Performance of Highway Safety Devices

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Accident records were compiled over a 5-year period (1971-1975) to evaluate performance of light-post guiderail and median barrier, slip-base sign posts, frangible-base luminaire supports, and impact attenuation devices. Guiderail and median barrier injury rates were very low, with only eight serious injuries and no fatalities recorded in 392 accidents. Penetration of the barrier occurred in only 4 percent of mid-section accidents. Based on only 10 accidents, slip-base sign supports appear to be performing satisfactorily. Based on 78 accidents, performance of aluminum frangible-base luminaire supports is excellent. Of 393 impacts recorded on four types of attenuators, only six severe injuries and one fatality occurred; most serious accidents were related to specific problems with individual attenuators or with secondary collisions.

In the 1960s New York State research on highway safety devices resulted in development of improved guiderail to protect errant vehicles by safely redirecting them back onto the roadway. For situations where use of guiderail is impractical, such as elevated gores, impact attenuation devices were developed to stop cars at safe deceleration levels. Breakaway supports were designed to lessen impact severities with highway sign and luminaire supports.

Although these new or improved devices were developed through carefully controlled testing programs, satisfactory performance in controlled tests does not assure that actual in-service performance will be without problems (1). The objective of the additional research reported here was to document field performance of New York's traffic barriers, as well as that of impact attenuators, slip-base sign supports, and frangible-base luminaire supports.

SAFETY DEVICES STUDIED

Guiderail and Median Barrier

New York's standard guiderails and median barriers use lightweight posts (S3x5.7) that yield on impact, allowing the rail element to deflect gradually and absorb the vehicle's lateral energy. This system was developed when early crash tests showed that heavy posts could produce high decelerations (2). Rail elements now used include cable, corrugated W-beam, and structural tubing (box-beams). Rail type and post spacing for a given installation, either guiderail or median barrier, are selected on the basis of available deflection space behind the rail. By installing the most flexible system possible for the available deflection distance, decelerations on the impacting vehicle are held as low as possible. Details of New York's light-post barriers are shown in Figure 1. In addition, concrete median barriers and heavy-post barriers are used (on rare occasions) for special situations.

Sign and Luminaire Supports

Collisions with fixed sign supports or luminaire poles may produce extremely high decelerations, resulting in severe injuries or death to vehicle occupants. Thus, bases were designed that release at ground level upon impact. Sign supports used in New York (see Figure 2), patterned after those developed in Texas (3, 4), employ a slip connection at the base consisting of two horizontal plates—one attached to the foundation near ground level and the other welded to the support leg. These plates are bolted together through slots that allow the plates to slip apart on impact, releasing the support leg. A hinge in the support's upper portion allows the leg to swing free of the vehicle, while remaining attached to the sign so it will not be thrown into the highway.

Luminaire supports having a frangible cast aluminum base (see Figure 3) were designed to fracture with a maximum change in the impacting vehicle's momentum of 4895 N/s (1100 lb/s), according to Federal Highway Administration (FHWA) standards in effect in the late 1960s (5). Upon impact, the cast aluminum base shatters, releasing the aluminum lamp pole, which passes over the vehicle and usually falls off the roadway. The luminaires evaluated included a 9.1-m (30-ft) pole, a 20.3-cm (8-in) base diameter, and a 4.6-m (15-ft) mast arm.

Impact Attenuators

Where fixed objects cannot be removed or converted to a safe design and adequate space is not available to install guiderail, the vehicle must come to a complete stop while keeping decelerations to a tolerable level. New York's designs allow a maximum average deceleration of 6 *g*.

Sand-Filled Plastic Barrels

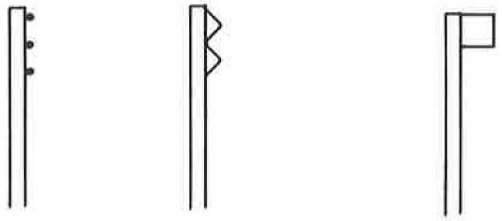
Sand-filled plastic barrels (see Figure 4a) are frangible polyethelene barrels 91.4 cm (36-in) deep and 91.4 cm (36 in) in diameter. Upon impact, the barrels shatter and the sand is accelerated, transferring energy from the vehicle to the sand. The amount of sand in the barrels varies from 181 kg (400 lb) in the front to 952.6 kg (2100 lb) in rear units to achieve uniform deceleration as the vehicle penetrates the array.

Water-Filled Vinyl Tubes

This attenuator employs water-filled flexible vinyl tubes having orifices in the top. The tubes are compressed on impact, transferring energy from the vehicle to the liquid, which is forced through the orifice into the air.

These tubes are arranged in two configurations—one for high speeds [above 64.4 km/h (40 mph)] and the other for lower speeds. The high-speed devices (see Figure 4b), termed "cell-sandwich units," have plywood panels between groups of tubes to distribute impact force across the full width of tubes. Panels mounted along the sides of the unit provide redirection capability for side impacts. The low-speed units (Figure 4c), called "cluster units," consist of individual vinyl tubes bolted together in rows. The entire unit is attached to a back-up wall or to the object being shielded. No interior or side panels are used.

Figure 1. Design details of light-post barriers.



Barrier Type	Cable Guiderail	W-Beam Guiderail	Box-Beam Guiderail
Post Size	← S3x5.7 with 8"x24"x¼" soil plate →		
Post Length	63" min	63" min	63" min
Rail Element	Three 3/4" ϕ steel cables	10- or 12-gage, 12" deep steel W-beam	6"x6"x3/16" steel structural tube
Post-to-Rail Connection	5/16" ϕ hookbolt	Hex-head, 4000-lb min tensile strength, 1/16" ϕ 1½" long bolt, with support bolt at bottom	5"x3½"x3/8" long angle with 3/8" ϕ bolt through tube, ½" ϕ bolt through post
Mounting Height To Top of Rail	30" (center of top cable)	33"	30"

Barrier Type	W-Beam Median Barrier	Box-Beam Median Barrier
Post Size	← S3x5.7 with 8"x24"x¼" soil plate →	
Post Length	63" min	53-3/4" min
Rail Element	Two 10- or 12-gage 12" deep steel W-beams	6"x8"x¼" steel structural tube
Post-to-Rail Connection	Hex-head, 4000-lb min tensile strength, 1/16" ϕ 1½" long bolt, with support bolt at bottom	¼" thick special steel rail support plate, with two 3/4" bolts through post
Mounting Height To Top of Rail	33"	30"

Figure 2. Typical sign support details, showing slip base (left) and upper hinge (right).

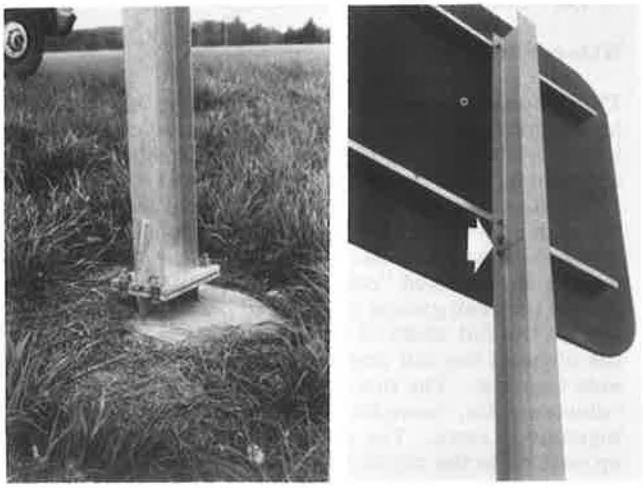
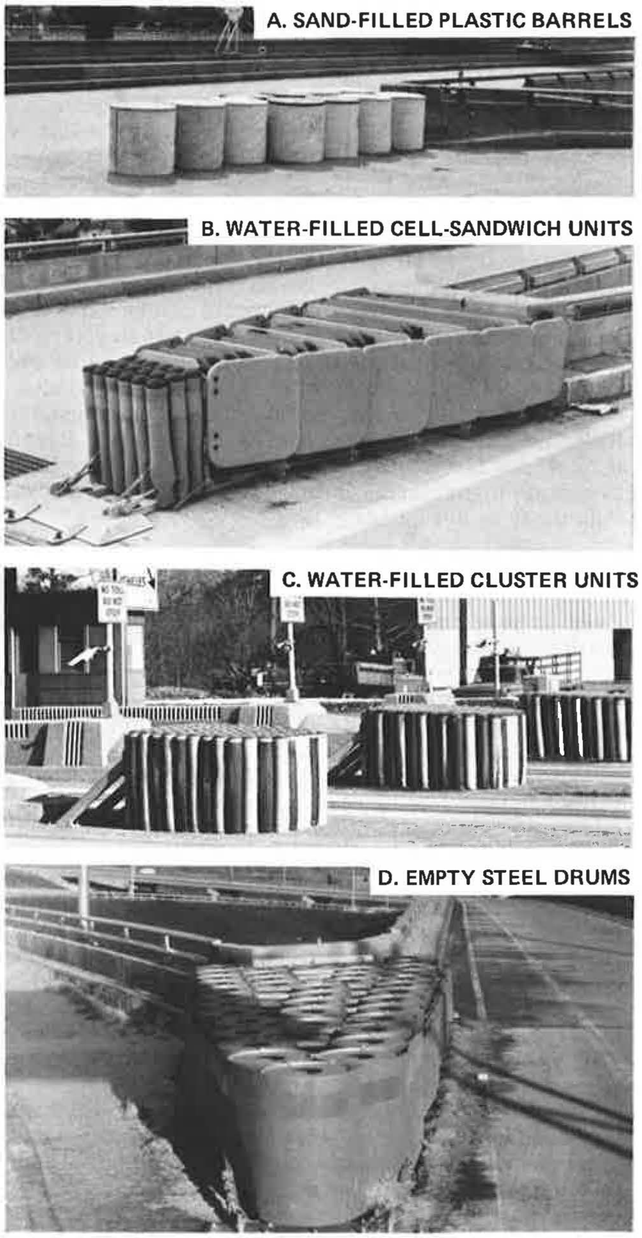


Figure 3. Typical aluminum frangible-base luminaire support.

Figure 4. Typical impact attenuation devices.



Empty Steel Drums

Consisting of 20-gage, 208-L (55-gal) steel drums with 20.3-cm (8-in) holes cut in the top and bottom, this device is commonly referred to as the "Texas Barrel" system (see Figure 4d). The drums are tack-welded or clipped together at the rims and anchored to a back-up wall. The energy of the impacting vehicle is absorbed in crushing the drums.

Data Collection Methods

This evaluation of highway safety hardware is based on accident experience on New York State highways. Data sources were as follows:

1. Guiderail and median barrier. The guiderail and median barrier sample consists of 47 construction contracts in the eastern half of New York State (except New York City) on which the guiderail installation was completed by 1971. These contracts cover 367 km (228 miles) of highway and include 145 839 m (478 473 ft) of barrier. In addition to locations monitored on the state highway system, guiderail and median barriers on 314 km (195 miles) of the New York State Thruway were monitored from April 1 to October 1, 1973.

The department's highway maintenance subdivision handled data collection on the state system. When an installation was struck at one of the selected sites, the maintenance foreman responsible for repair completed and forwarded a special accident form. Cost data were transmitted when they became available. Research personnel also checked for accident locations on departmental printouts, and obtained actual police reports from the Department of Motor Vehicles when available. On the Thruway, data collection was coordinated by the N. Y. State Thruway Authority's traffic and safety engineer. State police completed a special report form at the time of an accident, and attached a copy of the police accident report. These reports, along with guiderail repair data, were then forwarded.

2. Impact attenuators. Since only a limited number of attenuators were in service at the beginning of the study, all sites across the state were monitored. New installations put in service during 1971 to 1975 were added to the study. When data collection ended, 70 units were being monitored, including 21 water-filled cell-sandwich units, 11 water-filled cluster units, 35 sand-filled plastic barrel units, and 3 empty steel drum units. On the state system, data collection was conducted in the same manner as for guiderail and median barrier. In New York City, data collection was coordinated through the New York City Department of Highways, the maintenance supervisor for impact attenuators, and the manager of the Traffic Engineering Division of the Port Authority of New York and New Jersey.

3. Sign and luminaire supports. State highways where guiderail and median barrier data were also being collected were monitored, but only a few reports were received on breakaway sign supports and none on frangible-base luminaire supports. Performance of these sign and luminaire supports thus was also monitored along the Thruway. From April 1 to October 1, 1973, slip-base supports were monitored on the Thruway's entire 900-km (559-mile) length, while luminaire support observations were restricted to the Niagara and New England sections, totaling 58 km (36 miles).

In addition, a 20-km (12½-mile) section of I-90 in Albany was selected for the monitoring of luminaire supports, where a total of 392 poles were in service. On both state roads and the Thruway, data collection procedures and forms were identical to those used for guiderail and median barrier. For I-90, researchers obtained a listing of all impacts on luminaire supports directly from the utility company, including the accident date and pole number. These data were then used to search Albany police records for accident reports.

Study Variables and Evaluation Criteria

The safety devices studied include a number of design and construction variables that could be expected to affect performance. Several other variables also must be known to describe each accident. The major ones included were as follows:

1. Barrier or impact attenuator type. Five types of guiderail and median barrier, 4 impact attenuators, 1 slip-base sign support, and 1 frangible-base luminaire support were included.

2. Impact location on barrier. Location of impact on the barrier was recorded.

3. Impact conditions. Vehicle speed and trajectory before impact and secondary impacts with other objects were recorded when available.

4. Vehicle size. Only passenger car accidents are included; in most cases, specific vehicle weight and size were unavailable, because of the large number of hit-and-run accidents, and because police accident reports do not indicate vehicle model.

5. Barrier mounting height. An earlier study of performance of New York barriers (1) indicated that mounting height of the rail element plays an important role in a barrier's performance; in 1969, the specified mounting height to the center of the rail was increased to 68.6 cm (27 in) for all rail types, and actual field measurements were made in this study to determine rail height on each of the 47 contracts and on the Thruway. (These measurements characterize the range of heights on each contract, but do not define actual heights at individual accident sites.)

Several parameters were used to evaluate performance of safety appurtenances:

1. Severity of injury. Injuries were categorized as none, minor, severe, or fatal. Hit-and-run accidents were classified as no injuries, because it is reasonable to assume that most included no injuries, or at worst injuries of a very minor nature.

2. Vehicle reaction. A vehicle's reaction on impact is a primary indicator of the performance of a safety device. Data collected include barrier penetration and post-impact vehicle trajectories for guiderail and median barrier, when known. For attenuators, the final position of the vehicle was noted when available. For sign and luminaire support bases, vehicle trajectory and whether the vehicle stopped at the support were noted when possible.

3. Maintenance requirements. Accident damage repairs were reported in this study in terms of equipment, materials, and labor costs necessary to restore the device to operation. Routine maintenance activities such as winterizing were reported for attenuators.

GUIDERAIL AND MEDIAN BARRIER PERFORMANCE

In all, 392 impacts on guiderail and median barrier were recorded during the study period (90 percent occurred during 1972 and 1973). Police reports were included for all Thruway accidents, but for only 31 on state roads.

Severity of Injury

Injury data for all barrier accidents are given in Table 1. W-beam guiderail accidents are reported separately for the Thruway and state highways. Because police reports were generated by all Thruway accidents and by accidents on only a few state roads, the level of injuries reported may have been different. Accidents for the other barrier types were not separated, because accidents for each barrier type occurred almost exclusively on one system or the other.

The low number of severe injuries and the lack of fatalities indicate good performance by these barriers. The number of injuries recorded is too small to permit meaningful comparisons among guiderail types. However, by combining minor and severe injuries, a comparison between all guiderail and all median barrier and between the two types of median barrier was made using the χ^2 analysis technique. While the small difference between guiderail and median barrier injury rates was not statistically significant, the difference between W-beam and box-beam median barrier is significant at the 95 percent confidence level. Two factors may partially explain this difference. First, nearly all W-beam median barrier accidents were recorded on the Thruway, but box-beam median barrier accidents occurred predominantly on state roads. Because of the differences in police reporting, injury data possibly were more complete for the Thruway, with some very minor injuries going unreported on state roads. Second, warrants for use of the two types of median barrier are different, and as a result different types of impacts can be expected on each. Box-beam, the stiffer of the two barriers, is normally used in narrow medians up to 3 m (10 ft) wide; as a result, it is exposed to relatively low-angle hits. W-beam median barrier, on the other hand, is used in wider medians—generally 3 m (10 ft) or more. Because it is placed farther from the roadway, it is more likely to sustain higher-angle impacts—generally more severe than those at low angles.

Barrier Penetration and Rail Height

Barrier penetrations are given in Table 2. An "unrecorded" category accounts for hit-and-run accidents and police reports with incomplete data. However, nearly all these vehicles were probably contained. End-section accidents are not included, since end sections are not designed to prevent penetration.

With the exception of cable guiderail, penetration rates are very low. Because of the small sample for midsection cable accidents, little significance can be attached to this penetration rate. All these penetration rates, with the exception of cable guiderail, are below those recorded in an earlier New York study of traffic barriers (1). The small number of penetrations recorded precludes statistical comparison between barrier types, or with data from the earlier study for individual barrier types. However, the overall penetration rate is significantly lower in this study.

That earlier study identified rail mounting height as a possible contributing factor to barrier penetration, and mounting heights were increased in 1969. Because rail heights could not be obtained at individual accident sites, height was measured at 161-m (1/10-mile) increments on all contracts included in this study on state roads, and randomly along the Thruway (see Table 2).

Because considerable variability was observed within each contract, rail heights could not be determined at specific accident sites to identify relationships with barrier penetration. Such analysis is further frustrated by the small number of penetrations recorded. However, it can be concluded that overall penetration rates are significantly lower than in the previous study, and average barrier heights are higher than the previous standard.

Results of End-Section Accidents

Some 29 accidents involving barrier end sections were recorded in this study as follows: 11 cable guiderail, 2 W-beam guiderail, 6 box-beam guiderail, and 10 box-beam median barrier, and 1 impact involved a barrier transition. No injuries were recorded on the 11 end-section impacts on cable guiderail.

The proportion of end-section accidents on cable guiderail was greater than on other barrier types. This is attributed to greater flexibility, which enables a vehicle to deflect the cable barrier outward and remain in contact with it. In three of the accidents involving de-

Table 1. Severity of injuries for barrier accidents.

	No Injuries		Minor Injuries		Severe Injuries		
Barrier Type	No.	Percent of Total	No.	Percent of Total	No.	Percent of Total	Total Accidents
Cable guiderail	21	91.3	2	8.7	0	0.0	23
W-beam guiderail (state)	9	81.8	2	18.2	0	0.0	11
W-beam guiderail (thruway)	33	80.5	6	14.6	2	4.9	41
Box-beam guiderail	33	89.2	4	10.8	0	0.0	37
All guiderail	96	85.7	14	12.5	2	1.8	112
W-beam median barrier	73	82.0	14	15.7	2	2.2	89
Box-beam median barrier	177	92.7	10	5.2	4	2.1	191
All median barrier	250	89.3	24	8.6	6	2.1	280
All barriers	346	88.3	38	9.7	8	2.0	392

Table 2. Barrier penetration in midsection accidents.

	Penetrated		Contained		Unrecorded			
Barrier Type	No.	Percent of Total	No.	Percent of Total	No.	Percent of Total	Total	Mean Mounting Height (cm)
Cable guiderail	4	33.3	5	41.6	3	25.0	12	71.9
W-beam guiderail	4	8.0	40	80.0	6	12.0	50	79.7
Box-beam guiderail	0	0.0	7	22.6	24	77.4	31	75.9
W-beam median barrier	5	5.6	81	91.0	3	3.3	89	74.2
Box-beam median barrier	2	1.1	19	10.5	160	88.4	181	75.4
All barriers	15	4.1	152	41.9	196	54.0	363	

Note: 1 cm = 0.39 in.

parture ends, the vehicle impacted the barrier at distances from the end of 27.4, 30.5, and 83.8 m (90, 100, and 275 ft), and followed along the barrier to the end anchor.

Only two impacts were recorded on W-beam guiderail end sections, both hit-and-run, but no problems were identified from these accidents. Six accidents involving box-beam guiderail end sections were recorded; one resulted in a minor injury, but the barrier performed satisfactorily in all six. Reports provided by maintenance personnel indicated that the vehicles were redirected parallel to the barrier in every case.

Ten box-beam median barrier end-section impacts were recorded, all hit-and-run. As with other barrier types, maintenance reports indicated satisfactory performance, with vehicles redirected along the barrier. No end-section impacts were recorded on W-beam median barrier.

Accident Damage and Repair Costs

Data on accident damage and repair costs provided by maintenance personnel are given in Table 3, including the rail length and number of posts damaged, as well as replacement quantities. Lack of normal distributions somewhat complicates analysis of these data, but differences between barrier types can be tested by means of the Mann-Whitney U test (6).

Average barrier damage tended to decrease as rail stiffness increased. Cable guiderail, the most flexible, had the highest average length of barrier damaged per accident—31.9 m (104.7 ft). Conversely, box-beam, the stiffest guiderail, had only 7.7 m (25.4 ft) damaged per accident. The same trend is apparent for median barriers. Grouping the state and Thruway W-beam guiderail for this analysis, all differences in barrier damage between guiderail types and between median barrier types are statistically significant at the 95 percent confidence level. Post damage is also related to barrier stiffness. With the exception of box-beam guiderail, most damaged posts had to be replaced.

Table 3 also summarizes accident repair costs for each barrier type. The Mann-Whitney U test was again applied to test differences among the three guiderail types and between the two median barriers. Grouping all W-beam guiderail together, the differences among the three guiderail types are not significant. However, W-beam median barrier was significantly more expensive than box-beam median barrier, although the absolute difference is not great. Although box-beam median barrier had the lowest average repair cost of all barriers, it also had the greatest range, with several very expensive accidents recorded.

Based on the limited sample reported here and considering differences in repair criteria and methods between the state and Thruway maintenance forces, differences in repair costs between barrier types appear to be minor—certainly insufficient to dictate the choice of barrier type to be used.

Summary

The 392 accidents recorded in this study indicate good performance by these barrier types. In nearly 90 percent of the accidents on the state system, the vehicle was able to leave the scene unassisted, indicating successful barrier performance. No fatalities were recorded, and most injuries were minor. Barrier penetration rates were lower overall than those recorded in an earlier New York study. Although few end-section accidents were recorded, performance was generally satisfactory. Accident damage was generally less for the stiffer barriers. Differences in total repair costs between barrier types were small, and do not appear sufficient to affect choice of barrier type.

SIGN AND LUMINAIRE SUPPORT PERFORMANCE

Slip-base sign supports produced the fewest accident reports—only ten. Three resulted in injuries—two minor and one serious; in all three, a secondary collision was involved. In all ten accidents, the base mechanism was reported to have released properly. In one, the slip-base was mounted 30.5 cm (12 in) above ground rather than the specified maximum 10 cm (4 in), which

Table 3. Barrier damage in accidents.

Barrier Type	Total Reports	Posts (mean)		Rail (mean length in m)		Repair Cost ($)	
		Damaged	Replaced	Damaged	Replaced	Mean	Range
Cable guiderail	23	8.0	6.0	31.9	0.0	243	40-1014
W-beam guiderail (state)	11	5.8	3.3	28.3	4.7	183	58-382
W-beam guiderail (thruway)	41	4.2	3.2	14.0	9.4	227	36-626
All W-beam guiderail	52	4.6	3.2	16.8	8.4	219	36-626
Box-beam guiderail	36	5.7	1.8	7.7	2.1	224	60-878
W-beam median barrier	89	4.8	4.0	16.5	11.7	250	64-1079
Box-beam median barrier	191	3.9	3.3	10.6	0.7	207	15-1329

Note: 1 m = 3.28 ft.

Table 4. Accident performance of frangible-base luminaire supports.

Accidents	Thruway	I-90	Total
Total accidents	24	54	78
Police reports	24	35	59
Hit-and-run	0	19	19
Injuries			
None	15	48	63
Minor	8	4	12
Severe	1	2	3
Fatal	0	0	0

Table 5. Accidents involving impact attenuators.

Accidents	Sand Barrels	Sandwich Units	Cluster Units	Steel Drums
Total impacts	242	63	84	4
Police reports	9	6	30	0
Hit-and-run	233	57	54	4
Injuries				
None, unknown	238	59	68	4
Minor	3	0	14	0
Severe	1	3	2	0
Fatal	0	1	0	0
Units in service	35	21	11	3

resulted in snagging the vehicle undercarriage and an abrupt stop, with the sign falling on it. Each support leg is designed to hold the sign erect if the other is impacted. However, this sign structure was previously struck on the opposite leg, and when the leg support hinge was bent back into position, it was apparently weakened so that it alone could not support the sign. As a result of this failure, damaged supports are no longer simply bent back into position. Rather, the supporting flange is cut through, and a steel plate the same thickness as the flange is welded into position.

Most accidents involving sign supports also involved other highway appurtenances such as guiderail and fencing, with cost data lumped into a single amount. Thus, cost data could not be obtained for sign supports alone.

In all, 59 police-investigated accidents involving luminaire supports were recorded, plus an additional 19 hit-and-run accidents, as summarized in Table 4. On the Thruway, nine injury accidents were recorded—eight minor and one severe. On I-90, four accidents resulted in minor injuries and two in severe injuries. Several injuries reported may have been caused by secondary impacts with other vehicles or with other fixed objects such as retaining walls, bridge rails, guiderail, or rock cuts, either before or after striking the luminaire base. Accident repair cost data (1973 costs) were received for 19 Thruway accidents. For six accidents where the poles could be reused, repair costs ranged from $257 to $392, with an average of $362. For the remaining 13 accidents where poles were replaced, repair costs ranged from $583 to $796, averaging $715. No cost data were available on the I-90 accidents.

Although the number of impacts recorded in this study on sign supports and luminaire bases is small, excellent performance by these safety devices is indicated. Collision with a rigid sign support or luminaire base would normally result in a very severe impact. Therefore, the small number of injuries recorded here, more than half of which involved secondary impacts with other objects, indicated a substantial reduction in injuries over what would be expected for similar supports with rigid bases.

IMPACT ATTENUATOR PERFORMANCE

Table 5 summarizes 393 collisions with impact attenuators reported during the years 1971 through 1976.

Severity of Accidents

Sand-Filled Plastic Barrels

Some 242 impacts were recorded by maintenance personnel. Police investigated nine, of which four resulted in injuries—three minor and one severe.

Water-Filled Cell-Sandwich Units

A total of 63 impacts on cell-sandwich units were recorded by maintenance personnel. All but six were hit-and-run. Three serious injuries and one fatality were reported. The former all occurred at the same location, which also sustained one hit that produced no injuries. This high injury rate at a single attenuator may be related to an installation problem involving the restraining cables, which was subsequently corrected. A fifth impact was recorded after the modifications, with no injuries.

In the single fatal accident involving a cell-sandwich unit, a subcompact vehicle skidded into the device sideways. The vehicle compressed the unit about 50 percent, and then rotated and made contact with the right side panels. The vehicle was then deflected across the ramp and struck a concrete bridge parapet. It is not known at what point during the accident the fatal injury occurred.

Water-Filled Clusters

Some 84 impacts were reported at 11 locations by maintenance personnel, with police reports for 30. Twenty-nine of the police reports were received for three sites on the George Washington Bridge where frequent police patrols resulted in reports for accidents that might go unreported elsewhere. In one serious injury impact, impact speed was reported at 80 km/h (50 mph). The other serious injury included a collision with another

Table 6. Repair costs for impact attenuators.

Attenuation Device	Total Impacts	Repair Costs ($)					
		Labor	Materials	Equipment	Total	Low	High
Sand-filled barrels							
All accidents	242	102	391	34	527	18	2523
Multiple-barrel damage	140	136	584	46	766	118	2523
Single-barrel damage	85	50	105	17	171	28	374
Modified arrays	17	80	228	23	331	18	716
Cell-sandwich units							
All accidents	63	92	72	31	195	34	1890
Modified site excluded	59	83	63	29	176	34	1890
Cluster units (New York City)							
All accidents	25	92	263	32	388	36	2718
Less replaced units	21	64	18	25	107	36	250
Cluster units (Port Authority)	59	123	128	—[a]	251	0	NA
Steel drums, all accidents	4	289	2	58	349[b]	112	623[b]

[a] Included as 25 percent overhead on labor costs.

[b] Damage from two accidents on one unit was repaired at one time.

Table 7. Summary of nonimpact maintenance on New York City impact attenuators.

Year	Sand Barrels	Sandwich Units	Cluster Units
1974			
Units in service	19	16	7
Total repairs	22	21	8
Total average cost, $	99	107	114
Average materials cost, $	46	26	29
1975 (through September)			
Units in service	21	17	8
Total repairs	25	6	6
Total average cost, $	103	228	253
Average materials cost, $	33	101	124

vehicle after first striking the cluster unit. Of 14 minor injury accidents, seven involved secondary impacts with other vehicles, or with the bridge parapet either before or after striking the cluster unit.

Empty Steel Drums

Attenuators made from empty steel drums were installed at three locations. Four impacts were reported, all hit-and-run accidents with no police reports filed. Because of the minor damage to the devices, it is apparent that all were relatively minor. Therefore, the performance of this device in more severe collisions remains unknown.

Maintenance Requirements

Accident repair costs for attenuators are given in Table 6. These costs were highly variable, depending upon impact severity. Cell-sandwich units had the lowest overall average repair cost and sand barrels the highest. However, for a more complete picture, several considerations must be noted in analyzing these costs.

Repairs on the cluster units were very easy. The unit was simply straightened as necessary, and the cells refilled with antifreeze solution. A total of 25 impacts were recorded on all cluster units maintained by New York City. However, four resulted in damage much more severe than the other 21, which required major reconditioning or replacements. The average repair cost on the New York City cluster units, excluding these extraordinary expenses, was $102, with a maximum of $250. Repair costs for 59 recorded impacts on cluster units maintained by the Port Authority averaged $251.

Not considering the four major repairs noted before, repair costs on the cell-sandwich units were more variable than on the cluster units. Because they are installed at higher-speed locations, the potential for variability in impact severity is greater. As discussed in the section on accident severity, one unit required rebuilding after four impacts because of a construction deficiency. In addition, two hits on this unit before rebuilding resulted in damages of $431 and $1143. Because of this extraordinary damage, these impacts are not considered typical. Maintenance costs without them averaged $176 for 59 reported impacts.

While minor impacts on cell-sandwich units and cluster units may often go undetected, except for obvious scrapes and scuff marks, nearly all impacts on sand-barrel units result in broken barrels that generate a maintenance report. These minor impacts, termed "nuisance hits", may often be caused by the presence of the attenuator itself, since less recovery room is available in the gore area. To reduce damage to the entire array by minor impacts, the three leading barrels were positioned 2.7 m (9 ft) in front of the main array of four units. Seventeen minor hits on the three leading barrels of these modified arrays, and 85 single-barrel hits on the standard arrays, are reported separately in Table 6. The average cost for 140 multiple-barrel hits was $766, and this is the figure that can most properly be compared with repair costs on cell-sandwich and cluster units, where nuisance hits did not normally generate repair cost reports.

Only three repairs were made for four impacts on the steel drum units, at an average cost of $349. Because used paint drums were used as replacements, material costs were very low. However, labor costs were very high for these repairs. Maintenance personnel reported difficulty in disassembling the damaged drums from the unit and replacing new drums in the proper positions. More experience in repairing these devices may achieve some reductions in labor costs.

In addition to impact repairs, routine maintenance is also required on these devices. This includes winterizing, repair of minor damage from vandalism and other deterioration, and removal of debris that collects in the units. Repair cost data for nonimpact maintenance for all units maintained by New York City for 1974 and for the first 9 months of 1975 are summarized in Table 7.

DISCUSSION

All four types of attenuators performed very well in preventing serious injuries to occupants of impacting vehicles. Except for several injuries on the cluster units attributed to secondary collisions and high-speed impacts, no large differences are apparent between any of the attenuator types in terms of injury severity. Although large differences in maintenance costs are apparent among systems, total cost also depends on initial cost of the installation and the number of impacts it can withstand before replacement is required.

The study's principal findings are that

1. Guiderail and median barrier performed well in 392 accidents recorded in this study.
2. The barrier penetration rate recorded was significantly lower than in an earlier New York study of barriers.
3. Twenty-eight barrier end-section accidents resulted in no injuries.
4. No large differences in barrier accident repair costs were recorded.
5. Only ten impacts were recorded on slip-base sign supports. Although two resulted in minor injuries and a third in a hospitalization injury, secondary impacts were involved in all three.
6. Seventy-eight impacts on frangible-base luminaire supports resulted in minor injuries in 12 cases, and hospitalization injuries in three more. Several of these injuries probably resulted from secondary collisions with other fixed objects or vehicles.
7. Of 393 impacts recorded on impact attenuators, only 17 minor injuries, 6 hospitalization injuries, and 1 fatality were recorded.
8. Accident repair costs were highest for the sand-barrel units and lowest for the cell-sandwich units, but this may be offset by the higher initial cost of both types of water-filled cells, and the possible need for major reconstruction or replacement after a limited number of impacts.

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Abridgment

Cost-Effectiveness Model for Guardrail Selection

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In view of the problems of ever-increasing highway construction costs and the limited funding available, it is critical to guardrail selection and installation that a cost-effectiveness formulation be included as an aid in the decision-making policy. This is particularly true for the rural, low-volume highway. For such roads, strict adherence to the conventional guardrail warranting and selection procedures could lead to the installation of guardrails of maximum effectiveness at some sites and no installations at other sites because of the lack of available funds. Thus, a need exists for effective criteria for the selection of guardrail types based on a cost-effectiveness analysis. A typical cost-effective procedure can be used to evaluate the options of (a) removing or reducing the hazard so that the guardrail is no longer warranted, (b) installing the most cost-effective guardrail systems that funds permit, or (c) leaving hazards unshielded at sites where guardrail installation is not cost-effective. This report focuses principally on the second of these options; the guardrail is assumed to be warranted. However, the third option (c) can also be exercised for the included hazard types of fixed objects or embankments. Of course, the value of such a cost-effectiveness decision-making policy need not be limited to low-volume roads and could result in more efficient use of available funds for all types of highway systems.

The objective of this program was to develop a cost-effectiveness model for guardrail selection that would include cost parameters for various guardrail configurations as well as criteria for analysis of system effectiveness under various dynamic impact conditions. Eleven guardrail types were selected for inclusion in the program. Five of the designs (G1, G2, G3, G4S, G4W) were included in NCHRP Report 118 (1). The remaining six systems were arbitrarily selected from commonly used designs and some of the newer designs coming into use. Most of the systems have now been included in the 1977 American Association of State Highway and Transportation Officials (AASHTO) Guide (2). The corresponding system notations follow (1 m = 3.3 ft):

System in This Report	Notation in AASHTO Guide
A	GR2, except for post size
B	G4(1W), except for round rather than square posts
C	Not included (W-beam on 0.2 x 0.2-m wood posts with blockouts at 3.8-m spacing)
D	G4 (2W)
E	G4 (2S)
G1	G1
G2	G2
G3	G3
G4S	G4 (1S)
G4W	G4 (1W)
Thrie	G9

Selected impact category values used in the study for vehicle sizes, vehicle speeds, and angles of impact are