VEHICLE-ARRESTING SYSTEM USING CHAIN-LINK FENCE

E. L. Marquis, G. G. Hayes, and T. J. Hirsch, Texas Transportation Institute, Texas A&M University

Several areas along highways can be dangerous to errant high-speed vehicles that run off the roadway. Among these are medians between twin bridge approaches, dead ends, and barriers that close off entrance and exit ramps. A chain-link vehicle-arresting system was designed to prevent motorists from entering the median area between twin bridges and was tested. When the system proved a failure, it was modified by the manufacturer and retested under head-on and angle impacts. Retesting verified that dangerous median configurations could be successfully protected by a net system. It was also found that breakaway support posts would improve vehicle entrapment in the net.

SEVERAL FEATURES or areas along highways can be hazardous to vehicles leaving the travel way at high speeds. 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, and
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, either guardrails or no protective device is used in these areas. Guardrails, 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-lbm/ft (3-kg/m) steel delineator posts. Each end of the fence is attached to a Van Zelm metal bender energy absorber mounted on a standard wooden guardrail post (Fig. 1). Devices similar to this metal bender 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 that 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 (Fig. 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 simulate field conditions. Then 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 of sufficient size to fit over the top of a standard 7-in. (180-mm) guardrail post was placed in the center of the metal bender. 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, who provided brass bushings for all metal benders in stock, new tapes, and some financial support for retesting, was contacted. The retesting with brass bushings verified that the median configuration could be successfully protected by a dragnet system. As a result of the first retest, it was found that the fence support post could be made to break away to improve the fence-vehicle entrapment performance. For the final test, the fence posts were cut 4 in. (100 mm) above ground line, and a simple bolted lap splice was used as a breakaway feature.

DESCRIPTION OF ARRESTING SYSTEM

The basic arresting system consists of a chain-link fence attached through cables at each end of energy-absorbing devices. These devices, called metal benders, are cases containing a coil of metal tape that 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. When 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.

Figure 1 shows the system tested here. In this test series, the design resistance of each metal bender was 4,000 lbm (1800 kg). Previous tests of a similar system indicated that reasonably 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 net itself consisted of 11-gauge chain-link fence, 48 in. (1.2 m) high, with $^3/_8$-in. (9.5-mm) galvanized restraining cables threaded through the top and bottom. The net was supported in an upright position by five 2-lbm/ft (3-kg/m) Texas Highway Department standard delineator posts driven 2 ft (0.6 m) into the ground. The posts were cut and lap-spliced with brass screws to provide the 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. (180-mm) diameter wooden guardrail posts embedded 48 in. (1.2 m) in 12-in. (0.3-m) diameter concrete footings. The metal bender case with its contained coil of tape fits around the post and rests on a collar that 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 2 shows the layout of an installation on US-59 in Texas.

VEHICLE AND INSTRUMENTATION

The vehicle used in all three full-scale tests was a 1965 Pontiac sedan that weighed 4,400 lbm (1995 kg) including an anthropometric dummy secured in the driver's seat with a lap belt anchored through a load cell that indicated lap-belt force.

Longitudinal 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 allowed the electronic data with 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 film, which includes 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 (Figs. 3, 6, and 8) were made from these high-speed motion pictures.

DESCRIPTION OF TESTS

Test 2146-D1

Test 2146-D1 was a head-on impact in the center of the net at 62.9 mph (101.2 km/h). 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 (1.8 m) of tape was pulled from the metal bender, whereas 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 (6.43 m) and had slowed to

55 mph (88.5 km/h). The average deceleration to this point was 1.4 g. The test data for all tests are given in Table 1, and Figure 3 shows sequential photographs of the first test. Figure 4 shows the vehicle 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 (Fig. 5) was added, and static tests of the metal bender were conducted. These static tests were conducted by using a small crane to pull the tape at very slow speeds (about 1 fps or 0.3 m/s). A load cell was placed in line with the tape and crane to measure the pull-out force during the tests. About 50 ft (15 m) of tape was pulled during each test. The loads on the tape were relatively constant at 3,950 lbf (17 570 N) (rated capacity of MPB-5 metal bender was 4,000 lbf or 17 800 N).

Dynamic Test of Metal Bender With Bushing

After the static tests, a new tape was installed in one metal bender that was attached to an iron pipe, and the running end of the tape was attached through 200 ft of 1-in. (60 m of 250-mm) cable to a 5-ton (4.5-Mg) truck. The truck was driven at about 25 mph (40 km/h) past the metal bender and reached the end of the cable. The truck's momentum pulled out 67 ft (20 m) 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

Test D2 was intended as a rerun of test D1. The center, head-on impact speed was 57.1 mph (91.5 km/h). The vehicle stopped 60 ft (18 m) after impact, and again the center support post was bent over and allowed the vehicle to pass over it, whereas the net broke away from the other posts. Sequential photographs are shown in Figure 6. The net entrapped the front of the vehicle quite low as shown in Figure 7. The center post bending away from the vehicle may have caused this.

The left-hand tape pulled out 37 ft (11.3 m), whereas the right-hand tape pulled out 39 ft (11.9 m). This represents about 300 kip/ft (5.25 MN/m) of work, assuming 4,000 lbf (17 800 N) on each tape, as compared to 480 kip/ft (7.0 MN/m) of kinetic energy in the vehicle at impact. The predicted stopping distance (1) was 85 ft (26 m), which is 25 ft (7.6 m) 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, as compared to 2.0 g measured by the accelerometers. The decelerations are near to the accelerometer's lower limits, and thus the accelerometer data are only approximate.

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 at 30 deg to the perpendicular to the net. The wire mesh was reused. The deformation due to the previous test can be seen in Figure 8. The impact speed was 60.1 mph (96.7 km/h) giving an initial kinetic energy of 530 kip/ft (7.7 MN/m). 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 (20 m) with 34 ft (10 m) of tape expended on the left and 52 ft (16 m) on the right. Again, the predicted stopping distance of 92 ft (28 m) 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 Figure 8.

In the test, the center net-support post was made breakaway by cutting it in two

Figure 1. Chain-link vehicle-arresting system.

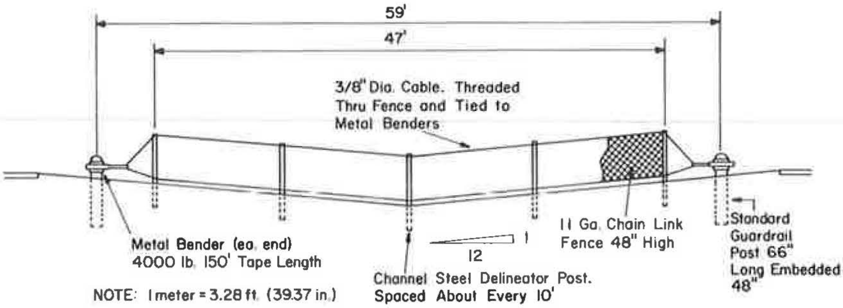


Figure 2. Layout of installation on US-59.

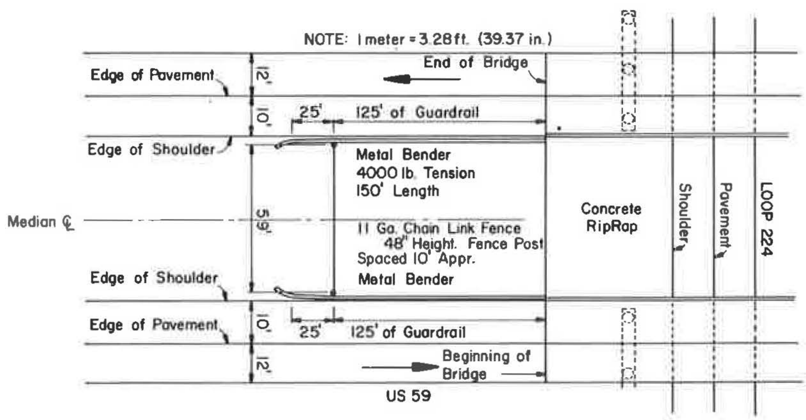


Table 1. Test data.

Specification	Test D1	D2	D3
Angle (deg)	0	0	30
Film data			
Initial speed (fps)	92.2	83.8	88.1
Final speed (fps)	80.8[a]	0	0
Maximum forward travel (ft)	21.1	59.8	69.4
Time to maximum forward travel (s)	0.26[a]	1.31	1.49
Average deceleration (g)[b]	1.4[a]	2.0	1.8
Electronic data			
Peak longitudinal deceleration (g)	3.1	2.0	—[c]
Peak lateral deceleration (g)	2.8	6.3	—[c]
Peak seat-belt force (lbf)	148	220	150
Physical measurements			
Tape runout (ft)			
Right	6.0[a]	39.3	52.0
Left	6.0[a]	36.7	34.0
Stopping distance (ft)		59.8	69.4

Note: 1 fps = 0.3 m/s; 1 ft = 0.3 m; 1 lbf = 4.4 N.

[a]At time metal tapes failed.

[b]$a = (V_o^2 - V_f^2)/2gs$.

[c]Collision with guide cable anchor masks interaction with net.

Figure 3. Test D1.

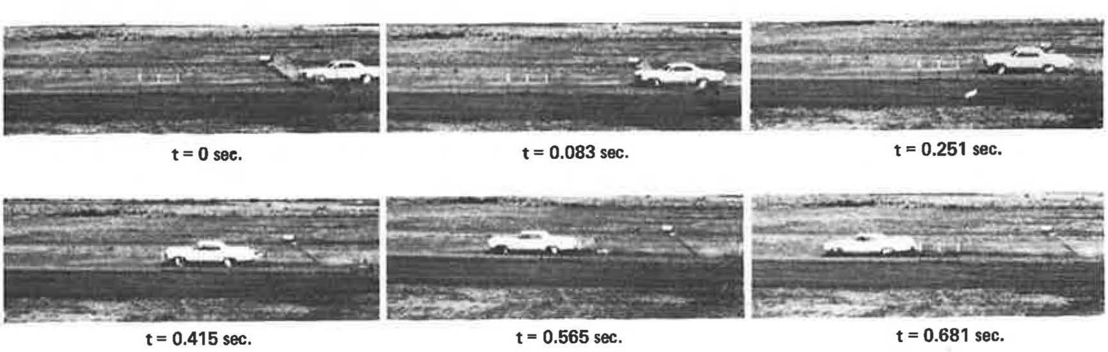
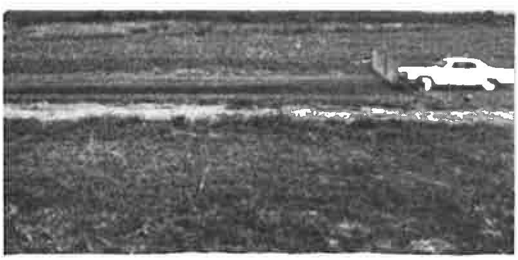


Figure 4. Vehicle after test D1 in which both tapes failed.

Figure 5. Brass bushing placed inside coil of reserve tape.

Figure 6. Test D2.



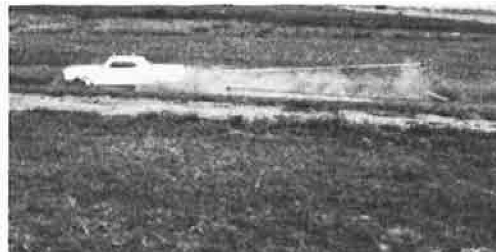
t = 0 sec.

t = 0.186 sec.

t = 0.267 sec.

t = 0.296 sec.

t = 0.916 sec.



t = 1.786 sec.

about 4 in. (100 mm) above the ground and fastening the two parts together with a lap splice secured by $^{3}/_{16}$-in. (4.7-mm) brass screws (or bolts). The post bent around the front of the car as shown in Figure 9. Note that the net entrapped the nose of the vehicle more securely than it did in test D2 (Fig. 7), 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 break away for noncentric impacts.

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 4,400-lbm (1995-kg) car was stopped in a straight line from approximately 60 mph (97 km/h) with tolerable decelerations with no noticeable damage in both the head-on and 30-deg impacts.

The stopping distance predictions based on previously developed equations were greater than observed, assuming 4,000 lbf (17 800 N) of tension from each metal bender. The stopping distance in the head-on test was 60 ft (18.3 m) as opposed to the predicted 85 ft (25.9 m), and in the angled test was 69 ft (19.8 m) compared to 92 ft (28 m) 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. Observation of the film data over a period after the tapes broke indicates a deceleration of about 0.15 g. Because the vehicle traveled 60 ft (18.3 m) in test D2 and 65 ft in test D3, this could account for 40 and 43 kip-ft (54 and 58 kJ) of energy respectively. The initial kinetic energy of the vehicle was 480 kip-ft (650 kJ) in the head-on test and 530 kip-ft (720 kJ) 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 because of rolling by the total tape pullout distance. In the head-on test, 76 ft (23.2 m) of tape was expended, whereas, in the 30-deg test, 86 ft (26.2 m) was used. This gives equivalent tape tensions of 5.8 and 5.7 kips (25.8 and 25.4 kN) respectively. (In test D3 some energy was lost in the collision with the guide cable anchor.) Less than 1 fps (0.3 m/s) of speed change would account for enough energy to make two equivalent tape tensions equal at 5.8 kips (25.8 kN). It is concluded that in both the head-on and angled test configurations 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 the magnitude seen here. Until further dynamic tests are conducted on these modified metal benders, it would seem that a dynamic load factor of 1.4 would be appropriate for use on metal benders with center holes when vehicle decelerations are being estimated. For estimating vehicle stopping distance, it would be conservative to use the 4,000 lbf (17 800 N) rated tape tension for these metal benders.

The breakaway net-support post seemed to permit better entrapment of the vehicle in test D3 than in test D2. Therefore, it seems desirable to convert all posts to the breakaway type inasmuch as noncentric impacts are likely in the field. These posts can be made breakaway by cutting, overlapping, and fastening with brass screws near the ground.

CONCLUSIONS

The dragnet installation using the Van Zelm metal benders is suitable for certain highway applications. The results of tests reported here show that the system may be installed in V-ditch medians with side slopes of 12:1 ratio, such as those found in wide medians. Certain precautions are necessary to ensure optimum performance of an installation.

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 (Fig. 5).

Figure 7. Vehicle entrapped in net after test D2.

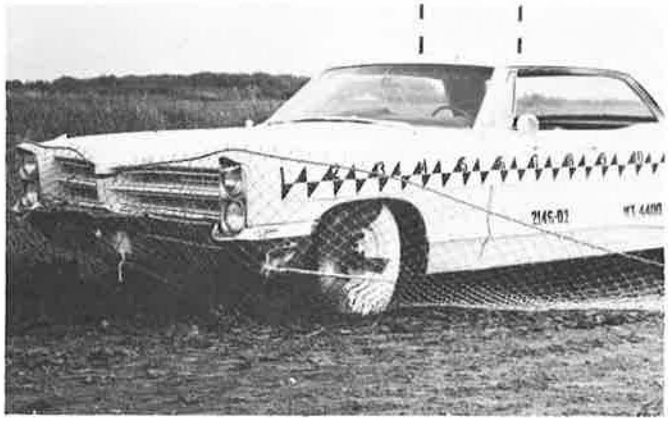


Figure 8. Test D3.

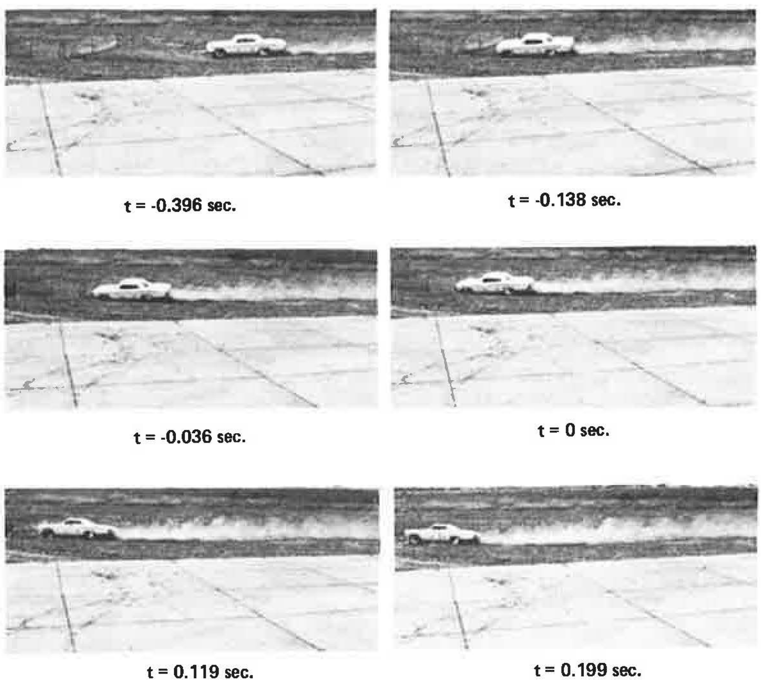


Figure 9. Vehicle entrapped in net after test D3.

2. The posts supporting the chain-link fence or other net fencing should be breakaway (Fig. 1), and the ties holding the fence to the posts should be single-strand aluminum wire spaced at approximately 12 in. (30 cm) on center.

3. The posts supporting the metal benders should be similar to standard guardrail posts so that they will break away 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 metal bender configuration, the minimum tape length and minimum site dimensions should be determined by using the rated tape force without applying the dynamic load factor.

5. On the other hand, the average decelerations should be estimated by computing the stopping distance by 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 for both installation and maintenance. However, there are apparent side effects, such as additional dynamic energy that was not absorbed in earlier configurations. Additional research is needed to determine more precisely the dynamic force and properties of this type of assembly.

ACKNOWLEDGMENT

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

REFERENCES

1. Hirsch, T. J., Hayes, G. G., and Ivey, D. L. Dragnet Vehicle Arresting System. Texas Transportation Institute, Tech. Memo. 505-4, Feb. 1969.
2. Damon, A., Stoudt, H. W., and McFarland, R. A. The Human Body in Equipment Design. Harvard Univ. Press, Cambridge, 1966.
3. Dragnet: Vehicle Safety Barrier System. The Entwistle Co., Boston.