Emergency Opening System for Authorized Vehicle Lanes

JAMES R. MORGAN, JOHN W. STRYBOS, HAYES E. ROSS, Jr., and JAMES G. DARDEN III

ABSTRACT

An emergency opening system (EOS) for an authorized vehicle lane was developed and crash tested. The design consisted of two steel box tubes mounted on top of each other. The beams were supported by pins at the ends connected to modified concrete median barrier sections. Factors considered in the development of the system were ease of operation and ability to redirect errant vehicles. Three full-scale crash tests were conducted to evaluate the impact behavior of the design. All the occupant risk values as well as the vehicle trajectory hazard were below recommended values for all the crash tests. In addition, the EOS was still operational after the first two tests. In the third test, the anchorage system for the downstream concrete median barrier failed; however, damage to the EOS was slight.

A $52 million project is under way in Houston to install an authorized vehicle lane (AVL) down the center of Interstate 45. This AVL will provide buses, vanpools, and other authorized traffic with an expressway free from normal traffic congestion over a distance of 13.1 miles (21.1 km). Concrete median barriers (CMBs) will be used to separate traffic within the AVL from the normal I-45 traffic. Limited access to the AVL will ensure smooth flow uninterrupted by unauthorized vehicles. However, in the event of a mechanical problem, minor breakdown (e.g., a flat tire), accident, or other emergency, this limited access will also impede the wrecker or other emergency equipment and cause major traffic congestion. Such an eventuality makes the implementation of a gate or emergency opening system (EOS) for the AVL essential.

The design of an EOS for a CMB involves several key parameters. The EOS must function as a median barrier in its ability to safely redirect errant vehicles and stop them from entering adjacent traffic lanes. This should be achieved without endangering the driver during vehicle redirection. At the same time, the operator of the emergency vehicle must be able to open the EOS into the AVL. This requires that the EOS either be lightweight or include provision for mechanical or electrical devices to aid in its operation. Furthermore, it would be desirable to have an EOS that would remain operational following moderate impacts with little or no maintenance. Guidelines and designs also are needed to properly transition the CMB on both the upstream and downstream ends of the EOS. An EOS meeting these requirements was designed, fabricated, and tested at the Texas Transportation Institute (TTI) proving grounds. Details of the EOS and descriptions of the tests and system performance are presented in the following sections.

EMERGENCY OPENING SYSTEM

The EOS must perform as a median barrier in its ability to safely redirect errant vehicles and stop them from entering adjacent traffic lanes. Furthermore, it must able to be opened and closed by the operator of the emergency vehicle. Finally, the barrier should be relatively inexpensive to build and maintain, and it should not be too difficult to install. Consultation with several state highway departments found that there was no system now in operation that would satisfy all these requirements.

The strength of the EOS was achieved by using two square steel tubes mounted on top of each other and separated vertically by 1.38 in. (3.5 cm). The tubes were mounted between two modified CMB sections 30 ft (8.9 m) long that were separated 30 ft. The details of the EOS design and operation are given in Figures 1 and 2. The size and orientation of the steel members were selected on the basis of information from a computer analysis. The EOS was analyzed with a computer program developed to study the behavior of an automobile striking a deformable barrier of general configuration (1). In the computer program, a dynamic, inelastic large displacement structural analysis problem is solved in two dimensions by using a step-by-step method. The automobile is modeled as a plane body of arbitrary shape surrounded by inelastic springs. During impact, the automobile slides along the barrier. Forces between the automobile tires and the pavement as well as the interaction forces between the automobile and the barrier are taken into account. The barrier is modeled as an assemblage of beams, posts, springs, and damping devices with loads applied to the barrier only at the nodes. For the purposes of this study the barrier was modeled as a system of 20 beam elements. Impact with a large, 4,500-lb (2040-kg) vehicle traveling at 60 mph (96.6 km/hr) and 25 degrees was investigated. The joint loads, 250 kips (34.6 kN) axial and 50 kips (6.9 kN) lateral shear, and deflections from this simulation were used to design all the appurtenances of the EOS.

The connections and supports of the EOS were designed by using the applicable standards (2,3) to transmit and contain the peak loads obtained in the computer simulation. The details of the EOS design have been presented elsewhere (4). The system consists of a 30-ft-long steel beam section, which is pinned at each end to a 30-ft-long modified CMB. A 3.25-in. (8.3-cm) diameter steel pin in quadruple shear transfers the load at each end of the EOS through tongue plates to a base plate bolted to the CMB. Further details of the system, in both as-tested and modified configurations, are available elsewhere (4).

Tests were conducted after the EOS was fabricated to demonstrate the ease of operation by a single emergency vehicle operator. The complete EOS tested was 90 ft (27.4 m) long and cost approximately

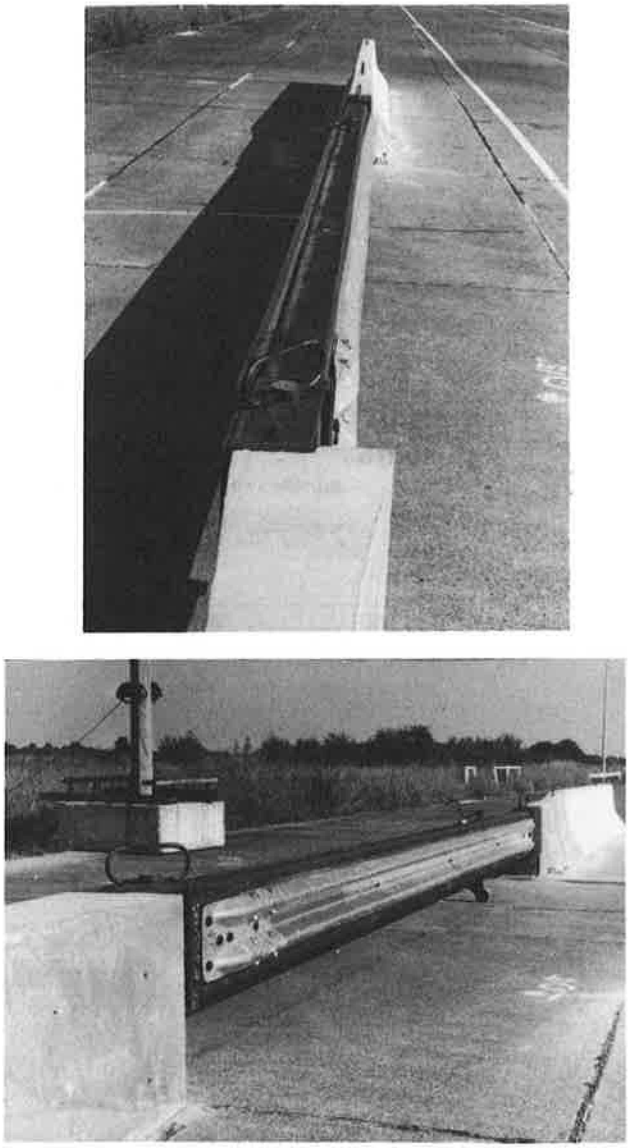


FIGURE 1 Emergency opening system.

$19,300. The cost included two 30-ft-long modified CMB sections. At a cost of $215 per foot ($705 per meter), the barrier compares favorably with other alternatives. The average cost of repairing the EOS after three full-scale crash tests was approximately $300. This value does not include the cost to replace the downstream CMB section after the third test.

TEST DESCRIPTION

Instrumentation

Test vehicles were equipped with triaxial accelerometers mounted near the center of gravity. Yaw, pitch, and roll were sensed by on-board gyroscopic instruments. The analog signals were telemetered to a base station for recording on magnetic tape and display on a real-time strip chart. Provision was made for transmission of calibration signals before and after the test, and an accurate time reference signal was simultaneously recorded with the data.

Tape switches near the impact area were actuated by the vehicle to indicate elapsed time over a known distance to provide a quick check of impact speed. The initial contact also produced an "event" mark on the data record to establish the instant of impact.

High-speed motion pictures were obtained from various locations, including overhead, to document the events and provide a time-displacement history. Film and electronic data were synchronized through a visual-electronic event signal at initial contact.

Crash Test Results

Three full-scale crash tests, designed to evaluate the limits of performance of the barrier, were conducted on the EOS. The vehicle impact point for Tests 1 and 3 was 6 ft (1.8 m) upstream from the downstream end of the gate system. This point of impact should cause the maximum forces on the CMB anchorage system and the maximum forces on the steel gate to the CMB section connection. In addition, this impact point should give the greatest possibility of vehicle snag on the barrier. The impact point for Test 2 was 6 ft upstream from the midpoint of the gate. This point of impact should cause maximum beam deflections and maximum forces in the beam. The tests are summarized in Table 1.

Test 1

In the first test, an 1,800-lb (815-kg) Honda Civic 1200 (1977) impacted the EOS 6 ft upstream from the downstream end of the steel gate system at 55.2 mph (88.8 km/hr) and 15 degrees. Figure 3 shows sequential photographs of this test. The test vehicle was smoothly redirected. The vehicle exit angle and speed were 5.5 degrees and 48.0 mph (77.3 km/hr), respectively. The occupant impact velocities were 14.15 ft/sec (4.31 m/sec) longitudinal and 16.42 ft/sec (5.00 m/sec) lateral. The peak 50-msec average acceleration was 4.27 *g* longitudinal (Figure 4) and 7.52 *g* lateral (Figure 5). All the occupant risk values as well as the vehicle trajectory hazard are below recommended values (5) for this type of test.

The test vehicle and installation after the test are shown in Figures 6 and 7. Damage to the vehicle occurred when the W-beam corrugation dragged the front bumper down and the left front tire snagged on one corner of the downstream CMB section. The vehicle damage consisted of sheet metal damage to the left front fender, a flattened left front tire, and a left front tire rim that was bent from the impact with the CMB. The EOS was damaged by having the paint scraped off the W-beam at the impact point and some surface cracking in the downstream end of the CMB. The only repair to the gate was repainting the W-beam at the impact point. The EOS was still operational after this test, which was considered a success based on the barrier safety performance and the relatively light damage incurred by the system.

Test 2

In Test 2 the strength of the gate system was examined. A 4,500-lb (2040-kg) Plymouth Grand Fury (1977) impacted the EOS 6 ft upstream from the midpoint of the steel gate at 60.7 mph (97.7 km/hr) and 25.25 degrees. Figure 8 shows sequential photographs of this test. The test vehicle was smoothly redirected. The occupant impact velocities were 18.89 ft/sec (5.76 m/sec) longitudinal and 22.77 ft/sec (6.94 m/sec) lateral. The vehicle exit angle was 4 degrees and the vehicle exit velocity was 47.96 mph (77.2 km/hr). The peak 50-msec average acceleration was 5.77 *g* longitudinal and 9.32 *g* lateral. The

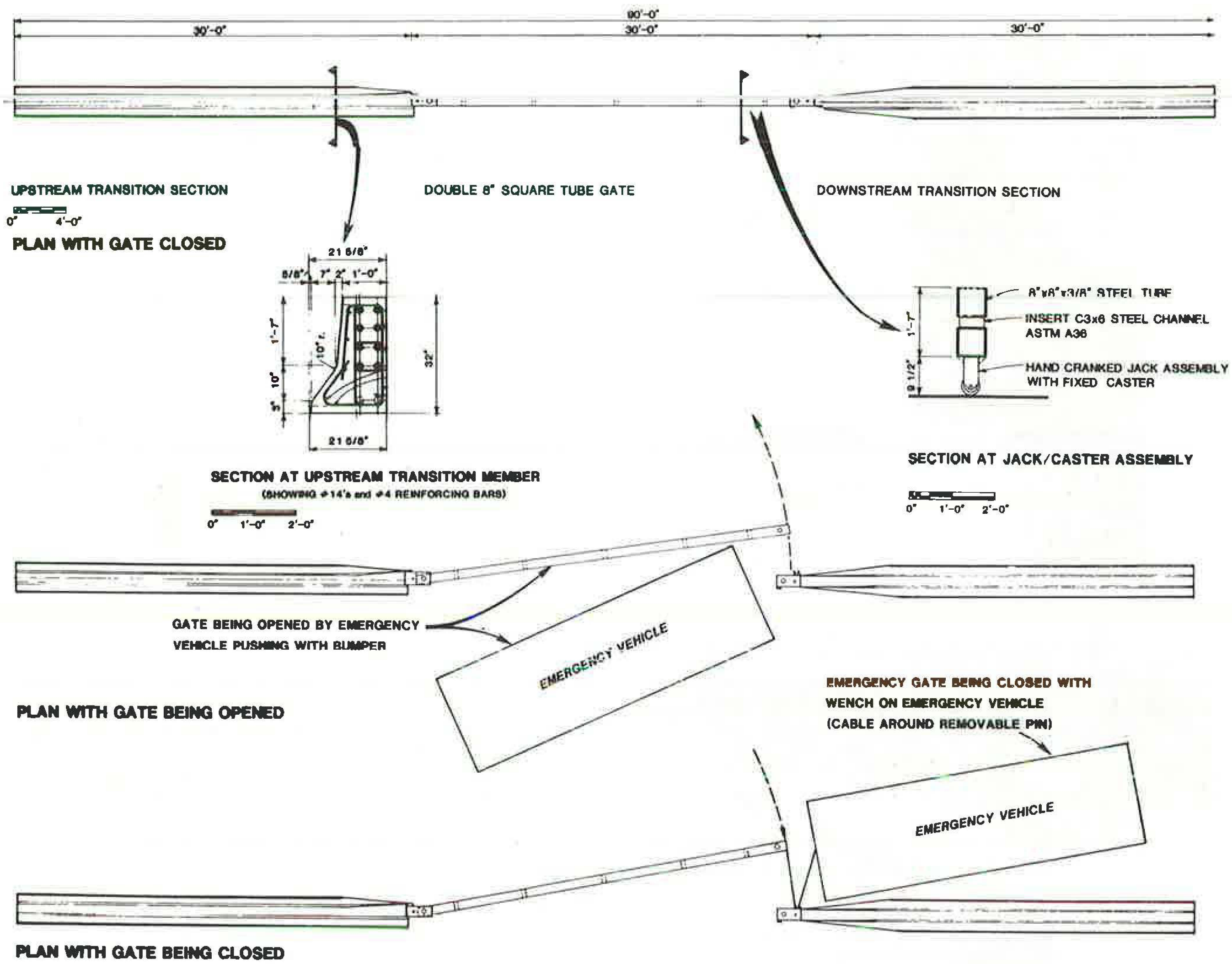


FIGURE 2 EOS in operation.

TABLE 1 Summary of Crash Tests

	Test 1	2	3
Vehicle weight (lb)	1,800	4,500	4,500
Impact speed (mph)	55.2	60.7	60.04
Impact angle (degrees)	15.0	25.25	25.5
Exit speed (mph)	48.0	47.96	39.01
Exit angle (degrees)	5.5	4.0	1.75
Maximum beam deflection (in.)			
Dynamic	3.36	17.16	30.84
Permanent	0.0	1.63	23.88
Maximum CMB movement (in.)			
Dynamic	2.04	15.12	31.68
Permanent	0.0	3.75	24.00
Maximum CMB roll (degrees)	0.0	3.5	9.0
Maximum CMB yaw (degrees)	0.0	0.0	5.5
Occupant impact velocity (ft/sec)			
Longitudinal	14.15	18.89	25.62
Lateral	16.42	22.77	20.54
Vehicle accelerations (*g*)			
Occupant ridedown			
Longitudinal	1.49	8.21	4.11
Lateral	10.83	7.78	6.99
Peak 50-msec avg			
Longitudinal	4.27	5.77	8.59
Lateral	7.52	9.32	8.32
Vehicle damage classification			
Traffic Accident Data	10LFQ4	11LFQ5	11FL6
Vehicle Damage Index	10LFEW3	11LDEW4	11FDAW6

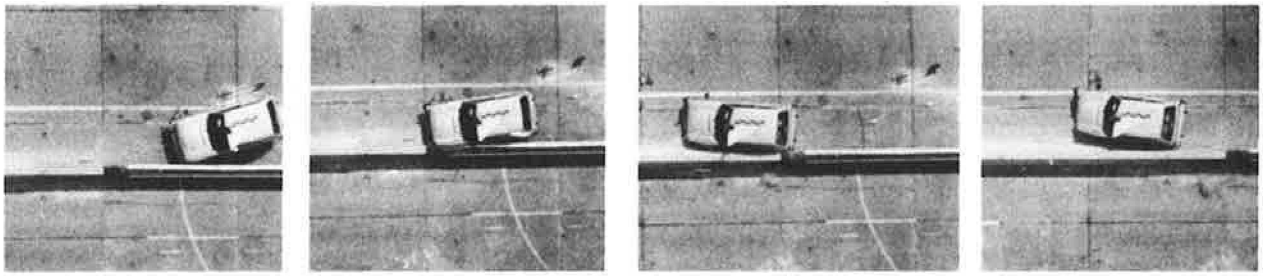
Note: 1 lb = 0.45 kg; 1 mph = 1.61 km/hr; 1 in. = 2.5 cm; 1 ft/sec = 0.3 m/sec.

vehicle accelerations were within acceptable limits (5) for this type of test. The longitudinal occupant impact velocity was also within acceptable limits, but the lateral occupant impact velocity exceeded the recommended value, although it was less than the limiting value. In addition, this type of test was not required to meet the NCHRP (5) criteria.

The damage incurred by the test vehicle and installation is shown in Figures 9 and 10. The vehicle sustained sheet metal damage to the left front fender. The EOS damage included the W-beam on the vehicle impact side of the gate, which had to be replaced, and noticeable flexural cracking in the CMB sections. The permanent beam deflection was 1.63 in. (4.1 cm). The gate could still be opened after this test, which was considered very successful based on the safety performance of the system.

Test 3

In Test 3 the strength of the beam-to-CMB connection was examined. A 4,500-lb Plymouth Grand Fury (1977) impacted the EOS 6 ft upstream from the downstream end of the steel gate system at 60.04 mph (96.6 km/hr) and 25.5 degrees. Figure 11 contains sequential photographs of this test. The test vehicle was smoothly redirected. The vehicle exit angle was 1.75



0.000 sec | 0.095 sec | 0.240 sec | 0.328 sec

FIGURE 3 Sequential photographs, Test 1.

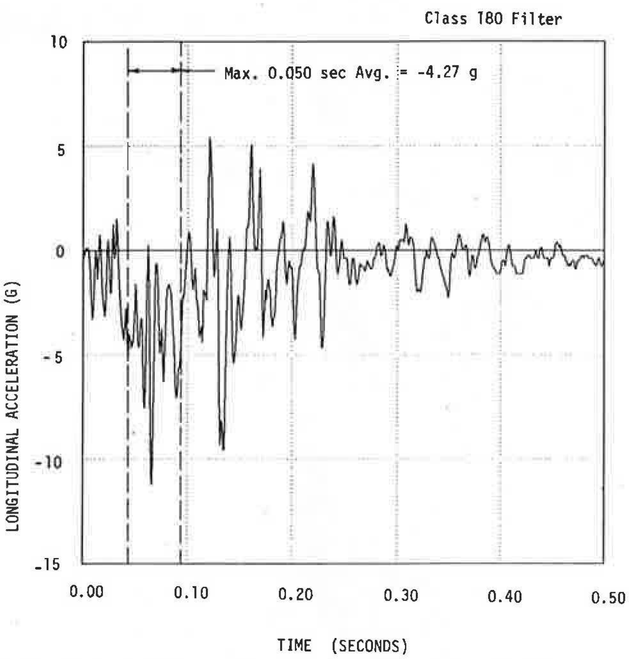


FIGURE 4 Vehicle longitudinal acceleration trace, Test 1.

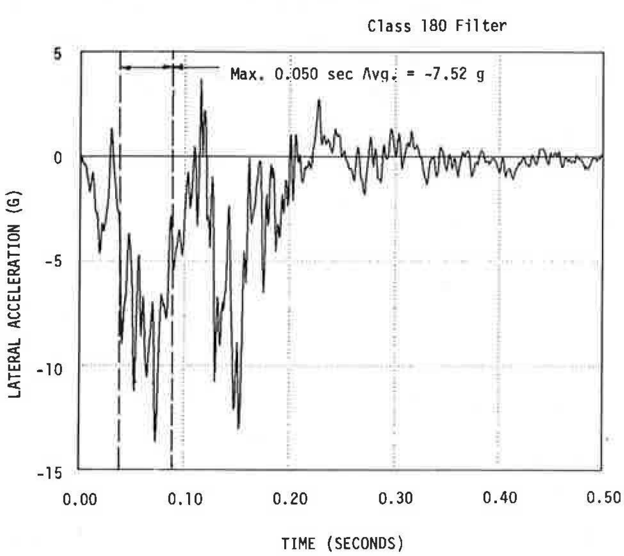


FIGURE 5 Vehicle lateral acceleration trace, Test 1.

FIGURE 6 Test vehicle after Test 1.

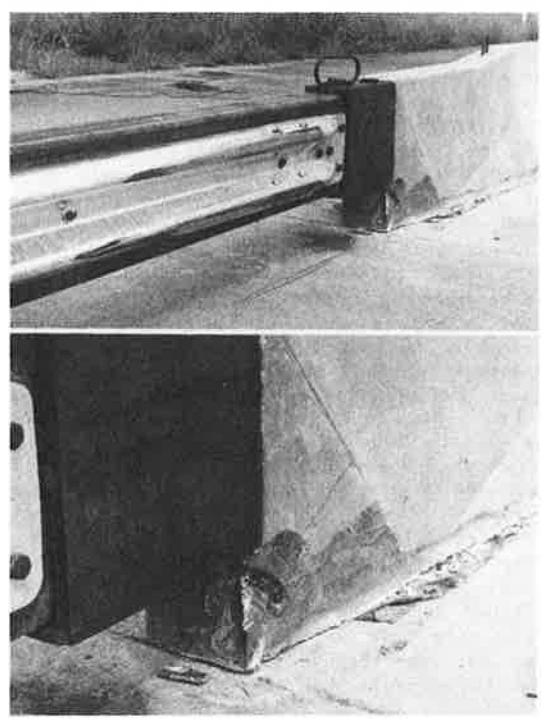


FIGURE 7 Test installation after Test 1.

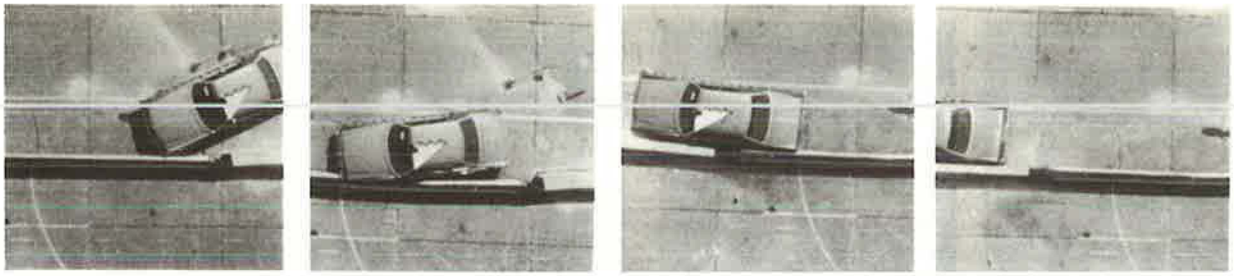


FIGURE 8 Sequential photographs, Test 2.

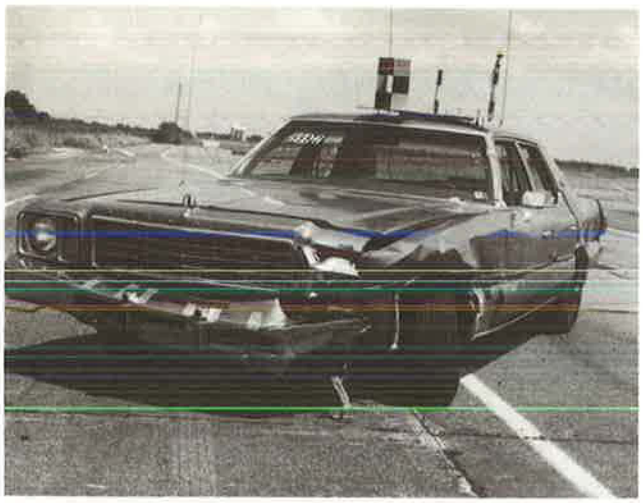


FIGURE 9 Test vehicle after Test 2.

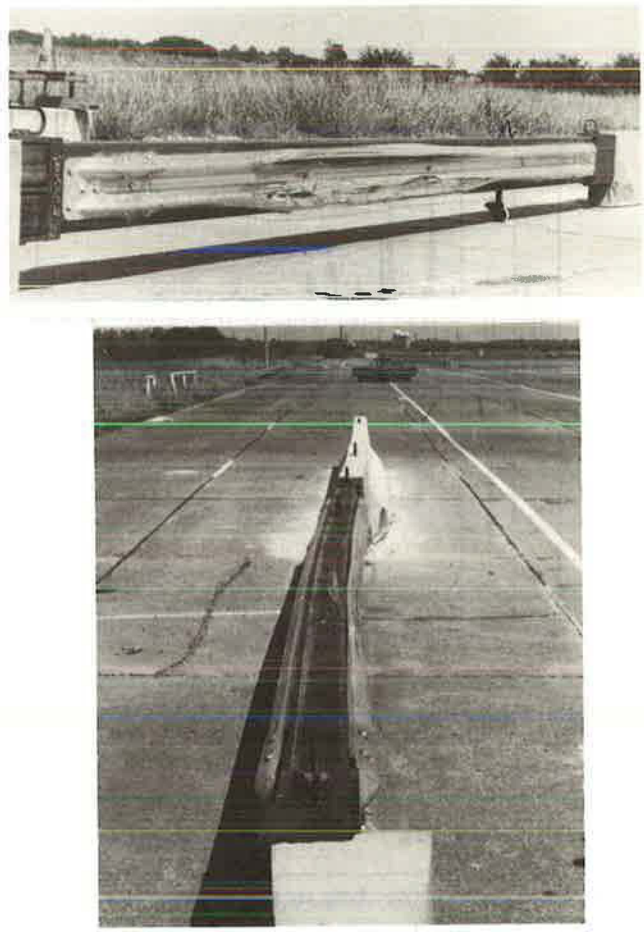


FIGURE 10 Test installation after Test 2.

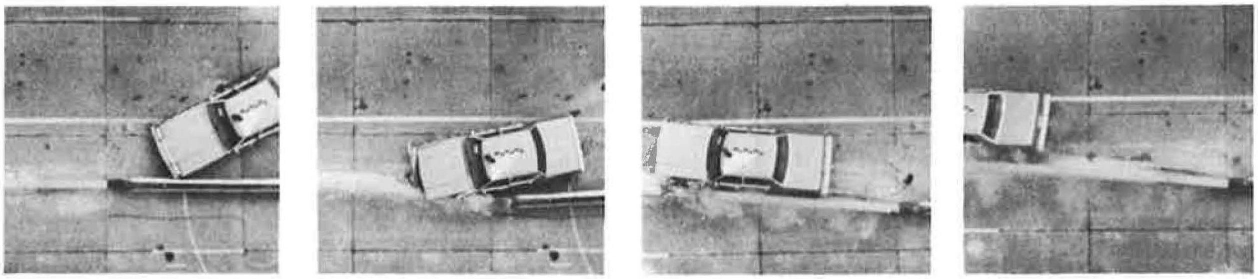
degrees and the vehicle exit speed was 39.01 mph (62.8 km/hr). The occupant impact velocities were 25.62 ft/sec (7.81 m/sec) longitudinal and 20.54 ft/sec (6.26 m/sec) lateral. The peak 50-msec average acceleration was 8.59 g longitudinal and 8.32 g lateral. The vehicle accelerations were within acceptable limits (5) for this type of test. The lateral occupant impact velocity was also within recommended limits, but the longitudinal occupant impact velocity exceeded the recommended value, although it was less than the limiting value. In additional, this type of test was not required to meet the NCHRP criteria (5).

Damage incurred by the vehicle and test installation for Test 3 is shown in Figures 12 and 13. The test vehicle was severely damaged in this test when it snagged on the downstream CMB section. The permanent deflection of the gate was 23.88 in. (60.66 cm). The gate section of the EOS sustained damage to the W-beam on the impact side of the tubes, which had to be replaced. The downstream CMB section was severely damaged because of flexural cracking and failure of one of the anchor rods in the concrete. The upstream CMB section was also severely damaged because of flexural cracking. In addition, the gate could not be opened because the metal tubes were binding about the pin connections. However, this test was still considered a success because of the barrier's safety performance and because the vehicle did not penetrate the barrier. The damage to the barrier would be minimized if proper anchorage were achieved, and although the forces on the vehicle would increase, they should not exceed those of a CMB.

SUMMARY AND CONCLUSIONS

An EOS for an AVL was developed and crash tested. The system, as shown in Figures 1 and 2, consisted of two steel box tubes mounted on top of each other. The steel beams were supported by pin connections to modified CMB sections. Factors considered in the development of the EOS were ease of operation and ability to redirect errant vehicles.

Three full-scale crash tests were conducted to evaluate the impact behavior of the design. In the first test, an impact severity test, a small vehicle was smoothly redirected. In Test 2, a beam-strength



0.000 sec 0.191 sec 0.476 sec 0.690 sec

FIGURE 11 Sequential photographs, Test 3.

test, a large vehicle was smoothly redirected. The connection strength was tested in the third test, in which a large vehicle was redirected. All the vehicle accelerations were below recommended values for all the crash tests. In addition, all the occupant impact velocities were within acceptable limits. Even though the lateral occupant impact velocities for Tests 2 and 3 exceeded the recommended value, they fell below the limiting value. Furthermore, this type of test was not required to meet NCHRP Report 230 criteria (5). In addition, the EOS was still operational after the first two tests. The anchorage system for the downstream CMB failed in Test 3, which caused the hinge mechanism on the gate to bind. With adequate anchorage for the CMB support sections, the as-tested design would remain operational after three successive severe hits.

The full-scale crash tests showed that the system tested can be used by an emergency vehicle to gain immediate access to an AVL. In addition, the tests showed the barrier's safety performance characteristics. Finally, with proper measures to protect oncoming traffic, the EOS could be adapted for use on any highway system that is separated by CMBs.

Several modifications in the EOS were recommended, on the basis of observations during the test program, to improve the operation and performance of the system. These modifications are enumerated in TTI Report 105-1F (4), and the intent of the major changes is summarized as follows:

1. To further reduce maintenance, the W-beams, end shoes, and the side straps have been eliminated (which causes the EOS gate repair cost per crash to drop essentially to zero);

2. To improve postimpact operation of the system, an improved anchorage system is being implemented for the CMB (which will eliminate binding of the gate after a crash and also reduce damage to the CMB);

FIGURE 12 Test vehicle after Test 3.

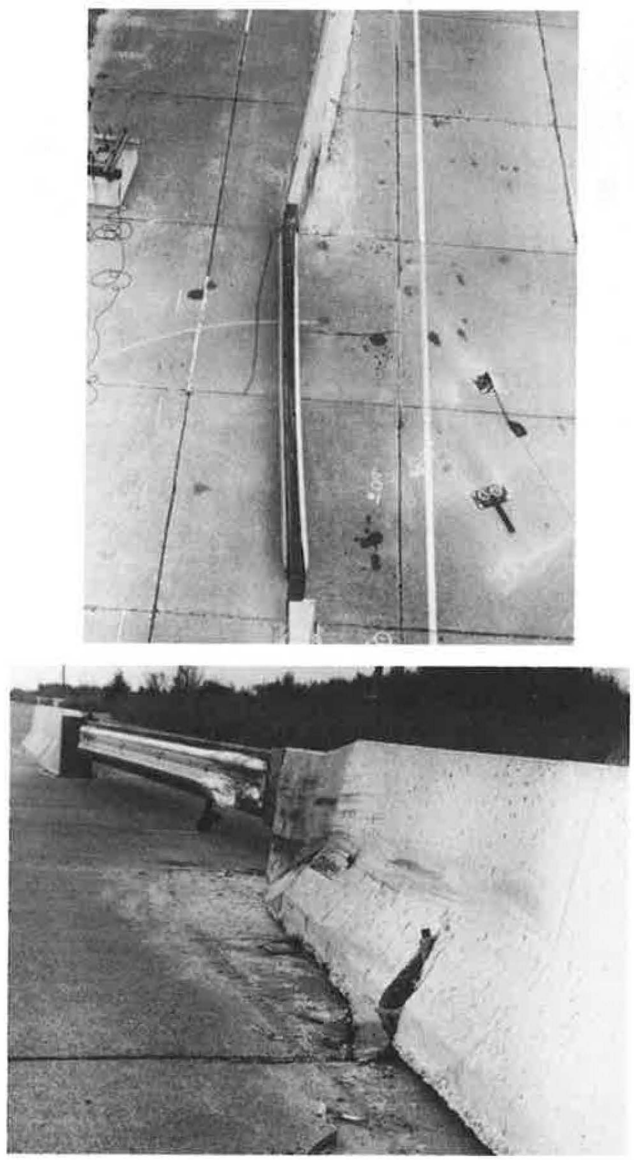


FIGURE 13 Test installation after Test 3.

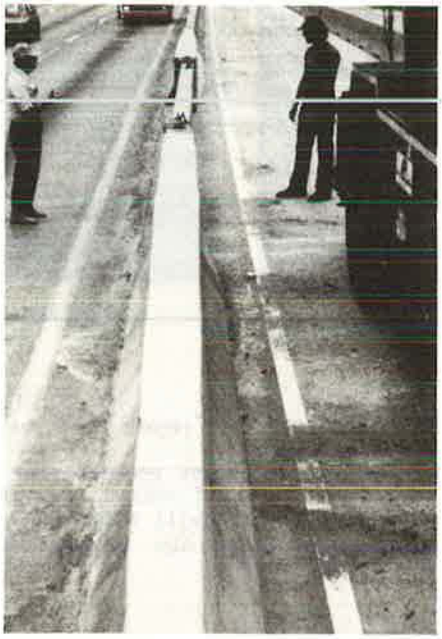


FIGURE 14 EOS as implemented.

3. To reduce the snagging potential of the EOS, a smoother transition section has been designed; and
4. To allow the gate to be opened with greater ease and from either end, the caster system has been rearranged.

At the writing of this paper the concepts and modified designs presented here are being implemented on the I-45 AVL project in Houston, Texas (Figure 14).

ACKNOWLEDGMENTS

This research study was conducted by TTI for the Texas State Department of Highways and Public Transportation (SDHPT). Technical liaison and guidance was provided by William V. Ward and James G. Darden III of the Houston Urban Project of SDHPT. The crash tests were carried out by personnel of the Highway Safety Research Center of TTI. This paper is based on a Master of Engineering thesis by John W. Strybos.

REFERENCES

1. G.H. Powell. Barrier VII: A Computer Program for Evaluation of Automobile Barrier Systems. FHWA, U.S. Department of Transportation, April 1973.
2. Building Code Requirements for Reinforced Concrete. ACI 318-77. American Concrete Institute, Detroit, Mich., 1977.
3. Manual of Steel Construction. American Institute of Steel Construction, Chicago, Ill., May 1981.
4. J.W. Strybos, J.R. Morgan, and H.E. Ross, Jr. Emergency Opening System for an Authorized Vehicle Lane. Research Report 105-1F. Texas Transportation Institute, Texas A&M University System, College Station, March 1984.
5. J.D. Michie. Recommended Procedure for the Safety Performance Evaluation of Highway Appurtenances. NCHRP Report 230. TRB, National Research Council, Washington, D.C., March 1981.