CRASH TEST PERFORMANCE OF A PROTOTYPE LIGHTWEIGHT CONCRETE ENERGY-ABSORBING GUARDRAIL SYSTEM

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This paper presents the results of a series of crash tests that compare the performance of standard G4 guardrail with that of a similar guardrail equipped with energy-absorbing cartridges constructed of lightweight concrete. Test results indicate that the cartridges can reduce acceleration loads on vehicles by 20 to 30 percent, improve resistance to pocketing and overriding, and reduce maintenance costs in some instances. Cartridge design is compatible with existing hardware and is adaptable to special needs. The low cost of the cartridges suggests a favorable cost-benefit ratio.

•PROTECTION of motorists from roadside hazards that cannot economically be removed commonly results in the placement of guardrail systems. With proper design and installation, guardrails provide redirection and prevent penetration of errant vehicles (1, 2).

Some recent effort has been directed toward energy-absorption systems used in conjunction with deflecting guardrails to improve vehicle dynamics and reduce accident costs. One such study evaluated a fragmenting-tube absorber system (3). Lightweight concrete barriers have been tested with some success for vehicle barriers at gores (4). This paper deals with tests of a guardrail system that combines these concepts, substituting energy-absorbing cells of lightweight concrete for the wood blockout already in common use in many states (1).

The cost of this system is such that the energy-absorbing components can be substituted for the rigid blocks in a new G4 installation for an additional cost of about 40 cents per foot, or less than 10 percent additional cost.

A test guardrail incorporating vermiculite concrete cartridges is shown before and after a 55-mph test in Figure 1. Seven-in. diameter, spiral-wrapped lightweight vermiculite concrete cylinders with 3-in. diameter holes were used to make an energy-absorbing cartridge for each guardrial post, as shown in Figures 2 and 3. Response of the cylinders is controlled by the geometry of the block, the strength and flow characteristics of the matrix, and the spacing of the spiral wrap wire.

The initial failure of the cylinder fills the center hole progressively from the weak front boundary. As the center hole fills, the apparent pressure within the crushed cylinder increases, causing the crushed matrix to flow through the spiral wrap wire. The pressure within the cylinder can be carefully controlled for a given loading rate by increasing or decreasing the spacing of the spiral wrap wires.

The cylinder response is similar in time sensitivity to that of a hydraulic cylinder in that higher rates of loading increase the apparent pressure within the cylinder, which causes a greater resisting force. The crushed vermiculite matrix flowing through the spiral wrap wire can be controlled in a way similar to the orifice control on a hydraulic

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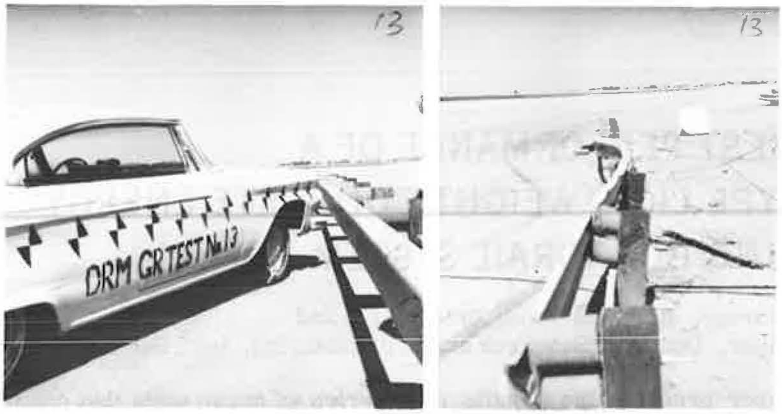

Figure 1. Guardrail system before and after 55-mph, 28-deg impact.

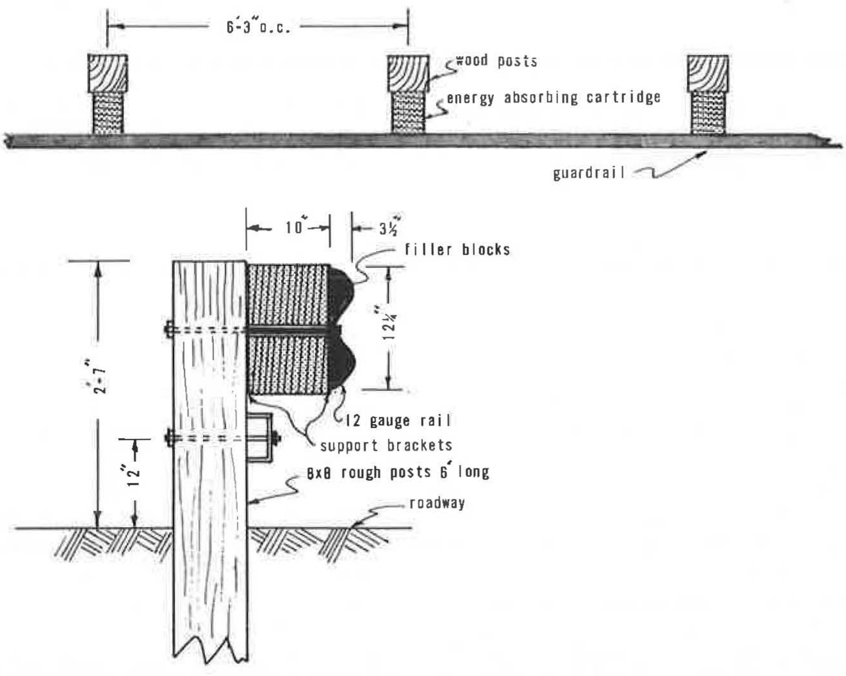

Figure 2. Schematic of energy-absorbing guardrail.

cylinder. As the spacing of the wire increases, the apparent pressure within the cylinder decreases for a given rate of loading. The front half of the cylinder was made softer by increasing the wire spacing. Wire spacing was decreased from 1¼ in. over the front half of the cylinder to less than ¾ in. over the back part of the cylinders, providing a continuously increased resistance from front to back. The effect of slight mix variations and casting techniques is minimized by the great influence of the spiral wrap wire on the overall character of the cell.

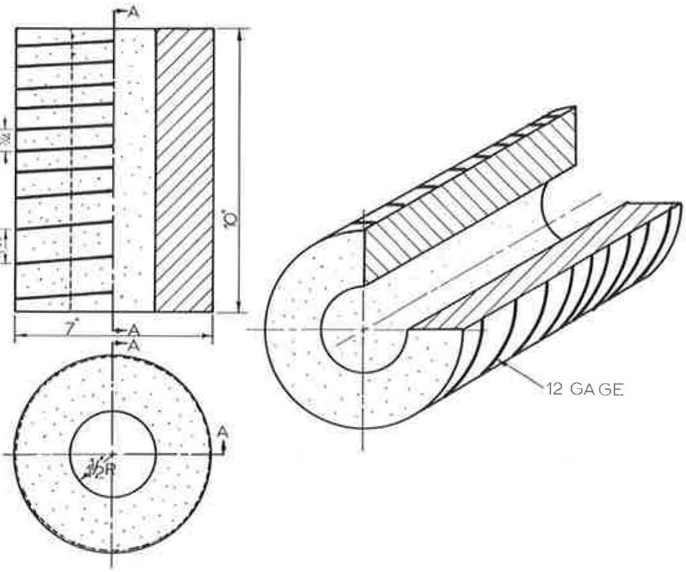

Figure 3. Energy-absorbing lightweight concrete cylinder.

Each cartridge is composed of two hollow cylinders of lightweight concrete fastened to plywood headers. Each cylinder is precast, cured, and wound with steel reinforcing wire before assembly (Fig. 3). Completed cells are weatherproofed by a sealant coating before installation.

TEST PROCEDURE

A series of full-scale vehicle crashes has been conducted during the progress of development and feasibility analysis for this device. Four tests are presented here that compare the performance of the G4 standard rail (1) with that of a modified G4 rail in which the energy-absorbing vermiculite concrete (VC) cartridges are substituted for the standard wood blockout.

Vehicles of the same year and model were chosen for each comparison to provide a uniform basis. Barrier posts were buried in fresh 45-in. deep, 12-in. diameter holes in a hard clay soil and held firmly by a well-compacted sand fill. Impact points were established to prevent any post that shifted due to test loads from being subjected to direct impact loads in a subsequent test.

Visual data were gathered by high-speed movie cameras placed strategically around the impact site. Vehicle accelerations at the left-rear floor pan were measured electronically by two accelerometers connected by hardline to a recorder in a mobile in-

TABLE 1

OVERALL CONDITIONS OF TEST

Test No.	Barrier Type	Impact Speed (mph)	Vehicle Weight (lb_f)	Impact Angle (deg)	Kinetic Energy ($ft\text{-}lb_f \times 10^{-5}$)
14	G4 with VC cartridge	39.8	4,600	28	2.45
15	G4 with wood blockout	39.6	4,600	26.5	2.41
13	G4 with VC cartridge	55.0	3,500	28	3.52
16	G4 with wood blockout	59.5	3,600	27	4.27

TABLE 2

TEST OUTCOMES

Test No.	Duration of Contact (msec)	Maximum Dynamic Lateral Penetration		Accelerations, G				Speed Change During Contact (mph)	Exit Angle (deg)	Trajectory Distances	
		Top of Post (in.)	Rail (in.)	Longitudinal		Lateral				Reentry (ft)	Stop (ft)
				Peak	Average	Peak	Average				
14	336	6	14.8	-5.6	-1.65	5.0	2.4	11.5	12.0	30	120[a]
15	372	8.7	13.3	-8.4	-2.0	7.4	3.0	15.3	10.0	50	208
13	397	11.9[b]	21.9	-12.0	-3.7	10.0	2.3	32.3	7.0	55	136
16	242	34.7[c]	26.7	-17.0	-6.0	8.8	4.2	31.6	8.5	45	69

[a]Bumper pressed against wheel, braking car after hit. [b]Soft footing for this post. [c]Post shattered.

strument van. Redundant measurements of accelerations were recorded by an Impactograph.

Camera framing speeds were established by reference to synchronous clocks in the field of view during the tests. Duration of vehicle-barrier contact was established by visual reference to the high-speed movies. Velocity-change calculations from the film were compared with those obtained from integrating longitudinal-axis accelerometer traces and the average value reported. In most cases, these figures agreed within 1 mph; in no case with the difference greater than 2.2 mph, which reconfirmed confidence in the data.

Impact velocity was measured by a digital clock actuated by fixed switches on the approach run, which also fired flashbulbs visible in the high-speed movies, allowing correlation of electronic and film data. Photographic and manually measured records of vehicle and barrier damage were summarized for comparison of results.

TEST RESULTS

Tables 1, 2, and 3 give the conditions, measurements, and damage resulting from the four tests (all tests having impact angles greater than 26 deg). The first two rows of the tables compare G4 and modified guardrails at about 40 mph. The last two rows

TABLE 3

DAMAGE REPORT

Test No.	Residual Lateral Rail Deflection (in.)	Damage Codes		Results of Test
		Vehicle[a]	Barrier[b]	
14	8	0111	2321	Bumper bent against right front tire, acting as brake
15	11	2121	3231	Two wood blocks split
13	18	2122	4554	Wheel climbed channel, causing post to split, then shatter
16	24	2232	4343	1 post split, 3 wood blocks split

[a]Vehicle condition after test—XXXX:

1st digit—wheel and tire condition
- 0, intact
- 1, tire blown
- 2, rim torn

2nd digit—suspension hardware
- 0, intact
- 1, bent
- 2, torn loose

3rd digit—main vehicle frame
- 0, intact
- 1, minor bending
- 2, moderate distortion
- 3, severe distortion
- 4, broken or torn

4th digit—body parts
- 0, minor deformation
- 1, major deformation
- 2, structural parts torn off

[b]Barrier condition after test—XXXX:

1st digit—number of posts disturbed or broken
2nd digit—number of blockouts destroyed
3rd digit— number of 6 ft 3 in. lengths of guardrail deformed or destroyed
4th digit—number of 6 ft 3 in. lengths of channel rub-rail destroyed or bent

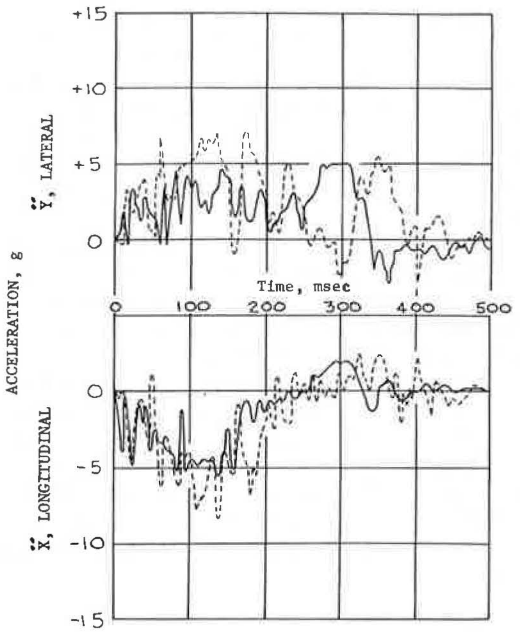

Figure 4. Acceleration histories: Test 14 (solid line)—39.8 mph, 28 deg, VC cartridge; test 15 (broken line)—39.6 mph, 26.5 deg, wood blockout.

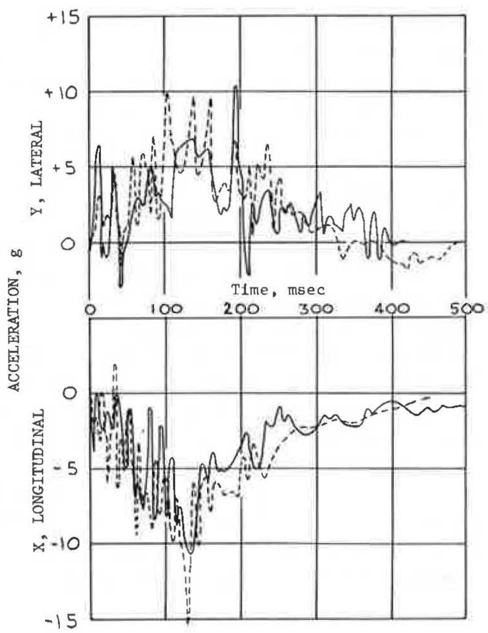

Figure 5. Acceleration histories: Test 13 (solid line)—55 mph, 28 deg, VC cartridge; test 16 (broken line)—59.5 mph, 27 deg, wood blockout.

make a similar comparison at about 60 mph (test controls failed to establish a 60 mph speed in test 13; however, the steep angle partially compensated for this). Figures 4 and 5 show acceleration histories for comparable tests.

DISCUSSION OF RESULTS

Table 2 gives data showing that the initial exit trajectory of the vehicle is not greatly different in either case. In the low-speed test pair, the durations do not differ significantly, while a notable difference in speed change occurs. This is also borne out in the presentation of acceleration measurements, showing the standard G4 system to subject the vehicle to greater loads for the duration of impact. In the high-speed series the velocity change is comparable, but the shorter duration of the wood-block impact again leads to higher average loads. In both series, peak accelerations were found to be higher in the wood-block tests.

It was intended that all tests be made at different impact points on the test guardrail to ensure undisturbed soil conditions for each test. This condition was achieved for all except test 16. Because of a guidance error, the impact point of test 16 was nearly the same as that for test 13 thus making the soil conditions softer for test 16. The loads on the car would probably have been more severe during test 16 if the soil conditions had been undisturbed, as they were for test 13.

The maximum dynamic deflections of rail and posts demonstrate the effect of the VC cartridges. Although the rail deflection is roughly the same for the tests in each pair, the accompanying post deflection is much smaller in the case of the vermiculite blocks. This indicates a reduction in maintenance costs per impact, substituting cartridge compression for post disturbance.

The effect of the energy-absorbing distances provided by the VC cartridges is further illustrated in the comparison of vehicle decelerations, as given in Table 2 and shown in Figures 4 and 5. Both peak and average decelerations are reduced by substitution of the cartridges. Reductions of 20 to 30 percent are typical.

Table 3 gives a summary of the damage inflicted on vehicle and barrier for each test. The lesser residual lateral rail deflection, in the case of the VC cartridge test in each pair, suggests that the rail is given freedom to deform more gradually over a greater distance. This should lead to a decreased friction between rail and vehicle and is probably a deterrent to pocketing.

The damage codes given in Table 3 are meant to condense qualitative photographic impressions and measurements from the vehicle and barrier after test. Generally, the higher numbers indicate greater damage.

In the low-speed series, serious damage to tire and suspension was averted in test 14, resulting in a smooth runout, although the bumper was pressed against the tire. Test 15 caused significant tire-wheel damage, resulting in a rough runout that was significantly more hazardous. Two wood blockouts were split in this test, and three posts were displaced, whereas test 14 caused displacement of only two posts.

In the high-speed series, damage to the vehicle was somewhat more severe in test 16, primarily in the degree of distortion at frame and suspension parts. The barrier damage in these tests was roughly equivalent. It was noted in several tests using the VC cartridges that the guardrail, after the cartridges were partially crushed, appeared to rise and fall rather freely with the vehicle. The decrease of vertical stiffness in the overall guardrail system provided by the VC cartridge blockout allowed the W-beam to move vertically in unison with the vehicle. This apparently provided greater resistance to overrunning the guardrail system.

CONCLUSIONS

The following statements appear to be warranted by the results of these preliminary tests:

1. The presence of the VC cartridges has at least five beneficial effects: (a) impact acceleration loads can be reduced by 20 to 30 percent; (b) at moderate speed, vehicle rideout trajectory and control may be improved because vehicle suspension and frame damage is reduced; (c) post deflections were significantly reduced by the energy-absorbing VC cartridges during the test series (deflection of the posts accounted for the major part of the energy absorbed by the rail when wood blocks were used); (d) guardrail maintenance problems are reduced, at least at the lower speeds; and (e) the tendency of the vehicle to produce pockets in the guardrail beam is reduced.
2. The low cost, modular construction, quick-change features, and compatibility with hardware already in use suggest a favorable cost-benefit ratio in new construction. Modification and updating of existing guardrail systems can be readily and inexpensively accomplished.
3. The ease of controlling the geometry and the dynamic properties of the VC cartridge suggest broad adaptability to specialized needs, such as gradual stiffening at bridge rail transitions.

REFERENCES

1. Michie, J. D., and Calcote, L. R. Location, Selection, and Maintenance of Highway Guardrails and Median Barriers. NCHRP Rept. 54, 1968.
2. Olson, R. M., Post, E. R., and McFarland, W. F. Tentative Service Requirements for Bridge Rail Systems. NCHRP Rept. 86, 1970.
3. Stocker, A. J., Ivey, D. L., and Hirsch, T. J. Full-Scale Crash Tests of the Fragmenting-Tube-Type Energy-Absorbing Bridge Rail. Highway Research Record 302, 1970, pp. 28-37.
4. Ivey, D. L., Buth, E., and Hirsch, T. J. Feasibility of Lightweight Cellular Concrete for Vehicle Crash Cushions. Highway Research Record 306, 1970, pp. 50-57.