One-Way Guardrail Vehicle Arresting System

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The one-way guardrail vehicle arresting system was subjected to 4 full-scale vehicle crash tests. The system consists of 2 continuous parallel lengths of guardrail installed approximately 12 ft apart on a highway median. Each guardrail is constructed so that a vehicle that is out of control will lay down the first guardrail it encounters when traveling into the median. Once the vehicle crosses the first guardrail, it is trapped between the rigid faces of guardrail on both sides and cannot reenter the highway it has left or cross the median strip into the opposing traffic. The purpose of this program was to determine if the one-way guardrail could arrest errant vehicles traveling at velocities of approximately 60 mph and impacting at angles of 10 to 30 deg. The one-way guardrail vehicle arresting system performed as designed in 3 of the 4 tests conducted. From the test results, this system would seem to be an adequate device for containing vehicles with velocities somewhat less than 60 mph or angles of attack slightly less than 30 deg. All tests in which the vehicles were contained show deceleration levels well within the tolerance limits of restrained humans. The system could be used in certain problem areas where the risk of a secondary collision is unacceptably high when a vehicle rebounds from contact with a guardrail or where a disabled car would block traffic through an area of limited access.

THE ONE-WAY GUARDRAIL vehicle arresting system was developed by the Martin Marietta Corporation under a contract with the U.S. Bureau of Public Roads. The arresting system was fabricated and delivered by Martin Marietta to the Highway Safety Research Center of the Texas Transportation Institute. The system was installed at the Texas A&M Research Annex, and the vehicle crash tests were conducted by personnel of the Highway Safety Research Center.

This arresting system prevents a vehicle that goes out of control from crossing a highway median by entrapping the vehicle in the median. This entrapment prevents it from encountering oncoming traffic or returning to the roadway from which it came.

Included in this paper are photographs of the vehicle and barrier at the various stages of each test. High-speed motion picture film was analyzed to give vehicle velocities and average decelerations as each test transpired. The movement of the vehicle during each test is shown by a position-time diagram.

DESCRIPTION OF BARRIER

The arresting system consists of 2 continuous parallel lengths of guardrail installed approximately 12 ft apart on a highway median. The function of the installation is shown in Figure 1. The guardrail is composed of the standard W-beams, and bumper plates were bolted to 4-in. wide-flange posts that were installed so that the entire guardrail leaned at an angle of 15 deg toward the middle of the median. The web and outward

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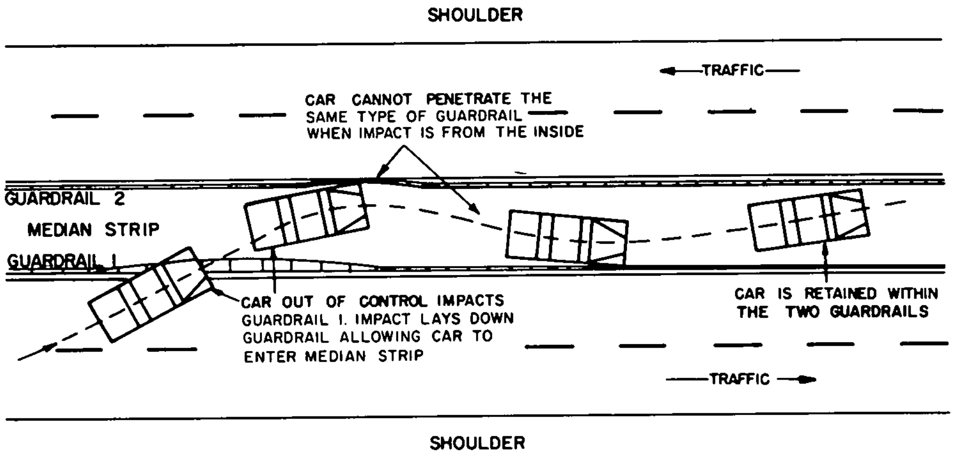

Figure 1. Idealized function of one-way guardrail installation.

flange of each post were precut at the ground line so that the post would bend inward under a rather minimal force. Details of these components are shown in Figures 2 and 3. This allows a vehicle that is out of control to lay down the first guardrail it encounters when traveling into the median. Once the vehicle crosses the first guardrail, it is trapped between the rigid faces of guardrail on both sides and cannot reenter the highway it has left or cross the median strip into the opposing traffic. Additional information and design data on this vehicle arresting system are given in reports published by the Martin Marietta Corporation (2, 3).

DESCRIPTION OF TESTS

Four guardrail crash tests were conducted in this phase of the program. The vehicles ranged in weight from 1,600 to 4,400 lb, and angles of attack varied from 10 to 30

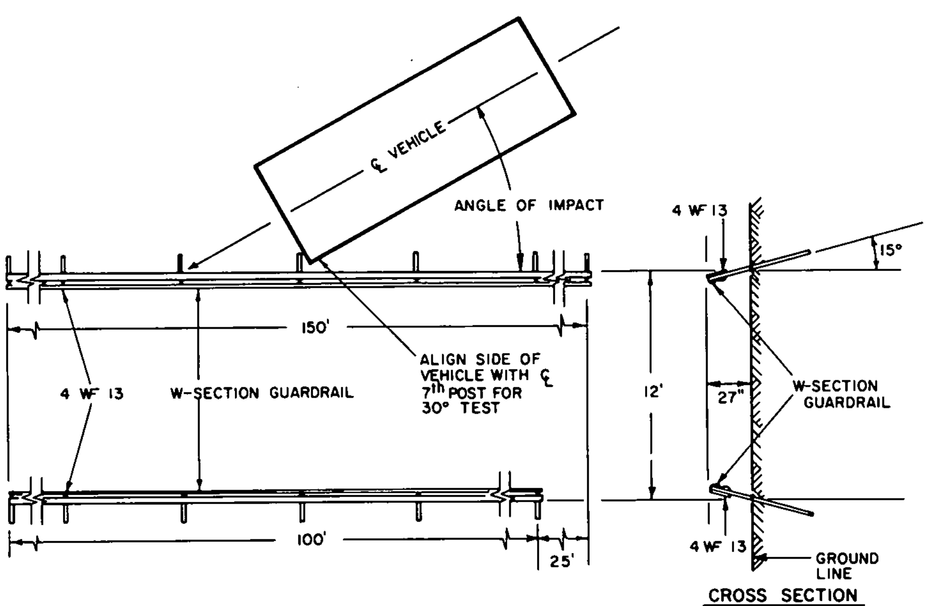

Figure 2. Plan view of one-way guardrail arresting system.

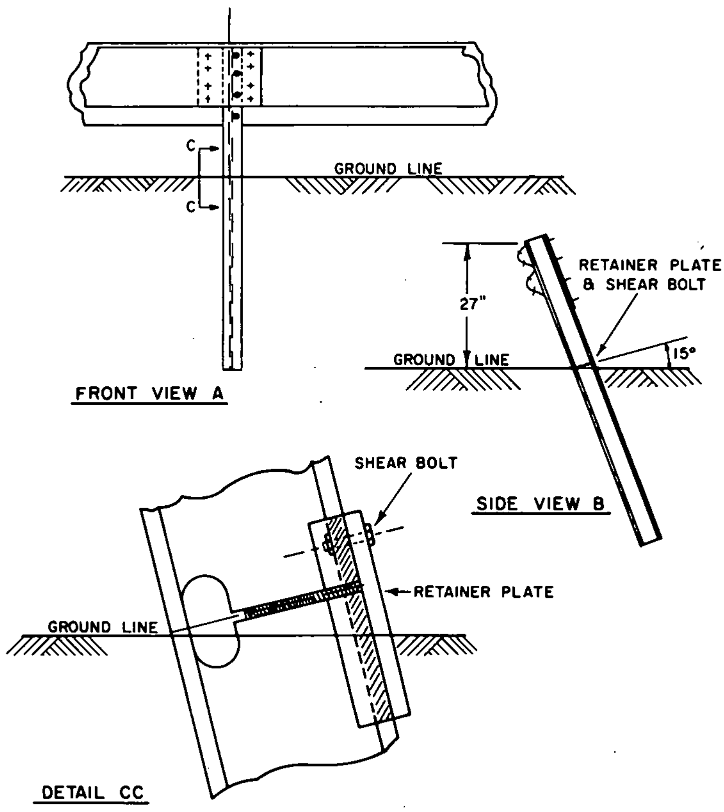

Figure 3. Detail of one-way guardrail system.

deg. The angle of attack is defined as the angle between the initial trajectory and the line of the guardrail. The desired vehicle test velocity for all tests was 60 mph.

Two Hycam high-speed motion picture cameras, operating at 500 frames per second, and several documentary cameras, running at approximately 110 frames per second, were used to record the tests. One of the cameras was used to photograph the vehicle during and immediately preceding impact with the first guardrail, and the other was positioned to record subsequent vehicle movement. One documentary camera was mounted at one end of the guardrail installation.

Impact velocities were determined electronically as well as photographically. A pair of tape switches was placed so that they would be crossed by the right front wheel of the vehicle just before impact with the first guardrail. The time between actuation of the first and second switch was measured electromechanically, permitting the speed to be calculated.

The description of each test includes selected photographs of the vehicle and arresting system. A drawing of the path that the vehicle traveled in relationship to the arresting system provides a summary of the test. Deceleration levels are given in relationship to the vehicle frame.

Test 1

A small vehicle weighing 1,600 lb was directed into the guardrail arresting system at an attack angle of 30 deg and velocity of 47 mph. The arresting system performed as designed, redirecting and containing the vehicle (Fig. 4). A comparison of the vehicle and guardrail before and after the test indicates that the damage to both was minor (Figs. 5 and 6). Figure 7 shows the point of impact with the first guardrail and demonstrates proper performance of the one-way design. Calculated average decelerations

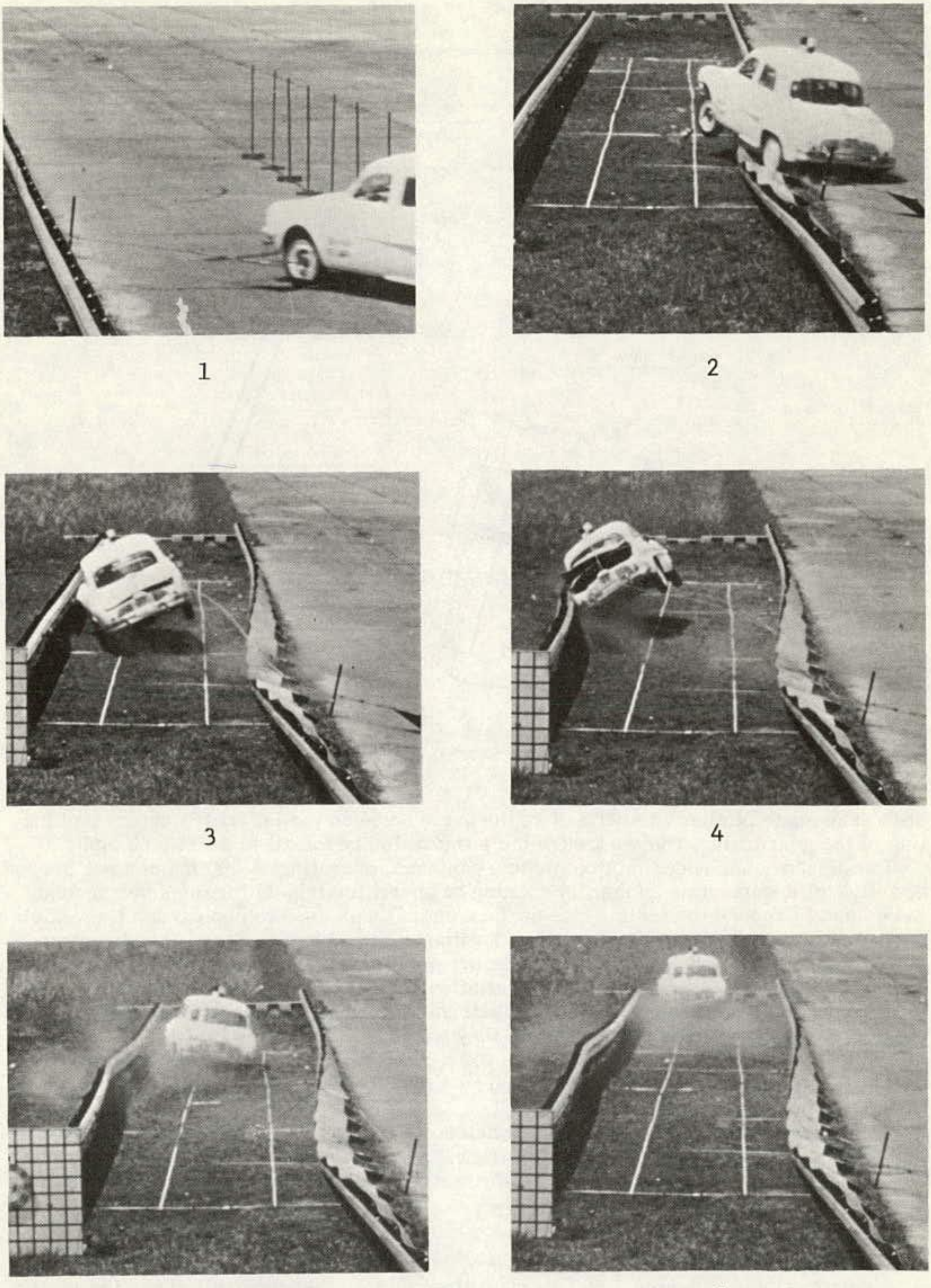

Figure 4. Sequential photographs during test 1.

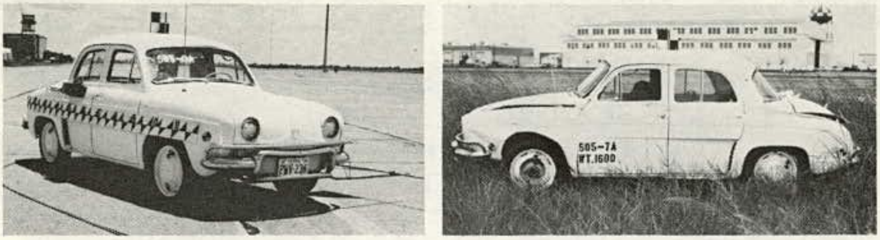

Figure 5. Vehicle before and after test 1.

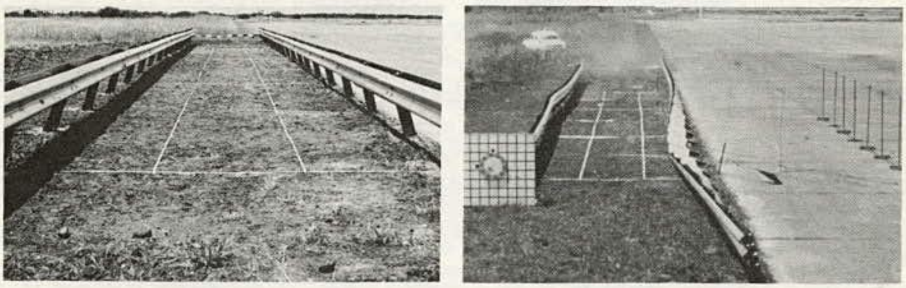

Figure 6. Guardrail before and after test 1.

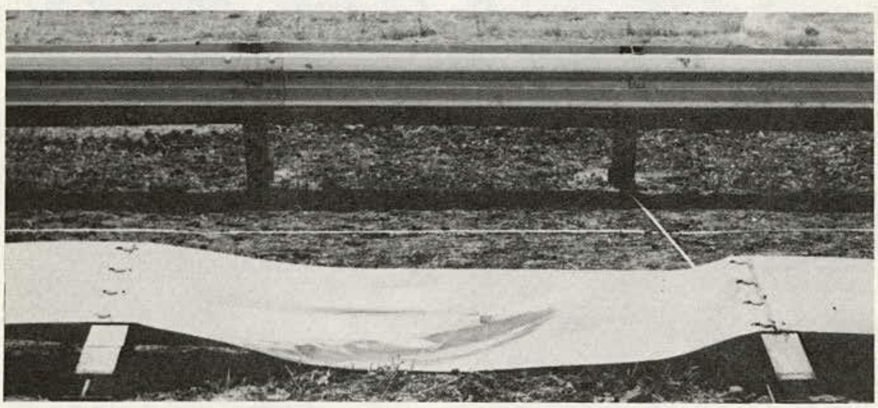

Figure 7. First guardrail laid down in test 1 as design predicted. Tread-mark shows point of vehicle contact.

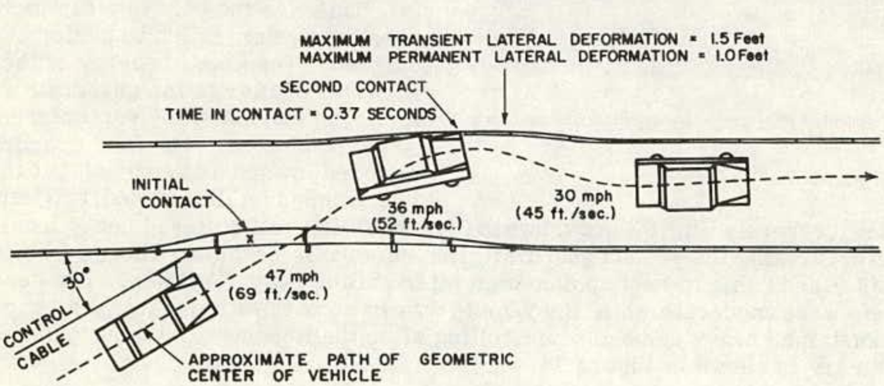

Figure 8. Summary of test 1.

Figure 9. Sequential photographs by overhead camera during test 2.

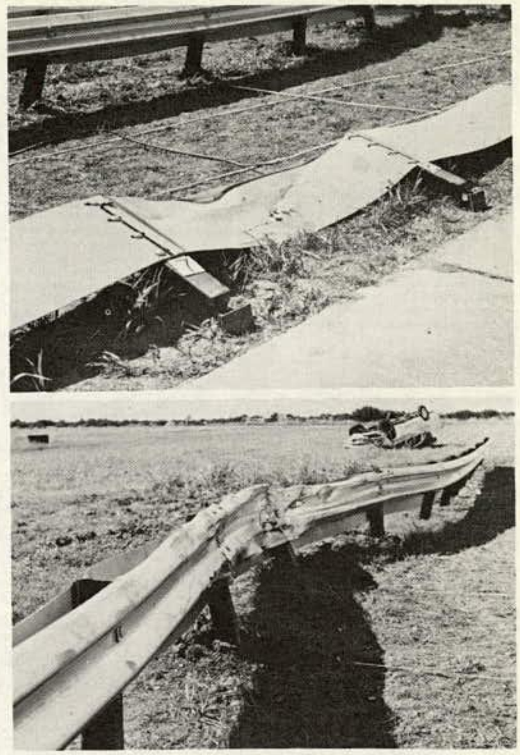

Figure 10. First and second guardrail and position of vehicle after test 2.

in the longitudinal and transverse directions were below 2.5 g throughout the test, an extremely acceptable level. Figure 8 shows a summary of test 1.

Test 2

A full-size automobile weighing 4,300 lb impacted the guardrails at an angle of 30 deg and a velocity of 61 mph. The arresting system failed to contain the vehicle. This was the only test in which the arresting system failed to perform as designed. The kinetic energy of the vehicle perpendicular to the guardrail was 267 kip-ft, the largest value encountered in the 4 tests conducted. The first guardrail collapsed inward as designed, but the vehicle ramped on the second rail after deforming it severely (Fig. 9). As shown in Figure 10, the rail suffered heavy local damage. After striking the second guardrail, the automobile became airborne for approximately 36 ft and came to rest upside down after rolling over $1\frac{1}{2}$ times. The deceleration levels were moderate while the vehicle was in contact with the guardrails, but the vehicle sustained heavy damage while rolling after the impact with the second rail. The test summary is shown in Figure 11.

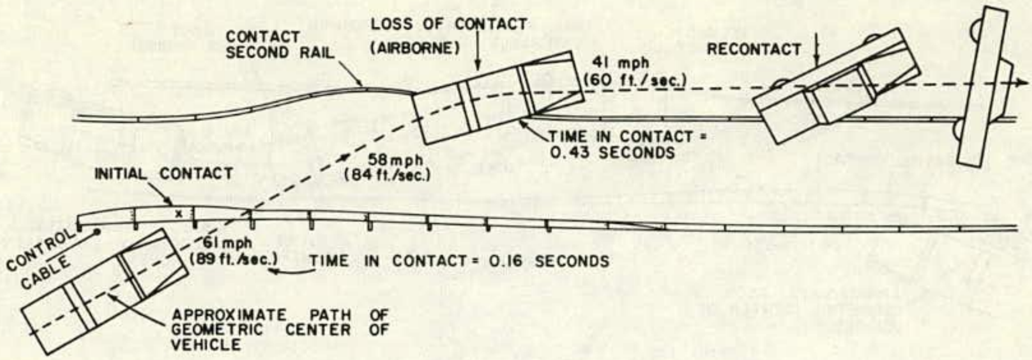

Figure 11. Summary of test 2.

Test 3

In test 3, the total kinetic energy of the 4,180-lb vehicle, traveling at 64 mph, was slightly more than that of the vehicle used in test 2. However, the impact angle was reduced to 20 deg, which reduced the kinetic energy perpendicular to the guardrail to 197 kip-ft and allowed the vehicle to be successfully contained. The vehicle recontacted the first guardrail from inside the system after being redirected by the second guardrail. The critical point was during contact with the second guardrail. The sequence photographs shown in Figure 12 indicate that the vehicle came very close to

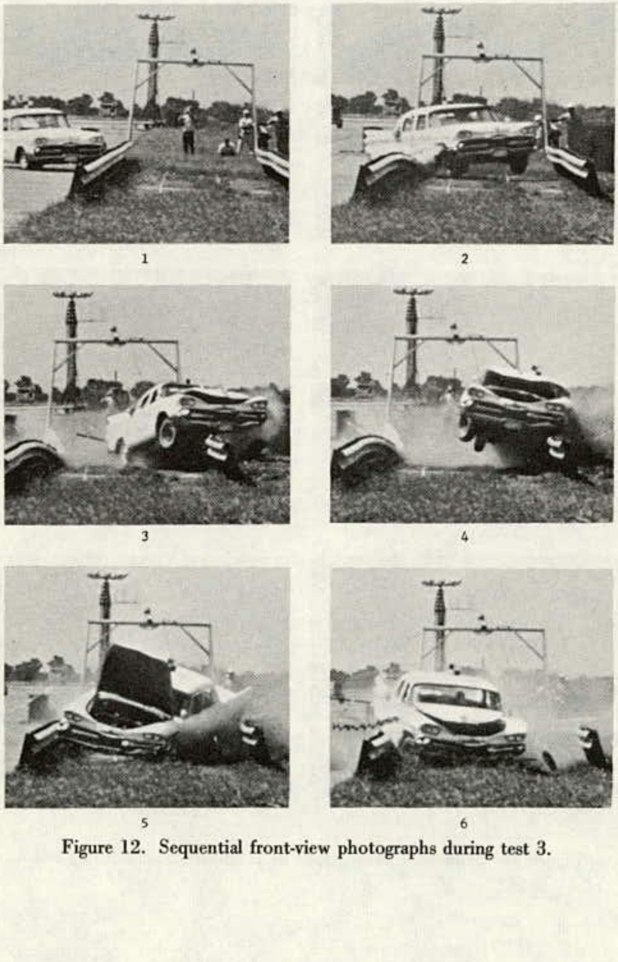

Figure 12. Sequential front-view photographs during test 3.

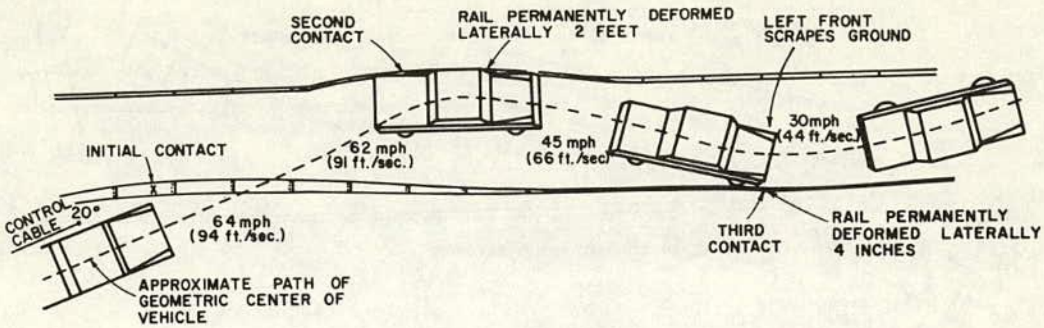

Figure 13. Summary of test 3.

jumping the second guardrail. Considerable damage was done to the vehicle suspension at that point. The left front of the vehicle contacted the ground when the first guardrail was recontacted. This probably contributed significantly to the decelerations experienced at that point. The average decelerations at the various contact points were all below 2.3 g, which is a very moderate level. A summary of test 3 is shown in Figure 13.

The strength of the soil had a definite influence on these tests. It is possible that, if the soil had been much softer or significantly stronger than the condition tested, different results might have been obtained.

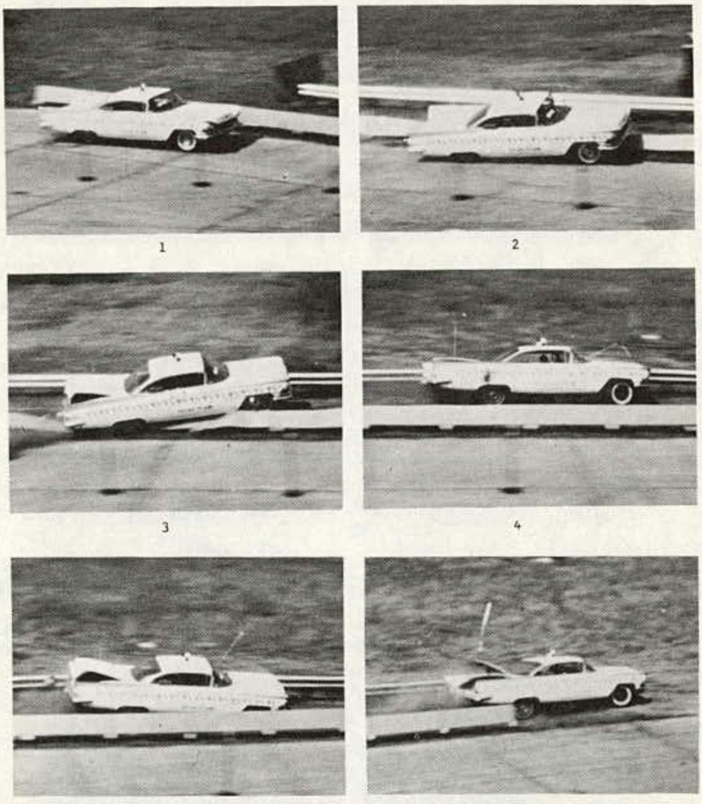

Figure 14. Sequential photographs by overhead camera during test 4.

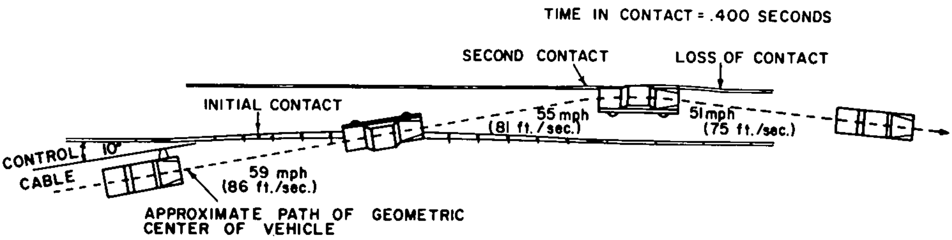

Figure 15. Summary of test 4.

Test 4

The arresting system performed as designed in test 4, which was conducted with a low (10 deg) angle of attack. The 4,400-lb vehicle, moving at 59 mph, was subjected to minor decelerations, the largest of which was 1.7 g. This deceleration occurred during contact with the second guardrail and was in a transverse direction relative to the vehicle (Fig. 14). The automobile did not severly deflect the second guardrail as in the two previous tests. During the test, the left front tire blew out, which may have contributed to the vehicle damage. This damage was confined to the left front suspension and fender area. Figure 15 shows a summary of the test.

SUMMARY

The characteristics of the 4 tests are given in Table 1. The vehicles ranged in weight from 1,600 to 4,400 lb. Angles of attack varied from 10 to 30 deg. The desired vehicle test velocity was 60 mph. In 3 of the 4 tests, the actual velocity achieved ranged from 61 to 64 mph. In test 1 a velocity of only 47 mph was achieved by the compact vehicle. In 3 of the 4 tests, the one-way guardrail arresting system performed as designed—redirecting the vehicle and containing it within the 2 guardrails, an area that would be the median strip in a highway or tunnel application. In test 2, the 4,300-lb vehicle, with a velocity of 61 mph and an attack angle of 30 deg, was not contained. This was the test in which the vehicle had the maximum kinetic energy in a direction perpendicular to the guardrail installation.

Table 2 gives the average g-levels that were sustained by the vehicle during contact with the first and second guardrails. The maximum average longitudinal g-level, 2.2 g, was encountered in test 2 during contact with the second guardrail. The maximum average transverse g-level encountered in these tests was 2.4 g in test 1. These deceleration levels for vehicle arresting guardrails and median barrier systems could easily be tolerated by a properly restrained passenger (1). For vehicle speeds slightly less than 60 mph or attack angles slightly less than 30 deg, the one-way guardrail vehicle arresting system would seem to be an effective or adequate device.

The importance of the soil in which this arresting system is installed should be emphasized. The installations tested at

TABLE 1

CHARACTERISTICS OF FOUR TESTS

Characteristic	Test 1	Test 2	Test 3	Test 4
Angle of attack, deg	30	30	20	10
Vehicle weight, lb	1,600	4,300	4,180	4,400
Impact speed, mph	47	61	64	59
Kinetic energy of vehicle, kip-ft	118	533	576	513
Kinetic energy perpendicular to guardrail, kip-ft	59	267	197	89

TABLE 2

AVERAGE VEHICLE DECELERATIONS

Test	Guardrail Contacted	Longitudinal g-Level	Transverse g-Level
1	1	2.1	0.6
	2	1.5	2.4
	1	—	—
2	1	0.5	0.0
	2	2.2	1.8
	1	—	—
3	1	0.3	0.0
	2	2.1	2.2
	1	1.9	1.5
4	1	0.2	0.0
	2	0.7	1.7
	1	—	—

Note: Decelerations are given relative to the orientation of the vehicle's frame at impact, and are taken from the film.

the Research Annex were in soil that had a cohesion of approximately 2,000 lb/sq ft (4). This allowed a significant deflection of the guardrail support posts during the main collision with the second guardrail. Had the soil been extremely hard with a very high cohesion, it is possible that the test results could have been significantly different.

CONCLUSIONS

The one-way guardrail vehicle arresting system performed as designed in 3 of the 4 tests conducted. The system should be effective for vehicle velocities somewhat less than 60 mph or angles of attack slightly less than 30 deg. In all tests where the vehicle was contained, the deceleration levels were well within the tolerance limits for restrained humans.

It should be emphasized that the functioning of this system is dependent to some degree on the properties of the soil surrounding the guardrail support posts. If a low-cohesion soil cannot be avoided in a given location, the guardrail system could be made to function properly by increasing the embedment length or by placing concrete around the wide-flange support posts.

The system could be used in certain problem areas where the risk of a secondary collision is unacceptably high when a vehicle rebounds from contact with a guardrail. It could also be used where a disabled car would block traffic through an area of limited access.

ACKNOWLEDGMENTS

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