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Analysis of Accidents Involving Crash Cushions

JERRY G. PIGMAN, KENNETH R. AGENT, and TOM CREASEY

ABSTRACT

This paper is an analysis of 127 accidents involving crash cushions in Kentucky. The primary data base was for the period 1980-1982, with some additional data before and after this period. An attempt was made to document each accident with a police report, photographs, and a repair form. The largest number of accidents (63) involved a Hi-Dro cell cushion or cluster, followed by 33 accidents involving a Guardrail Energy-Absorbing Terminal (G.R.E.A.T.) crash cushion, 19 with a temporary G.R.E.A.T. system, 10 with sand barrels, and 2 with steel drums. Average repair cost was lowest for the Hi-Dro cell cushion ($392) and highest for the Hi-Dro cell cluster ($2,839). Other repair costs were $1,886 for the G.R.E.A.T. system, $887 for sand-barrel installations, and $1,760 for steel-drum installations. For those accidents in which performance was noted, crash cushions performed properly 85 percent of the time. Instances of improper performance generally involved either rebounding of a vehicle into or across the adjacent roadway or overturning of a vehicle. All the various types performed well. Results from the cost-effectiveness analysis show that crash cushion installations produce a benefit/cost ratio in the range of 1.0-2.0.

Hazardous fixed objects located within the driving environment continue to present severe safety problems to errant vehicles and their drivers. When the roadway is wholly or partially on structure, the gore area is characterized by bridge abutments or massive bases for sign supports. Bridge piers and other fixed objects located in medians have previously been inadequately shielded by guardrail or not shielded at all. In addition, roadways with narrow medians separated only by guardrail have proven to be ineffective and the source of many severe or fatal accidents. More recent designs have incorporated the concrete median barrier. At other locations where guardrail is deemed adequate, the breakaway-cable-terminal guardrail end treatment is now being used.

On the basis of the 1978 revision of the Handbook of Highway Safety Design and Operating Practices (1), highway traffic barriers may be classified into two general groups: (a) longitudinal barriers, such as guardrails, concrete median barriers, and bridge railings, which redirect vehicles away from roadside hazards; and (b) crash cushions, which incorporate various methods to reduce the rate of deceleration for vehicles (1). Running off the road has been shown to account for approximately 40 percent of all fatal accidents, and collisions with fixed objects are frequently the culmination of the out-of-control vehicle's trip (2). Recent design standards have emphasized the need to install barriers only when the consequence of striking a barrier is less than that of striking the object being shielded. This problem of barrier overuse can be of considerable consequence in gore areas where past research has shown that the rate of accidents is approximately four times that of run-off-the-road accidents at other locations (3). Gore areas that are not or cannot be modified to provide favorable terrain and unobstructed recovery zones have been recognized as misfits in the environs of the highway. Bridge piers in narrow medians and openings between parallel bridges on divided highways are also potential hazards from which the driver should be protected. Crash cushions are an alternative means of shielding the errant vehicle at these types of locations.

Analyses of accidents involving crash cushion impacts have shown these installations to be very effective. A study by FHWA in 1973 included analysis of 188 crash cushion installations in 36 states (4). It was determined that there were 5 fatalities in a total of 393 accidents. It was also found that the total accident experience increased because of a reduction of clear area in the gores and a higher accident reporting level in the after period. Installation and maintenance costs were also reported from the study in 1973. Installation costs were lowest for the sand-barrel installations and the liquid-cell clusters and highest for the steel-drum installations.

Another analysis of accidents involving crash cushions was performed by the Texas Transportation Institute (TTI) (5) that included 135 steel drums and sand barrels. Included were 400 impacts over a 7-year period. Results from crash experience showed that elimination of the redirection panels on steel-drum crash cushions at sites with low probability of angular impacts would improve the safety and reduce construction and maintenance costs.

The design and evaluation of crash cushions began in Kentucky in 1970 with the installation of a sand-barrel system and a liquid-cell system. Following those installations, a survey of the Interstate system was made and the result was a list of 23 gore sites that were considered to be candidates for crash cushion installations or other types of improvements (6). Barriers were installed at 16 sites, and 7 sites were contour graded. Accident experience was monitored at five crash cushion locations in Kentucky from 1970 through 1972 (6). Included were three sand-barrel installations and two liquid-cell installations. At one sand-barrel installation, there were 24 police-investigated accidents during a 37-month period before the barrier was installed. After installation, there were only four accidents in a 24-month period, all minor ones as compared with two fatalities and seven incapacitating injuries before installation. Increased recovery area and the conspicuous nature of the sand barrels were determined to be responsible for the large decrease in accidents. At another sand-barrel installation, a considerably different accident history resulted. In a 36-month period before installation, 33 police-investigated accidents were reported. After installation, 18 accidents occurred in a 18-month period. Reduced recovery area was determined to be the primary cause of the continued high number of accidents. Modifications were made to the gore area so that the more compact liquid-cell unit could be installed and the result was a significant decrease in the number of accidents.

CRASH CUSHION USE IN KENTUCKY

Crash cushions were first installed in Kentucky in 1970. During that year, three sand-barrel systems (Kentucky's Type II) were installed at an average cost of $3,583 per unit and three Hi-Dro cell systems (Kentucky's Type IV) were installed at an average cost of $6,844 per unit. Average unit costs were obtained from tabulations of contracts awarded by the Kentucky Department of Highways and from records of installations by state personnel. Prices for other types of crash cushions did not vary as much, even though the sample of locations was relatively small.

Crash cushion installations were relatively infrequent during the early 1970s, with the exception of several Hi-Dro cell clusters installed at toll booths. Recent crash cushion installations in Kentucky have been almost exclusively the Guardrail Energy-Absorbing Terminal (G.R.E.A.T.) System. Presented in Table 1 is a summary of crash cushion installations by year for the period 1970 through

TABLE 1 Summary of Crash Cushion Installations by Year

	Crash Cushion Type							
				IV				
Year	I	II	III	Cluster	Cushion	V	VI	VI-T
1970		3			3			
1971								
1972				12				
1973				12		1		
1974				6				
1975				6	4		6	
1976				16			15	
1977				10	2		14	8
1978		1		10			20	6
1979				7			20	20
1980				2	7		2	10
1981				20			5	10
1982				2			17	26
1983							22	59
Total		4		103	16	1	121	139

Note: Crash cushion types are defined as follows: I, Energite module inertial barrier; II, Fitch-type energy-absorbing barrier system; III, Hi-Dro cell-type energy-absorbing barrier system; IV, Hi-Dro cushion-type energy-absorbing barrier system; V, steel crash-cushion-type energy-absorbing barrier system; VI, Guardrail Energy-Absorbing Terminal (G.R.E.A.T.) system; VI-T, Guardrail Energy-Absorbing Terminal (G.R.E.A.T.)-temporary system.

1983. Numbers of crash cushions were obtained from tabulations of contracts awarded by the Kentucky Department of Highways. From Table 1, it may be seen that 384 crash cushions were installed during the 14-year period. Many of the temporary G.R.E.A.T. systems were installed for short periods of time on construction projects and then reused. There have been four sand-barrel systems and only one steel-drum system installed in Kentucky. A total of 119 Hi-Dro cell systems have been installed; 103 are clusters installed at toll booths and 16 are cushions installed at other locations such as gore areas and bridge piers. As noted, most of the recent crash cushions have been the G.R.E.A.T. type, and they now total 121. In addition, there are a large number of temporary G.R.E.A.T. installations (a total of 139).

DATA COLLECTION

Initially, police reports of accidents involving crash cushions were collected for 1980, 1981, and 1982. The accident reports were made available through the Accident Surveillance Section of the Division of Traffic of the Kentucky Transportation Cabinet. An inventory of all Kentucky routes having crash cushion installations was used, and accident reports pertaining to these routes were reviewed and appropriately selected. This established a 3-year data base for accidents involving all types of crash cushions.

The next step involved obtaining photographs to aid in the documentation process. When the accident report indicated that photographs had been taken at the scene, a request was made by telephone or in writing to the reporting police agency. Some photographs were obtained through communication with maintenance officials from each highway district, either through written correspondence or through notification that would allow the study team members to investigate the scene shortly after the accident had occurred. When available, repair forms also were obtained from maintenance officials. Therefore, an individual accident possibly could be documented by a police accident report, photographs, and a repair form. However, most cases could not be documented this thoroughly.

Finally, some accidents occurring either before 1980 or after 1982 were included for the purpose of strengthening the sample size. These cases were either already in possession before the beginning of the study or were discovered in the search process. In all, information on 127 accidents involving crash cushions was obtained.

RESULTS

Data for a total of 127 crash cushion accidents were included in the analysis. A summary of accident locations and information available is given in Table 2. A detailed description of each crash cushion accident was presented in an appendix to the full report (7), in which a narrative describing the accident, an accident diagram (when sufficient information was available), and photographs, when available, were included.

The largest number of accidents (63) involved a Hi-Dro cell cushion or cluster (Type IV). Of these 63, 41 involved Hi-Dro cell cluster installations on the toll road system. This was followed by 33 accidents involving a G.R.E.A.T. crash cushion (Type VI) and 19 with a temporary G.R.E.A.T. (Type VI-T). There were 10 accidents involving sand barrels (Type I or II) and 2 involving steel drums (Type V).

The large majority of accidents occurred from 1980 through 1982: 42 in 1980, 28 in 1981, and 25 in 1982. There were 16 accidents from the period before 1980 and 16 after 1982.

The largest number of accidents occurred in District 6 (49 accidents) followed by District 5 (31 accidents). This was expected because those two districts had the largest number of crash cushions. Four districts had no crash cushion accidents, and two districts had only one accident each.

Repair costs were available for several of the accidents included in this analysis as well as others. The lowest average repair cost was $395 for 45 repairs of the Hi-Dro cell crash cushion. One accident required replacement of the Hi-Dro cell crash cushion at a cost of about $11,000. This compares with an average cost of $2,839 for 19 repairs of Hi-Dro cell clusters. The average cost of 52 repairs to sand-barrel installations was $887. This includes repairs over the past 10 years, and costs for the most recent repairs have averaged about twice that amount. The average cost of 20 repairs to G.R.E.A.T. crash cushion installations was $1,886. The average cost to repair three steel-drum installations was $1,760.

The possible sources of information concerning the accidents included accident reports, photographs, and repair forms. Accident reports were obtained for 125 of the 127 accidents. Photographs were obtained for 19 accidents, and a repair form was obtained for 28 accidents. All three sources of information were obtained for only nine accidents. Following is a discussion of the results from analyses of crash cushion accidents.

Crash Cushion Performance

A summary of the performance of crash cushions for each accident is given in Table 3. In addition to crash cushion performance, information concerning type of crash cushion, vehicle size, impact severity, type of impact, crash cushion placement, initial vehicle contact area, vehicle action after impact, and crash cushion damage is given. Subjective judgment was used to determine many of these variables. A description of the variable categories is given in Table 4.

Performance was rated in 116 of the accidents as either proper or improper. In proper performance the crash cushion performed as designed with the impact energy fully attenuated in head-on, broadside, and angle collisions. For sideswipe impacts, proper performance was defined as the condition when the vehicle was redirected at a shallow angle back into the adjacent traffic lane. In six accidents, insufficient information was available to rate performance. The other five accidents involved impact with a high-speed heavy truck in which the crash cushion was destroyed. Performance was not rated in those accidents because the crash cushions were not designed for such impacts, so a "does not apply" category was used. Performance of the crash cushions was judged to be very good; 85 percent of the collisions resulted in proper performance.

The detailed analysis of the data given in Table 3 is summarized in Table 5. Crash cushion performance was determined as a function of type of crash cushion, vehicle size, impact severity, and type of impact.

All types of crash cushions were found to have a high percentage of proper performance. Performance was termed improper in only 17 accidents. The problem was related primarily to rebounding of the vehicle into or across the roadway at a sharp angle or to rolling over of the vehicle. One of these two vehicle actions occurred in 14 of the 17 improper-

TABLE 2 Summary of Accident Locations and Information Available

Accident No.	District	County	Route	Milepoint	Crash Cushion Type	Date	Information Available: Accident Report	Photographs	Repair Forms
001	2	Christian	Pennyrile	11.8	IV	11/21/82	X		
002	2	Christian	Pennyrile	11.7	IV	2/05/80	X		
003	2	Henderson	Audubon	10.2	IV	12/12/82	X		
004	2	Hopkins	Western Kentucky	24.4	IV	6/01/81	X		
005	2	Hopkins	Western Kentucky	24.4	IV	12/17/82	X		
006	2	Hopkins	Western Kentucky	24.4	IV	12/31/82	X		
007	2	Hopkins	Western Kentucky	24.4	IV	7/07/83	X		
008	2	Hopkins	Western Kentucky	24.4	IV	7/26/83	X		
009	2	Muhlenberg	Western Kentucky	58.0	IV	10/26/83	X	X	X
010	2	Muhlenberg	Western Kentucky	58.0	IV	1/14/82	X		
011	2	Muhlenberg	Western Kentucky	58.0	IV	6/21/80	X		
012	2	Muhlenberg	Western Kentucky	58.0	IV	5/07/80	X		
013	2	Ohio	Green River	47.9	IV	11/26/81	X		
014	2	Ohio	Western Kentucky	47.8	IV	7/01/83	X		X
015	2	Webster	Western Kentucky	62.6	IV	7/21/83	X	X	X
016	2	Webster	Pennyrile	62.6	IV	12/18/82	X	X	X
017	2	Webster	Pennyrile	62.6	IV	6/16/82	X	X	X
018	2	Webster	Pennyrile	62.6	IV	1/06/81	X		
019	2	Webster	Pennyrile	62.6	IV	7/22/80	X		X
020	3	Barren	Cumberland	3.1	IV	5/22/81	X		X
021	3	Butler	Green River	13.8	IV	11/14/80	X		X
022	4	Grayson	Western Kentucky	107.0	IV	8/04/82	X		
023	4	Grayson	Western Kentucky	107.0	IV	11/23/80	X		
024	4	Grayson	Western Kentucky	107.0	IV	3/17/80	X		X
025	4	Grayson	Western Kentucky	107.0	IV	3/01/80	X		X
026	4	Grayson	Western Kentucky	107.0	IV	4/18/77	X	X	X
027	4	Grayson	Western Kentucky	107.0	IV	10/11/79	X		
028	4	Grayson	Western Kentucky	107.0	IV	5/29/80	X		X
029	4	Grayson	Western Kentucky	107.0	IV	7/17/81	X		X
030	4	Grayson	Western Kentucky	107.0	IV	10/30/81	X		
031	4	Grayson	Western Kentucky	107.0	IV	1/04/83	X	X	X
032	4	Grayson	Western Kentucky	107.0	IV	10/14/83	X		X
033	4	Grayson	Western Kentucky	107.0	IV	3/20/84	X		
034	4	Nelson	Bluegrass	33.3	IV	12/23/79	X		
035	4	Nelson	Bluegrass	33.3	IV	11/17/84	X	X	X
036	4	Nelson	Bluegrass	9.7	IV	2/04/82	X		X
037	4	Nelson	Bluegrass	33.3	IV	4/15/81	X		
038	4	Nelson	Bluegrass	33.7	IV	11/18/80	X		
039	5	Franklin	US-421	3.0	VI	3/04/82	X		
040	5	Franklin	KY-676	Unknown	VI	3/17/80	X	X	
041	5	Henry	I-71	37.1	VI-T	10/15/81	X		
042	5	Jefferson	I-64	2.7	V	8/29/82	X	X	X
043	5	Jefferson	I-64	2.7	V	4/11/80	X		
044	5	Jefferson	I-64	4.5	IV	3/17/80	X		
045	5	Jefferson	I-65	123.5	VI	1/30/84	X		
046	5	Jefferson	I-65	133.0	IV	3/09/83	X		
047	5	Jefferson	I-65	136.3	IV	10/09/82	X		
048	5	Jefferson	I-65	136.4	IV	10/02/82	X		
049	5	Jefferson	I-65	133.0	IV	7/29/82	X	X	
050	5	Jefferson	I-65	133.0	IV	6/24/82	X		
051	5	Jefferson	I-65	136.5	IV	6/10/82	X	X	X
052	5	Jefferson	I-65	133.0	IV	4/27/82	X		
053	5	Jefferson	I-65	136.5	IV	4/26/82	X		
054	5	Jefferson	I-65	136.4	IV	2/09/82	X		
055	5	Jefferson	I-65	136.3	IV	11/05/81	X		
056	5	Jefferson	I-65	136.7	IV	2/07/81	X		
057	5	Jefferson	I-65	125.0	VI-T	12/09/80	X		
058	5	Jefferson	I-65	126.0	VI	12/05/80	X		
059	5	Jefferson	I-65	125.0	VI-T	12/04/80	X		
060	5	Jefferson	I-65	136.7	IV	4/01/80	X		
061	5	Jefferson	I-65	123.5	VI	1/31/78	X	X	X
062	5	Jefferson	I-264	7.5	II	11/12/82	X		X
063	5	Jefferson	I-264	19.9	VI	9/26/82	X		
064	5	Jefferson	I-264	19.1	II	9/26/82	X		X
065	5	Jefferson	I-264	7.5	II	8/27/82	X		X
066	5	Jefferson	I-264	19.9	VI	5/22/82	X		
067	5	Jefferson	I-264	7.5	II	2/09/82	X		
068	5	Jefferson	I-264	11.0	VI	7/27/80	X		
069	5	Jefferson	I-264	9.1	VI	3/06/80	X		
070	6	Campbell	I-275	77.0	VI	10/16/81	X		
071	6	Campbell	KY-9	13.7	VI	3/14/81	X		
072	6	Campbell	KY-9	13.7	VI	3/02/81	X		
073	6	Campbell	KY-9	13.7	VI	2/15/81	X		
074	6	Campbell	KY-9	13.7	VI	1/25/81	X		
075	6	Campbell	KY-9	13.7	VI	1/19/81	X		
076	6	Campbell	KY-9	13.7	VI	1/14/81	X		
077	6	Campbell	KY-6	13.7	VI	1/11/81	X		
078	6	Campbell	KY-9	13.7	VI	10/30/80	X		
079	6	Campbell	KY-9	13.7	VI	9/04/80	X		
080	6	Campbell	KY-9	13.7	VI	7/23/80	X		
081	6	Campbell	KY-9	13.7	VI	4/30/80	X		
082	6	Campbell	KY-9	13.7	VI	3/23/80	X		
083	6	Campbell	KY-9	13.7	VI	2/05/80	X		
084	6	Campbell	KY-9	13.7	VI	12/17/77	X	X	

TABLE 2 continued

							Information Available		
Accident No.	District	County	Route	Milepoint	Crash Cushion Type	Date	Accident Report	Photographs	Repair Forms
085	6	Campbell	KY-9	13.7	VI	11/06/76	X		X
086	6	Campbell	KY-9	13.7	VI	3/07/77	X		X
087	6	Campbell	KY-9	13.7	VI	5/14/77		X	X
088	6	Campbell	KY-9	13.7	VI	5/26/77		X	X
089	6	Kenton	I-75	191.3	II	12/22/72	X		X
090	6	Kenton	I-75	191.3	II	10/26/72	X		X
091	6	Kenton	I-75	191.3	II	4/29/72	X		X
092	6	Kenton	I-75	191.3	II	5/17/72	X		X
093	6	Kenton	I-75	191.3	II	6/03/72	X		X
094	6	Kenton	I-75	191.3	II	8/04/72	X		X
095	6	Kenton	I-75	191.3	IV	1/18/84	X		
096	6	Kenton	I-75	191.3	IV	12/23/83	X		
097	6	Kenton	I-75	191.3	IV	10/23/83	X	X	
098	6	Kenton	I-75	184.7	VI	12/27/81	X		
099	6	Kenton	I-75	191.3	IV	11/08/81	X		
100	6	Kenton	I-75	191.3	IV	8/15/81	X		
101	6	Kenton	I-75	184.0	VI	6/18/81	X		
102	6	Kenton	I-75	191.3	IV	4/11/81	X		
103	6	Kenton	I-75	191.4	IV	3/13/81	X		
104	6	Kenton	I-75	186.7	VI-T	11/18/80	X		
105	6	Kenton	I-75	186.5	VI-T	11/11/80	X		
106	6	Kenton	I-75	186.6	VI-T	11/11/80	X		
107	6	Kenton	I-75	186.7	VI-T	11/09/80	X		
108	6	Kenton	I-75	186.9	VI-T	11/08/80	X		
109	6	Kenton	I-75	186.7	VI-T	10/05/80	X		
110	6	Kenton	I-75	186.8	VI-T	9/30/80	X		
111	6	Kenton	I-75	186.5	VI-T	9/26/80	X		
112	6	Kenton	I-75	187.0	VI-T	9/21/80	X		
113	6	Kenton	I-75	191.3	IV	9/06/80	X		
114	6	Kenton	I-75	191.3	IV	8/30/80	X		
115	6	Kenton	I-75	190.6	VI-T	6/10/80	X		
116	6	Kenton	I-75	190.6	VI-T	6/07/80	X		
117	6	Kenton	I-75	184.1	VI	5/15/80	X		
118	6	Kenton	I-75	188.0	VI-T	5/04/80	X		
119	7	Anderson	Bluegrass	58.8	IV	9/19/81	X		
120	7	Anderson	Bluegrass	58.8	IV	4/17/81	X		
121	7	Anderson	Bluegrass	58.8	IV	4/13/80	X	X	
122	7	Fayette	I-75	116.9	VI-T	10/04/81	X		
123	7	Fayette	I-75	112.0	VI-T	7/02/80	X		
124	7	Fayette	I-75	113.5	VI-T	9/23/79	X	X	
125	7	Scott	I-75	128.3	VI-T	8/13/83	X	X	
126	11	Harlan	US-119	14.0	VI	12/17/81	X		
127	12	Pike	US-23	Unknown	VI	2/13/83	X	X	

performance accidents. Of the three accidents with Hi-Dro cell crash cushions in which there was improper performance, all involved a rollover. Of the seven G.R.E.A.T. crash cushion accidents with improper performance, three were rollover and four involved a rebound. Two of the three accidents with a temporary G.R.E.A.T. installation with improper performance involved a rebound and in the other the temporary G.R.E.A.T. crash cushion was knocked from its base by the impact. Of the two sand-barrel accidents with improper performance, one involved a rebound and in the other the vehicle impacted the bridge abutment. In one of the two Hi-Dro cell cluster accidents with improper performance, a large automobile knocked the cluster from its brace and impacted the abutment in front of the toll booth. The other accident with improper performance involved a rebound into a light pole. Except for five heavy-truck accidents in which the crash cushions were destroyed, the crash cushions prevented the vehicles from impacting the shielded object with two exceptions. One exception occurred when a vehicle hit a sand-barrel installation next to a back corner, which allowed impact with a bridge abutment. The other was the improper performance of the Hi-Dro cell cluster.

When vehicle size was analyzed as to performance, the percentage with proper performance was high for all vehicle types. All but one nonsevere impact was rated proper. The one improper nonsevere impact involved a rebound. Performance was also high for all types of impact. Improper performance was higher for angle than head-on impacts because of the higher possibility of rebound and rollover.

In most instances, crash cushion damage was not known. In those accidents in which damage was documented, it was judged to be either moderate or heavy. The most common location for crash cushion accidents (55 accidents) was gore areas, where various types of crash cushions were used. There were 41 accidents at toll booth locations, all of which involved a Hi-Dro cell cluster. There were 19 accidents in construction zones, all involving a G.R.E.A.T. temporary crash cushion. There were seven accidents at the termination of a concrete median barrier and five at a bridge pier, primarily involving G.R.E.A.T. crash cushions. Usually the initial vehicle contact area was the front (62 accidents); this was followed by the right front (25 accidents) and the left front (11 accidents).

The primary vehicle action after impact was that the vehicle was stopped by the crash cushion (52 accidents). The second most common action was that the vehicle rebounded left or right (23 accidents). In six accidents, the vehicle overturned. In the remaining accidents with a known vehicle action after impact, the vehicle either continued in the same direction (12 accidents), spun clockwise or counterclockwise (7 accidents), or ramped (1 accident).

TABLE 3 Crash Cushion Performance

Crash Cushion Type	Accident No.	Vehicle Size Category	Impact Severity	Type of Impact	Crash Cushion Placement	Initial Vehicle Contact Area	Vehicle Action After Impact	Crash Cushion Performance	Crash Cushion Damage
IV	001	Auto-L	Severe	Head-on	Toll	1	Rb-R	Proper	Unknown
IV	002	Auto-U	Nonsevere	Head-on	Toll	1	Stop	Proper	Slight
IV	003	Auto-L	Nonsevere	Angle	Toll	4	Rb-R	Proper	Unknown
IV	004	Auto-L	Severe	Angle	Toll	2	Rb-L	Proper	Unknown
IV	005	SUT	Nonsevere	SS	Toll	6	Stop	Proper	Slight
IV	006	Auto-L	Nonsevere	Angle	Toll	2	Cont	Proper	Unknown
IV	007	Comb	Nonsevere	SS	Toll	6	Cont	Proper	Slight
IV	008	Auto-L	Nonsevere	Angle	Toll	1	Stop	Proper	Slight
IV	009	Comb	Severe	Angle	Toll	2	Stop	Proper	Moderate
IV	010	Auto-L	Nonsevere	SS	Toll	2	Stop	Proper	Slight
IV	011	Auto-U	Nonsevere	Head-on	Toll	1	Stop	Proper	Unknown
IV	012	Auto-U	Nonsevere	Angle	Toll	2	Rb-L	Proper	Unknown
IV	013	Auto-S	Nonsevere	Angle	Toll	2	Stop	Proper	Slight
IV	014	Comb	Severe	BSD	Toll	7	Unknown	Unknown	Slight
IV	015	Auto-L	Severe	Head-on	Toll	1	Bb-L	Improper	Extensive
IV	016	Auto-S	Nonsevere	Angle	Toll	4	Rb-R	Improper	Slight
IV	017	Comb	Nonsevere	SS	Toll	6	Rb-L	Proper	Slight
IV	018	Auto-L	Nonsevere	SS	Toll	4	Stop	Proper	Unknown
IV	019	Auto-U	Nonsevere	SS	Toll	2	Rb-L	Proper	Slight
IV	020	Auto-L	Nonsevere	Angle	Toll	4	Rb-R	Proper	Slight
IV	021	Auto-L	Nonsevere	Head-on	Toll	1	Stop	Proper	Slight
IV	022	Comb	Nonsevere	SS	Toll	2	Cont	Proper	Unknown
IV	023	Auto-L	Nonsevere	Unknown	Toll	–[a]	Unknown	Proper	Slight
IV	024	Comb	Nonsevere	SS	Toll	2	Cont	Proper	Slight
IV	025	Auto-L	Nonsevere	SS	Toll	2	Stop	Proper	Slight
IV	026	Auto-L	Severe	Head-on	Toll	1	SP-CCW-90	Proper	Moderate
IV	027	Auto-L	Nonsevere	Angle	Toll	1	Stop	Proper	Slight
IV	028	Comb	Nonsevere	SS	Toll	6	Stop	Proper	Slight
IV	029	Auto-U	Severe	BSD	Toll	3	SP-CCW-180	Proper	Moderate
IV	030	Comb	Nonsevere	SS	Toll	6	Stop	Proper	Slight
IV	031	Auto-L	Severe	Head-on	Toll	1	Rb-R	Proper	Heavy
IV	032	Comb	Nonsevere	SS	Toll	6	Cont	Proper	Slight
IV	033	Comb	Nonsevere	SS	Toll	6	Stop	Proper	Unknown
IV	034	Auto-U	Nonsevere	Angle	Toll	1	Cont	Proper	Slight
IV	035	Comb	Nonsevere	SS	Toll	6,7	Cont	Proper	Slight
IV	036	Auto-L	Severe	Angle	Toll	–[a]	Rb-R	Proper	Moderate
IV	037	Comb	Nonsevere	SS	Toll	2	Cont	Proper	Unknown
IV	038	Comb	Nonsevere	SS	Toll	6,7	Cont	Proper	Slight
V	044	Comb	Severe	BSD	Gore	5	Stop	Proper	Unknown
IV	046	Auto-L	Unknown	Head-on	Gore	1	Stop	Proper	Unknown
IV	047	Auto-U	Nonsevere	Head-on	Gore	1	Stop	Proper	Unknown
IV	048	Auto-L	Severe	Head-on	Gore	1	Stop	Proper	Unknown
IV	049	Auto-L	Severe	Head-on	Gore	2	Over	Improper	Heavy
IV	050	Auto-U	Nonsevere	BSD	Gore	5	Unknown	Proper	Unknown
IV	051	Comb	Severe	Angle	Gore	4	Cont	DNA[b]	Heavy
IV	052	Auto-U	Severe	Head-on	Gore	1	Stop	Unknown	Unknown
IV	053	Comb	Severe	Head-on	Gore	1	Stop	Unknown	Unknown
IV	054	Auto-L	Severe	Head-on	Gore	2	Unknown	Proper	Unknown
IV	055	Comb	Severe	Angle	Gore	2	Unknown	Proper	Unknown
IV	056	Auto-L	Severe	Head-on	Gore	1	Over	Improper	Unknown
IV	060	Auto-L	Severe	Head-on	Gore	1	Stop	Proper	Unknown
IV	095	Auto-L	Severe	Head-on	Gore	1	Stop	Proper	Heavy
IV	096	Auto-U	Severe	Head-on	Gore	1	Stop	Proper	Unknown
IV	097	Comb	Severe	Angle	Gore	1	Unknown	Proper	Heavy
IV	099	Auto-U	Severe	Head-on	Gore	1	Stop	Proper	Unknown
IV	100	Auto-L	Severe	Head-on	Gore	–[a]	Unknown	Proper	Unknown
IV	102	Auto-L	Severe	Head-on	Gore	1	Unknown	Proper	Moderate
IV	103	Auto-L	Severe	Head-on	Gore	4	Stop	Proper	Unknown
IV	113	Auto-L	Severe	SS	Gore	2	Over	Improper	Unknown
IV	114	Auto-L	Severe	Head-on	Gore	1	Stop	Proper	Unknown
IV	119	Auto-U	Severe	Head-on	Toll	2	SP-CW-90	Proper	Unknown
IV	120	Auto-U	Severe	Angle	Toll	1	Rb-L	Proper	Unknown
IV	121	Comb	Severe	Angle	Toll	2,3	Cont	Proper	Heavy
VI	039	Auto-L	Severe	Head-on	CMB	1	Stop	Proper	Unknown
VI	040	Auto-L	Severe	Unknown	CMB	4	Unknown	Proper	Heavy
VI	045	Comb	Severe	Head-on	BP	1	Stop	DNA	Extensive
VI	058	Auto-U	Severe	Unknown	BP	–[a]	Over	Improper	Unknown
VI	061	Comb	Severe	BSD	BP	8	Stop	DNA	Extensive
VI	063	Auto-U	Severe	Head-on	Gore	1	Unknown	Proper	Unknown
VI	066	Auto-U	Severe	SS	Gore	5	Unknown	Proper	Unknown
VI	068	Auto-L	Nonsevere	BSD	CMB	3	Stop	Proper	Slight
VI	069	Auto-S	Severe	BSD	CMB	3	Over	Improper	Unknown
VI	070	Auto-L	Severe	Head-on	Gore	1	Unknown	Proper	Moderate
VI	071	Auto-U	Severe	SS	Gore	2	Rb-L	Improper	Moderate
VI	072	Auto-U	Severe	Head-on	Gore	1	Stop	Proper	Moderate
VI	073	Auto-U	Severe	Angle	Gore	2	Unknown	Proper	Moderate
VI	074	Auto-U	Severe	Angle	Gore	2	Rb-L	Improper	Moderate
VI	075	Auto-U	Nonsevere	SS	Gore	3	Unknown	Proper	Moderate
VI	076	Auto-U	Nonsevere	SS	Gore	2	Cont	Proper	Unknown
VI	077	Auto-S	Nonsevere	Head-on	Gore	1	Stop	Proper	Moderate
VI	078	Auto-S	Severe	Head-on	Gore	1	Stop	Proper	Moderate
VI	079	Auto-L	Severe	Head-on	Gore	1	Stop	Proper	Moderate
VI	080	Auto-U	Severe	Head-on	Gore	2	Rb-R	Improper	Unknown

TABLE 3 continued

Crash Cushion Type	Accident No.	Vehicle Size Category	Impact Severity	Type of Impact	Crash Cushion Placement	Initial Vehicle Contact Area	Vehicle Action After Impact	Crash Cushion Performance	Crash Cushion Damage
VI	081	Auto-L	Severe	Angle	Gore	2	Rb-L	Improper	Moderate
VI	082	Auto-U	Nonsevere	Unknown	Gore	2	Unknown	Proper	Unknown
VI	083	Auto-U	Severe	Unknown	Gore	1	Over	Improper	Unknown
VI	084	Auto-L	Severe	Head-on	Gore	1	Stop	Proper	Moderate
VI	085	SUT	Nonsevere	Angle	Gore	3	Rb-L	Proper	Moderate
VI	086	Auto-S	Severe	Angle	Gore	2,3	Rb-L	Proper	Moderate
VI	087	Unknown	Unknown	Unknown	Gore	–[a]	Unknown	Unknown	Moderate
VI	088	Unknown	Unknown	Unknown	Gore	–[a]	Unknown	Unknown	Moderate
VI	098	Auto-L	Severe	Unknown	CMB	2	Unknown	Unknown	Unknown
VI	101	Auto-L	Severe	Head-on	Gore	1	Unknown	Proper	Unknown
VI	117	Auto-L	Severe	Head-on	CMB	1	Stop	Proper	Unknown
VI	126	Auto-L	Severe	Angle	BP	4	Unknown	Proper	Unknown
VI	127	Auto-L	Severe	Head-on	CMB	1	Stop	Proper	Heavy
VI-T	041	Comb	Severe	Angle	TCB	1	Rb-R	Proper	Unknown
VI-T	057	Auto-U	Severe	Head-on	TCB	1	Stop	Proper	Unknown
VI-T	059	Auto-L	Severe	Head-on	TCB	1	SP-CCW-180	Proper	Unknown
VI-T	104	Auto-S	Severe	Angle	TCB	4	SP-CCW-90	Proper	Unknown
VI-T	105	Auto-L	Severe	Head-on	TCB	1	Stop	Proper	Unknown
VI-T	106	Auto-U	Severe	Head-on	TCB	1	Unknown	Proper	Unknown
VI-T	107	Auto-L	Severe	SS	TCB	5	Unknown	Proper	Unknown
VI-T	108	Auto-S	Severe	Head-on	TCB	1	Rb-L	Improper	Unknown
VI-T	109	Auto-L	Severe	Head-on	TCB	1	Stop	Proper	Unknown
VI-T	110	Auto-L	Nonsevere	SS	TCB	5	Unknown	Proper	Slight
VI-T	111	Auto-L	Severe	Angle	TCB	4	Unknown	Proper	Unknown
VI-T	112	Auto-U	Severe	Angle	TCB	4	Rb-R	Improper	Unknown
VI-T	115	Auto-U	Severe	Head-on	TCB	1	Stop	Proper	Heavy
VI-T	116	Auto-L	Severe	Head-on	TCB	1	Unknown	Proper	Unknown
VI-T	118	Auto-L	Severe	Head-on	TCB	1	Stop	Proper	Unknown
VI-T	122	Auto-L	Severe	Head-on	TCB	1	SP-CW-90	Proper	Unknown
VI-T	123	Comb	Severe	Head-on	TCB	1	Stop	Proper	Unknown
VI-T	124	Auto-L	Severe	SS	TCB	5	Rb-R	Improper	Heavy
VI-T	125	Comb	Severe	Head-on	TCB	1	Ramp	DNA	Heavy
II	062	Auto-S	Severe	Head-on	Gore	1	Stop	Proper	Heavy
II	064	Comb	Severe	Head-on	BP	1	Stop	DNA	Extensive
II	065	Auto-L	Severe	Head-on	Gore	1	Stop	Proper	Heavy
II	067	Auto-L	Severe	Angle	Gore	1	Stop	Improper	Unknown
II	089	Auto-L	Severe	Head-on	Gore	1	Stop	Proper	Moderate
II	090	Auto-L	Severe	Head-on	Gore	1	Stop	Proper	Heavy
II	091	Auto-L	Severe	Head-on	Gore	1	Stop	Proper	Heavy
II	092	Auto-L	Severe	Head-on	Gore	1	SP-CW-90	Proper	Heavy
II	093	Auto-L	Severe	Head-on	Gore	1	Stop	Proper	Heavy
II	094	Auto-L	Severe	Head-on	Gore	1	Rb-L	Improper	Heavy
V	042	Auto-L	Severe	Head-on	Gore	1	Unknown	Proper	Heavy
V	043	Auto-L	Severe	Head-on	Gore	1	Unknown	Proper	Unknown

Note: Refer to Table 4 for definition of variable categories.
[a]Unknown. [b]Does not apply; crash cushions are not designed to attenuate impacts of large or heavy trucks.

Vehicle Size and Impact Severity

Information concerning vehicle size and impact severity is presented in Table 6. Impact severity for crash cushion accidents is high; 68 percent of the impacts are termed severe. If the less severe toll booth accidents are excluded, 85 percent of the remaining collisions are rated as severe. This is reflected in the vehicle damage; 66 percent of the impacts result in disabling vehicle damage. This percentage is increased to 86 percent if toll booth accidents are excluded.

The percentage of accidents involving an injury was high (38 percent), as would be expected. The proportion involving either a fatality or incapacitating (severe) injury was 16 percent. When toll booth accidents are excluded, the percentage of injury accidents increases to 46 and fatal or severe injury accidents to 19. Although these percentages are high, they are substantially lower than those determined for accidents involving a breakaway-cable-terminal (BCT) guardrail end treatment. In BCT accidents, the proportion of injury-producing accidents was determined to be 71 percent, whereas 29 percent resulted in a fatality or severe injury (8). This comparison illustrates the better performance of a crash cushion versus a BCT end treatment.

There were four fatal accidents involving crash cushions. Three involved a Hi-Dro cell crash cushion and one involved a Hi-Dro cell cluster. One involved a head-on collision of a large car with a Hi-Dro cell crash cushion in a gore. The car rolled over after impact, partially ejecting the driver. The second involved an angle collision of a large truck with a crash cushion in a gore. The crash cushion was destroyed because it was not designed for a high-speed impact with such a large vehicle. The truck continued on and the cab eventually vaulted over a bridge railing. The third fatal accident occurred when a van sideswiped a crash cushion and then overturned. The fatal accident involving the Hi-Dro cell cluster occurred when a large car hit the cluster head-on, knocked the cluster from its brace, and hit the abutment in front of the toll booth. The percentage of injury accidents was lower for trucks (26 percent) compared with large cars (41 percent). There were only nine small cars in the sample, but the percentage of injury accidents involving these vehicles was substantially higher (67 percent) than that for either trucks or large cars.

Cost-Effectiveness Analysis

In order to determine the cost-effectiveness of crash cushion installations in Kentucky, an analysis

TABLE 4 Description of Variable Categories

Variable	Category	Description
Vehicle size	Auto-L	Full or mid-size passenger car, full-sized pickup truck, van
	Auto-S	Compact or subcompact car, small pickup truck
	Auto-U	Automobile, unknown size
	SUT	Single-unit truck (two-axle, six tires or larger)
	Comb	Combination tractor and semitrailer or full trailer
Impact severity	Severe	Impact sufficient to cause heavy or extensive damage to crash cushion, disabling damage to vehicle, and/or fatal or incapacitating injury (injury severity 1 or 2)
	Nonsevere	Functional or nonfunctional to vehicle, slight or moderate damage to crash cushion, and/or nonincapacitating, possible, or no injury (injury severity 3, 4, or 5)
Type of impact	Head-on	At a shallow angle (15 degrees or less) with front end of vehicle
	Angle	At a moderate or sharp angle (16 degrees or greater) with front, right front, or left front of vehicle
	BSD	Broadside, impact at a shallow angle (15 degrees or less) with left or right side of vehicle
	SS	Sideswipe, impact to side of crash cushion with side of vehicle
	Unknown	Cannot be determined from available data
Injury severity	1	Fatal
	2	Incapacitating injury
	3	Nonincapacitating injury
	4	Possible injury
	5	No injury
Vehicle action after impact	Stop	Stopped by crash cushion
	SP-CW-D	Spun clockwise D degrees
	SP-CCW-D	Spun counterclockwise D degrees
	Over	Overturned
	Ramp	Ramped
	RB-L	Rebounded left
	RB-R	Rebounded right
	Cont	Continued in same direction
Crash cushion performance	Proper	Crash cushion performed as designed; impact energy fully attenuated in head-on, broadside, and angle collisions; for sideswipe impacts, vehicle redirected at a shallow angle back into adjacent traffic lane
	Improper	Performance other than as designed
	DNA	Does not apply
Crash cushion damage	Slight	Damage insufficient to affect performance should crash cushion be struck again before repairs are made
	Moderate	Up to 50 percent damage
	Heavy	Between 50 and 100 percent damage; rendered useless
	Extensive	Total destruction of crash cushion in addition to damage to protected structure behind crash cushion
Vehicle damage	1	No damage
	2	Nonfunctional damage
	3	Functional damage
	4	Disabling damage
Crash cushion contact area	End	End of crash cushion
	Side	Side of crash cushion
Crash cushion placement	Toll	Protecting toll booth at toll plaza
	Gore	Area between roadway split
	BP	Protecting median bridge pier
	CMB	Terminating concrete median barrier
	TCB	Terminating temporary concrete barrier in construction zone
Initial vehicle contact area	1	Front
	2	Right front
	3	Right side
	4	Left front
	5	Left side
	6	Right side of trailer
	7	Left side of trailer
	8	Bottom of trailer
Vehicle make	AMC	American Motors
	Buick	Buick
	Chev	Chevrolet
	Dodge	Dodge
	Ford	Ford
	Frtln	Freightliner
	GMC	General Motors
	Intl	International
	Kenw	Kenworth
	Linc	Lincoln
	Mack	Mack
	Merc	Mercury
	Olds	Oldsmobile
	Pblt	Peterbilt
	Plym	Plymouth
	Pont	Pontiac
	Toyo	Toyota
	Volks	Volkswagen
	White	White
	Dia	Diamond
Vehicle style	2-Dr-Sd	2-door sedan
	4-Dr-Sd	4-door sedan
	SW	Station wagon
	PU	Pickup
	SD	Sedan
	Semi	Combination tractor and semitrailer
	Truck	Truck (single unit)
	Van	Van

TABLE 5 Detailed Analysis of Crash Cushion Performance

		Proper Performance		Improper Performance	
Variable	Category	No.	Percent	No.	Percent
Crash cushion type	IV				
	Cushion	18	86	3	14
	Cluster	38	95	2	5
	VI	21	75	7	25
	VI-T	15	83	3	17
	II	5	71	2	29
	V	2	100	0	0
Vehicle size	Auto-S	6	67	3	33
	Auto-L	51	88	7	12
	Auto-U	22	73	7	27
	Truck	20	100	0	0
Impact severity	Severe	61	79	16	21
	Nonsevere	37	97	1	3
Type of impact	Head-on	49	88	7	12
	Angle	22	81	5	19
	Broadside	4	80	1	20
	Sideswipe	21	88	3	12

Note: Refer to Table 4 for definition of variable categories.

was made that included installation costs, maintenance repair costs, and accident savings resulting from these installations. Installation costs were obtained, when available, from average unit bid prices prepared by the Kentucky Department of Highways. Additional installation cost summaries were obtained from other reports when data were not available for Kentucky (9,10). Average installation costs used for this analysis are presented in Table 7. Installation costs were tabulated for all crash cushions installed in Kentucky. Maintenance repair costs were available from repair forms used by Department of Highways employees responsible for repair of damaged crash cushions. As part of the arrangement with maintenance employees in each highway district, repair information was provided along with accident reports for collisions occurring during the study period. Repair costs were also tabulated for all data available since the first crash cushion installations in 1970. Values used for the 3-year analysis period were annual averages since installa-

TABLE 6 Vehicle Size and Impact Severity

Crash Cushion Type	Accident No.	Vehicle Year	Vehicle Make	Vehicle Style or Model	Vehicle Size	Impact Severity	Injury Severity	Vehicle Damage	Crash Cushion Damage
IV	001	76	Olds	Cutlass	Auto-L	Severe	5	4	Unknown
IV	002	76	Chev	2-Dr-Sd	Auto-U	Nonsevere	5,5,5	2	Slight
IV	003	77	Olds	Cutlass	Auto-L	Severe	4,5	4	Unknown
IV	004	81	Ford	PU	Auto-L	Severe	5	4	Unknown
IV	005	72	Chev	Truck	SUT	Nonsevere	5	1	Slight
IV	006	78	Ford	PU	Auto-L	Nonsevere	5	4	Unknown
IV	007	78	Intl	Semi	Comb	Nonsevere	5	1	Slight
IV	008	73	Olds	2-Dr-Sd	Auto-L	Nonsevere	5	2	Slight
IV	009	83	Pblt	Semi	Comb	Severe	5	2	Moderate
IV	010	67	Plym	4-Dr-Sd	Auto-L	Nonsevere	5	3	Slight
IV	011	77	Buick	2-Dr-Sd	Auto-U	Nonsevere	5	1	Unknown
IV	012	79	Pont	2-Dr-Sd	Auto-U	Nonsevere	4	3	Unknown
IV	013	72	Chev	Vega	Auto-S	Nonsevere	5	2	Slight
IV	014	79	Kenw	Semi	Comb	Severe	5	4	Slight
IV	015	79	Ford	PU	Auto-L	Severe	1	4	Extensive
IV	016	81	Chev	Chevette	Auto-S	Severe	3,3	4	Slight
IV	017	78	Intl	Semi	Comb	Nonsevere	5	2	Slight
IV	018	77	Linc	2-Dr-Sd	Auto-L	Nonsevere	5,5,5,5,5	2	Unknown
IV	019	79	Pont	2-Dr-Sd	Auto-U	Nonsevere	5	2	Slight
IV	020	71	Chev	El Camino	Auto-L	Nonsevere	5	4	Slight
IV	021	68	Dodge	2-Dr-Sd	Auto-L	Nonsevere	5	2	Slight
IV	022	75	Frtln	Semi	Comb	Nonsevere	5	2	Unknown
IV	023	73	Ford	Sd	Auto-L	Nonsevere	5	1	Unknown
IV	024	69	Frtln	Semi	Comb	Nonsevere	5,5	1	Slight
IV	025	77	Ford	SW	Auto-L	Nonsevere	5	1	Slight
IV	026	69	Dodge	Van	Auto-L	Severe	4	4	Moderate
IV	027	70	Pont	4-Dr-Sd	Auto-L	Nonsevere	5	3	Slight
IV	028	71	GMC	Semi	Comb	Nonsevere	5	2	Slight
IV	029	78	Chev	Sd	Auto-U	Severe	4	4	Moderate
IV	030	73	GMC	Semi	Comb	Nonsevere	5	1	Slight
IV	031	78	Merc	2-Dr-Sd	Auto-L	Severe	2,2	4	Heavy
IV	032	74	Dia	Semi	Comb	Nonsevere	5	2	Slight
IV	033	78	Pblt	Semi	Comb	Nonsevere	5,5	2	Unknown
IV	034	73	Buick	Sd	Auto-U	Nonsevere	5	2	Slight
IV	035	75	White	Semi	Comb	Nonsevere	5	2	Slight
IV	036	69	Olds	4-Dr-Sd	Auto-L	Severe	5	3	Moderate
IV	037	78	Ford	Semi	Comb	Nonsevere	5	2	Unknown
IV	038	78	Pblt	Semi	Comb	Nonsevere	5	1	Slight
IV	044	77	Intl	Semi	Comb	Severe	5	4	Unknown
IV	046	74	Linc	Sd	Auto-L	Unknown	5	3	Unknown
IV	047	79	Dodge	Sd	Auto-U	Nonsevere	4	2	Unknown
IV	048	74	Chev	2-Dr-Sd	Auto-L	Severe	5	4	Unknown
IV	049	73	Pont	Catalina	Auto-L	Severe	1	4	Extensive
IV	050	79	Ford	Sd	Auto-U	Nonsevere	5	2	Unknown
IV	051	79	Mack	Semi	Comb	Severe	1	4	Heavy
IV	052	81	Chev	Sd	Auto-U	Severe	2,3	4	Unknown
IV	053	79	GMC	Semi	Comb	Severe	2,5	4	Unknown
IV	054	75	Chev	Sd	Auto-L	Severe	2,5	3	Unknown
IV	055	71	GMC	Semi	Comb	Severe	5	4	Unknown
IV	056	73	Chev	Sd	Auto-L	Severe	3	4	Unknown
IV	060	80	Ford	T-Bird	Auto-L	Severe	5	4	Unknown
IV	095	74	Buick	2-Dr-Sd	Auto-L	Severe	2	4	Extensive
IV	096	76	Ford	Sd	Auto-U	Severe	5	4	Unknown
IV	097	–[a]	Frtln	Semi	Comb	Severe	5	4	Extensive
IV	099	76	Chev	2-Dr-Sd	Auto-U	Severe	3	4	Unknown

TABLE 6 continued

Crash Cushion Type	Accident No.	Vehicle Year	Vehicle Make	Vehicle Style or Model	Vehicle Size	Impact Severity	Injury Severity	Vehicle Damage	Crash Cushion Damage
IV	100	72	Pont	2-Dr-Sd	Auto-L	Severe	5,5	4	Unknown
IV	102	79	Dodge	Diplomat	Auto-L	Severe	4	4	Unknown
IV	103	-[a]	Olds	Sd	Auto-L	Severe	5,5	4	Unknown
IV	113	74	Ford	Van	Auto-L	Severe	1,3,3	4	Unknown
IV	114	76	Chev	Monte Carlo	Auto-L	Severe	4	4	Unknown
IV	119	79	Ford	Sd	Auto-U	Severe	2	4	Unknown
IV	120	79	Chev	PU	Auto-U	Severe	2	4	Unknown
IV	121	79	White	Semi	Comb	Severe	5	3	Heavy
VI	039	77	AMC	Pacer	Auto-L	Severe	5,5,5	4	Unknown
VI	040	75	Merc	2-Dr-Sd	Auto-L	Severe	5	4	Heavy
VI	045	84	Pblt	Semi	Comb	Severe	2	4	Heavy
VI	058	74	Chev	Unknown	Auto-U	Unknown	5	4	Unknown
VI	061	-[a]	Kenw	Semi	Comb	Severe	3	4	Extensive
VI	063	78	Ford	PU	Auto-U	Severe	5	4	Unknown
VI	066	80	Merc	Sd	Auto-U	Nonsevere	5	4	Unknown
VI	068	67	Ford	PU	Auto-L	Nonsevere	5	2	Slight
VI	069	76	Chev	Monza	Auto-S	Severe	2	4	Unknown
VI	070	68	Plym	2-Dr-Sd	Auto-L	Severe	4	4	Unknown
VI	071	77	Pont	2-Dr-Sd	Auto-U	Severe	4,4	4	Unknown
VI	072	77	Pont	2-Dr-Sd	Auto-U	Severe	5	4	Unknown
VI	073	76	Chev	2-Dr-Sd	Auto-U	Severe	2,4,5	4	Unknown
VI	074	79	Ford	2-Dr-Sd	Auto-U	Severe	3,3	4	Unknown
VI	075	75	Olds	2-Dr-Sd	Auto-U	Nonsevere	5,5,5,5	4	Unknown
VI	076	78	Ford	2-Dr-Sd	Auto-U	Nonsevere	5	2	Unknown
VI	077	77	Ford	Mustang	Auto-S	Nonsevere	4	2	Unknown
VI	078	78	Ford	Mustang	Auto-S	Severe	3	4	Unknown
VI	079	78	Merc	Cougar	Auto-L	Severe	4	3	Unknown
VI	080	80	Plym	2-Dr-Sd	Auto-U	Severe	5	4	Unknown
VI	081	77	Chev	Nova	Auto-L	Severe	4	4	Unknown
VI	082	75	Chev	2-Dr-Sd	Auto-U	Nonsevere	5	2	Unknown
VI	083	71	Chev	2-Dr-Sd	Auto-U	Severe	4	4	Unknown
VI	084	75	Dodge	PU	Auto-L	Severe	5	2	Heavy
VI	085	71	Ford	Truck	SUT	Nonsevere	5	3	Moderate
VI	086	70	VW	2-Dr-Sd	Auto-S	Severe	5	4	Moderate
VI	087	-[a]	Unknown	Unknown	Unknown	Unknown	-[a]	-[a]	Moderate
VI	088	-[a]	Unknown	Unknown	Unknown	Unknown	-[a]	-[a]	Moderate
VI	098	72	Ford	2-Dr-Sd	Auto-L	Severe	2,2	4	Unknown
VI	111	70	Olds	2-Dr-Sd	Auto-L	Severe	5	4	Unknown
VI	117	68	Ford	2-Dr-Sd	Auto-L	Severe	2	4	Unknown
VI	126	77	Ford	PU	Auto-L	Severe	5	4	Unknown
VI	127	76	Merc	Montego	Auto-L	Severe	5	4	Heavy
VI-T	041	80	Intl	Semi	Comb	Severe	3	4	Unknown
VI-T	057	79	Chev	PU	Auto-U	Severe	5	4	Unknown
VI-T	059	71	Ford	4-Dr-Sd	Auto-L	Severe	5	4	Unknown
VI-T	104	78	Ford	Pinto	Auto-S	Severe	2	4	Unknown
VI-T	105	78	Chev	Monte Carlo	Auto-L	Severe	4	4	Unknown
VI-T	106	78	Dodge	2-Dr-Sd	Auto-U	Severe	3	4	Unknown
VI-T	107	78	Chev	2-Dr-Sd	Auto-L	Severe	5,5,5,5	4	Unknown
VI-T	108	80	Toyo	2-Dr-Sd	Auto-S	Severe	4,5	4	Unknown
VI-T	109	77	Ford	LTD	Auto-L	Severe	5	4	Unknown
VI-T	110	77	Pont	2-Dr-Sd	Auto-L	Nonsevere	5,5	2	Unknown
VI-T	111	77	Chev	SW	Auto-L	Nonsevere	5	4	Unknown
VI-T	112	80	Chev	2-Dr-Sd	Auto-U	Severe	5	4	Unknown
VI-T	115	79	Pont	2-Dr-Sd	Auto-U	Severe	4	4	Extensive
VI-T	116	69	Dodge	Sd	Auto-L	Severe	5,5	4	Unknown
VI-T	118	73	Pont	2-Dr-Sd	Auto-L	Severe	5,5	4	Unknown
VI-T	122	69	Plym	4-Dr-Sd	Auto-L	Severe	2	4	Unknown
VI-T	123	78	Kenw	Semi	Comb	Severe	3,3	4	Unknown
VI-T	124	77	Ford	T-Bird	Auto-L	Severe	5,5,5,5,5	3	Extensive
VI-T	125	83	White	Semi	Comb	Severe	4	4	Extensive
II	062	75	Volks	2-Dr-Sd	Auto-S	Nonsevere	5	3	Unknown
II	064	78	Intl	Semi	Comb	Severe	5	4	Unknown
II	065	71	Ford	PU	Auto-L	Severe	5	4	Unknown
II	067	78	Chev	Sd	Auto-U	Severe	2	4	Unknown
II	089	62	Ford	2-Dr-Sd	Auto-L	Severe	5	4	Moderate
II	090	66	Olds	4-Dr-Sd	Auto-L	Severe	2	4	Heavy
II	091	66	Plym	Sd	Auto-L	Severe	5	4	Heavy
II	092	67	Chev	Sd	Auto-L	Severe	5	4	Heavy
II	093	64	Ford	Sd	Auto-L	Severe	5	3	Heavy
II	094	65	Chev	SW	Auto-L	Severe	3	4	Heavy
V	042	70	Chev	4-Dr-Sd	Auto-L	Severe	2	4	Unknown
V	043	72	Dodge	PU	Auto-L	Severe	5	4	Unknown

Note: Refer to Table 4 for definition of variable categories.
[a]Unknown.

tion. A summary of these average costs is included in Table 7.

Accident savings were determined by calculating the reductions in injuries that resulted because collisions were with crash cushions rather than with a fixed, non-energy-absorbing object such as a bridge abutment. For this analysis, accident data were summarized for collisions with bridge abutments during the period 1980 through 1982. There were 394 accidents of this type and the average cost per accident was calculated. The costs for each fatal ($200,000), each non-fatal-injury ($8,000), and each property-

TABLE 7 Summary of Installation and Repair Costs

Crash Cushion Type	Annualized Installation Cost[a] ($)	Avg Installation Cost ($)	Avg Repair Cost per Accident ($)
I and II	641	3,937	887
IV			
Cushion	3,225	19,824	392
Cluster	779	4,788	2,839
V	1,082	6,650	1,760
VI	1,968	12,098	1,886
VI-T	2,338	14,369	1,886

[a]Installation costs amortized over a 10-year period at a 10 percent rate.

damage-only ($1,090) accident were those reported by the National Safety Council for 1982 (11). The cost per accident for each reported collision involving a bridge abutment was found to be about $21,000. Similarly, the cost per accident for each collision with a crash cushion in 1980 through 1982 (95 accidents) was found to be about $11,000. Therefore, the saving per accident was determined to be $10,000. The total savings would be $950,000 over a 3-year period or an annual saving of about $317,000.

Installation costs were amortized over a 10-year period at a 10 percent interest rate and the annual costs were determined for each type of crash cushion. Average annual installation costs for the analysis period were determined to be $274,707. Total repair costs for the three-year period were $178,506, or $59,502 per year. The result was an average cost of approximately $334,000 per year. Comparing the average annual accident savings of $317,000 with the average annual cost of $334,000 yields a benefit/cost ratio of approximately 1.0. It should be noted that additional savings likely resulted in the form of reduced accident costs because of nonreported accidents involving crash cushions. In many cases, crash cushions are capable of absorbing an impact or redirecting a vehicle without disabling the vehicle. The result is reduced accident severity when this is compared with the consequences of impacting a rigid object such as a bridge abutment. However, these successful impacts were not included in the cost-effectiveness analysis because no accident report was filed.

Another approach to evaluate the cost-effectiveness of crash cushion installations is application of accident reduction factors obtained from a national survey conducted by the Kentucky Transportation Research Program as part of another study (12). Several states reported reduction factors for crash cushions and those reductions averaged approximately 75 percent for fatal accidents and 50 percent for injury accidents. When these factors are applied to the numbers of various types of crash cushion accidents for the period 1980 through 1982, the expected reduction in fatal and injury accidents may be estimated. If no crash cushions had been installed, there would have been 9 more fatal accidents and 36 more injury accidents expected as well as 45 fewer property-damage-only accidents. This would have resulted in an annual accident cost saving of approximately $680,000. With an average annual cost of about $334,000 for crash cushion installation and repair cost, the benefit/cost ratio would be about 2.0.

Therefore, the range of benefit/cost ratios for crash cushions would be from 1.0 to 2.0, depending on what approach is used to estimate the reduction in accidents. The conservative estimate of 1.0 was obtained when the severity of crash cushion accidents was compared with the severity of bridge abutment accidents in Kentucky. The higher benefit/cost ratio of 2.0 resulted when the severity of crash cushion accidents was compared with the reductions expected because crash cushions were installed.

CONCLUSIONS

An analysis of accidents involving crash cushions, which includes Hi-Dro cell, G.R.E.A.T., G.R.E.A.T.-T, sand-barrel, and steel-drum types, indicates that the crash cushions have been performing their function properly (85 percent proper performance). Vehicles have generally been stopped by the crash cushions. The instances of improper performance have generally involved either the rebounding of the vehicle into or across the adjacent roadway or the overturning of the vehicle. All the various types have performed well.

Accident severity was high but less than that for similar impacts into BCT guardrail end treatments (8). This illustrates the increase in impact attenuation of a crash cushion over a guardrail end treatment.

Results from the cost-effectiveness analysis show that crash cushion installations produce a benefit/cost ratio in the range of 1.0 to 2.0.

It is recommended that the use of crash cushions be continued at locations where they are cost-effective. Primary examples of these locations include (a) gore areas on elevated structures; (b) other gore areas where guardrail end treatments must be joined together; (c) bridge piers in narrow medians at high-speed, high-volume locations; and (d) the ends of concrete barrier walls. Any of the types studied could be used, depending on site geometrics.

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