

# EVALUATION OF CRASH CUSHIONS CONSTRUCTED OF LIGHTWEIGHT CELLULAR CONCRETE

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Lightweight cellular concrete crash cushions have now progressed to the point that experimental installations are being made in the continental United States. This report describes the development of these safety devices and presents the results of the most recent vehicle crash tests. This crash cushion is composed of vermiculite concrete, lightweight welded wire fabric, and cylindrical cardboard forms. At the present stage of development, the crash cushion is an effective system that protects motorists from collisions with rigid obstacles whether they collide in a head-on or side-angle attitude.

•THE feasibility of vehicle crash cushions constructed of lightweight cellular concrete was demonstrated by a series of three head-on vehicle impacts on prototype installations (1). The concrete crash cushion is one of a group of first-generation devices that include the barrel crash cushion, the Fitch inertia barrier, and the Hi-Dro Cell barrier. The evaluation sequence that was followed with all of these systems is (a) feasibility testing, (b) full-scale head-on testing, and (c) side-angle testing. Because of the excellent performance of the concrete cushion in the first three tests conducted, several states were interested in applying the concept to some of their potentially hazardous areas. The basic cushion (2) that was tested under the Federal Highway Administration's 4S Program (Fig. 1, Mod I) and the side-fender panels previously tested as part of barrel crash cushion designs (3) were incorporated in a concrete cushion designed for Florida. The results of two side-angle tests of the system constructed for Florida (Fig. 1, Mod II) were reported to Florida in November 1970 (2).

It was decided that additional tests would be conducted to further evaluate the concrete cushion for both side-angle impacts and head-on impacts involving small vehicles. Further modifications of the cushion were made prior to the final series of tests that resulted in the design shown as Mod II in Figure 1. The most significant concrete cushion designs that have been tested are shown in Figures 2 through 4. This report describes in detail the three tests that were conducted on the Mod III concrete crash cushion.

## EXPERIMENTAL PROGRAM

Three full-scale vehicle crash tests (designated D, E, and F) of the Mod III concrete crash cushion (Fig. 4) were conducted in this final test series; the results are given in Table 1. Properties of the concrete used in the various cushions tested are as follows,

Test	Average Compressive Strength (psi)	Average Unit Weight (pcf)
A	50	32
B	71	32
C	57	21
Florida 1 and 2	64	22
D, E, and F	64	22



Figure 3. Florida Tests 1 and 2, Mod II concrete crash cushion.

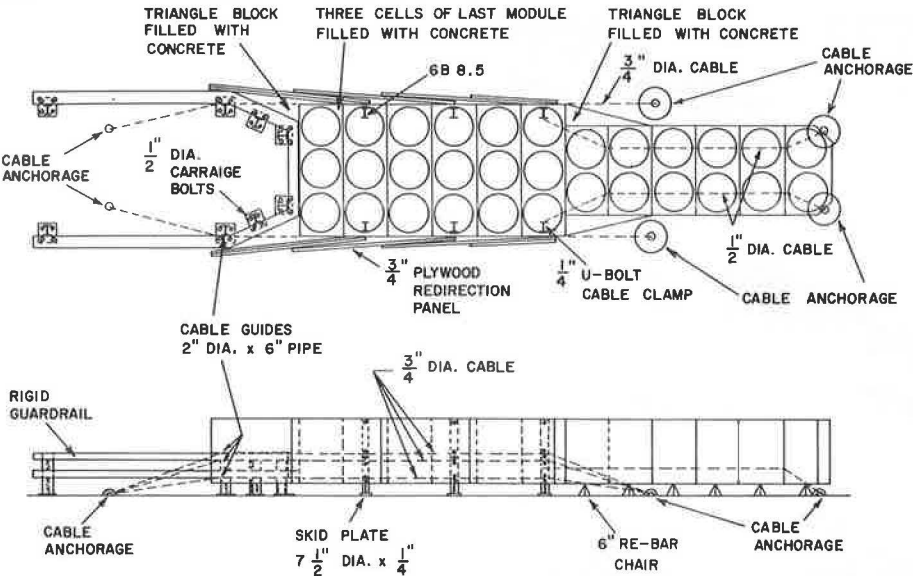
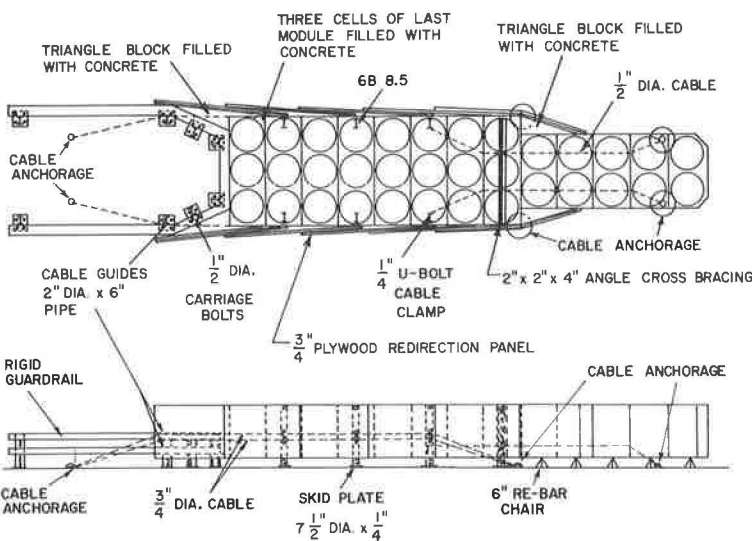


Figure 4. Tests D, E, and F, Mod III concrete crash cushion.



Accelerometers and an impact-o-graph were used on each test to record vehicle decelerations. Statham strain-gauge-type accelerometers were used, and all electronic data were passed through an 80-Hz low-pass active filter. High-speed cameras were also used to record the vehicle position and speed throughout the test.

#### Test D

In this test a 1963 Chevrolet weighing 3,790 lb was impacted into the cushion at a 10-deg angle from the longitudinal axis of the cushion (Fig. 5). The contact point was 18 ft in advance of the rigid backup rail. The speed at contact was 57.2 mph, and the speed at loss of contact was 49.6 mph. The average longitudinal deceleration was 1.3 g. The distance that the vehicle was in contact with the barrier was 20.4 ft over a period of approximately  $\frac{1}{3}$  sec. The vehicle laterally penetrated the barrier a maximum distance of about 2 ft. The vehicle was smoothly redirected, and damage was relatively light (Fig. 6). Figure 7 shows that only five modules were significantly damaged and that the cushion could probably still sustain a head-on impact. The test was considered extremely successful in regard to both passenger safety and vehicle damage.

#### Test E

In this test a 1962 Chevrolet, weighing 3,820 lb was impacted into a Mod III barrier at a 20-deg side angle. The point of contact was 16 ft in advance of the rigid backup rail. The impact speed was 59.7 mph, and vehicle speed at loss of contact with the barrier was 29.3 mph. This represented an average deceleration of 5.6 g in the longitudinal direction. The vehicle was in contact with the cushion for approximately 16 ft. Photographs of this test are shown in Figures 8 through 10. As the vehicle made contact and slid down the side of the cushion, a slight ramping tendency was observed. This interaction finally culminated in the generation of a high roll-initiating force as the vehicle reached the end of the cushion. The vehicle rolled in a counterclockwise direction (when viewed in the direction of vehicle travel); ramped on the rear of the cushion near the end of the backup rail; traveled beyond the cushion installation, skidding on its left side; rolled clockwise to an upright position; and continued to roll over onto its top. It came to rest approximately 80 ft past the barrier. Although the decelerations, which were caused by vehicle-cushion interaction, were within the range of human tolerance, the roll condition that occurred after the vehicle left the cushion was not within passenger safety limits. This is the only test conducted to date in which an unacceptable reaction of the vehicle occurred. Recommendations for modification of the barrier to preclude the recurrence of this situation are presented later in this paper.

#### Test F

A 1957 Volvo weighing 2,210 lb was impacted into the cushion head on at a speed of 61 mph. The average longitudinal deceleration was 10.2 g, with a peak longitudinal deceleration of 19 g. The interaction of the vehicle and cushion was considered acceptable. The damage done to the vehicle and cushion is shown in Figures 11 and 12.

The deceleration that occurs with a 2,000-lb vehicle is approximately twice that which occurs with a 4,000-lb vehicle. This is verified by comparing the preceding values with the 6.4 average and 10.4 maximum decelerations observed in Test C (1).

### DISCUSSION OF FINDINGS

Of the eight vehicle crash tests that have now been conducted on the concrete crash cushion, all but one have yielded results that appear very favorable in reference to passenger safety. The exception to this was the 20-deg, 59.7-mph, side-angle impact of the Mod III cushion (Test E). In this test the vehicle was subjected to a large moment about the roll axis toward the end of the contact zone. This resulted in a hazardous roll, after contact with the cushion was lost, and the vehicle came to rest upside down. This tendency in side-angle collisions has been noted in other crash tests, such as Test R-E (4) and USS Test 1 (the first test of a series of three tests conducted by United

Table 1. Summary of tests.

Factor	Test		
	D	E	F
Vehicle			
Year	1963	1962	1957
Make	Chevrolet	Chevrolet	Volvo
Weight, lb	3,790	3,820	2,210
Impact angle, deg	10	20	0
Film data			
Initial speed, V <sub>1</sub> , fps	83.9	87.5	89.7
Initial speed, V <sub>1</sub> , mph	57.2	59.7	61.2
Final speed, V <sub>2</sub> , fps	72.7	43.9	0
Final speed, V <sub>2</sub> , mph	49.6	29.3	0
Average deceleration <sup>a</sup> , G <sub>avg</sub> , g	1.3	5.6	10.2
Stopping distance or contact distance, S, ft	20.4	16.1	12.2
Time in contact, sec	0.286	0.235	0.364
Accelerometer data			
Longitudinal deceleration			
Peak g	6.2	14.7	19.0
Average g	1.4	4.2	6.4
Time, sec	0.294	0.268	0.446
Transverse deceleration			
Peak g	9.8	12.7	—
Average g	2.4	3.3	—
Time, sec	0.302	0.273	—

<sup>a</sup>G<sub>avg</sub> = (V<sub>1</sub><sup>2</sup> - V<sub>2</sub><sup>2</sup>)/2gS

Figure 5. Test D sequential photographs (view parallel with barrier).

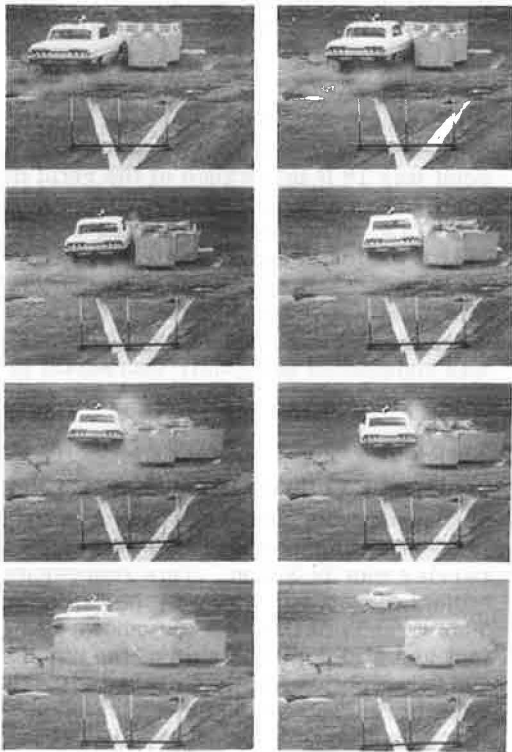


Figure 6. Vehicle after Test B.



Figure 7. Barrier before and after Test D (end view).

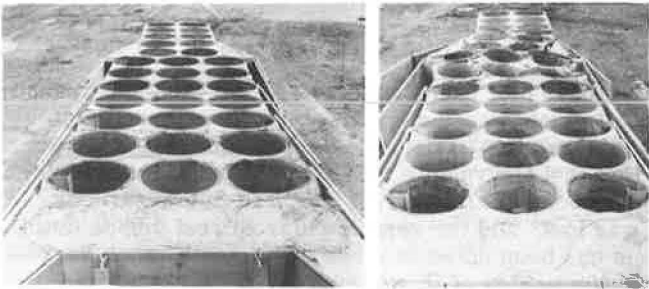


Figure 8. Vehicle before Test E and in final position.

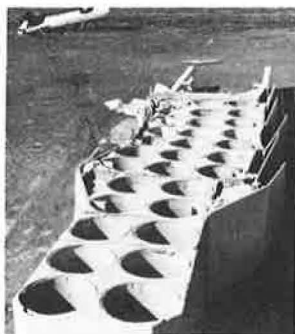


Figure 9. Barrier before and after Test E.

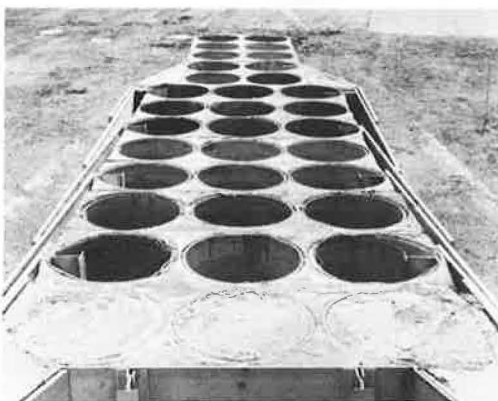


Figure 10. Test E sequential photographs (view perpendicular to barrier).



$t = 0 \text{ sec}$



$t = 0.104 \text{ sec}$



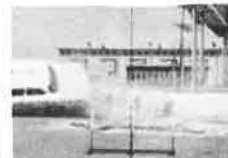
$t = 0.153 \text{ sec}$



$t = 0.213 \text{ sec}$



$t = 0.315 \text{ sec}$



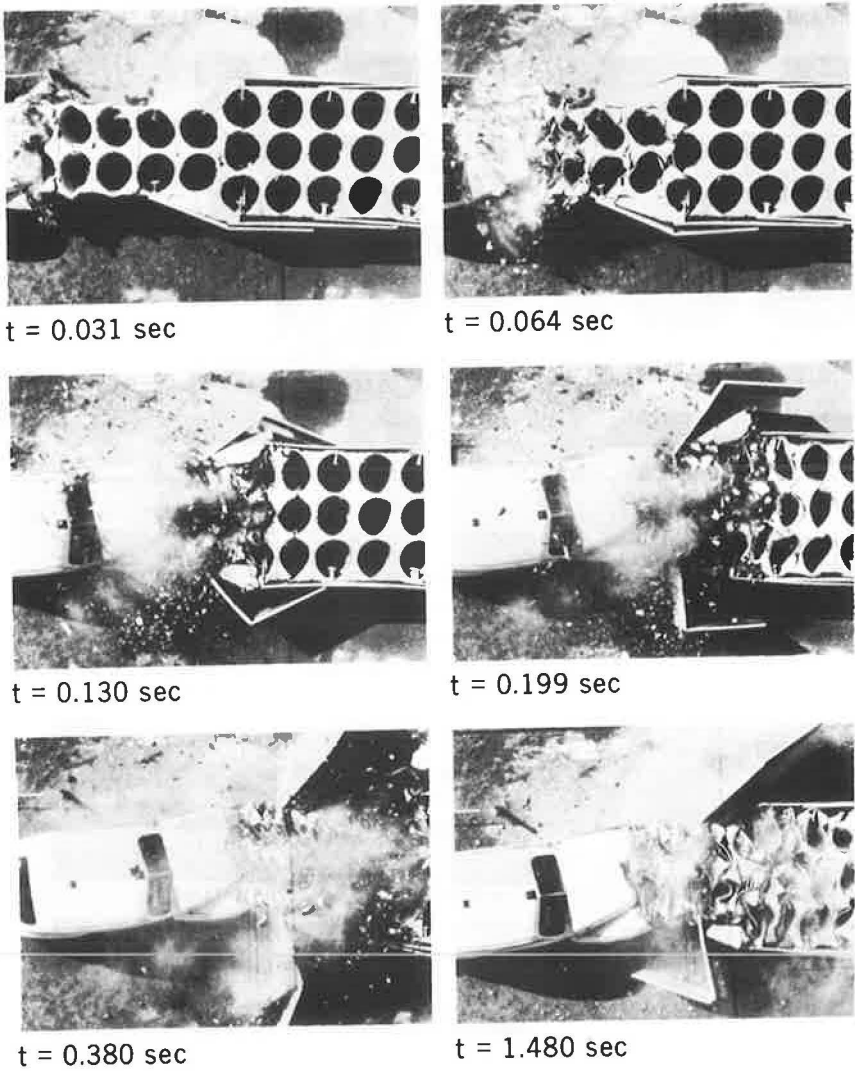
$t = 0.536 \text{ sec}$



Figure 11. Vehicle before and after Test F.



Figure 12. Test F sequential photographs (overhead view).



States Steel Corporation, U.S.S. Contract 6339, Texas A&M Research Foundation Project RF 719, March 1970; no formal publication). In both of these tests, the vehicle contact-wheel appeared to ride up the side panels, which resulted in the vehicle becoming airborne as contact with the barrier was lost. The phenomenon observed in Test E, however, appears to be significantly different from that observed in previous tests. From observation of the high-speed test film, it appeared that the following events occurred:

1. The vehicle contacted the cushion at  $t = 0$  sec (Fig. 10), which is approximately 16 ft in advance of the rigid backup rail.
2. The vehicle began to displace the barrier laterally and slide along the side panels (Fig. 10;  $t = 0.104$  and  $t = 0.153$  sec). There was a slight ramping tendency during this stage, with the contact side of the vehicle rising approximately 1 ft as compared to its elevation at contact. This ramping was less severe than that which occurred in Test R-E and USS Test 1.
3. At  $t = 0.213$  sec (Fig. 10), the vehicle frame appeared to be in a state of severe torsion, as indicated by the sudden elevation of the right front quadrant of the vehicle. It was at this point, where contact with the last module of the cushion was made, that the severe upward thrust on the right front of the vehicle caused the counterclockwise roll motion. The last module of the Mod II and III cushions was made of solid vermiculite, whereas the other modules had sonotube openings. Because of the comparative rigidity of this module, one of the two following events had to occur: (a) The contact area of the vehicle is suddenly forced to the outside to pass the rigid module in a relatively violent redirection (barrier force causes a moment about the yaw axis of the vehicle) (2, Florida Test 1); or (b) the contact area of the vehicle is forced upward to pass over the rigid module resulting in a rolling motion (barrier forces cause a moment about the roll axis of the vehicle). In the slightly elevated position that the right front of the vehicle had achieved in Test E, the path of least resistance was over the final rigid module.

The question remaining to be answered is why this roll phenomenon occurred in Test E but not in Test D or Test 1 of the Florida series. In Test D, the impact angle was only 10 deg, and the vehicle had been almost completely redirected before reaching the solid module. Thus, traumatic force was not necessary to get by the rigid portion of the cushion. In Florida Test 1, the impact angle was 20 deg, as in Test E, but the contact point was only 6 ft in advance of the rigid module. In all other respects, the final 8 ft of the Florida Mod II cushion was identical to the final 8 ft of the FHWA Mod III cushion. It is hypothesized that the ramping that occurred in Test E was initiated when the vehicle struck the cushion at a point where the cables supporting the redirection panels were low; whereas, in Florida Test 1, the cables at the impact point were almost fully elevated. It would therefore appear that the Mod III cushion has a weak point if struck at an angle of 20 deg, close to where the side panels start. No such weakness was demonstrated by tests on the Mod II cushion because the panels extend only 11 ft from the rigid backup rail, and angle hits in advance of the panels result in an acceptable "pocketing" interaction (2, Florida Test 2).

It is believed that this weakness in the Mod III cushion can be overcome by (a) replacing the solid module at the rear of the Mod III cushion with a standard hollow module and (b) elevating the side cables 6 in. at the rear of the cushion. The first step results in reducing the forces imparted to the vehicle at this point in the interaction and reduces the vehicle reaction necessary to get by the final module. The second step results in elevating the vertical position of maximum lateral resistance and thus reduces the slight ramping tendency that has been noted.

## CONCLUSION

It has been shown that the lightweight concrete crash cushion can be used to effectively decelerate a vehicle for both the head-on and side-angle crash conditions. Seven of eight tests show deceleration levels within the tolerance of restrained humans. The single test of the Mod III cushion resulted in an undesirable reaction of the vehicle during a cushion impact; modifications to prevent future reactions of this type have been



recommended. Because these proposed modifications have not been tested, full-scale tests incorporating these modifications are planned by FHWA.

The lightweight cellular concrete crash cushion can be installed by semiskilled laborers using one of two methods. The formwork can be placed in the field, and a local vermiculite applicator can supply the necessary concrete; or the precast modular construction method can be used. The cost per installation compares favorably with that of the barrel crash cushion. By using the modular construction technique that permits mass production we can realize considerable savings. Close quality control should be exercised on the geometry of the module and on the vermiculite concrete. Control of batch proportions and unit weight will give predictable crushing strengths. Replacement of segments of the crash cushion after a collision is feasible. For a cast-in-place cushion, the crushed material can be removed, the affected portion of the barrier reformed, and fresh vermiculite placed in the necessary areas. Fast-setting cement will alleviate the problem of curing time. The precast cushion, which has three tube modules weighing approximately 250 lb, could be handled by two men. Modules that are crushed during a collision can be unbolted, removed, and replaced during a low-density traffic period.

The lightweight, low-strength concrete used in these crash cushions exhibits relatively poor durability when it is subjected to cycles of freezing and thawing and allowed to become saturated with water. Several waterproofing agents were tested with limited success (5). The best method of achieving protection to date has been used by Wisconsin. In Milwaukee, rubberized tarpulin covers were used to protect vermiculite cushions against absorbing water and the accumulation of ice and snow in the sonotube voids. There has been no durability problem in Wisconsin on the cushions covered in this way. Additional information about concrete crash cushions can be found in the original report (5).

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