ENERGY-ABSORBING CORRUGATED METAL HIGHWAY BUFFER

Richard J. Fay and Michael A. Kaplan, Denver Research Institute, University of Denver

A new concept in energy-absorbing highway buffers was developed and tested with scale models. The buffer is made of corrugated-metal elements that deform plastically on impact and absorb the energy of the impacting vehicle. The buffer has a parabolic shape to form a gradual transition between an energy-absorbing buffer for frontal impacts and an energy-absorbing guardrail for glancing, side impacts. The model buffer was found to perform well in a variety of situations including head-on, angled, and glancing impacts. Scale-model testing was found to be a valuable tool; tests were conducted for a small fraction of the cost and time of full-scale tests. Additional scale-model tests and some full-scale tests will need to be conducted before the design is completed.

•ENERGY-ABSORBING highway buffers should be designed according to certain performance criteria (1):

1. The buffer mass activated at impact should be small compared to the weight of the impacting vehicle;
2. The impacting vehicle should be assumed to be rigid;
3. The force-displacement curve should be such that a range of vehicles can be stopped without excessive loads being imposed on the lighter vehicles or excessive stopping distances being required for the larger vehicles;
4. Buffer deformation and motion should be localized to the immediate area of the impacting vehicle;
5. The buffer should not eject material onto the traveled roadway;
6. The buffer should not store mechanical energy;
7. The center of gravity of each portion of the barrier should be above the center of vehicle load application;
8. The buffer should not produce significant angular accelerations until the vehicle has been entrapped; and
9. The lateral stiffness of the buffer should be increased greatly toward the base.

The objective of our program was to develop a simple, inexpensive buffer satisfying those criteria and capable of performing well in a broad spectrum of impact situations including head-on, head-on off-center, angled-nose, angled-side, and glancing impacts. Further, it was desired that the barrier meet specific requirements of potential locations in the Colorado highway system. In general, those included (a) the capability to stop 60-mph vehicles weighing from 2,000 to 6,000 lb and having an average deceleration not exceeding 12.5 g in head-on impacts, (b) the capability to stop vehicles impacting the nose at speeds as high as 60 mph and angles as great as 20 deg to the longitudinal axis with lateral barrier displacement not exceeding 7 ft, and (c) the capability to stop vehicles impacting the side at speeds as high as 60 mph and angles as great as 10 deg with lateral barrier displacement not exceeding 7 ft and the vehicle not impacting the rigid support structure.

The authors initially conceived the idea of using a family of parabolic corrugated-metal arches oriented parallel to the surface of the roadway so that they would form a guardrail for glancing side impacts and would deform plastically to absorb the energy of a vehicle impacting the nose. This buffer was subjected to a variety of scale-model tests; modified buffers were also tested. Scale-model testing was used throughout the program to minimize costs. The validity of this approach has been demonstrated (2).

TESTING

Buffer testing was done with 1:25 scale models and a facility developed earlier (2). In the model tests, only the features known to affect the performance were simulated. The vehicle was a rigid wooden block equipped with wheels; it had no doors, fenders, lights, or other trim and did not deform on impact with the barrier. However, it had the proper mass and mass distribution (it was hollowed out on the underside), size, and coefficient of friction between the tires and the operating surface. Therefore, it was similar to the full-sized vehicle dynamically, except for minor differences that might occur from suspension-system deformation on the full-sized vehicle. The rigid model vehicle had the advantages of being reusable, being standardized, and giving conservative results (vehicle deformation reduces the amount of energy that the buffer must dissipate). The scale-model vehicle was equipped with brakes to simulate the resistance to rebound of a vehicle with the transmission in gear.

Scale Factors

It was shown in the earlier report (2) that the 1:25 scale model should have a fifth of full-scale velocity to produce impact accelerations of the same magnitude in the model and the prototype. For ease of interpretation, the results of the tests were appropriately factored to full scale.

Facilities

The scale-model barrier (buffer) testing facility is shown in Figure 1. It consists of a table equipped with a pneumatic launcher for the scale-model vehicle, an adjustable mounting for the barrier, a backstop to prevent the vehicle from leaving the table, and instrumentation for controlling the speed and taking data from the barrier crash. The speed of the vehicle was controlled by a pressure regulator in the pneumatic system. A timing station equipped with photo transistors and an electronic chronograph was used to take vehicle velocity data prior to impact with the buffers. A 16-mm high-speed movie camera mounted above the table was used to photograph the interaction of the vehicle and the barrier. A Vanguard motion analyzer was used to analyze the movies to determine the approximate displacement, velocity, and acceleration of the vehicle as functions of time. A 35-mm camera was used to take before-and-after photographs of the buffers.

Buffer Construction

The buffers were made of 0.003-in.-thick 1100-0 aluminum sheet cut into strips and corrugated by a pair of specially designed rollers. The corrugated strips were formed by hand, on curved dies, to the desired shape. Contact cement was used to fasten these together to form the buffers.

BUFFER DEVELOPMENT

Three well-defined types of metal arch buffers were studied in the course of the project: Type 1 consists entirely of 2 or more parabolic corrugated-metal arches, type 2 consists of metal arches and barrels, and type 3 consists of corrugated-metal arches and corrugated-metal stiffening elements.

Type 1

The original buffer, shown in Figure 2, performed well in head-on impacts (Fig. 3) and satisfied many of the buffer performance criteria. We learned that the force-displacement curve could be modified considerably by adjusting the corrugation depth and metal thicknesses in the 2 arches and by varying the number of arches in the buffer.

Figure 1. Scale-model barrier testing facility.

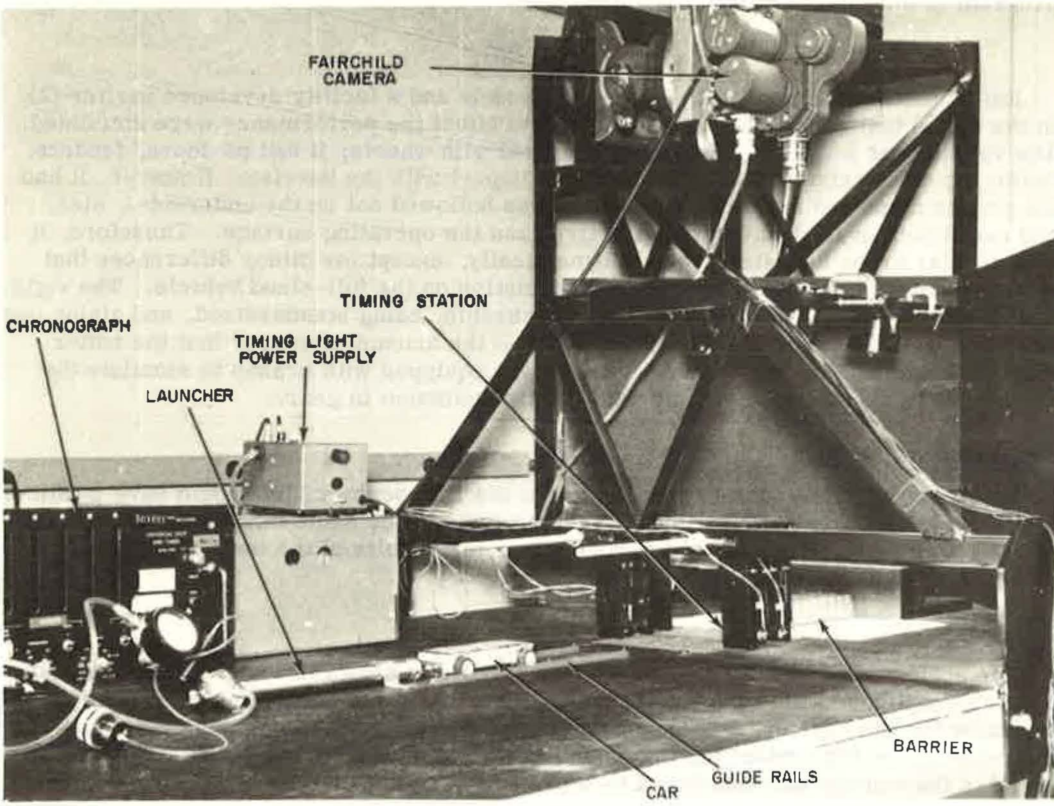
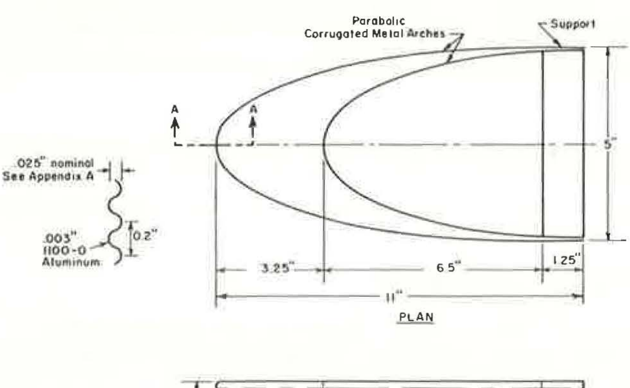
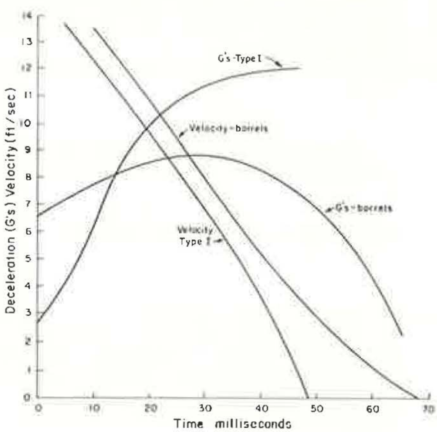


Figure 2. Type 1 buffer.



Note: Barrier elements are fastened together by contact cement at overlap points or as indicated.

Figure 3. Performance of type 1 buffer and Texas barrel barriers in head-on impact.



In glancing impacts the buffer acted as an energy-absorbing guardrail, redirecting the vehicle. Although holding considerable promise, this buffer had 2 serious limitations: (a) It provided no protection from the supporting structure for a hard glancing or an angled-side impact because the buffer arches terminated flush with the side of the support, and (b) it exhibited excessive lateral displacement in impacts at angles greater than approximately 10 deg.

In an attempt to maintain the simplicity of the buffer while providing protection from the support and minimizing the lateral displacement, we added stiffening leaves to the sides in the hope that this would increase lateral stiffness near the support so that a glancing vehicle would be redirected around the support. These were relatively ineffective in protecting the vehicle from the support, but the lateral displacement in angled impacts was reduced and the head-on performance was not adversely affected.

Type 2

From the results with the type 1 buffer, we concluded that it was necessary to increase lateral rigidity and to space the outside arch away from the side of the support to prevent vehicle contact with the rigid structure. This led to the development of the type 2 buffer (Fig. 4), which was wider, at its base, than the support. The stand-off between the outer arch and the side of the support was filled with scaled 55-gal drums like those used in the barrel buffer test reported earlier (2). The barrels were attached to the 2 arches, stiffening the buffer laterally.

Type 2 buffer performed very well in head-on, glancing, and angled-side impacts, but the lateral deflection in angled impacts was excessive. Also, the portion involving the barrels was too rigid. In some off-center head-on impacts and in some angle impacts on the nose, the barrel sections tended to act as columns, causing high g forces on the vehicle.

Type 3

The barrels were eliminated to minimize the column effect, internal stiffeners were added to provide lateral stiffening, and the spacers between the 2 arches were retained. The resulting type 3 buffer (Fig. 5) performed well in a variety of impact situations including head-on and nose impacts at angles as great as 20 deg to the longitudinal axis as well as angled and glancing impacts. Figure 6 shows a scale-model buffer before and after a head-on impact with a scale-model 4,000-lb vehicle at approximately 60 mph. (In all subsequent tests discussed in this report, a scale-model 4,000-lb vehicle was used.)

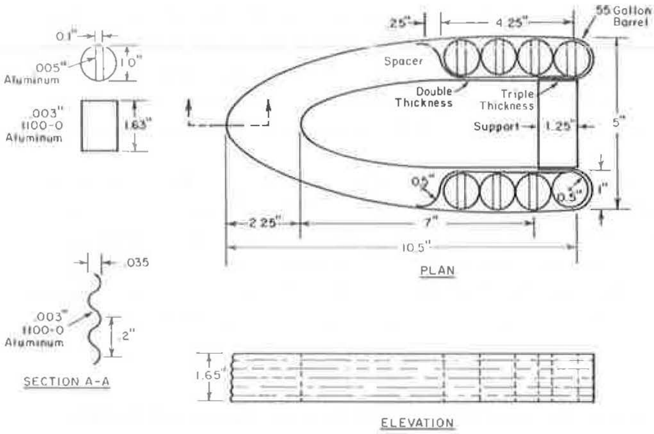
High-speed movies were taken of several impacts with the type 3 buffer and analyzed to determine the approximate displacement, velocity, and deceleration of the vehicle as a function of time. Figure 7 shows the results of the head-on test shown in Figure 6. The average deceleration of 7 to 8 g was well within the established limits of 12.5 g average.

A nose impact at 20 deg with the longitudinal axis is shown in Figure 8; the performance curves are shown in Figure 9. The deceleration peak is higher than the head-on impact because stopping distance is limited by the need to hold the lateral deflection of the buffer within the 7-ft limit. Other buffers that use cables for longitudinal stability have still higher decelerations in angle impacts.

The results of 3 tests with 4.0- and 4.5-ft off-center head-on impacts are shown in Figures 10, 11, and 12. The performance is a considerable improvement over that of the type 2 buffer. Performance curves for a 4.5-ft off-center impact are shown in Figure 13. Since significant lateral vehicle movement resulted, both the longitudinal x and transverse y displacements, velocities, and decelerations are plotted; the resultant deceleration is also plotted. In this case, the deceleration is higher than desired although, for this vehicle, it comes close to averaging 12.5 g. A reduction in the overlap of the interior brace would probably bring the deceleration for the off-center impacts down to a more desirable level. In the test shown in Figure 14, a 6.0-ft offset was used and the vehicle was redirected as desired.

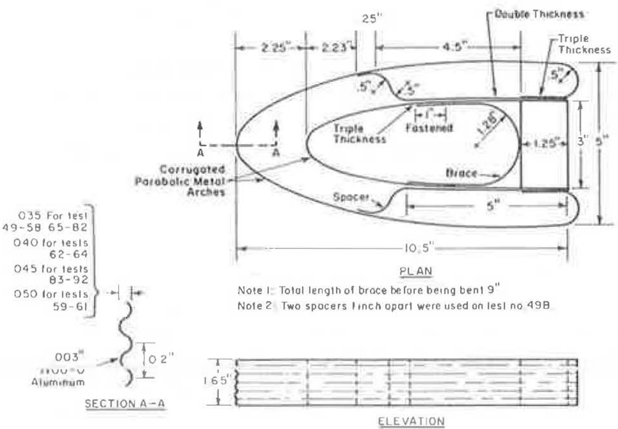
The results of 5- and 10-deg nose impacts are shown in Figures 15 through 18. Buffer performance in these tests was excellent.

Figure 4. Type 2 buffer.



Note. Barrier elements are fastened together by contact cement at overlap points or as indicated.

Figure 5. Type 3 buffer.



Note. Barrier elements are fastened together by contact cement at overlap points or as indicated.

Figure 6. Type 3 buffer test 83, head-on impact at 59.24 mph.

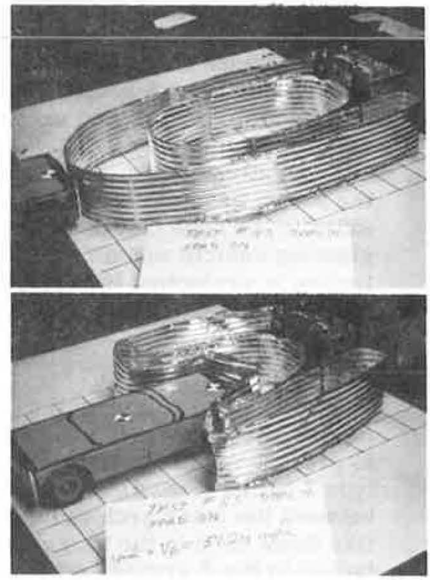
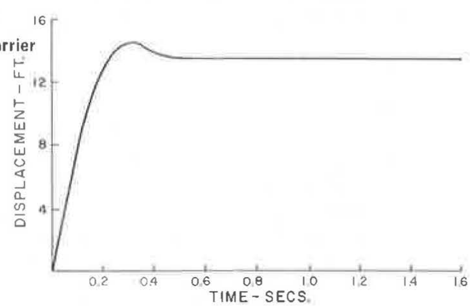
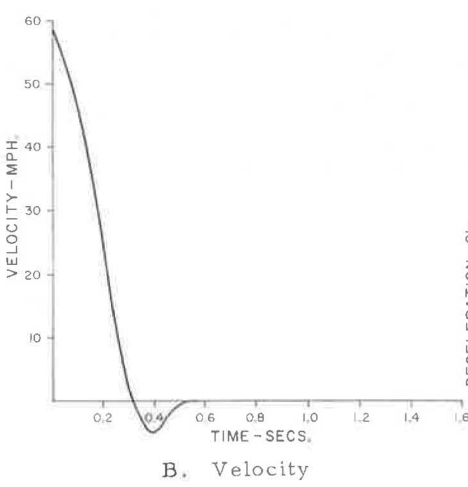


Figure 7. Performance curves for type 3 buffer test 83.

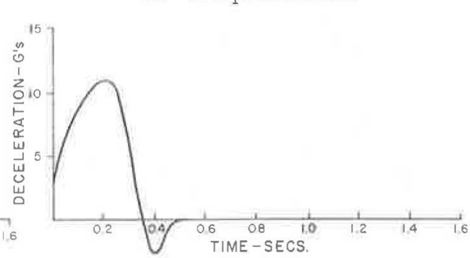
Dependent variables and time are given for full scale barrier
Type of Impact: Head on
Velocity of Impact: 59.24 MPH
Weight of Vehicle: 4000 lbs.



A. Displacement



B. Velocity

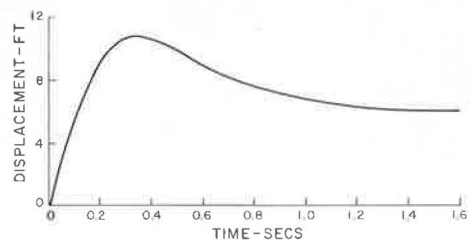


C. Deceleration

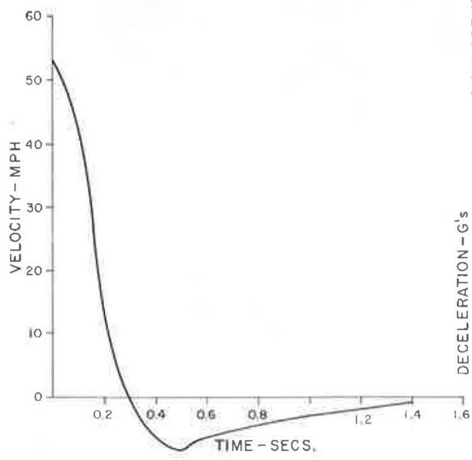
Figure 8. Type 3 buffer test 84, 20-deg angle nose impact at 53 mph.

Figure 9. Performance curves for type 3 buffer test 84.

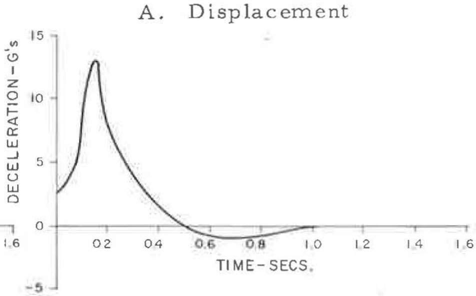
Dependent variables and time are given for full scale barrier
Type of Impact: 20°, nose
Velocity of Impact: 53.0 MPH
Weight of Vehicle: 4000 lbs.



A. Displacement



B. Velocity



C. Deceleration

Figure 10. Type 3 buffer test 85, 4-ft off-center head-on impact at 53 mph.

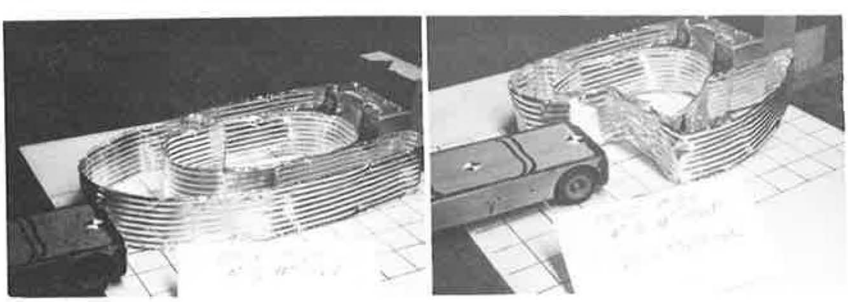


Figure 11. Type 3 buffer test 86, 4-ft off-center head-on impact at 53 mph.

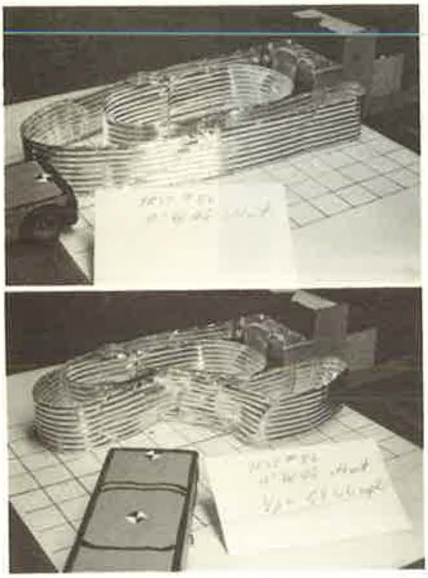


Figure 12. Type 3 buffer test 87, 4.5-ft off-center head-on impact at 54.84 mph.

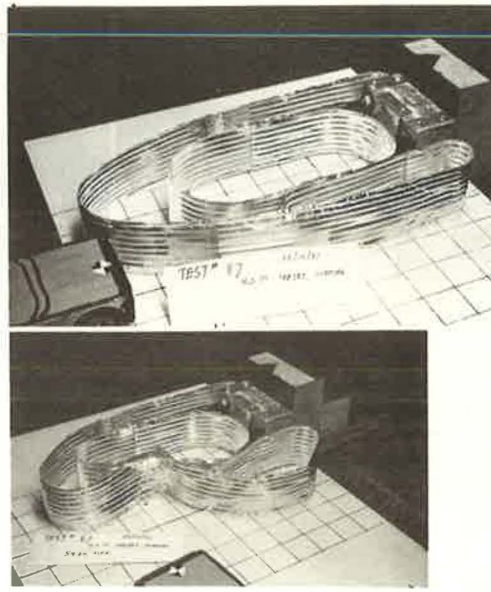
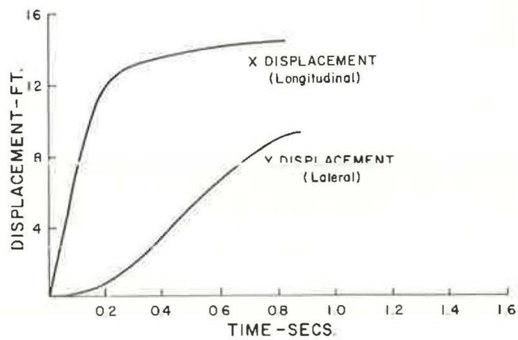
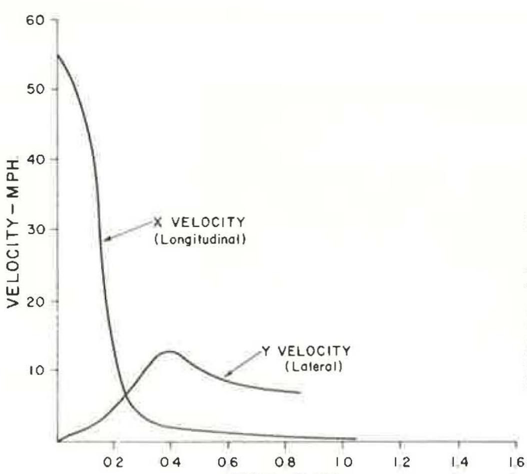


Figure 13. Performance curves for type 3 buffer test 87.

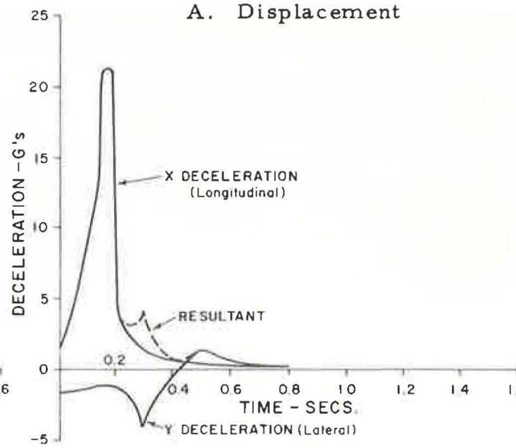
Dependent variables and time are given for full scale barrier
Type of Impact: 4.5 ft. offset, head on
Velocity of Impact: 54.84 MPH
Weight of Vehicle: 4000 lbs.



A. Displacement



B. Velocity



C. Deceleration

Figure 14. Type 3 buffer test 90, 6.0-ft off-center head-on impact at 62.99 mph.

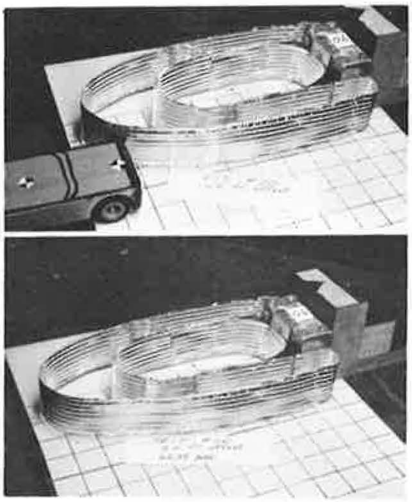


Figure 15. Type 3 buffer test 91, 5-deg angle nose impact at 62.5 mph.

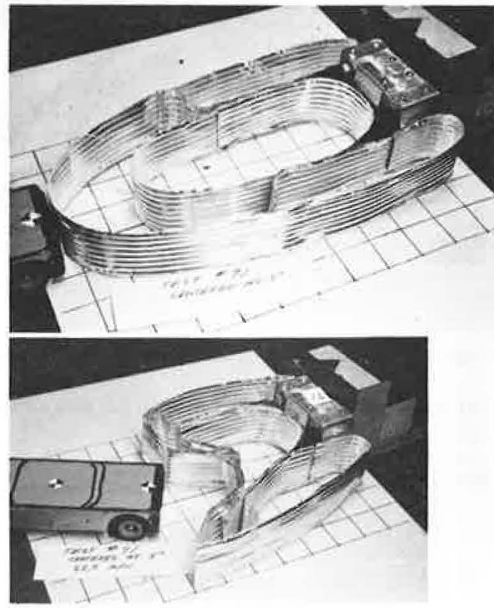
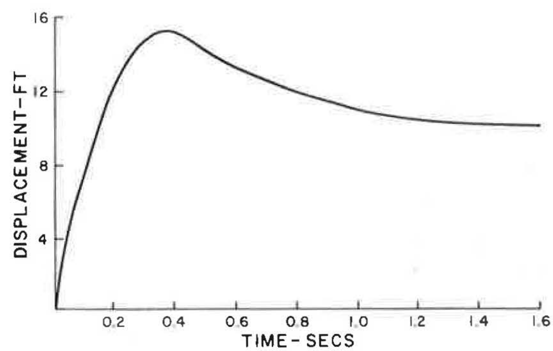
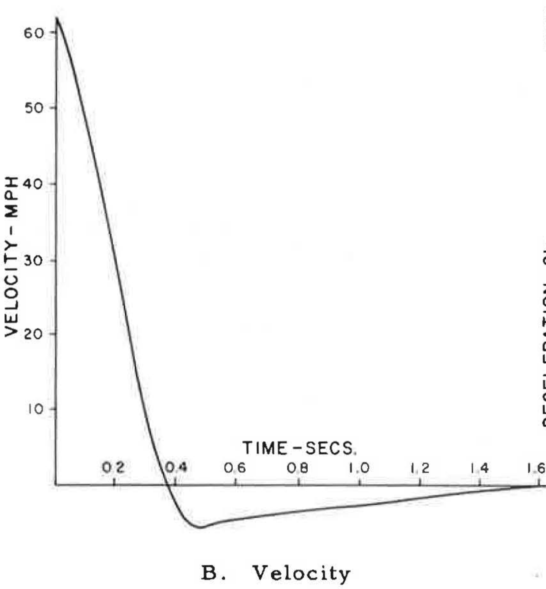


Figure 16. Performance curves for type 3 buffer test 91.

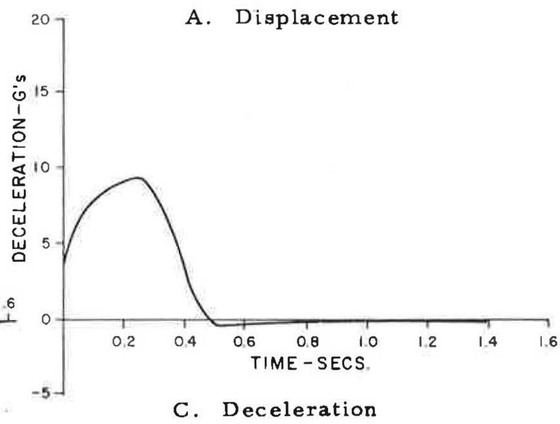
Dependent variables and times are given for full scale barrier
Type of Impact: 5.0°, nose
Velocity of Impact: 62.5 MPH
Weight of Vehicle: 4000 lbs.



A. Displacement



B. Velocity



C. Deceleration

Figure 17. Type 3 buffer test 92, 10-deg angle nose impact at 61.96 mph.

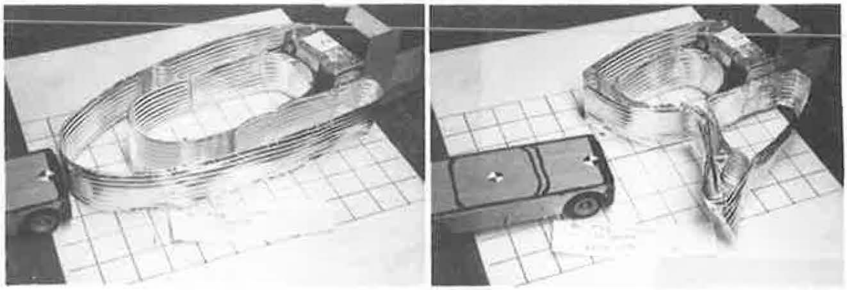
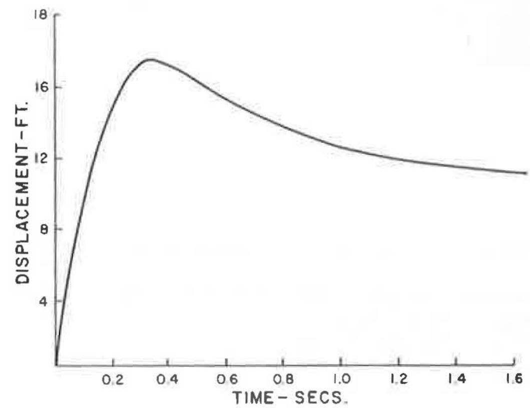
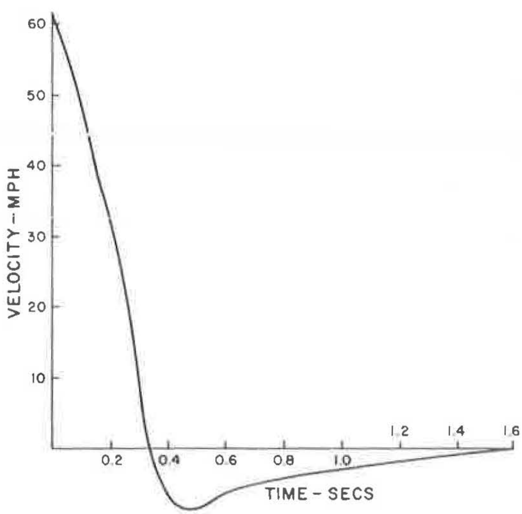


Figure 18. Performance curves for type 3 buffer test 92.

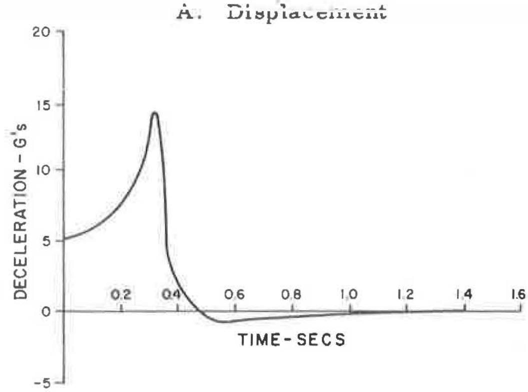
Dependent variables and time are given for full scale barrier
Type of Impact: 10°, nose
Velocity of Impact: 61.96 MPH
Weight of Vehicle: 4000 lbs.



A. Displacement



B. Velocity



C. Deceleration

CONCLUSIONS

The corrugated-metal arch buffer, although simple in design, performed very well in a wide variety of scale-model impact situations. The type 3 buffer has demonstrated an overall performance that merits additional studies and, eventually, full-scale tests. In addition, another version of this barrier should be developed for locations where lateral space is limited. This would require the addition of lateral stiffening such as cables, breakaway posts, or shoes in guides to limit the lateral deflection of the buffer in angled impacts so that the buffer cannot encroach on the traveled roadway.

This study has demonstrated the usefulness of scale modeling in the development of a new buffer. The entire program, costing little more than one full-scale buffer crash test, included several different impacts on variations of 3 types of buffers. The results of these tests in the form of before-and-after measurements, photographs, and high-speed films provided valuable insights that can be gained only through testing. The tests were done at a fraction of the cost of full-scale tests. Therefore, the program had a great deal of flexibility within a limited budget.

ACKNOWLEDGMENT

This work was made possible by a contract with the Colorado Department of Highways.

REFERENCES

1. Kaplan, M. A., Hensen, R. J., and Fay, R. J. Space Technology for Auto-Highway Safety. Highway Research Record 306, 1970, pp. 25-38.
2. Fay, R. J., and Wittrock, E. P. Scale-Model Test of an Energy-Absorbing Barrier. Highway Research Record 343, 1971, pp. 75-82.