CRASH TEST EVALUATION OF STRONG-POST, ENERGY-ABSORBING GUARDRAIL USING A LAPPED W-BEAM FOR TRANSITIONS AND MEDIAN BARRIERS

Grant W. Walker, Dynamics Research Manufacturing, Inc.; and
Charles Y. Warner, Brigham Young University

Crash tests, including tests with human drivers, were performed to evaluate a lapped W-section strong-post guardrail designed for transition sections and median barriers. Energy-absorbing cartridges were used to limit the vehicle loads imposed while keeping rail deflection to a minimum. Results show that full-sized conventional vehicles can survive impacts at a speed of 60 mph and an angle of 10 deg without complete loss of steering control.

•ACCIDENTS frequently occur at transitions from wide to narrow roadways, particularly on high-density traffic roads. Many of these transitions exist because construction costs have restricted the width of bridge decks, which reduces the number and/or width of lanes and shoulders. Bridge deck transitions invariably involve rigid bridge railings. One approach that is frequently used to improve this situation is to install a W-4 type guardrail as a funnel section (1). Although this procedure is successful for some low-energy impacts, it is not very successful for high-speed impacts. Vehicles striking the guardrail near the end of the bridge can vault the guardrail and enter the hazardous area beyond, or they may be disabled by the guardrail contact and thrown into the high-density traffic flow on the bridge deck, and create a hazard for other vehicles.

Tests of the W-4 guardrail in applications where limited deflection is allowed have shown that it typically inflicts severe damage on vehicle suspension parts, thus rendering vehicles uncontrollable after they separate from the rail. Further, in W-4 guardrail crashes where limited lateral deflection is available, high lateral loads coupled with the concentration of loading along the rather narrow W-beam result in sizeable longitudinal impulses on the vehicle.

This paper presents a prototype guardrail system-bridge rail transition region. The system is compatible with the W-4 guardrail. It allows gradual stiffening of the rail to provide adequate redirection of the vehicle past the rigid bridge parapet while protecting vehicle components that are essential to regaining driver control.

The system combines the energy-absorbing effects of the vermiculite concrete guardrail with a strengthened face beam that prevents penetration of the vehicle components into the support posts. It is composed of hardware components already generally used for these applications (1).

BARRIER DESIGN OBJECTIVES

The prototype barrier described in this paper was designed especially for the transition section. The following performance objectives were established:

1. Provide protection for conventional automobiles weighing up to 5,000 lb that impact the guardrail at speeds of up to 60 mph and angles of up to 25 deg.

Sponsored by Committee on Traffic Safety Barriers and Sign, Signal and Lighting Supports.

2. Safely prevent the automobile from penetrating laterally more than 12 in. past the impacting surface of the rail by providing as much energy absorption as is practicable within the 12-in. space. This would eliminate the serious consequences of wheel contact with the support posts during a crash.

3. Avoid penetration or ramping in impacts by conventional 2,000-to 5,000-lb automobiles at entry speeds of up to 60 mph and angles of up to 25 deg.

4. Employ readily available hardware components insofar as is possible. The resulting system must be compatible with existing W-4 guardrail and rigid concrete bridge rails and should minimize maintenance and refurbishing costs.

5. In view of the relatively large lateral force impulses that must be applied to the vehicle to meet the first 2 objectives, the design should embody means to distribute the impact loads more broadly over the vehicle surfaces.

6. Apply loads in such a way as to minimize damage to critical safety items on the vehicle, such as steering and suspension systems, so that vehicle control can be regained as quickly as possible.

Attachment hardware that prevents snagging of vehicle parts was developed during the course of the project. This was in response to test experience that showed deleterious effects from contact of safety critical parts such as tires and wheels with such unobtrusive barrier system elements as ⅝-in. carriage bolt heads. In some instances, such contact resulted in catastrophic damage to tires, steering, and suspension parts.

The broader distribution of forces over the vehicle structure was combined with shorter lateral stopping distances to increase the lateral acceleration loading on the vehicle. It was felt, however, that the net longitudinal loading would be reduced, because the net friction coefficient between vehicle and rail would be reduced, the tendency to pocket the rail would decrease, and the time in contact with the rail would decrease. It was felt that the sum of these four factors would improve survivability by reducing overall occupant impulses and by maintaining steering and suspension integrity.

TEST PROCEDURE

The system tested was built of common guardrail components coupled with vermiculite concrete attentuation cartridges (2). Figure 1 shows the system demonstrating the use of conventional steel W-beam sections, lapped and supported on closely spaced, heavily treated Douglas fir posts. The posts were set in compacted earth fill and buried to a depth of 3 ft. Energy-absorbing cartridges were constructed of helicell elements (Fig. 2) and held in place between rail and post by the hardware shown in Figure 3. The helicell unit is constructed of lightweight concrete that is restrained by a tightly wrapped wire coil. Upon longitudinal impact, the concrete material shatters and "flows" into the hollow center core of the cell and exits between the wire strands, which regulate the maximum size of debris particles. The spent cartridge is replaced, and new or straightened rails are fastened through the cartridges to the posts.

In the early tests in this series, fastening bolts were used to connect the W-beams, cartridges, and blocks as suggested by usual practices (Fig. 3, Detail A). It was noted, however, that in this attachment system the ⅝-in. bolts snagged vehicle components. Similar snagging has been experienced in earlier tests with W-4 and modified W-4 sections. Wheel and tire damage is often inflicted by attachment bolts for the 6 ⌐¬ 8.2 rubbing rail in the W-4 configuration. In view of the sometimes catastrophic results of these snagging loads on steering and suspension performance, it was decided that an improved fastening system should be used. Tests were subsequently performed on a system that included fasteners (Fig. 3, Detail B).

This design was suggested by Bronstad and Burkett as a means of reducing shear strength of fasteners (3). The purpose here was not to reduce shear strength but to prevent bolt heads from deflecting into the path of vehicle components.

The tests in this series were conducted on an abandoned airport runway. A plan view of the test site is shown in Figure 4. Figure 5 shows the application that was simulated.

The data were collected in these tests by techniques similar to those used elsewhere (2). High-speed photometrics were obtained from four ground cameras. Vehicle

Figure 1. Guardrail treatment for bridge approach.

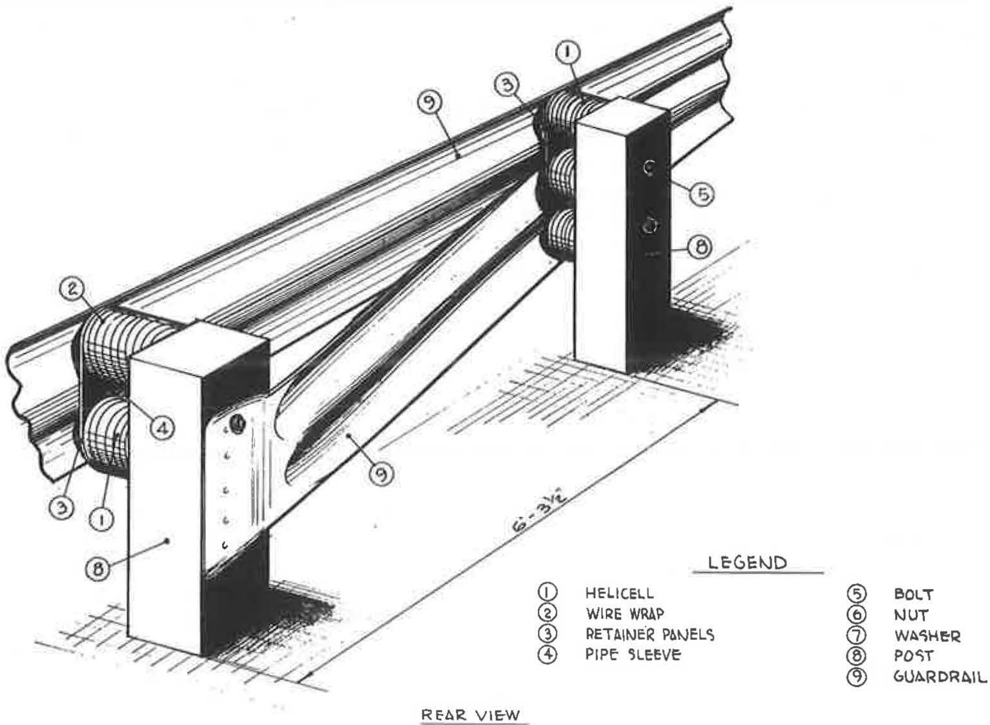


Figure 2. Helicell.

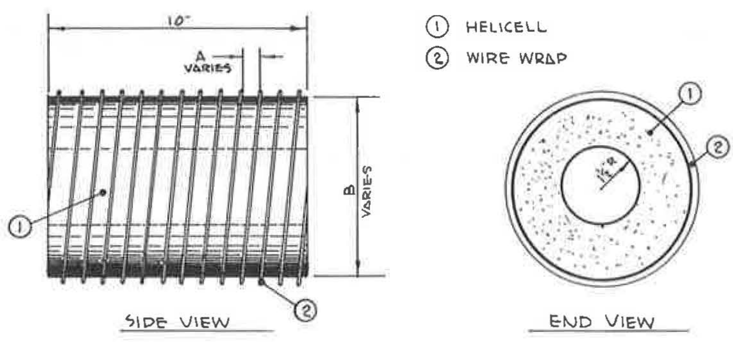


Figure 3. Fastening hardware.

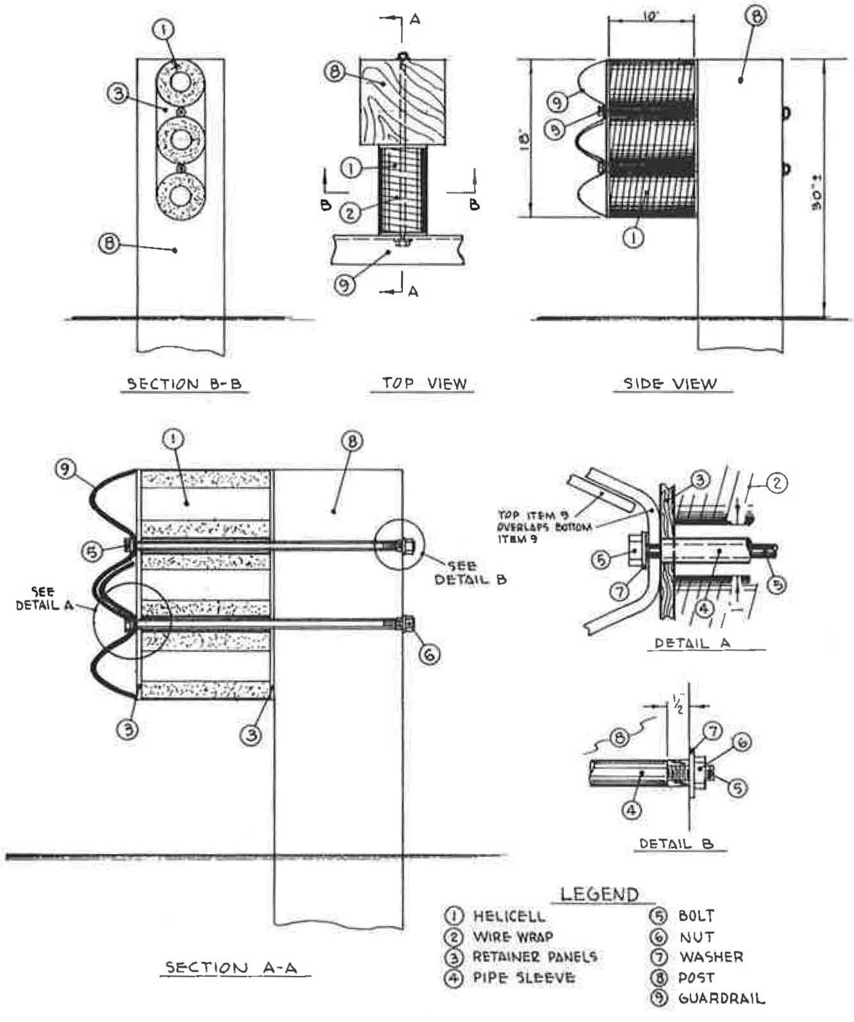


Figure 4. Test installation of simulated bridge approach.

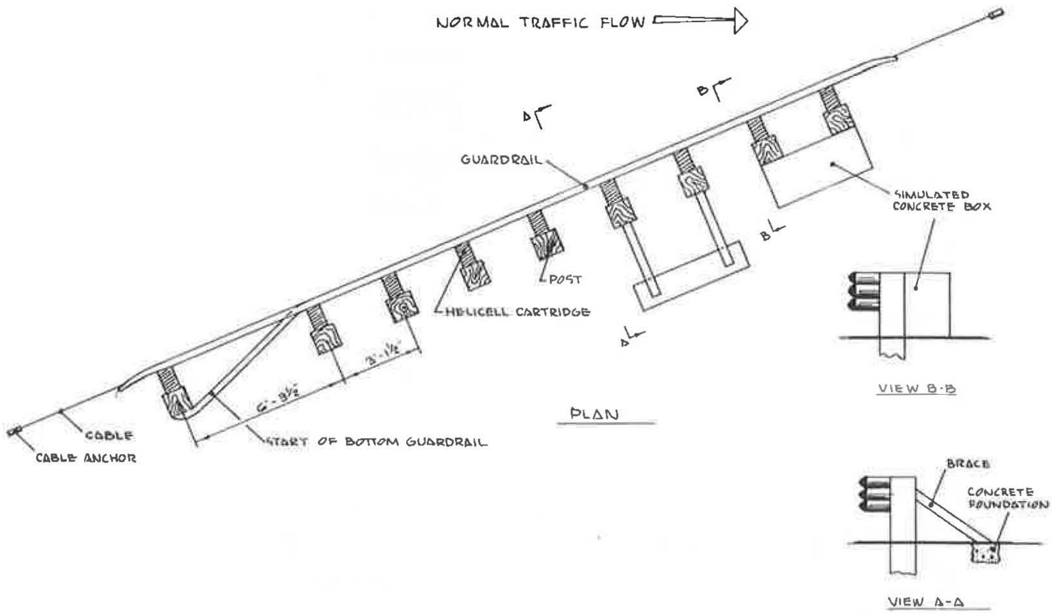
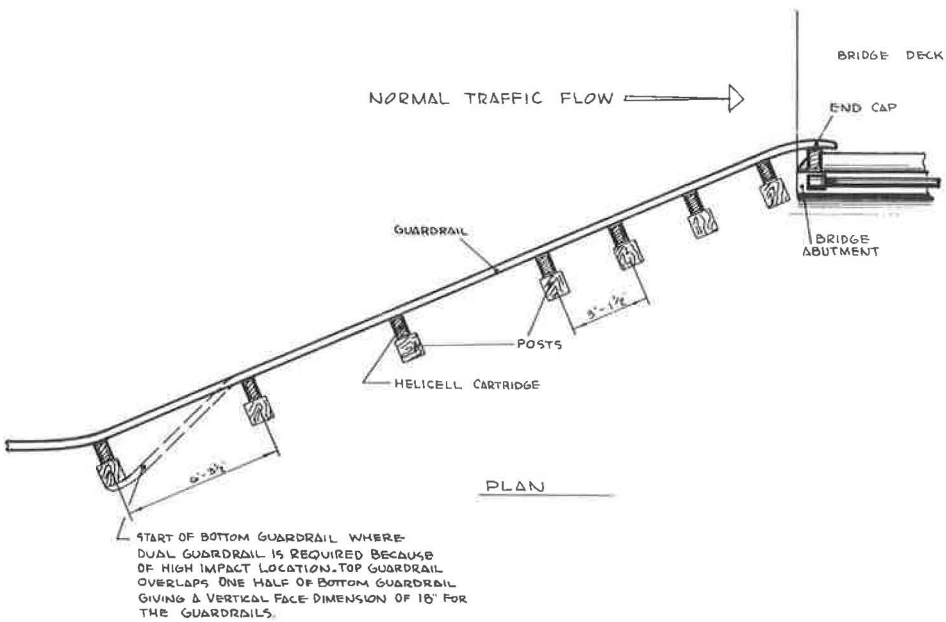


Figure 5. Guardrail protection at bridge approach using helicell cartridge backup.



impact speed was measured by trip-wire timers. Vehicle accelerations were measured by a biaxial strain-gauge accelerometer that was pack-mounted on the left side of the vehicle compartment floor, between the front and rear seats, with hard-line umbilicals leading to a direct-writing light beam oscillograph mounted in a chase vehicle. Electronic data were compared for internal consistency and were checked qualitatively against photometrics to determine overall agreement. Dynamic contact distance was measured from the photometric records.

TEST RESULTS

Table 1 summarizes the important parameters and results for this series of tests. Figure 6 shows acceleration-time histories as measured on the floor pan of the test vehicles. Figures 7 and 8 show vehicle and guardrail damage after a 57-mph, 24-deg impact (Test 1-14). A description of each test follows.

Test 1-12

In this test, a 1959 Buick Electra convertible weighing 4,600 lb impacted the rail at a speed of 47 mph and an angle of 30 deg.

The vehicle left the rail at approximately a 10-deg angle and rolled on all four tires. Damage was limited to sheet metal and minor suspension bending; there was no discernible frame damage. The right front tire remained inflated throughout the post-test roll, and the car was steerable following impact.

Six vermiculite concrete cartridges were activated, but there was reserve energy absorption capability following impact, and the vehicle came to rest more than 100 yd from the point of impact. Maximum deflection of the rail was in excess of 7 in., with post deflection limited to less than 1 in. Both longitudinal and lateral average g loads were less than 3 g.

Six $^5/_8$-in. bolts holding the rail to the posts were bent during impact. This increased the longitudinal acceleration loading and the velocity change. (Later in the test series the fastening hardware was changed, which eliminated this problem.) The axle or structural parts of the car did not penetrate the posts.

Test 1-13

In this test, a 1952 Cheverolet station wagon weighing approximately 3,800 lb impacted the rail at a speed of 50 mph and an angle of 25 deg. The results were similar to those of Test 1-12 in that the exit angle was near 10 deg and the damage to the car was limited to sheet metal and minor suspension damage. There was no damage to the vehicle frame. Run-out distance was approximately 150 yd, the trajectory curving back toward the rail. Both lateral and longitudinal average g loads were less than 3 g.

The car was steerable following impact. There was no discernible barrier post deflection with the rail deflecting in excess of 7 in. Several bolts holding the rail to the posts were snagged and bent by the car. The axle or structural parts of the car did not penetrate or snag the post, as is common in impacts with W-4 guardrail design.

Test 1-14

In this test, a 1960 Oldsmobile hardtop convertible weighing 4,300 lb impacted the rail at a speed of 56 mph and an angle of 24 deg. Again, damage to the vehicle was limited to moderate suspension bending and sheet metal deformation, at both front and rear of the car, with no discernible frame damage. The vehicle left the rail at a 10-deg angle and rolled freely on all four tires. Six rail bolts were snagged during impact. Both longitudinal and lateral average g loads, were approximately 4 g during impact.

There was reserve energy absorption capacity in the activated cartridges even though the test was run near the upper limit of guardrail test velocities and angles.

Because of the lack of frame damage, repair of the car would have been justified if it had been a late model.

Table 1. Test results.

	Overall Conditions of Test							Test Results									
									Max. Dynamic Lateral Deflection		Accelerations (g)						
											Long.		Lateral				
Test No.	Barrier Type	Impact Speed (mph)	Total Vehicle Weight (lb)	Impact Angle (deg)	Total Kinetic Energy (ft-lb $\times 10^{-5}$)	Change in Kinetic Energy During Impact (ft-lb $\times 10^{-5}$)	Exit Speed (mph)	Duration of Contact (sec)	Top of Post (in.)	Rail (in.)	Peak	Avg	Peak	Avg	Speed Change During Contact (mph)	Exit Angle (deg)	Run-out Distance (yd)
1-12	Strong post energy absorption	47	4,700	30	3.47	1.48	35	320	0	8+	5.0	2.7	5.0	3.0	12	10	100+
1-13	Guardrail with lapped W-section	49	3,800	25	3.00	1.08	39	360	0	6	5.0	2.5	6.0	2.6	10	10	150
1-14	Guardrail with lapped W-section	57	4,300	24	4.49	2.09	41	310	0	8+	7.5	4.0	6.0	4.5	15	10	80
1-15	Guardrail with lapped W-section	50	4,175	21	3.43	1.25	40.5	–	0	–	–	–	–	–	9.5	8	200
1-22	Guardrail with lapped W-section	60	3,200	21	3.84	0.51	55	290	0	5	5.0	2.5	9.0	6.0	5.0	12	90

Figure 6. Lateral and longitudinal load comparisons.

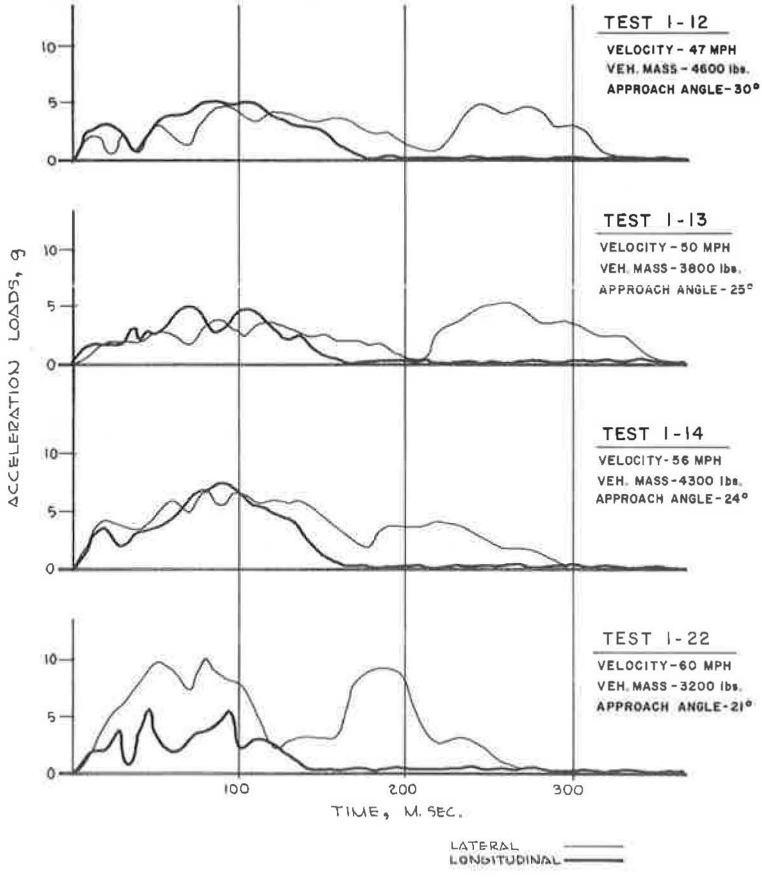
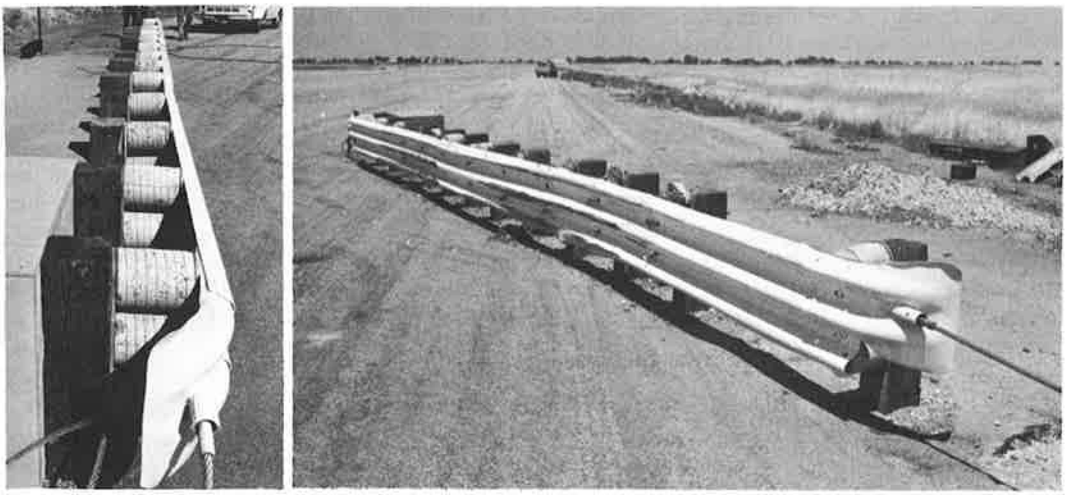


Figure 7. Test vehicle before and after impacts.

Figure 8. Guardrail before and after impacts.



Test 1-15

The minimal vehicle damage and low acceleration loads experienced in the previous tests suggested that tests with a properly restrained human driver could be run safely.

In this test, a 1955 Chrysler Windsor hardtop convertible weighing 4,000 lb and carrying a human driver impacted the rail at a speed of 50 mph and an angle of 21 deg, with a 8-deg exit angle. One purpose of this test was to determine whether an amateur driver, after impacting the rail on a typical hit, would be able to bring the car to a safe stop. The driver controlled the car following impact, steering the car to a stop approximately 200 yd from point of impact on a predetermined alignment.

Damage to the car was limited to sheet metal and suspension bending. The car was steerable following impact, rolling on all four wheels. The amateur driver, restrained by aircraft-type lap and double shoulder harness, reported no discomfort from restraint loading.

Three rail bolts snagged the body and wheel of the test car. There was no post deflection. Rail contact was 13.7 ft. Maximum compression of the rail was about 5 in. Six energy-absorbing cartridges were activated between 10 and 70 percent.

Test 1-22

In this test, a 1959 Studebaker Lark 4-door sedan weighing approximately 3,200 lb, including a human driver, impacted the rail at a speed of 60 mph and an angle of 21 deg.

This test included a secondary objective related to the vertical stiffness gradient in the energy-absorbing cartridges. It was decided that a soft-top, stiff bottom cartridge should be evaluated. Cartridges employing a wrap-wire spacing of 1, 1, and $^5/_8$ in. (top, center, and bottom cells) were used instead of the $^5/_8$-, $^5/_8$-, and $^5/_8$-in. wrap used in other tests.

The high center of gravity of the vehicle plus the greater resistance of the bottom energy-absorbing vermiculite concrete cell may have caused the 15- to 20-deg into the rail. This roll made the vehicle more difficult to control following impact. Nevertheless, the vehicle rolled on all four wheels and was steerable. The results of this test suggest that the top of the energy-absorbing cartridge should be made stiffer than the bottom to help rotate the car away from the rail and attempt to hold the left side wheels on the pavement. The soft-top stiffness gradient is not recommended.

DISCUSSION OF RESULTS

The overall objectives of the design have been satisfied. Penetration depth has been controlled by effective use of about 10 in. of lateral distance. Although the lateral loads applied to the test vehicles were greater than those experienced in impacts with more flexible guardrails, the longitudinal impulses and the damage to safety-sensitive vehicular components (steering, suspension, tires, and wheels) were significantly reduced. In tests with human drivers at speeds of about 50 mph and entry angles greater than 20 deg, steering control has been recovered after the impacts and the vehicles brought to a safe stop without overturning. This was effected in large part by the broadened force distribution resulting from the lapped W-beam and by the reduction in lateral loads provided by the energy-absorbing cartridges.

Expected exposure in service of the helicell units to moisture and freezing temperatures suggests that some steps should be taken to prevent intrusion of moisture. This has been accomplished by coating the helicell with asphalt emulsion and enclosing it in an aluminum foil skin. Repeated water-soak and freeze-thaw testing of treated cells indicates that the treatment is effective in preventing water intrusion, giving adequate water protection to prevent deterioration of helicell performance. The foil skin also help to contain the helicell debris during and after use.

Investigation of the effect of vertical stiffness gradient in the energy-absorbing cartridges suggests that better performance will result from a gradient that increases with increasing height. In Test 1-22, a decreasing gradient appeared to encourage the vehicle to roll toward the rail, making run-out recovery more difficult. It is expected that a rail system that is stiffer on top will keep the vehicle wheels more firmly loaded during impact. More extensive testing is needed to fully evaluate this secondary effect.

These test results, together with those published elsewhere (2), for a vermiculite concrete modified W-4 guardrail system, show satisfactory performance for both relatively stiff and relatively soft backup systems.

The vermiculite concrete cartridge is conceptually simple and easy to use. It may be used to construct guardrail systems that provide the graduated stiffness called for at rail-to-bridge transitions and, at the same time, hold vehicle crash loading at an acceptable level.

SYSTEM CHARACTERISTICS: REFURBISHMENT

Three factors about this system seem to contribute to ease of refurbishment. First, the use of energy-absorbing cartridges, coupled with strong-post design, tends to minimize the post refurbishment required. In these tests, no post was found to shift more than 1 in. in its earthen foundation. The time-consuming labor of resetting posts, and the attendant realignment, was greatly reduced. A second factor that improves the refurbishment posture is the use of guardrail and post components already on hand. Third, the bolt-sleeve attachment system adopted to reduce snagging during impact also reduces bending of attachment bolts.

In all but the severest impacts, one could reasonably expect to refurbish by simply removing the spent cartridges and permanently deformed W-beam and bolting replacement components in place. All refurbishment in this test series was accomplished by hand without the use of power machinery. After Test 1-22 was completed, the system was refurbished by simply jacking the steel rail into place and replacing five vermiculite concrete cartridges. The estimated total cost of refurbishment was less than $125, including on-site labor.

CONCLUSIONS

The results of the tests discussed in this paper allow the following conclusions to be made:

1. The system presented in this paper has thus far proved to effectively prevent excessive rail deflection without destruction of safety-related vehicle components. Insofar as has been determined, overall acceleration loads and velocity changes are reduced while post-crash controlability is increased, as compared to the performance of W-4 guardrail systems.
2. Overall cost of the system will vary with intended application. First cost will probably not greatly exceed that of the W-4 guardrail in comparable installations. Maintenance costs, including the cost of replaceable energy-absorbing cartridges, may be less than those for the W-4 because of the decreased post displacement.
3. The tests have demonstrated the feasibility of this system for safe, no-penetration deflection as is required in many median barriers and bridge transitions.
4. These tests and those presented elsewhere (2) are representative of performance that would be expected at the stiff and soft ends of a transition section. The test results indicate that vermiculite cartridges can be used effectively to improve the performance of guardrail systems in cramped medians and at bridge transitions.

REFERENCES

1. Michie, J. D., and Calcote, L. R. Location, Selection, and Maintenance of Highway Guardrails and Median Barriers. NCHRP Report 54, 1968.
2. Warner, C. Y., and Walker, G. W. Crash Test Performance of a Prototype Lightweight Concrete Energy-Absorbing Guardrail System. Highway Research Record 343, 1971, pp. 13-18.
3. Bronstad, M. E., and Burkett, R. B. Evaluation of Timber Weak-Post Guardrail Systems. Highway Research Record 343, 1971, pp. 34-56.