

# CRASH TESTS OF AN ARTICULATED ENERGY-ABSORBING GORE BARRIER EMPLOYING LIGHTWEIGHT CONCRETE CARTRIDGES

Grant W. Walker, Dynamics Research and Manufacturing, Inc.;  
Bruce O. Young, Energy Absorption Systems, Inc.; and  
Charles Y. Warner, National Highway Traffic Safety Administration

The concept of vermiculite concrete energy absorption has been further tested by incorporating cartridges into the Hi-Dro Cell sandwich unit designed for water-cell use. Repeated tests were performed with gradually increased use of the cartridges in place of water cells. Tests up to 55 mph with medium-weight automobiles indicate improved response, especially with regard to the approach to square-wave deceleration pulse. Harness-restrained drivers reported no discomfort in three separate impacts at speeds above 50 mph.

•INITIAL success with the use of vermiculite concrete modules in guardrails has encouraged other highway applications of these modules (1). The following is a report of crash tests performed to evaluate the substitution of vermiculite concrete cartridges for water cells in the Hi-Dro Cushion Cell sandwich gore barrier. The use of this barrier has already proved successful in test and actual conditions (2, 6).

Lightweight concrete crash barriers investigated by the Texas Transportation Institute were found to have acceptable head-on performance and low initial cost (7). No angle tests were conducted.

Experience gained in the development of the hardware for the Hi-Dro Cell sandwich unit suggested that its cost could be reduced by the substitution of vermiculite concrete cartridges for the water cells. The tests reported here cover a development program wherein this was accomplished and the head-on test performance evaluated for speeds up to 56 mph.

Experience gained from angle impacts into several systems using very similar deflection hardware suggests that acceptable angle-impact performance is obtainable. There does not appear to be any technological problem that would prevent equally good angle performance of this system. Crash tests to evaluate angle impact performance have just been initiated. Angle impacts in the 15-deg, 45-mph range have not produced adverse results, but more severe tests are planned.

## TEST PROCEDURE

The basic hardware for this test series was a cell sandwich unit that is shown in Figures 1 and 2 (5). Figures 3 through 6 show details of the construction of the cells and cartridges and show their arrangement in the barrier system. Sequential tests were conducted where vermiculite concrete cartridges were gradually substituted for water cells, starting from the nose and working toward the rear. In three tests at speeds above 45 mph, the complete unit was equipped with vermiculite concrete absorbers.

The data were collected in these tests by using techniques similar to those used elsewhere (1). High-speed photometrics were obtained from four ground cameras. Ve-

Figure 1. Impact attenuator with helicell nose section.

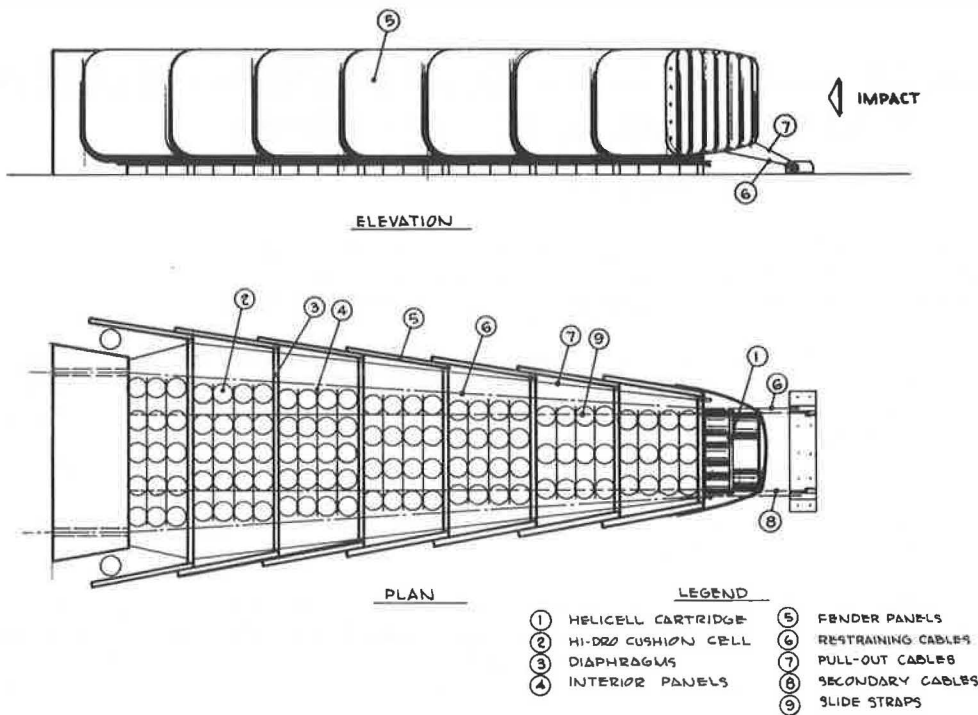


Figure 2. Impact attenuator with helicell cartridges.

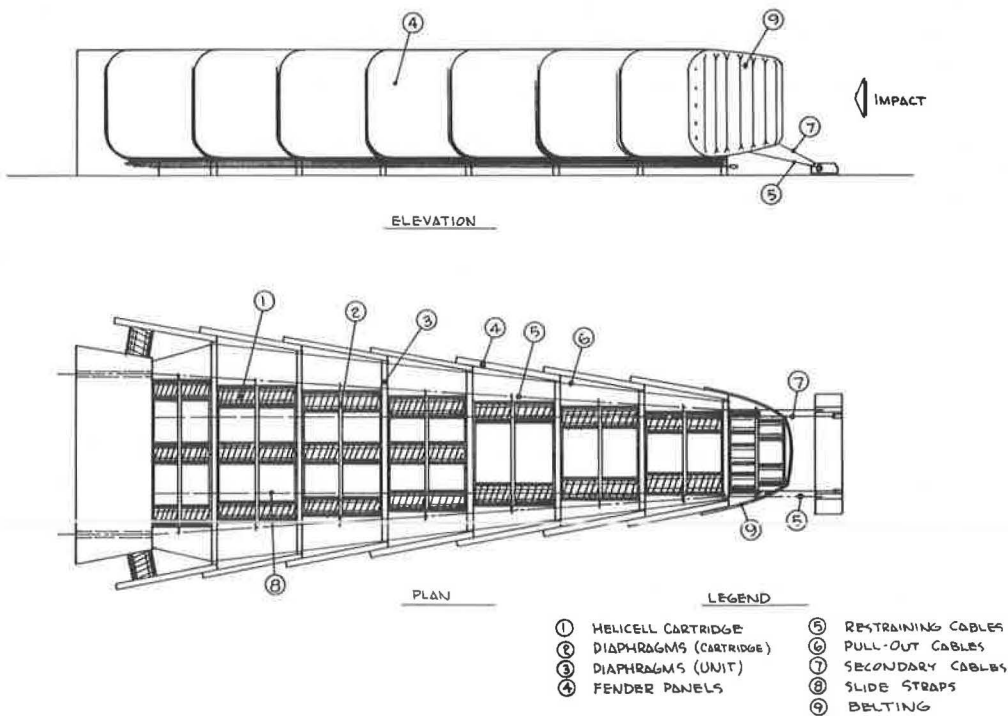


Figure 3. Vermiculite concrete cartridge.

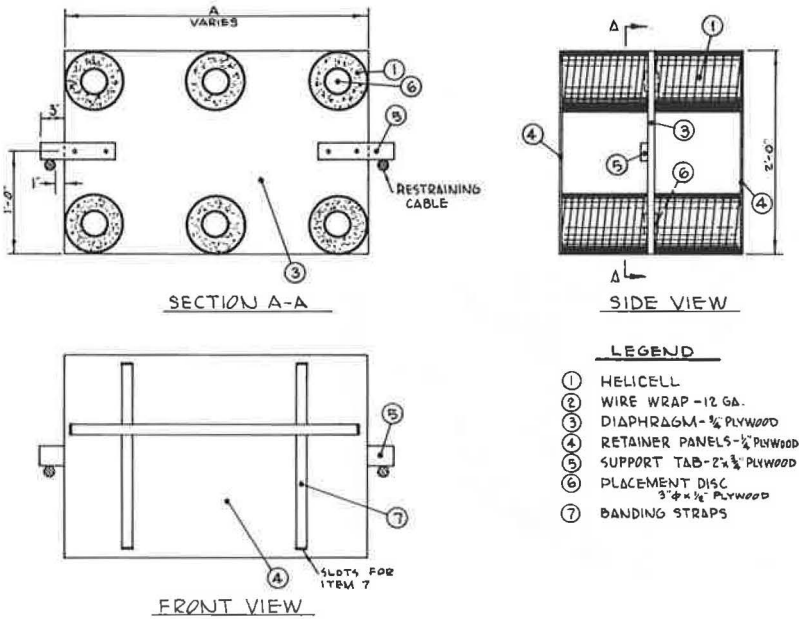


Figure 4. Helicell.

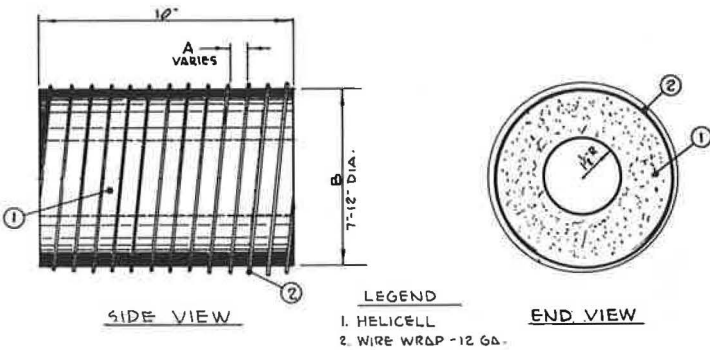


Figure 5. Cartridge mounting in unit.

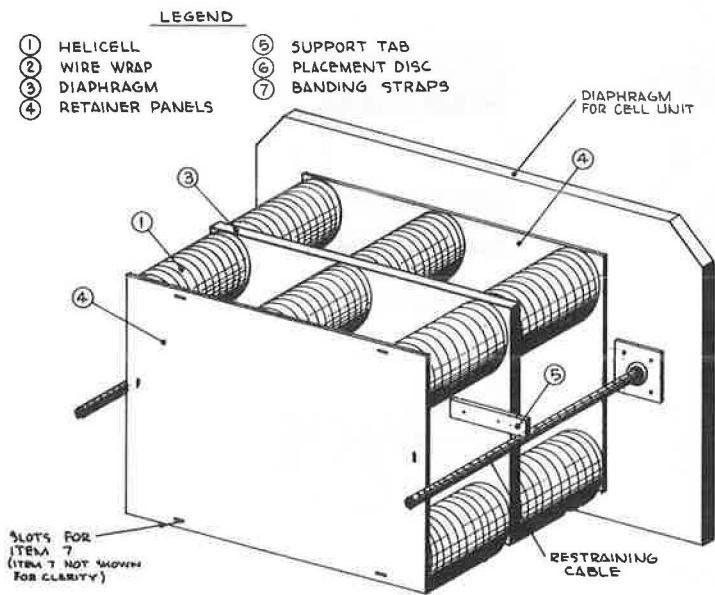
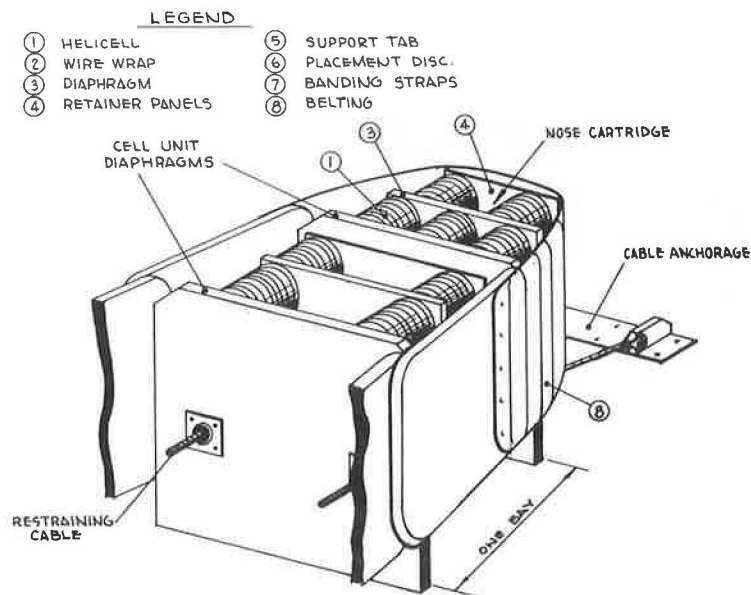


Figure 6. Nose treatment.



hicle impact speed was measured by trip-wire timers. Vehicle accelerations were measured by a biaxial strain-gauge accelerometer pack mounted on vehicle occupant compartment floor, between the front and rear seats, with hardline 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 photo-metrics to determine overall agreement.

Dynamic stopping distance was measured by using photometric records. Most of the tests reported here were run with human drivers; three tests were run at speeds of between 50 and 56 mph.

To make an orderly, safe transition from known to new performance, we decided to gradually replace the water in the cell sandwich system, starting at the nose and working through the entire system, at speeds between 45 and 50 mph. This was accomplished in a series of 7 tests that were performed safely using human drivers. The drivers were restrained with aircraft-type lap belts and double shoulder harnesses, plus an additional restraint that was attached to the rear of the driver's safety helmet to limit head motion.

Both drivers who participated in the program reported minimal belt loads for all but the last test. Because of their report, we decided to continue testing the vermiculite system, which was designed for 60 mph, into the mid-50-mph speed range. During the last test (at 56 mph), a firm belt load was reported on the shoulder harness, and moderate load was reported on the lap belt. Drivers reported no physical discomfort from the loads applied during the tests.

## TEST RESULTS

Pertinent test results are shown in Figure 7 and given in Table 1. The vehicles used were 1956-62 model lightweight standard sedans (Fig. 8), some of which were used in more than one crash test. In Test 1-2 a heavy, reinforced moving-barrier-type vehicle was used.

### Square-Wave Response

The substitution of lightweight concrete cartridges for water cells has significantly flattened the acceleration response. This is attributed primarily to the removal of significant mass elements from the system. The initial peaks that characterize the performance of the water system (Test 1-2, Fig. 7, and 3, 4, 5) are significantly moderated as the vermiculite crush mechanism is substituted for the momentum-exchange mechanism of energy attenuation. The improvement is apparent when one compares the results shown in Figure 7. One can see a gradual flattening of the pulse form. It should be noted that the speeds represented in the lower portion of the figure are generally higher.

The advantages of one wave form versus another in terms of occupant protection presupposes some form of occupant restraint system. It is unlikely that any of the reported vehicle wave forms would offer clearly superior occupant protection, and none of them would clearly prevent injury to an unrestrained or lap-belt restrained occupant. Hence, the relative survivability benefits of these vehicle pulse forms are unknown. On the other hand, the cost of the barrier system is directly related to the space it occupies in the roadway. The combined effects shown in Figure 7 of the lower peak g and more nearly uniform square-wave response suggest a more efficient utilization of space.

An important fact that is not apparent in the figure is that the overall length of the barrier was actually shortened during this progression, from 19.2 ft in Test 1-2 to 17.2 ft in Test 1-20.

### Velocity Sensitivity

Figure 9 shows the results of impact tests on individual cells. The data used to construct this figure are all derived from vehicle tests of helicell arrangements. Where more than one cluster was involved in a test, photometric data were used to calculate the dynamic loads on single cells within the cluster. Although the data are somewhat

Figure 7. Acceleration trace comparisons.

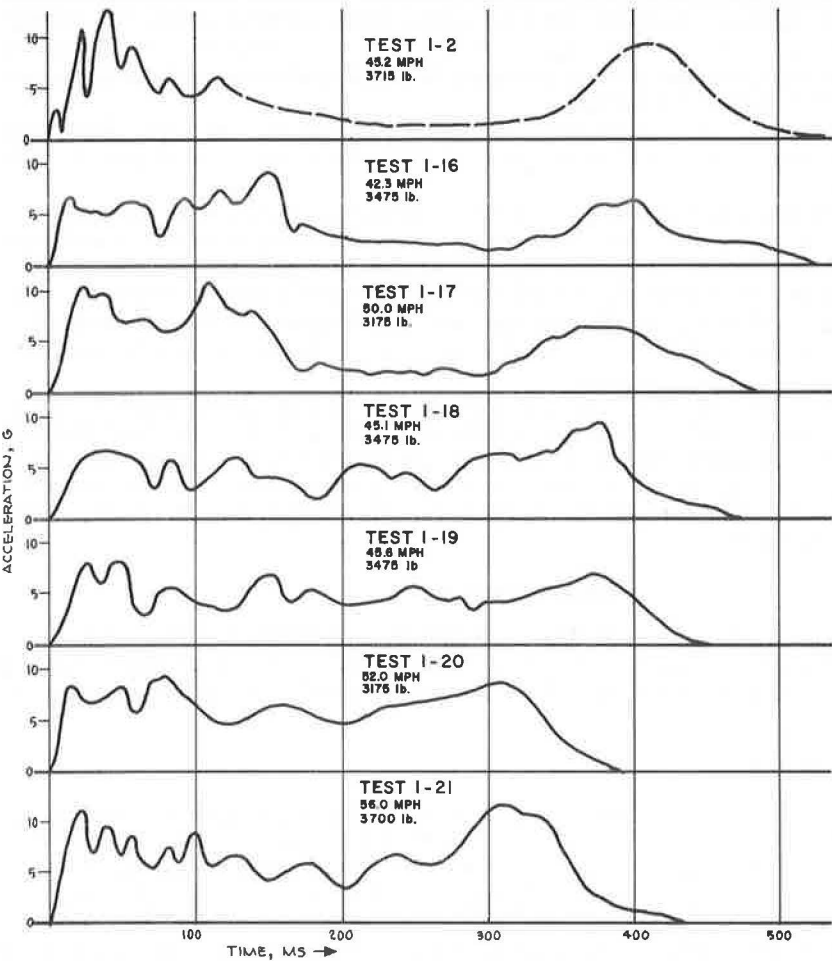


Table 1. Test data summary.

Test No.	Vehicle	Total Vehicle Weight (lb)	Impact Speed (mph)	Crush on Vehicle (in.)	Stopping Distance (ft)	Maximum g	Average g	No. of Bays (water)	No. of Bays (vermiculite)	Weight Reduction (lb)	Total Length (ft)
1-2	Test truck	3,715	45.2	0	13	14.5	5.25	8	1	135	19.2
1-16	1956 Studebaker Champ, 4-dr.	3,475	42.3	2	12.7	9	4.7	6	3	450	19.2
1-17	1959 Studebaker Lark, 4-dr.	3,175	50.0	8	13	11	6.4	6	3	450	19.2
1-18	1956 Studebaker Champ, 4-dr.	3,475	45.1	8	14.5	9.5	4.7	3	6	900	18.0
1-19	1956 Studebaker Champ, 4-dr.	3,475	45.6	0	13.5	8.0	5.1	0	9	1,400	17.2
1-20	1959 Studebaker Lark, 4-dr.	3,175	52	0	13.7	9.5	6.6	0	9	1,400	17.2
1-21	1962 Rambler, 4-dr.	3,700	56	10	14.5	11.5	7.2	0	10	1,550	18.3

Figure 8. Test vehicle before and after 53-mph impact.

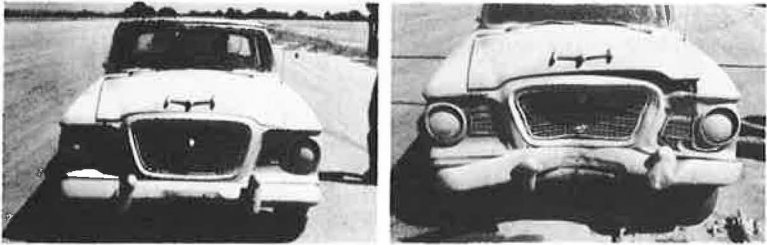


Figure 9. Vermiculite concrete cell velocity sensitivity.

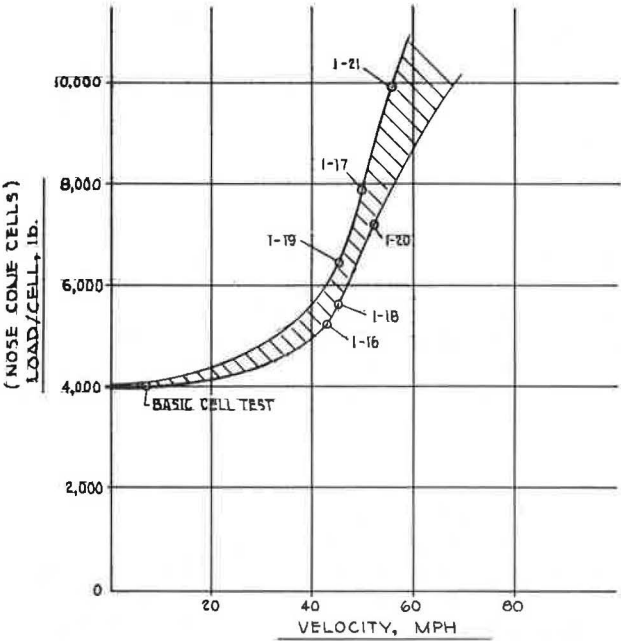
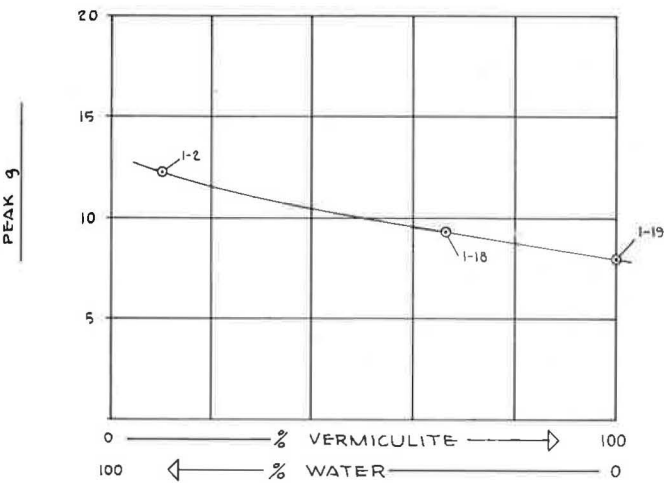


Figure 10. Peak g reduction at 45 mph with increasing use of vermiculite cartridges.



scattered, it is clear that some velocity sensitivity exists. It is not clear exactly what relation the total unit force bears to velocity; however, the potential clearly exists for the design of a unit whose response matches the velocity and mass of the arrested vehicle, similar in overall response to the water-filled plastic system (5).

### Mass Matching

The moderation of the initial peak is thought to be especially significant for impacts involving compact and subcompact class vehicles. Further tests are planned to investigate this more specifically, i. e., 2,000-lb, 60-mph impacts.

The capability of the lightweight concrete system for mass and velocity matching is demonstrated in the stopping distance column of Table. 1.

### Water Versus Rise

The effect of substitution of lightweight concrete cartridges for water cartridges is shown in Figure 10. Peak deceleration decreases with increasing use of concrete cartridges, particularly near the nose of the unit. This saving is primarily a result of mass reduction in the nose, with corresponding stiffness increase. The use of the lighter material has a lesser effect near the rear of the unit because dynamic effects are smaller in that region.

### Vehicle Rise

One concept that was explored in the later tests was the control of vehicle rise by raising the center of pressure in the force path through the cushion. This was done by inserting stiffer helicells into the upper part of each cartridge and by using slotted cable grommets in the forward diaphragms. An improvement in vehicle stability was seen in film records of crash tests in which the force center angled gently upward, starting from a point on the unit nose that is above the vehicle center of gravity. Further test work is planned to investigate this benefit.

### Weatherability

Exposure of the helicell units in service to moisture and freezing temperatures suggests that some steps should be taken to prevent intrusion of moisture. The most promising approach that has been attempted involves coating the helicell with asphalt roofing compound and enclosing the treated helicell in an aluminum foil skin. This inexpensive weatherproofing appears to offer adequate protection for all environments to which exposure is likely. Treated cells have been submerged in water for periods of days, frozen in 0-deg environments, thawed, and resoaked, without noticeable change in weight or characteristics occurring. The foil skin also serves to trap and hold most of the debris that is formed upon impact, which simplifies cleanup.

### Refurbishment Advantages

The use of lightweight concrete cartridges makes possible a considerable reduction in overall cushion weight compared to the water system; cartridges sufficient for total refurbishment weigh less than 500 lb. Use of these cartridges greatly simplifies refurbishing because of the following:

1. A crew of two men is adequate;
2. A  $\frac{1}{2}$ -ton pickup can easily carry men, material, and equipment to and from the site;
3. The materials for refurbishment can easily be stored near the crash site;
4. The refurbishment time is reduced by as much as 50 percent, thereby improving freeway usage and decreasing probability of secondary accidents;
5. Where practicable, user agencies can recycle cartridge components by simply replacing the vermiculite concrete cells; and
6. The cost of all cartridges needed to refurbish a typical 60-mph unit is estimated to be roughly \$500.



## CONCLUSIONS

This preliminary series of tests indicates a head-on crash performance that is about equivalent to the water cushion barrier with notable improvements in pulse-form flatness and initial peak deceleration.

The more nearly rectangular pulse form provided by the helicell barrier allows more efficient utilization of limited roadside space.

The helicell cartridges can be easily weatherproofed to allow use in all temperate-zone climates. Low component costs and modular construction reduce materials and labor costs for refurbishment.

Further tests are needed to verify the performance of this system in three areas: (a) low-to-moderate speed crashes with full-sized sedans, (b) several tests with compact cars, and (c) instrumented full-scale tests at oblique impacts. These tests will be completed in the near future.

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