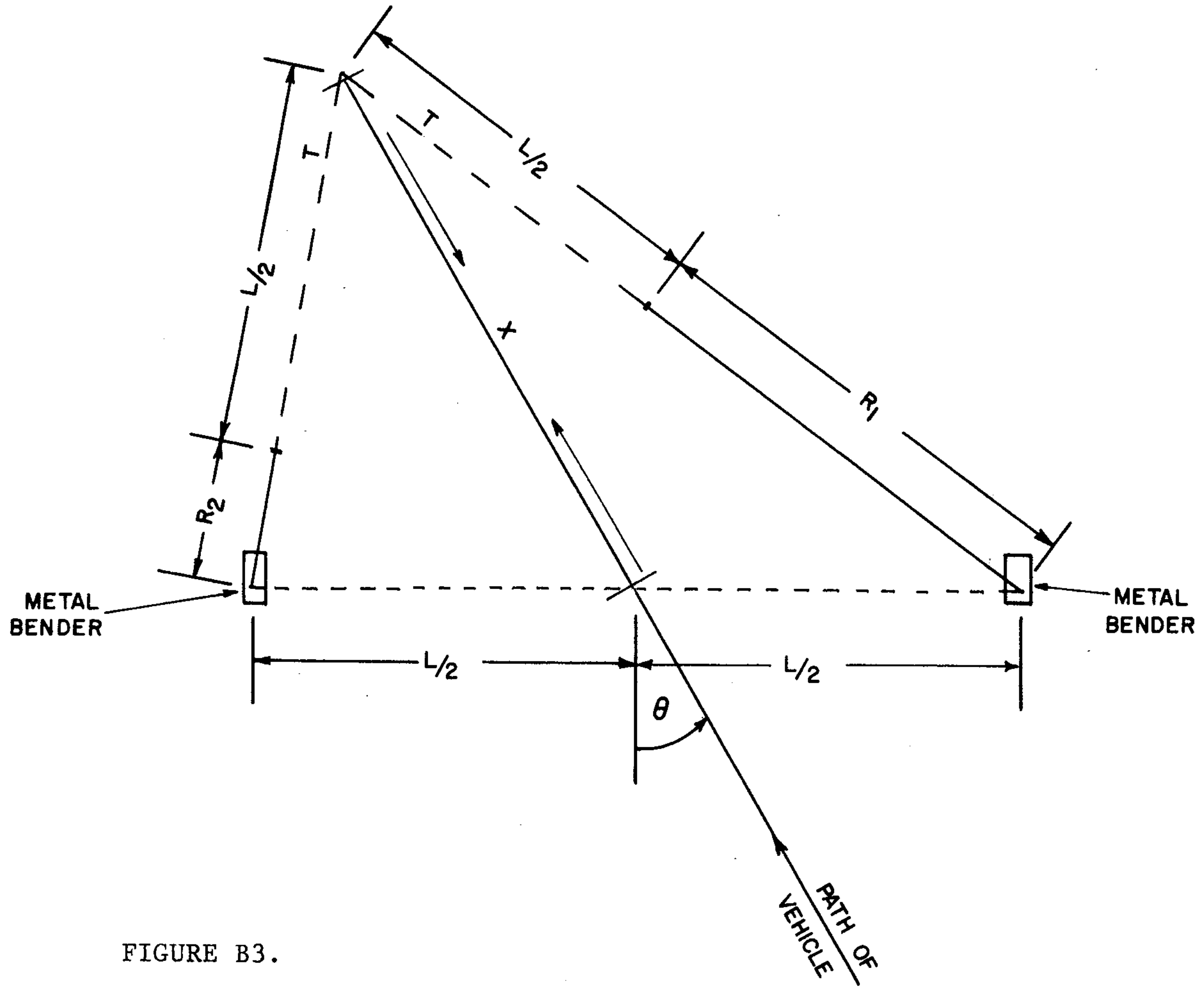

FIGURE B3.

L = Initial length of net and 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 $X \leqslant L \sin \theta$. (Derived from Law of Sines.)

Referring to Figure B3, 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:

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

Similarly,

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

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

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

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

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:

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

or $$KE = \frac{WV^2}{2g} = 2TR_{max} \qquad \text{(for } \theta = 0°\text{)}$$

since $R_{1_{max}} = R_{2_{max}} = R_{max}$ because of symmetry of the system when $\theta = 0°$

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

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

Similarly,

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

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

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

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

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

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

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

(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.

For $\theta = 30°$ (Tests 4C, 4D and 4F), Equations 7, 8, 9, 15 and 16 become, respectively,

(17) $$R_1 = \left(\frac{L^2}{4} + X^2 + \frac{L\,X}{2} \right)^{1/2} - \frac{L}{2}$$

(18) $$R_2 = \left(\frac{L^2}{4} + X^2 - \frac{L\,X}{2} \right)^{1/2} - \frac{L}{2}$$

(19) $$X = \left[\left(\frac{L}{4}\right)^2 + R_1^{\,2} + L\,R_1 \right]^{1/2} - \frac{L}{4} \qquad \text{(in terms of } R_1\text{)}$$

or $$X = \left[\left(\frac{L}{4}\right)^2 + R_2^{\,2} + R_2\,L \right]^{1/2} + \frac{L}{4} \qquad \text{(in terms of } R_2 \text{ if } X > \frac{L}{2}\text{)}$$

(20) $$\frac{WV^2}{2g} = T \left(\sqrt{\frac{L^2}{4} + X_{max}^2 + \frac{L\,X_{max}}{2}} + \sqrt{\frac{L^2}{4} + X_{max}^2 - \frac{L\,X_{max}}{2}} - L \right) \qquad \text{(for } X > \frac{L}{2}\text{)}$$

(21) $$\frac{WV^2}{2g} = T \left(\sqrt{\frac{L^2}{4} + X_{max}^2 + \frac{L\,X_{max}}{2}} - \frac{L}{2} \right) \qquad \text{(for } X \leqslant \frac{L}{2}\text{)}$$

For $\theta = 0°$ (Tests 4A, 4B and 4E), Equations 7 and 8 become,

(22) $$R_1 = R_2 = R = \left(\frac{L^2}{4} + X^2 \right)^{1/2} - \frac{L}{2}$$

And Equation 15 becomes,

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

From Equation 23,

$$X_{max}^2 = \left(\frac{KE}{2T} + \frac{L}{2}\right)^2 - \frac{L^2}{4} = \left(\frac{KE}{2T}\right)^2 + \left(\frac{KE}{2T}\right)L$$

(24) $$X_{max} = \sqrt{\left(\frac{WV^2}{4gT}\right)\left(\frac{WV^2}{4gT} + L\right)}$$

For head-on impacts, theoretical X_{max} can be determined from Equation 24. For 30° angled impacts, see Figure 27.

AN EXAMPLE OF HOW THESE EQUATIONS CAN BE APPLIED TO THE DESIGN OF AN ARRESTING SYSTEM USING VAN ZELM METAL BENDER ENERGY ABSORBING DEVICES

Given: Design factors dictate that the arresting system must stop vehicles with weights up to 4500 pounds and speeds up to 60 mph after en ering the system at angles of up to 20° with the perpendicular to the net. Geometric factors limit the distance between the end anchor posts to 30 feet and the maximum stopping distance to 30 feet.

Problem: What is the required minimum Metal Bender tape tension and tape lengths.

Solution: (See formulas on pages 51 through 54). The total tape pullout, for a particular energy and tension, is about the same regardless of the angle of impact. However, a preliminary calculation, using Equations 7, 8, and 9, shows that the stopping distance is greatest for $\theta = 20°$. Therefore use $\theta = \theta_{max} = 20°$ as a limiting case.

The critical design factors are:

$\theta_{max} = 20°$ $(\sin \theta_{max} = 0.342)$

$X_{max} = 30$ feet

$L = 30$ feet

Using these values in Equations 7 and 8:

$$R_{1max} = \left(\frac{L^2}{4} + X^2_{max} + L X_{max} \sin\theta \right)^{1/2} - \frac{L}{2}$$

$$= \left(225 + 900 + 308 \right)^{1/2} - 15$$

$$= 37.9 - 15 = 22.9 \text{ feet}$$

$$R_{2max} = \left(\frac{L^2}{4} + X^2_{max} - L X_{max} \sin\theta \right)^{1/2} - \frac{L}{2}$$

$$= \left(225 + 900 - 308 \right)^{1/2} - 15$$

$$= 28.6 - 15 = 13.6 \text{ feet}$$

The minimum tape length is R_{1max} = 23 feet, (approximately)

Total tape pullout = (22.9 + 13.6)feet = 36.5 feet.

The maximum vehicle kinetic energy is:

$$\frac{WV^2}{2g} = \frac{(4500)\ (88)^2}{64.4} \text{ foot-pounds} = 542{,}000 \text{ foot-pounds}$$

From Equation 10,

$$T_{min.} = \left(\frac{WV^2}{2g} \right) \left(\frac{1}{R_{1max} + R_{2max}} \right)$$

$$= \frac{542{,}000}{36.5} \text{ pounds} = 14{,}850 \text{ pounds}$$

Theoretically the minimum Metal Bender tape tension is 14,850 pounds and the minimum length of tape required for runout in each Metal Bender is about 23 feet. The Metal Bender tape tension should now be chosen on the basis of the available tape tensions, including some excess tape length as a safety factor.

A P P E N D I X C

Photographic and Electromechanical

Test Data

TABLE C1

TEST RF 505-4A

VAN ZELM METAL BENDER, HEAD-ON

1958 RENAULT, 4 DOOR SEDAN, 1460 LB.

HIGH SPEED FILM DATA

Time Milliseconds		Displacement ft	Velocity ft/sec
0		0	
			59.8
11.70		0.70	
			57.3
23.40		1.37	
			68.4
35.10	Impact	2.17	
			59.0
46.80		2.86	
			63.3
58.50		3.60	
			63.3
70.20		4.34	
			55.6
81.90		4.99	
			59.8
93.60		5.69	
			56.4
105.30		6.35	
			55.6
117.00		7.00	
			55.6
128.70		7.65	
			55.6
140.40		8.30	
			44.4
152.10		8.82	
			47.8
163.80		9.38	
			47.1
175.50		9.93	
			37.6
187.20		10.37	
			38.5
198.90		10.82	
			33.4
210.60		11.21	
			24.8
222.30		11.50	

TABLE C1

TEST RF 505-4A (continued)

Time Milliseconds	Displacement ft	Velocity ft/sec
		25.6
234.00	11.80	
		18.8
245.70	12.02	
		11.1
257.40	12.15	
		8.6
269.10	12.25	
		6.0
280.80	12.32	
		0.0
292.50	12.32	

TABLE C2

TEST RF 505-4B

VAN ZELM METAL BENDER, HEAD-ON

1960 MERCURY, 4 DOOR SEDAN, 4300 LB.

HIGH SPEED FILM DATA

Time Milliseconds	Displacement ft	Velocity ft/sec
0	0	
		86.2
13.00	1.12	
		90.0
26.00	2.29	
		86.2
39.00 Impact	3.41	
		83.0
52.00	4.49	
		87.7
65.00	5.63	
		83.9
78.00	6.72	
		86.2
91.00	7.84	
		80.7
104.00	8.89	
		78.5
117.00	9.91	
		78.5
130.00	10.93	
		73.1
143.00	11.88	
		73.1
156.00	12.83	
		70.0
169.00	13.74	
		66.1
182.00	14.60	
		64.6
195.00	15.44	
		65.4
208.00	16.29	
		56.2
221.00	17.02	
		57.0
234.00	17.76	
		54.6
247.00	18.47	
		46.2
260.00	19.07	

TABLE C2

TEST RF 505-4B (continued)

Time Milliseconds	Displacement ft	Velocity ft/sec
		46.2
273.00	19.67	
		43.9
286.00	20.24	
		38.5
299.00	20.74	
		33.9
312.00	21.18	
		28.5
325.00	21.55	
		23.1
338.00	21.85	
		20.8
351.00	22.12	
		16.1
364.00	22.33	
		12.3
377.00	22.49	
		12.3
390.00	22.65	
		6.2
403.00	22.73	
		3.8
416.00	22.78	
		2.3
429.00	22.81	
		0.0
442.00	22.81	

TABLE C3

TEST RF 505-4C

VAN ZELM METAL BENDER, 30^{o} ANGLE

1955 VOLKSWAGEN, 2 DOOR, 1620 LB.

HIGH SPEED FILM DATA

Time Milliseconds		Displacement ft	Velocity ft/sec
0		0	
			70.8
12.00		0.85	
			69.2
24.00		1.68	
			69.2
36.00	Impact	2.51	
			65.8
48.00		3.30	
			70.8
60.00		4.15	
			69.2
72.00		4.98	
			65.8
84.00		5.77	
			65.8
96.00		6.56	
			68.2
108.00		7.38	
			67.4
120.00		8.19	
			64.1
132.00		8.96	
			65.8
144.00		9.75	
			64.1
156.00		10.52	
			59.1
168.00		11.23	
			60.8
180.00		11.96	
			46.6
192.00		12.52	
			45.0
204.00		13.06	
			46.6
216.00		13.62	
			44.2
228.00		14.15	
			41.6
240.00		14.65	

TABLE C3

TEST RF 505-4C (continued)

Time Milliseconds	Displacement ft	Velocity ft/sec
		37.5
252.00	15.10	
		26.6
264.00	15.42	
		26.6
276.00	15.74	
		15.0
288.00	15.92	
		17.5
300.00	16.13	
		8.3
312.00	16.23	
		5.8
324.00	16.30	
		0.0
336.00	16.30	

TABLE C4

TEST RF 505-4D

VAN ZELM METAL BENDER, 30° ANGLE

1958 OLDSMOBILE, 4 DOOR, 4520 LB.

HIGH SPEED FILM DATA

Time Milliseconds		Displacement ft	Velocity ft/sec
0		0	
			78.2
11.90		0.93	
			82.4
23.80		1.91	
			74.8
35.70		2.80	
			82.4
47.60		3.78	
			75.6
59.50	Impact	4.68	
			80.7
71.40		5.64	
			79.0
83.30		6.58	
			77.3
95.20		7.50	
			74.8
107.10		8.39	
			77.3
119.00		9.31	
			73.1
130.90		10.18	
			78.1
142.80		11.11	
			71.5
154.70		11.96	
			79.8
166.60		12.91	
			68.8
178.50		13.73	
			73.1
190.40		14.60	
			70.6
202.30		15.44	
			69.8
214.20		16.27	
			65.6
226.10		17.05	
			60.5
238.00		17.77	

TABLE C4

TEST RF 505-4D (continued)

Time Milliseconds	Displacement ft	Velocity ft/sec
		68.1
249.90	18.58	
		55.5
261.80	19.24	
		57.2
273.70	19.92	
		54.6
285.60	20.57	
		50.4
297.50	21.17	
		51.2
309.40	21.78	
		42.8
321.30	22.29	
		46.3
333.20	22.84	
		34.5
345.10	23.25	
		40.3
357.00	23.73	
		31.9
368.90	24.11	
		37.8
380.80	24.56	
		21.0
392.70	24.81	
		31.1
404.60	25.18	
		23.5
416.50	25.46	
		29.4
428.40	25.81	
		26.9
440.30	26.13	
		25.2
452.20	26.43	
		18.5
464.10	26.65	
		26.1
476.00	26.96	
		23.5
487.90	27.24	
		23.5
499.80	27.52	

TABLE C4

TEST RF 505-4D (continued)

Time Milliseconds	Displacement ft	Velocity ft/sec
		16.8
511.70	27.72	
		28.6
523.60	28.06	
		10.9
535.50	28.19	
		0.0
547.40	28.19	

TABLE C5

TEST RF 505-4E

VAN ZELM METAL BENDER, HEAD-ON

1961 DODGE, 4 DOOR, 3760 LB.

HIGH SPEED FILM DATA

Time Milliseconds		Displacement ft	Velocity ft/sec
0		0	
			90.8
12.59		1.143	
			82.7
25.18		2.184	
			88.3
37.77		3.296	
			77.8
50.36		4.276	
			75.4
62.95		5.225	
			81.9
75.54		6.256	
			81.0
88.13	Impact	7.276	
			80.2
100.72		8.286	
			75.6
125.90		10.189	
			78.6
151.08		12.168	
			77.1
201.44		16.050	
			67.4
251.80		19.443	
			63.0
302.16		22.616	
			56.1
352.52		25.443	
			47.7
402.88		27.846	
			37.5
453.24		29.734	
			29.7
503.60		31.230	
			21.6
553.96		32.317	
			15.1
604.32		33.078	

TABLE C5

TEST RF 505-4E (continued)

Time Milliseconds	Displacement ft	Velocity ft/sec
		8.6
654.68	33.512	
		2.1
705.04	33.619	
		0.3
755.40	33.634	
		-2.6
805.76	33.501	
		-1.9
856.12	33.404	
		-3.2
906.48	33.241	
		-3.5
956.84	33.063	
		-3.2
1007.20	32.901	
		-3.0
1057.56	32.748	
		-4.0
1107.92	32.544	
		-4.5
1158.28	32.315	
		-3.4
1208.64	32.142	
		-3.6
1259.00	31.958	
		-6.4
1309.36	31.637	
		-4.0
1359.72	31.438	
		-5.2
1410.08	31.178	
		-5.4
1460.44	30.908	
		-3.0
1510.80	30.755	
		0.0
1561.16	30.755	

TABLE C6

TEST RF 505-4F

HIGH SPEED FILM DATA

Time Milliseconds		Displacement ft	Velocity ft/sec
0		0	
			90.5
10.06		.910	
			91.6
20.12		1.832	
			90.0
30.18		2.738	
			95.6
40.24	Impact	3.700	
			87.3
60.36		5.456	
			88.5
80.48		7.236	
			85.3
100.60		8.952	
			80.5
120.72		10.572	
			81.9
140.84		12.220	
			78.3
160.96		13.795	
			77.5
181.08		15.355	
			75.0
201.20		16.863	
			68.7
221.32		18.245	
			69.5
241.44		19.643	
			66.5
261.56		20.981	
			62.3
281.68		22.235	
			61.9
301.80		23.481	
			56.4
321.92		24.615	
			54.2
342.04		25.705	
			53.4
362.16		26.779	
			48.4
382.28		27.753	

TABLE C6

TEST RF 505-4F (continued)

Time Milliseconds	Displacement ft	Velocity ft/sec
		46.8
402.40	28.695	
		41.4
422.52	29.529	
		40.8
442.64	30.351	
		37.5
462.76	31.105	
		32.5
482.88	31.759	
		34.1
503.00	32.445	
		28.5
523.12	33.018	
		28.1
543.24	33.583	
		25.4
563.36	34.095	
		19.7
583.48	34.491	
		24.5
603.60	34.984	
		22.7
623.72	35.440	
		18.3
643.84	35.808	
		22.1
663.96	36.252	
		17.7
684.08	36.608	
		19.9
704.20	37.008	
		16.1
724.32	37.332	
		18.5
744.44	37.704	

Vehicle moved out of view

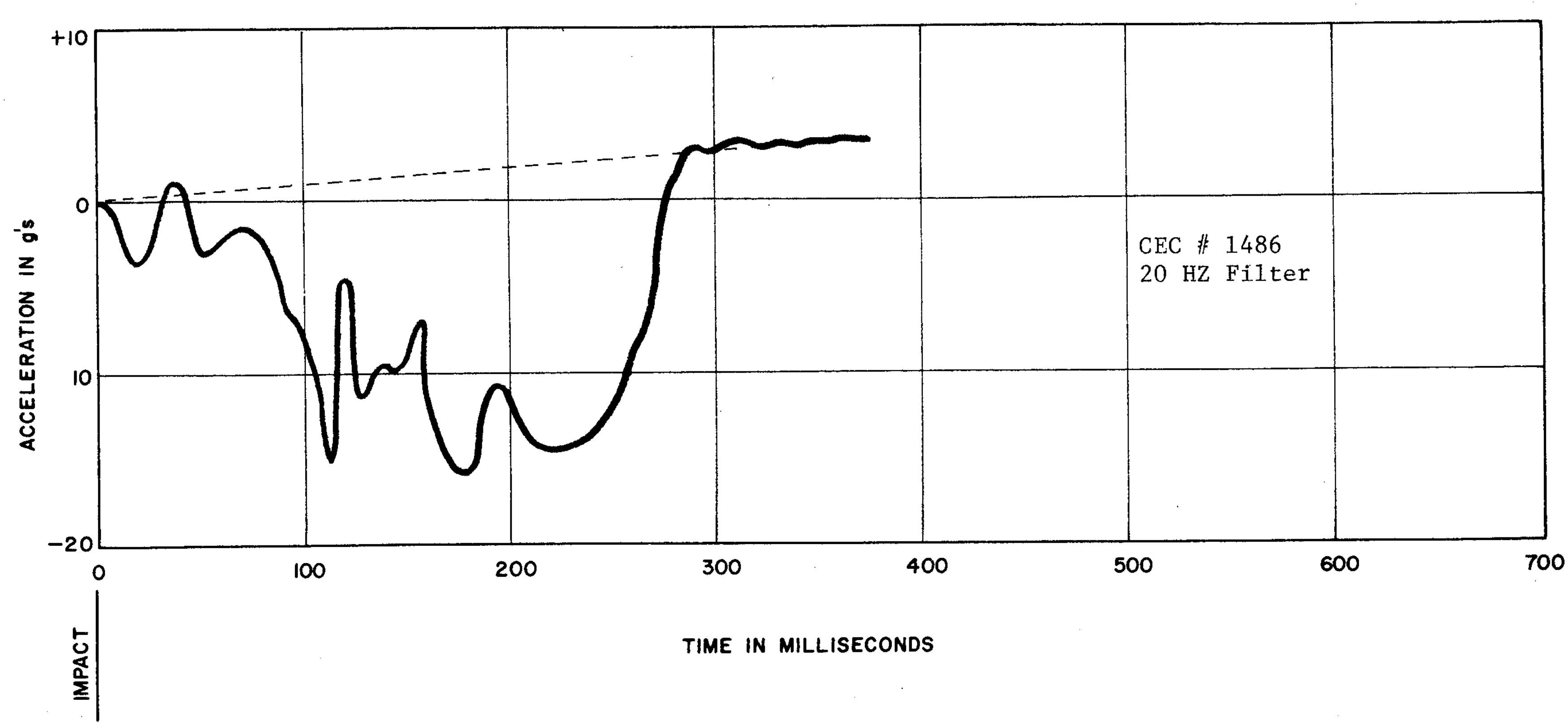

FIGURE C1, VEHICLE FRAME ACCELEROMETER DATA (LONGITUDINAL), TEST RF 505-4A

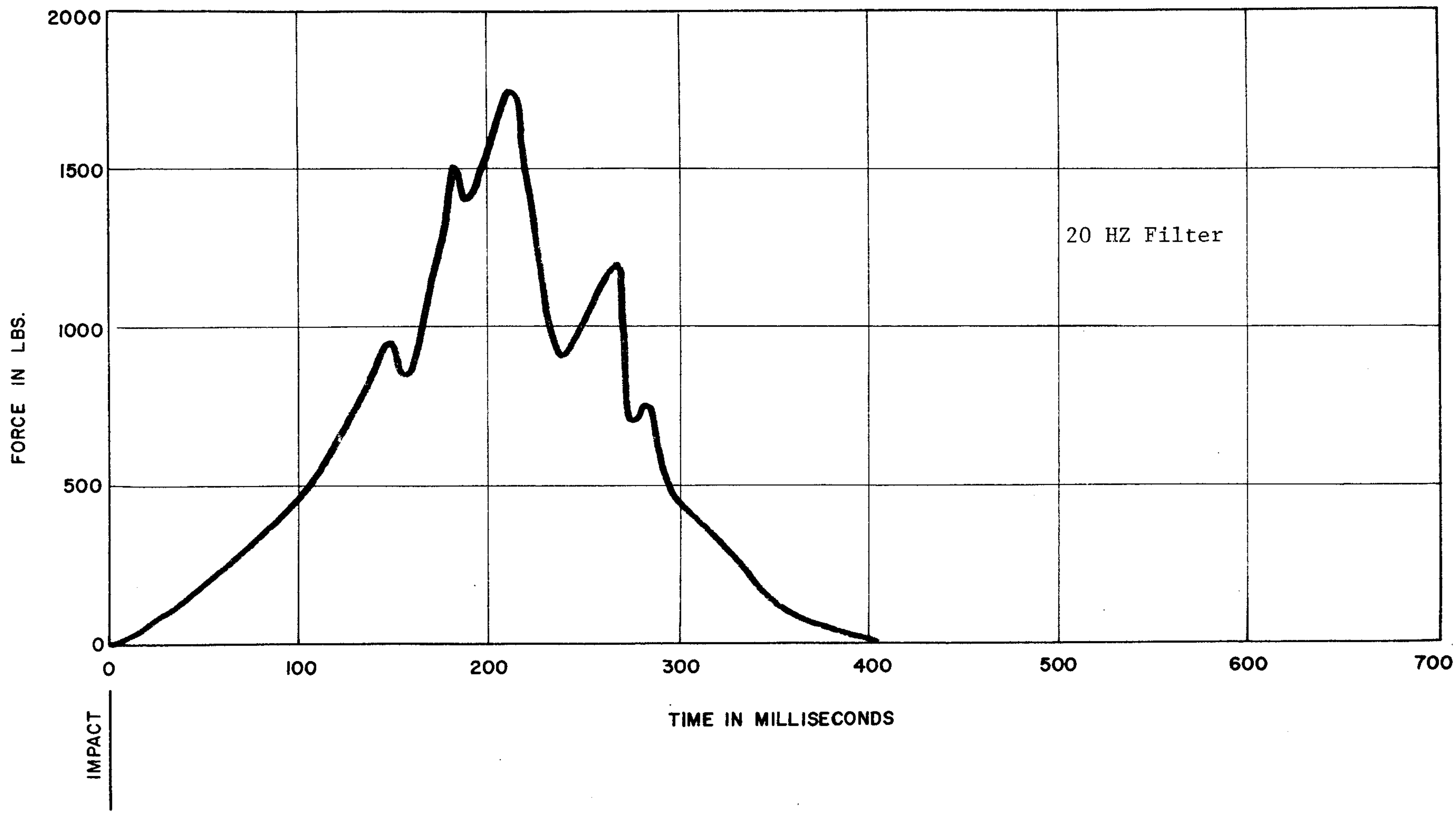

FIGURE C2, DUMMY SEATBELT FORCE DATA, TEST RF 505-4A

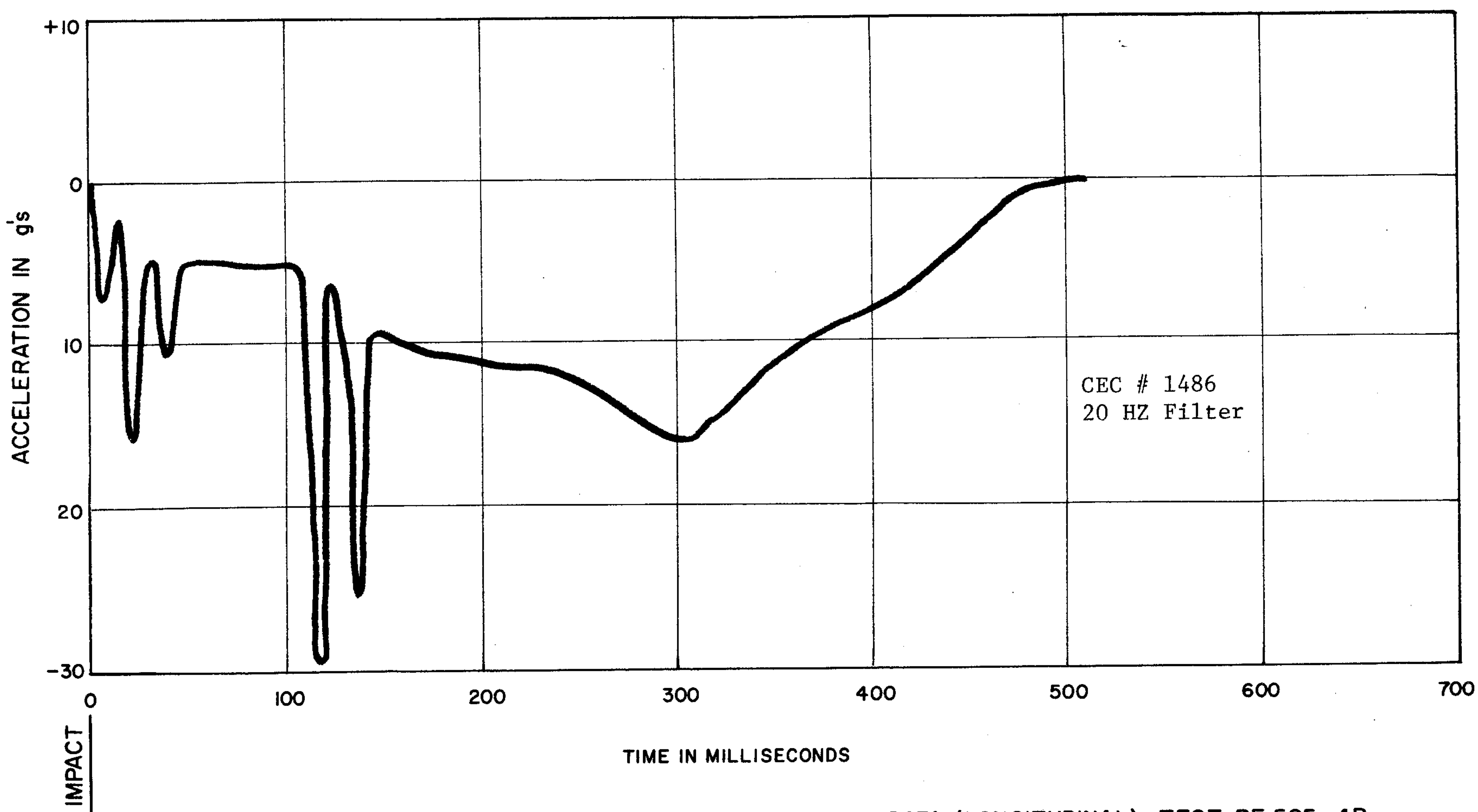

FIGURE C3, VEHICLE FRAME ACCELEROMETER DATA (LONGITUDINAL), TEST RF 505-4B

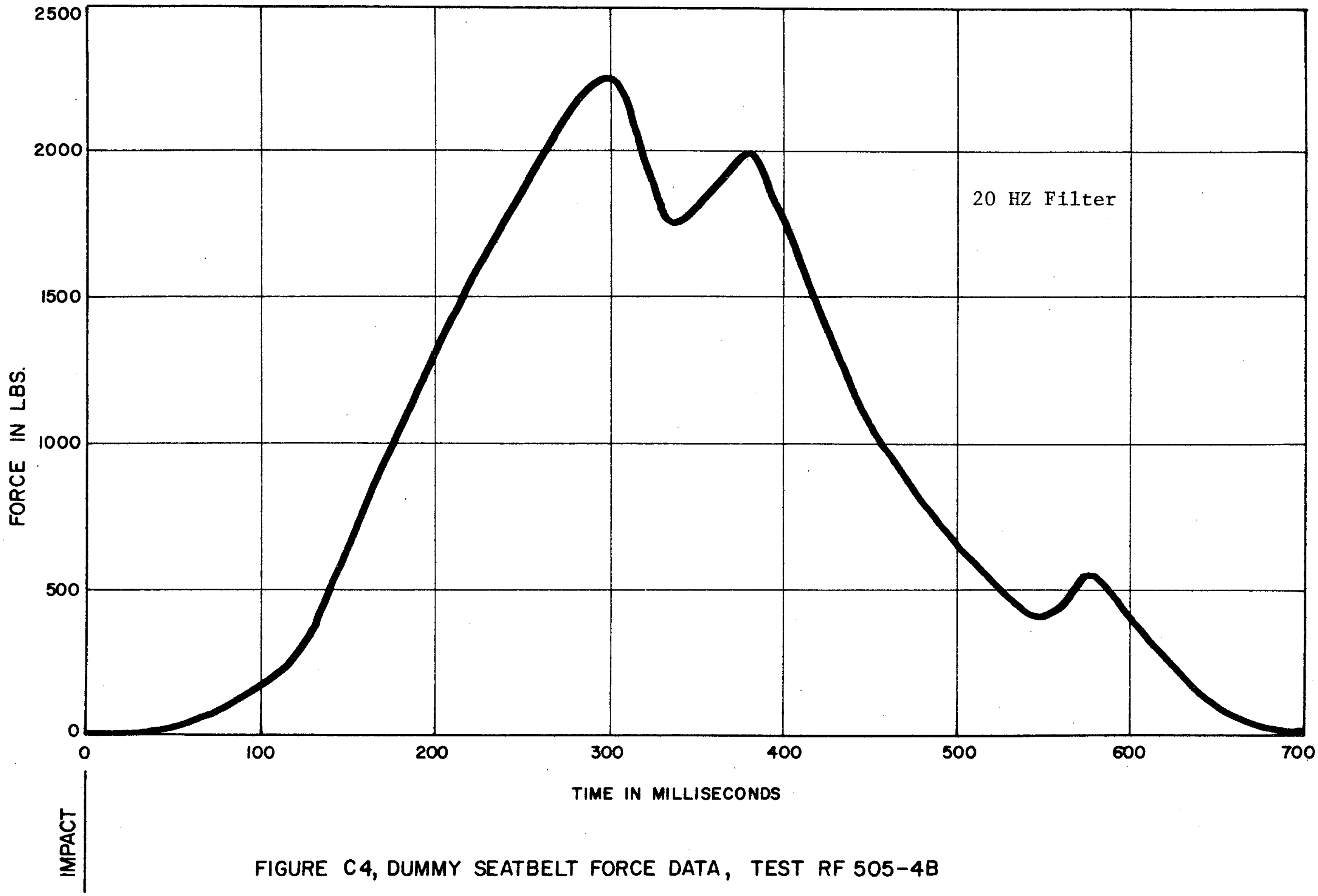

FIGURE C4, DUMMY SEATBELT FORCE DATA, TEST RF 505-4B

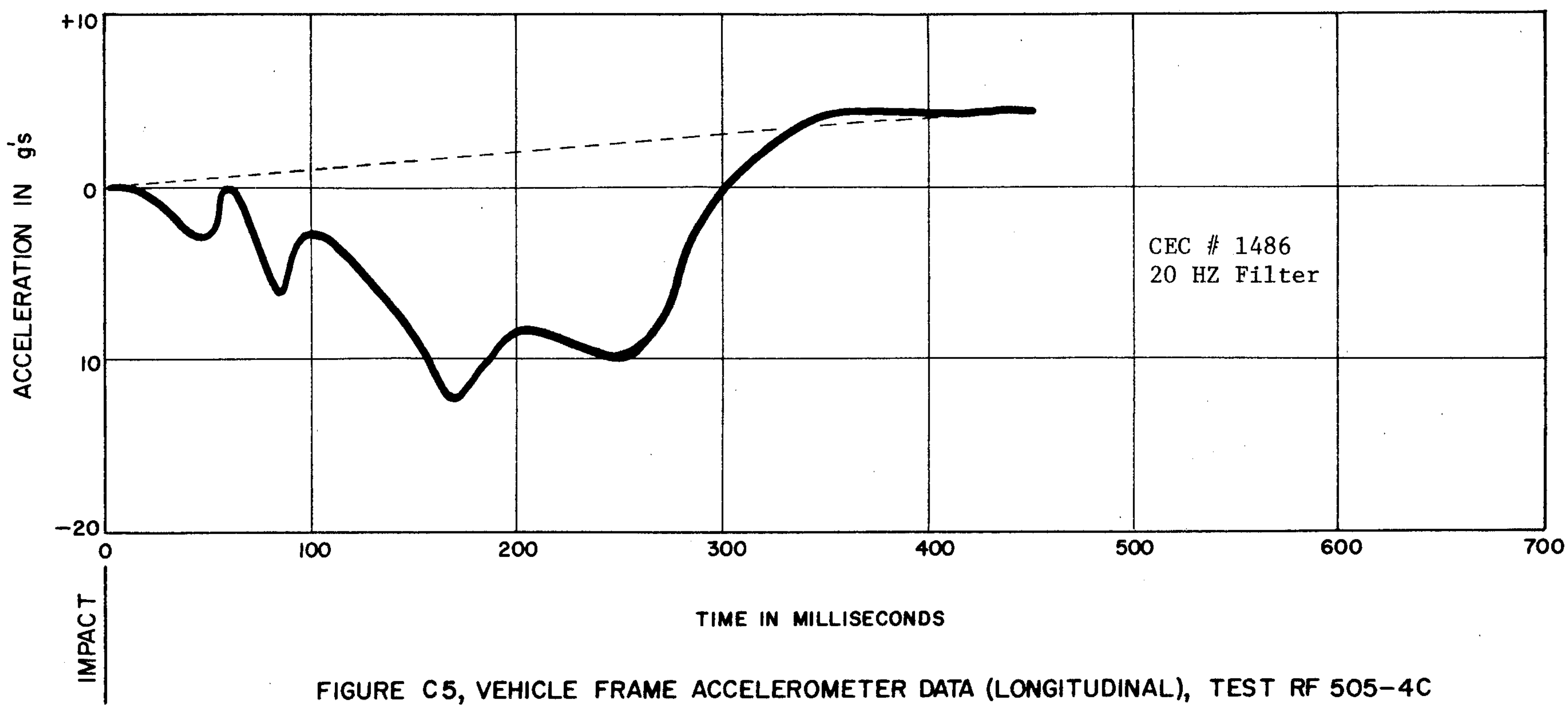

FIGURE C5, VEHICLE FRAME ACCELEROMETER DATA (LONGITUDINAL), TEST RF 505-4C

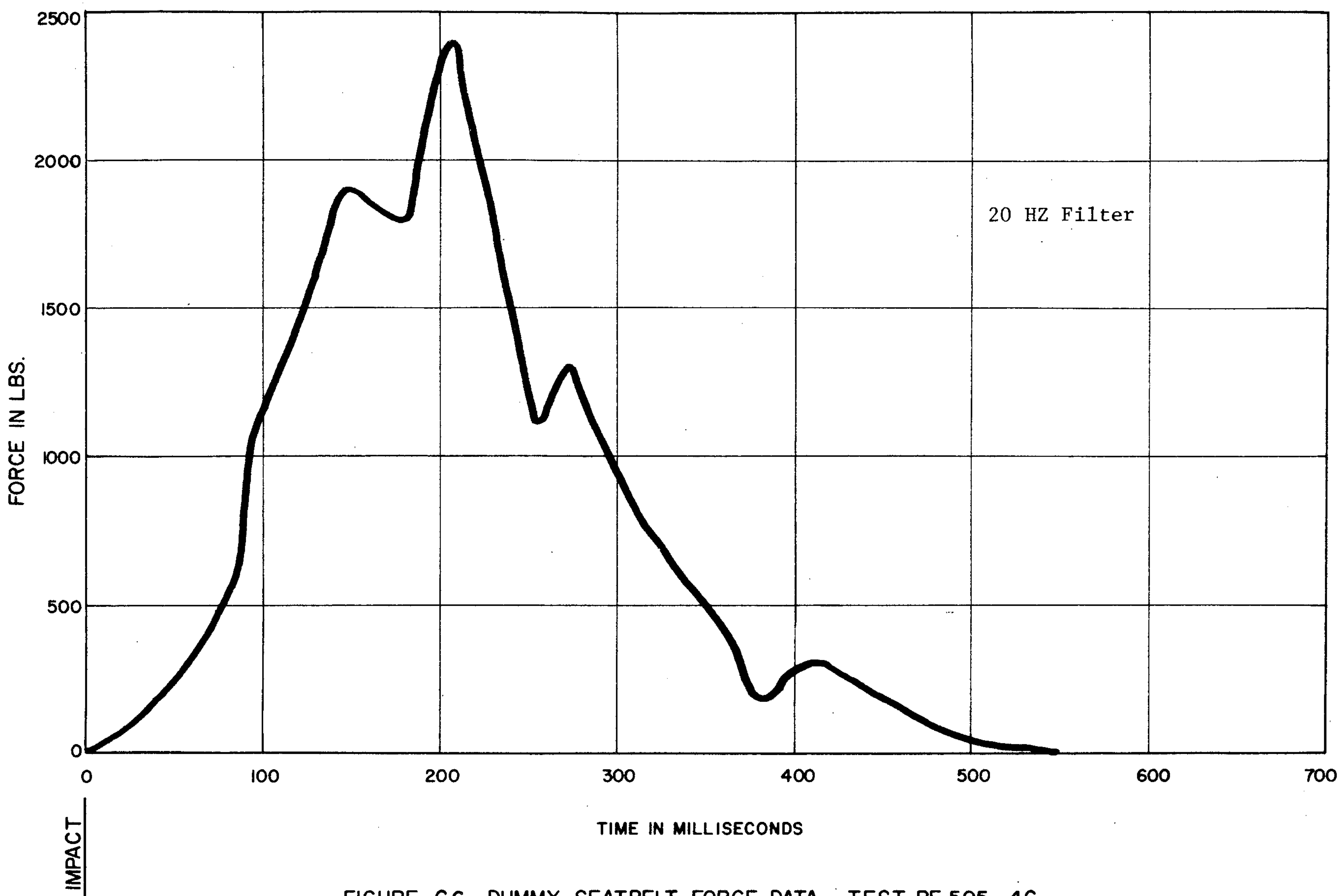

FIGURE C6, DUMMY SEATBELT FORCE DATA, TEST RF 505-4C

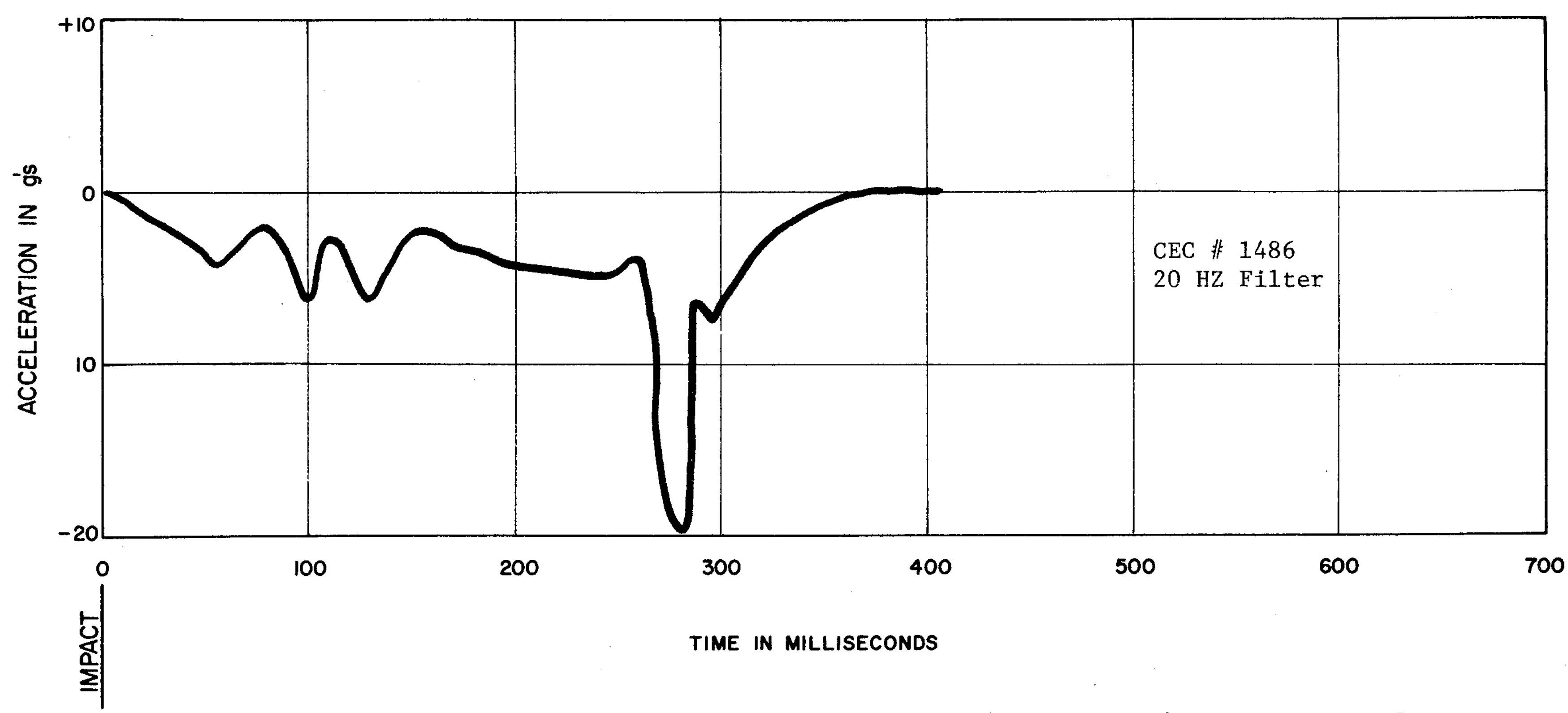

FIGURE C7, VEHICLE FRAME ACCELEROMETER DATA (LONGITUDINAL), TEST RF 505-4D

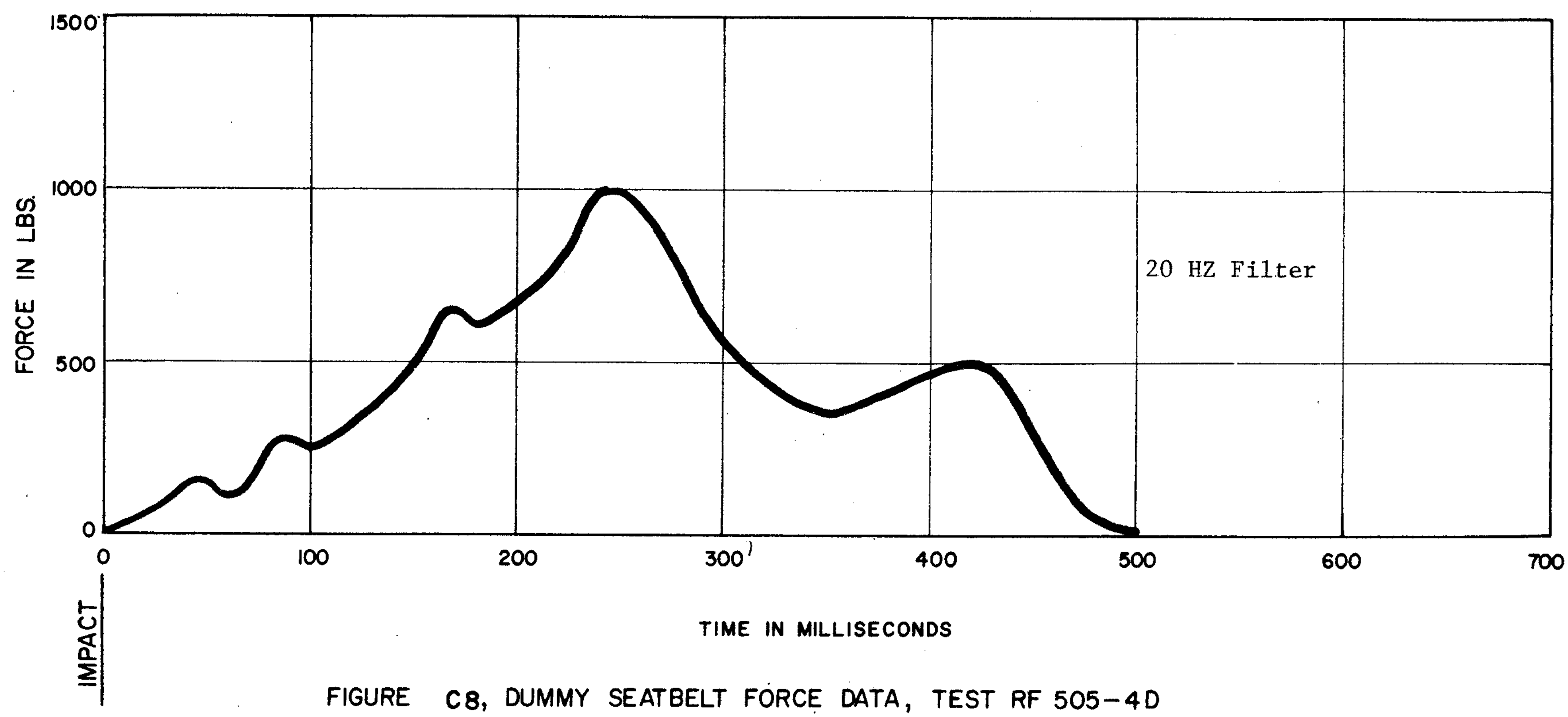

FIGURE C8, DUMMY SEATBELT FORCE DATA, TEST RF 505-4D

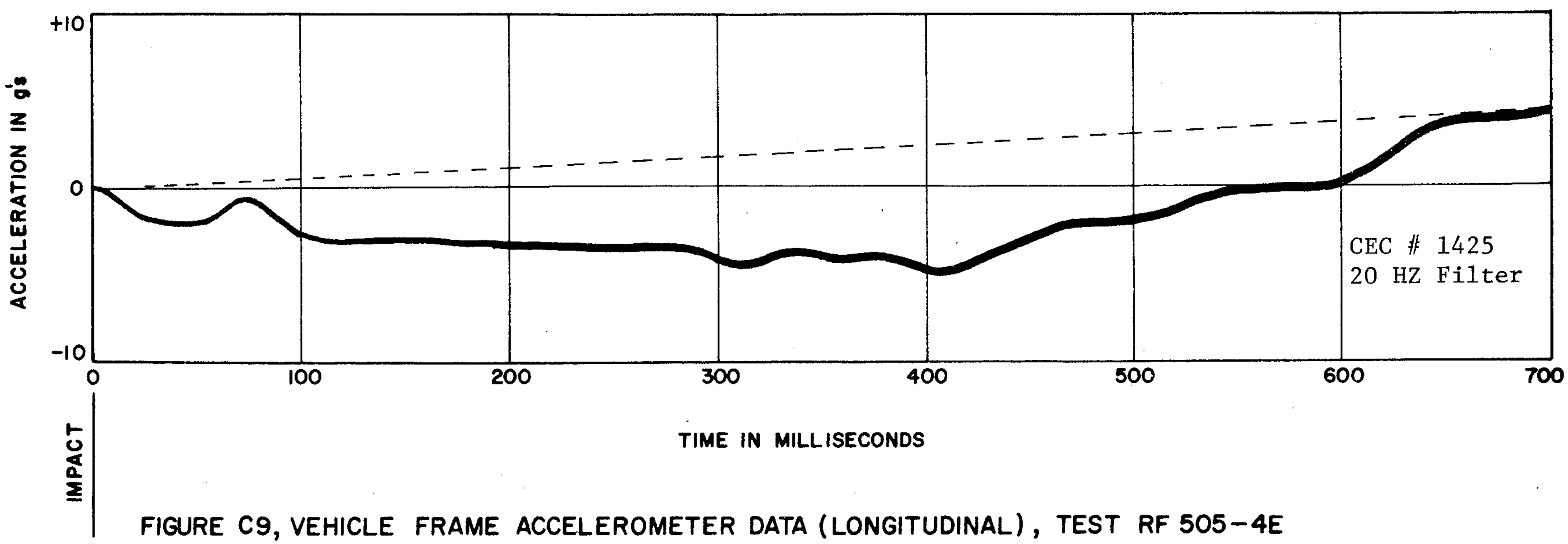

FIGURE C9, VEHICLE FRAME ACCELEROMETER DATA (LONGITUDINAL), TEST RF 505-4E

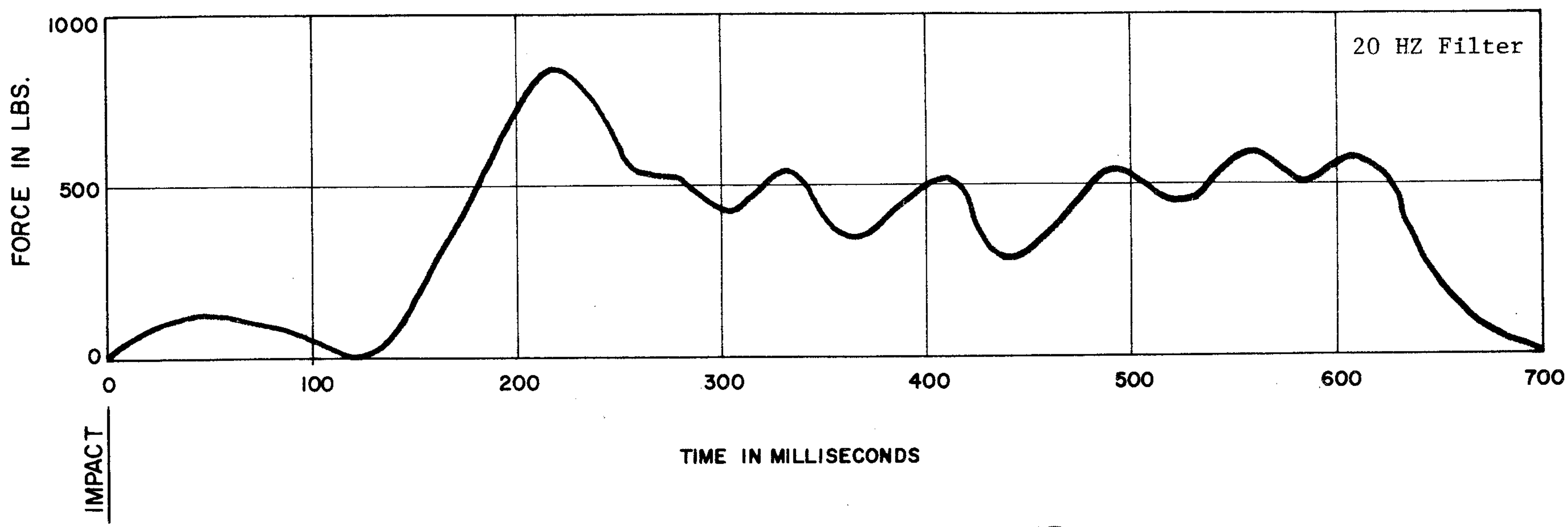

FIGURE C 10, DUMMY SEATBELT FORCE DATA, TEST RF 505-4E

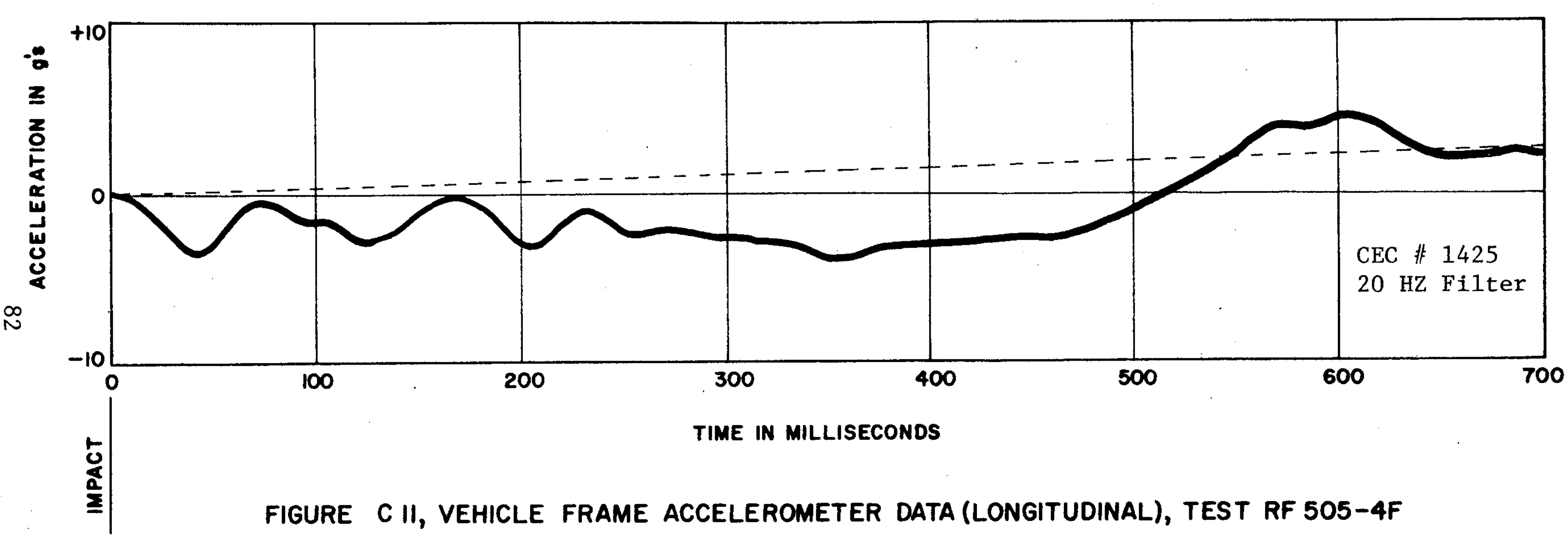

FIGURE C II, VEHICLE FRAME ACCELEROMETER DATA (LONGITUDINAL), TEST RF 505-4F

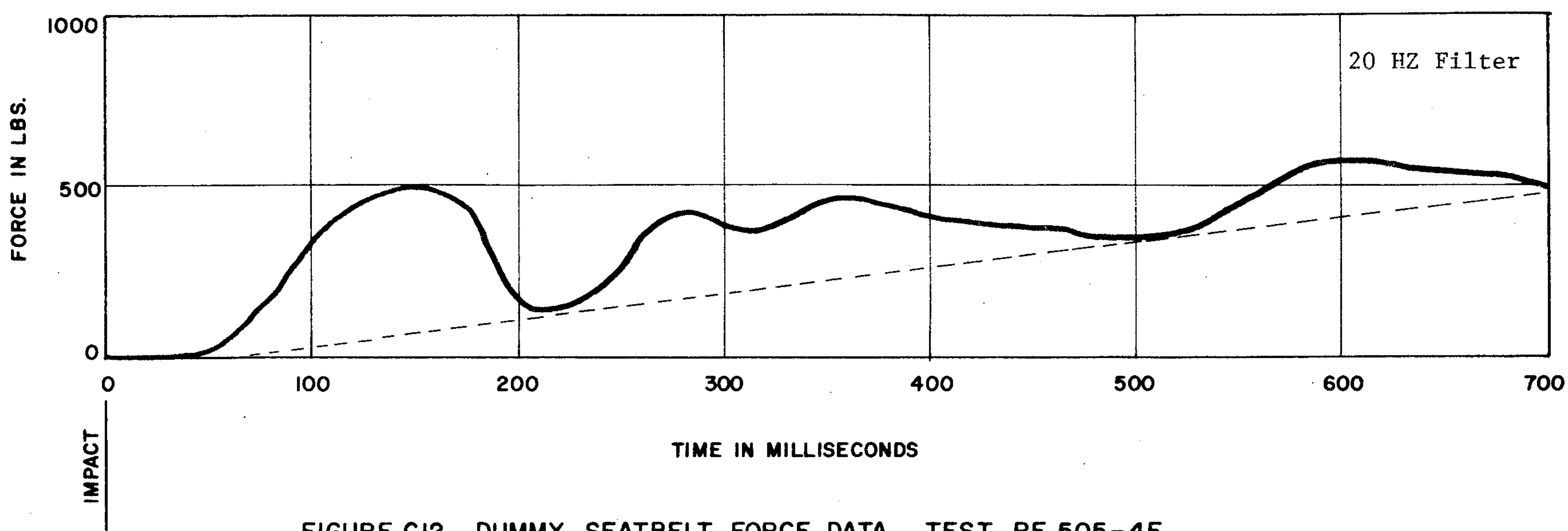

FIGURE C12, DUMMY SEATBELT FORCE DATA , TEST RF 505-4F