Highway Guardrails: Safety Feature or Roadside Hazard?

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On the basis of reported accident data, from 50 to 60 percent of guardrail accidents involve an injury or a fatality. From this highway engineers have concluded that guardrail installations are a roadside hazard and should be used only when absolutely necessary. On the other hand, by using a more in-depth study of accident data and estimates of the frequency of unreported accidents, a more positive view of guardrail performance is projected. Specifically, unreported guardrail impacts represent approximately 90 percent of the total impacts, with the other 10 percent being reported. Assuming no injuries or fatalities in the unreported drive-away accidents, only 6 percent of all guardrail impacts involve any injury or fatality. Furthermore, analysis reveals that terminals, as opposed to segments of typical lengths, are overrepresented in the accident data, comprising up to 40 percent of the guardrail accidents resulting in fatalities or injuries. Also, clinical data indicate that many of the 6 percentile accidents resulting in injuries or fatalities involve (*a*) guardrail installations that are obsolete, improperly constructed, or inadequately maintained, (*b*) noncrashworthy ends, or (*c*) collisions that are outside the practical design range of modern guardrail systems. It is concluded that properly installed and maintained longitudinal barriers may be successfully performing in 97 to 98 percent of all design range length-of-need impacts, with only 2 to 3 percent of the impacts causing occupant injuries or fatalities, a stark contrast to the erroneous 50 to 60 percent based on only reported accidents.

A cursory examination of fixed objects involved in ran-off-the-road single-vehicle accidents (Table 1) (*1*) reveals that guardrails rank as the third most frequent roadside object struck in fatal accidents. About 50 percent (*2*) to 60 percent (*3*) of reported guardrail accidents involve an injury or fatality.

In 1964 the authors of HRB *Special Report 81* (*4*), although not discussing the relative hazard of guardrails, advised engineers with the following statement: "As a basic principle, the highway should be designed through judicious arrangement and balance of geometric features, to preclude or minimize the need for guardrail." In 1968 the authors of *NCHRP Report 54* (*5*) cautioned engineers as to the relative hazard represented by guardrails: "Even properly designed guardrail and median barrier installations are formidable roadside hazards and provide errant vehicles with only a relative degree of protection." This statement was slightly modified in the 1971 *NCHRP Report 118* (*6*): "the longitudinal barrier affords only a relative degree of protection to vehicle occupants as a collision with this type of barrier can result in a severe accident."

Again, in 1977 according to the AASHTO Barrier Guide (*7*): "it cannot be overemphasized that a traffic barrier is itself a hazard." From the 1989 AASHTO *Roadside Design Guide* (*1*) the reader is advised that

> 60 percent of the fatal accidents . . . either overturned or collided with a fixed object. Some of these fixed objects were manmade and included . . . traffic barriers. Barrier warrants are based on the premise that a barrier should be installed only if it reduces the severity of potential accidents."

One researcher (*8*) concluded the following: "Barriers are unsafe. *When in doubt, leave them out!*"

From these statements, a reader might conclude that guardrails or longitudinal traffic barriers are not only a roadside hazard but that the perceived safety benefit, if any, is decreasing with time. It is the authors' opinion that this perception of guardrail performance is based on incomplete and misleading accident data and that the conclusions are invalid.

The purpose of this paper is to examine and assess the conventional wisdom of guardrail performance.

PURPOSE OF GUARDRAILS

In the incorporation of forgiving roadside technology into the national highway and street network, a first step for highway agencies is to establish an appropriate clear-zone width that is commensurate with the type of highway, local conditions, and funding. A minimum clear-zone width of 9.2 m (30 ft) has been FHWA policy since the mid-1960s for Interstate highways and for other roads when it is economically feasible. For lower-speed, less-traveled roads with restricted rights-of-way, a clear-zone width of less than 9.2 m (30 ft) is acceptable. Once a clear-zone width is established the hierarchy of safety treatment is the following: (*a*) remove all fixed objects and hazards that can cause abrupt decelerations or upset an errant vehicle and make the roadside area as smooth and level as possible; (*b*) if certain fixed objects such as sign and luminaire supports cannot be removed, then they should be converted to breakaway designs; and (*c*) if fixed objects and hazards cannot be removed or converted to breakaway designs, then the fixed objects or hazards should be shielded by a longitudinal barrier such as a guardrail. The purpose of a guardrail is to redirect an errant vehicle away from a roadside fixed object or hazard located in the clear zone that otherwise cannot be safety treated.

By necessity, the guardrail is located closer to the traveled way than the hazard or object that it is shielding and thus is exposed to a greater frequency of impact. Moreover, the length of a guardrail installation properly shielding a point hazard such as a pole increases the target exposure and the potential number of vehicle impacts; for longer roadside hazards such as steep embankments, the exposure of added guardrail installation length becomes insignificant.

Objective criteria for identifying roadside conditions needing guardrail shielding are specific for fixed objects and steep embankments located within the clear zone. For moderately sloped embankments of about 4:1 and steeper, an equal severity curve was

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TABLE 1 Fatalities from Impacts with Fixed Objects by Object Type

Fixed Object	1983	1984	1985	1986	1987
Tree/shrub	2841	3021	2989	3444	3299
Utility pole	1377	1426	1298	1495	1406
Guardrail	1310	1446	1258	1374	1326
Embankment	1288	1264	1211	1332	1396
Culvert/ditch	1259	1198	1337	1472	1393
Curb/wall	865	899	982	960	861
Bridge/overpass	803	738	628	577	571
Concrete barrier	263	240	225	197	203
Sign or light support	488	480	508	551	538
Other pole/support	495	434	481	518	495
Fence	434	455	431	478	484
Building	110	105	101	100	108
Impact attenuator	16	10	14	9	18
Other fixed object	565	629	630	699	729
TOTALS	12114	12345	12093	13206	12827

Source: Fatal Accident Reporting System (FARS), NHTSA

developed by Glennon and Tamburri in 1967 (*9*) and was subsequently revised by Ross in 1977 (*7*). On many secondary roads with low traffic volumes, guardrail installations have been used only at locations with adverse accident histories, even though they may be warranted in many other locations. Hence, many installations are placed at locations with high degrees of impact exposure with an attendant large number of reported accidents.

Because of practical limits, guardrails are typically developed to accommodate a large majority but not all vehicle impacts. For instance, guardrails are designed to perform with passenger sedans with masses in the 815- to 2040-kg (1,800- to 4,500-lb) range striking the barrier at 0 to 97 km/hr (60 mph) and at an angle of 0 to 25 degrees. Most guardrails will perform with less certainty for vehicles with masses greater than 2040 kg (4,500 lb) unless the speed and angle of approach are significantly reduced from 97 km/hr (60 mph) and 25 degrees. Also, guardrails are not specifically designed to handle motorcycles. The authors know that a number of guardrail failures occur when the vehicle or the impact conditions are beyond the design capacity. Classification of guardrail performance as unsatisfactory if failure occurs under these conditions would be akin to judging the performance of a collapsed 10-ton-capacity bridge brought down by a tractor trailer weighing 36,000 kg (40 tons).

Guardrail performance is dependent on the condition at impact; this includes both proper installation and maintenance. Evidence abounds that many guardrail installations are improperly installed or modified in critical details such as improperly flaring the guardrail ends or installing guardrails that are not maintained to the proper height and alignment or that are of insufficient length to properly shield the hazard. Such nonconformance is rarely detected or reported by investigating officers, and the fatality is attributed to a guardrail impact, reinforcing the notion that guardrails are hazardous.

IN-SERVICE PERFORMANCE

In essence highway agencies do not know the degree to which traffic barriers perform in service or specifically how well a specific guardrail design compares with another type. A procedure to perform in-service evaluation of safety appurtenances was recommended in *NCHRP Report 230* (*10*) and was then refined in *NCHRP Report 350* (*11*). The procedure reflects the magnitude of the task necessary to quantify the safety performances of roadside features. Such studies would include the following items:

- Exposure data that would include all impacts and not just those typically reported by police officers. Some method of identifying nonreported accidents is required, such as periodic inspection of barrier scrapes or documentation of tire marks on soft shoulders by maintenance forces. It is noted that the threshold damage cost for reporting property damage-only (PDO) accidents varies greatly among agencies, which introduces uncertainties in current data bases.
- The design feature and the actual condition of the safety feature struck. For example, there are a number of guardrail designs, such as cable or metal beam systems, each with unique performance characteristics. Importantly, the condition of the installation at the time of impact can directly affect the collision outcome. Low barrier height, improperly tensioned anchors, or an uneven approach terrain such as curbs can also reduce the effectiveness of an installation. Finally, a number of obsolete guardrail installations are still in existence today (1993), and these have little capacity to redirect modern automobiles.
- Reconstruction of reported accidents. Reported accidents need to be reconstructed to the extent that the impact velocity and angle of approach are determined, and these parameters need to be related to occupant injuries by means of an anthropometric model such as the flail space model. The trajectory of the vehicle after impact with the guardrails should be delineated to identify other harm-producing events.

Although some items of the recommended in-service evaluation procedures have been used in specific projects, the authors are unaware of any comprehensive use of the procedure.

The conventional wisdom that guardrails are hazards and offer a minimum degree of protection for errant motorists is based on incomplete and in many cases faulty data. Deficiencies in these data are attributed to several sources:

- Only severe impacts that include injuries or a disabled vehicle are generally reported; brush hits in which the vehicle is not severely damaged or occupant injuries do not occur are not generally recorded. Hence, only the most severe impacts can be analyzed, and little is known about the number and extent of the drive-aways. For this reason, the total number of impacts or even the failure rate (i.e., number of failures as a percentage of total impacts) cannot be calculated. If the number of reported accidents make up 90 percent or more of all impacts, then the reported accident would be fairly representative of all impacts. On the other hand, if the number of reported accidents make up less than 50 percent of all accidents, such inferences to their being representative would be weak or even nonexistent.
- Seldom is the type of guardrail indicated in the accident report because most officers are untrained in this technology. The guardrail could be one of the many modern systems or it could be an obsolete design such as the Tuthill system, which has not been built in more than 20 years. Moreover, sufficient information to document the condition of the guardrail at the time of the impact or whether it was properly installed is nearly always lacking. Barrier

failures (i.e., accidents resulting in serious injuries or fatalities) may be caused by an obsolete, improperly maintained installation rather than a generic guardrail in good condition.

- Accidents involving guardrails and resulting in fatalities and injuries are generally grouped according to the first harmful event, even though there may be several harmful events in an accident scenario and the guardrail impact may not be the most severe or even injury producing. For instance, studies have shown that the redirected vehicle can strike other unshielded fixed objects, overturn, or even interact with following or adjacent traffic. In some cases the vehicle may penetrate or vault an obsolete system and strike the shielded fixed object.
- Guardrail failures generally include all reported impacts, even events well beyond the design envelope. Combinations of vehicle mass, speed, and impact angles that exceed the crash test values may result in barrier failure (e.g., excessive deflection or penetration or severe injuries). However, it is arguable whether the occurrence of such accidents should in any way suggest that the installation is a hazard.

The intent of this section was to point out some of the inadequacies of current data systems that might lead to false conclusions regarding the efficacies of guardrail systems.

PERTINENT STUDIES

In evaluating the efficiencies of guardrails from existing data, four factors have been explored by researchers. The first factor is the magnitude of unreported accidents. The second factor is the effect of accident classification by first harmful event rather than most harmful event. The third factor is the significance of accidents in which impact conditions exceed the barrier capability. Finally, the fourth factor is whether the impact occurred within the length of need or on the end. These are discussed in more detail in the following paragraphs.

Unreported Accidents

Historically, only a part of all vehicle collisions are reported to police; the unreported collisions generally involve only minor property damage, although there may be a few exceptions in which even accidents resulting in fatalities and serious injuries fail to get into the reporting system. Accidents are broadly grouped according to descending severity by those involving fatalities (F accidents), injuries (I accidents), and PDO accidents. The reporting rate varies among states and locales within a state owing to several factors:

- The threshold dollar limit on PDO accidents varies. In some areas reports are prepared for PDO accidents in which $200 damage has occurred, whereas other agencies have established higher limits such as $500, $1,000, or even $2,000. When the investigating officer judges that the damage does not satisfy the threshold, a report is not prepared.
- The degree of reporting can vary with the proximity and availability of investigating officers. For remote sections of highway, motorists can make arrangements to leave the accident scene before the officer's arrival. Also, in urban areas during adverse weather conditions, a large number of fender benders can inundate the local reporting agency, encouraging the involved motorists to make other arrangements unless the collision was serious.
- In several areas the state aggressively pursues motorists who have damaged public property in a collision to get full reimbursement for the repair of any damage. For this reason many motorists will depart a site when a breakaway sign or luminaire support is knocked down without reporting the incident.
- Motorists with invalid licenses or inadequate property damage insurance or motorists possibly driving under the influence of alcohol are motivated to drive away.

There are probably other reasons that certain collisions go unreported, but these are believed to be the major ones.

To investigate the magnitude of unreported accidents with longitudinal barriers, two studies have been performed, one by Galati (*12*) and one by Carlson et al. (*13*). In 1969 Galati (*12*) investigated unreported accidents on the Schuylkill freeway median barrier. For the study the barrier was painted white. Once a month both sides of the median barrier were filmed, and the scuff marks and other damage were immediately repaired. Galati then correlated the scuff marks and damage areas with police accident reports that had been processed through the system. Using the premise that each scuff mark represented a collision or accident, he found that only one of eight collisions was reported, or about 13 percent.

In a like manner, Carlson et al. (*13*), using maintenance forces in New York, found that almost 90 percent of longitudinal barrier impacts are hit-and-run impacts and are never reported.

From these two studies it can be readily concluded that accident data relating to longitudinal barriers represent only about 10 to 13 percent of all barrier collisions and are probably skewed to the most severe type of accidents.

In 1986 Bryden and Fortuniewicz (*3*) reported on a detailed analysis of 3,302 reported accidents in which a roadside barrier was the first harmful event. Their tabular data have been modified by the authors of this paper to incorporate the estimated 90 percent unreported accidents in Table 2. It is assumed that the unreported accidents did not involve any injury or fatal events. Also, the data reflect both acceptable and unacceptable barrier performances. For instance, cases involving vehicle snagging, penetration, and vaulting are included along with redirection performance. Whereas the total number of accidents involving fatalities plus injuries (44 + 312 + 853 + 741) of 1,950 represents 59 percent of the 3,302 reported accidents, it is only 5.4 percent of the 36,302 estimated total impacts. Even including all reported accidents, some with obsolete barriers, the barriers performed without occupant injuries in 95 percent of the impacts. Clearly, this is a good performance record and removes the basis for the conventional wisdom that barriers are inherently hazardous.

A further analysis of Table 2 of second events reveals that 871 (2.4 percent) of the 36,302 total impacts reported a second event such as striking a fixed object. It is noted that only six impacts (less than 0.02 percent) involved a second event with a motor vehicle.

First and Most Harmful Event

Highway accidents may involve a single event or a sequence of events. For instance, two vehicles may collide and then one rebounds into a second vehicle and then into a roadside feature such as a luminaire support or guardrail. The most significant property damage or occupant injury may occur as a result of any one of the events or may be due to the cumulative effects of all of the events. Because it may require extensive accident reconstruction to sort out

TABLE 2 Injury Severity Related to Vehicle Damage, Barrier Function, and Secondary Collisions (*3*)

		Injury Severity											
		Fatal		A Injury		B Injury		C Injury		No Injury		TOTAL	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Reported Accidents	Barrier Function												
	Redirect	19	.85	190	8.47	576	25.68	533	23.76	925	41.24	2243	100
	Stop	1	.31	38	11.80	95	29.50	59	18.32	129	40.06	322	100
	Snag	1	5.88	2	11.76	5	29.41	3	17.65	6	35.29	17	100
	Penetrated	5	4.63	20	18.52	48	44.44	22	20.37	13	12.04	108	100
	Ran Under	0	0	3	37.50	1	12.50	4	50.00	0	0	8	100
	Broke Thru	5	5.81	11	12.79	34	39.53	19	22.09	17	19.77	86	100
	Went Over	12	5.71	43	20.48	63	30.00	70	33.33	22	10.48	210	100
	Deflect to Fx Obj	0	0	1	7.69	10	76.92	2	15.38	0	0	13	100
	Unknown	1	.34	4	1.36	21	7.12	29	9.83	240	81.36	295	100
	Total	44	1.33	312	9.45	853	25.83	741	22.44	1352	40.94	3302	100
Non Reported Impacts (Est)		-		-		-		-		33000		33000	
Total Impacts		44		312		853		741		34352		36302	
Reported Accidents	Second Event												
	Motor Vehicle	0	0	0	0	1	16.67	2	33.33	3	50.00	6	100
	Pedestrian	0	0	0	0	0	0	0	0	2	100.00	2	100
	Other Not Fixed Obj	0	0	0	0	0	0	1	50.00	1	50.00	2	100
	Light/Utility Pole	4	7.14	9	16.07	25	44.64	15	26.79	3	5.36	56	100
	Guardrail	1	1.00	11	11.00	36	36.00	25	25.00	27	27.00	100	100
	Sign Post	1	3.85	1	3.85	11	42.31	6	23.08	7	26.92	26	100
	Tree	7	6.48	21	19.44	41	37.96	23	21.30	16	14.81	108	100
	Building/Wall	0	0	0	0	3	75.00	1	25.00	0	0	4	100
	Curbing	1	14.29	3	42.86	0	0	3	42.86	0	0	7	100
	Fence	1	5.88	5	29.41	7	41.18	3	17.65	1	5.88	17	100
	Bridge Structure	3	7.69	5	12.82	15	38.46	10	25.64	6	15.38	39	100
	Culvert/Head Wall	1	7.69	7	53.85	3	23.08	2	15.38	0	0	13	100
	Median/Barrier	0	0	3	20.00	6	40.00	2	13.33	4	26.67	15	100
	Snow Embankment	0	0	0	0	4	50.00	0	0	4	50.00	8	100
	Earth Elem/RC/Ditch	2	1.09	27	14.75	62	33.88	68	37.16	24	13.11	183	100
	Fire Hydrant	0	0	1	50.00	0	0	1	50.00	0	0	2	100
	Other Fixed Object	0	0	3	60.00	0	0	0	0	2	40.00	5	100
	Overturned	15	5.81	55	21.32	107	41.47	69	26.74	12	4.65	258	100
	Fire/Explosion	0	0	0	0	3	50.00	0	0	3	50.00	6	100
	Submersion	2	50.00	0	0	1	25.00	0	0	1	25.00	4	100
	Ran Off Rdwy Only	0	0	0	0	2	66.67	1	33.33	0	0	3	100
	Other Non Collision	1	14.29	0	0	2	28.57	2	28.57	2	28.57	7	100
	Fixed Obj Sub Tot	21	3.60	96	16.47	213	36.54	159	27.27	94	16.12	583	100
	All Second Ev SubT	39	4.48	151	17.34	329	37.77	234	26.87	118	13.55	871	100
	No Second Event	5	0.21	161	6.62	524	21.55	507	20.86	1234	50.76	2431	100
	Total	44	1.33	312	9.45	853	25.83	741	22.44	1352	40.94	3302	100
Non Reported Impacts (Est)		-		-		-		-		33000		33000	
Total Impacts		44		312		853		741		34352		36302	

the severity of each of the events, accidents are generally coded according to the first harmful event, although in many cases it may not be the most harmful event. This procedure eliminates the need for sophisticated reconstruction and engineering judgment by investigating officers and promotes consistency in the data. On the other hand, this procedure can distort the severity risk of certain roadside features.

In a recent study, Viner (*14*) examined the relationship between first and most harmful events. Harmful events in ran-off-road fatalities are compared in Table 3. Note that overturn is the predominate most harmful event and hitting a tree is the second most predominate. Since the number of overturn most harmful events of 4,820 is double the first harmful events of 2,492, apparently vehicles interacting as a first harmful event with other roadside features subsequently overturned. In longitudinal barriers that would consist of guardrails, concrete traffic rails, bridge rails, and other traffic rails, the number of most harmful events is less than the number of first harmful events in all cases. Although one cannot be certain from these data, it is believed that a number of vehicles that are redirected in the first event subsequently roll over, producing the most harmful event. As shown in Table 2, 15 of 39 fatal second events (or 38 percent) involved an overturn, some of which may have been induced by atypical barrier conditions. In any case it appears that the first event with a longitudinal barrier is not causing the number of fatalities that were once thought to be the case. What may be most important here is that the stability of the vehicle as it departs from the collision with the traffic barrier in the first event is more significant than the injury-causing dynamics of the barrier collision.

Substandard Barriers and Excessive Impact Conditions

Most longitudinal barrier accident statistics are composites of both modern and obsolete systems, both properly and improperly con-

TABLE 3 Harmful Events in Ran-off-Road Fatalities

Harmful Event	First Harmful Event	Most Harmful Event
Tree	2,870	3,246
Overturn	2,492	4,820
Utility pole	1,235	1,298
Embankment	1,187	601
Guardrail	1,101	456
Ditch	750	302
Other	565	613
Culvert	537	281
Curb	506	117
Other fixed object	461	219
Other post	457	237
Fence	421	156
Sign post	295	99
Bridge pier	211	255
Concrete traffic barrier	211	83
Bridge rail	194	118
Luminaire support	148	146
Wall	143	127
Boulder	133	76
Bridge end	122	95
Building	101	143
Immersion	98	354
Shrubbery	66	13
Other noncollision	53	40
Other traffic rail	33	16
Fire hydrant	28	9
Impact attenuator	7	3
Overhead sign post	6	11
Unknown	4	272
Fire/explosion	0	229
Totals	14,435	14,435

structed and maintained systems, and collisions that are within and beyond the typical design performance range. To fairly appraise longitudinal barrier performance, it seems appropriate to eliminate those accident data involving defective barrier installations and those accidents in which the vehicle type, mass, impact speed, or orientation are outside typical crash test conditions.

In a New York Department of Transportation study, Bryden and Fortuniewicz (*3*) produced an analysis of traffic barrier accidents as shown in Table 4; using those data the authors have rearranged the format into Table 5. Although the data set is quite extensive, it represents conditions in only one state and may not be representative of national statistics. Nevertheless, the data set certainly illustrates the nature of substandard barriers and excessive impact conditions and may suggest the order of magnitude of these factors. In Table 4 the total number of barrier accidents of 3,302 is the same as that reported in Table 2. Of the 3,302 accidents, Bryden and Fortuniewicz (*3*) reported that 811 involved obsolete systems, which involved the highest proportion of fatal accidents (i.e., 2.22

TABLE 4 Traffic Accident Injury Severity (*3*)

Accident Category	No. of Accidents	Percent Injury Severity				
		Fatal	A	B	C	None
All	270,688	0.71		63.5		35.8
All Roadside	40,163	1.50		74.2		24.3
All Barrier	3,302	1.33	9.45	25.8	22.4	40.9
Obsolete Barrier[a]	811	2.22	13.19	30.6	23.4	30.6
Current Barriers[b]	2,071	1.16	9.37	27.0	24.6	37.9
Ideal Barrier[c]	1,313	0.53	7.31	25.1	24.7	42.4

[a] Non-standard, older systems.

[b] Current New York standard systems; includes ends, some impacts beyond typical performance range, and some barriers in need of repair/maintenance.

[c] Current New York standard systems in proper condition; impacts within typical performance range - no ends.

TABLE 5 Analysis of Barrier Performance Based on Reported Accident Data

	Total No.	PDO No.	PDO %	Fatal/Injury Number	Fatal/Injury Percentage
Current Barrier					
Ideal	1313	557	41	756	39
Atypical*	758	227	17	531	27
	2071	784	58	1287	66
Obsolete Barrier	811	248	18	563	29
Undefined (Barrier/ Impact)	420	320	24	100	5
All Reported Barrier Impacts	3302	1352	100	1950	100

*Atypical - impacts involving ends, barriers in need of repairs, and/or impacts beyond performance range (e.g. motorcycles, heavy trucks, speeds or angles clearly beyond design range).

percent). The category Current Barriers represents accidents with modern New York standard barriers including ends and installations in need of repair or maintenance and impacts that were beyond the design performance range of the installations. After excluding these anomalies, 1,313 ideal barrier impact accidents remained.

These data were reformulated in Table 5 to assess the severity of the accidents in terms of the injury plus fatality level (I + K accidents). As shown in Table 5, 29 percent of the I + K accidents are attributed to obsolete barrier installations, 27 percent of the I + K accidents are attributed to atypical impacts, and 39 percent of I + K accidents are attributed to ideal barrier impacts. From these findings it is evident that a significant part of the 6 percent barrier accidents that result in an injury or fatality may be attributed to obsolete installations and excessive impact conditions.

Length-of-Need and Terminal Sections

Generally, police-level accident data do not indicate whether the impacts occurred along a typical barrier section (i.e., length-of-need) or at the upstream end. Recognizing that modern crashworthy barrier terminals have not been universally implemented, one might surmise that barrier ends could be overrepresented in barrier accident data.

Griffin (*15*), using guardrail accident data reported in Texas in 1989, found that 20.1 percent of cases involved a guardrail end and that 79.9 percent involved something other than a guardrail end, as shown in Table 6. Although he lacked the necessary exposure data, he surmised that a greater percentage of impacts with guardrail termini are reported because of the severe nature of the collision, such as a high percentage of vehicle rollovers. Also noted in Table 6 is that the turndown guardrail terminal is involved in more than 41 percent of fatal accidents involving guardrails, in contrast to only 20.1 percent of nonfatal accidents.

It is recognized that the Texas data may not be representative of national data, in which one-fifth of barrier impacts involve a terminal. However, it is the authors' opinion that a significant number of barrier I + K accidents involve terminals, a hypothesis that has proved to be more technically challenging than accidents involving the typical barrier section.

TABLE 6 Estimated Numbers of Guardrail Accidents on Texas State-Maintained Highway System by Point of Impact (1989)

	Reported Accidents					
	Accidents on Turned Down Ends		Accidents Not on Turned Down Ends		Total	
	No.	%	No.	%	No.	%
Guardrail Accidents:						
Non-Fatal Accidents	700	95.1	2784	98.2	3484	97.6
Fatal Accidents	36	4.9	51	1.8	87	2.4
	736	100.0	2835	100.0	3571	100.0
	Nonfatal Accidents		Fatal Accidents		Total Accidents	
	No.	%	No.	%	No.	%
Guardrail Accidents:						
On Turndown Ends	700	20.1	36	41.4	736	20.6
Not on Turndown Ends	2784	79.9	51	58.6	2835	79.4
	3484	100.0	87	100.0	3571	100.0

DISCUSSION OF RESULTS

Unreported Accidents

Historically, unreported accidents have been considered nonevents, particularly to barrier developers. To improve a device the developer examined the failures or reported accidents to understand the mechanisms of the failures and then investigated how the device could be modified to eliminate or at least reduce the number of failures. It was thought that little if any worthwhile information could be gleaned from the successes or unreported accidents. Using only the reported accidents on longitudinal barriers or about 10 to 13 percent of all collisions, researchers have come to false conclusions that may have adversely affected guardrail use.

First, researchers have reported that about half of guardrail accidents result in an injury or fatality and have concluded that these devices are a roadside hazard and should be used only when absolutely necessary. On the other hand, when using the full 100 percent of guardrail collisions, the percentage of impacts involving injuries or fatalities drops to about 6 percent, or a 94 percent success rate. Moreover, researchers have analyzed only reported accident data to estimate typical impact conditions and have statistically developed some surprising typical impact angles and speeds of cars. Using the reported accident data, conclusions have been reached that 45 percent of all barrier impacts involve a nontracking vehicle (*16*). Clearly, these statistics may be important in characterizing impact conditions involving reported barrier impacts, but they are not representative of the complete spectrum of guardrail collisions.

The unreported accident problem may have significance in equally severe embankment warrant curves. In the original 1966 research, Glennon and Tamburri (*9*) compared the severity of a vehicle striking a guardrail with that of permitting the vehicle access to the slope. If the percentage of unreported accidents is the same for the two situations, then the procedure is valid. On the other hand, if the drive-away incidences of guardrail impacts are different from those in which the vehicle accesses the embankment slope, then the curve is in error. It is unlikely that the rate of unreported accidents is the same for both cases.

A second problem deals with the effect of unreported accidents on benefit-to-cost models used to justify guardrail placement. Currently, the typical guardrail impact is characterized as 3.0 on a scale of 10, with typical costs of $10,295 (*1*). This is excessively high when considering that 90 percent of impacts go unreported and certainly result in less than $500 in property damage. Using data from Table 2, the average barrier impact cost is computed to be about $2,500, with a severity index of 1.6.

It is noteworthy that the severity indexes of roadside hazards are typically estimated only from reported accident data. In some cases such as accidents with fixed objects, a high percentage of vehicles are disabled and cannot leave the site, and therefore a large percentage of impacts are reported. Although it is unknown, it is suspected that the reporting rate varies with hazard type, among other factors.

Effects of First and Most Harmful Events

The reporting of roadside accidents based on the first harmful event can be misleading and can misdirect needed barrier performance improvement. As shown in Table 3, the number of fatal accidents in which the guardrail is the most harmful event is less than 50 percent of the accidents in which the guardrail is listed as the first harmful event. This is also true for other barrier types such as concrete safety shapes and bridge rails. Historically, researchers have concentrated on the vehicle-barrier dynamics, assuming that the most harmful event occurred at this point. Using Viner's analysis (*14*), it is becoming clear that many injury-producing events are occurring after the barrier impact, such as rollover of the vehicle. Whereas both *NCHRP Report 230* (*10*) and *NCHRP Report 350* (*11*) have performance objectives of maintaining the vehicle in an upright attitude, the postimpact trajectory criterion of test vehicles has been a secondary assessment factor to date. To further improve the 94 percent performance rate of guardrails, it would seem that more attention is needed in improving the stability and trajectories of vehicles after collision with longitudinal barriers along with ensuring consistent and proper layout procedures.

Length of Need and Terminals

Engineers should be aware that a significant number of reported longitudinal barrier accidents involve upstream terminals and are overrepresented when compared with hazard length exposure and injury severity.

This is a fortunate finding in one respect: safety upgrading funds can be more specifically targeted to substandard barrier terminals with a relatively high benefit-to-cost ratio.

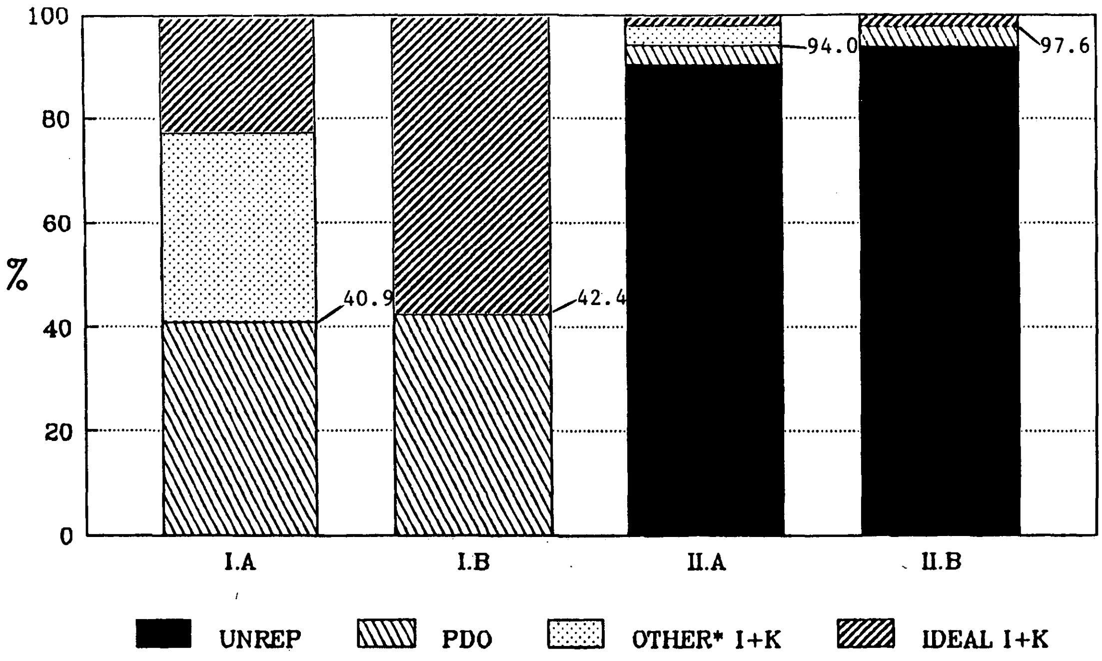
Condition and Design of Barriers

Bryden and Fortuniewicz (*3*) explored the magnitudes of (*a*) obsolete installations, (*b*) improperly laid out or constructed installations, and (*c*) improperly maintained installations as well as collision conditions beyond the device's design capabilities on the outcomes of barrier accidents. As shown in Table 5, roughly one-half (i.e., 56 percent) of 1,950 I + K accidents involved ideal barrier impacts. Hence, only 2.3 percent of all length-of-need barrier impacts in which the barrier is at standard conditions and the collision conditions are within the expected performance envelope results in an accident of I + K severity. Conversely, between 97 and 98 percent of all of these impacts involve at most PDO.

The significance of the unreported accident data is evident in Figure 1. Bar graph I.A indicates that barriers are performing without any injury or fatalities in about 41 percent of reported accidents. When other I + K accidents are screened out, the success ratio increases slightly to 42 percent. Although this difference in PDO accidents is not large, a review of injury severities and fatal accident rates does indicate improved success rates. More important, the success ratios increase to 94 percent for the all-barrier impacts, including estimated unreported accidents, and to 97.6 percent for ideal barrier impacts, including estimated unreported accidents.

CONCLUSIONS AND RECOMMENDATIONS

Longitudinal barriers have been improperly given poor performance ratings based only on reported accident data. Using estimates of unreported accidents, the success rate of longitudinal barriers is at least 94 percent, considering all types of barriers in all kinds of conditions during impacts that are within and outside the normal



I Reported Accidents Only
- A. All barrier impacts
- B. Ideal barrier impacts

II Reported Plus Estimated Unreported Accidents
- A. All barrier impacts
- B. Ideal barrier impacts

* Other - includes obsolete barriers, barrier ends, impacts outside barrier performance range, and current barriers not properly maintained

FIGURE 1 Barrier accident data analysis.

performance range. When I + K accidents involving obsolete, improperly constructed, or improperly maintained barriers and atypical impact conditions are eliminated, the success rate is at least 97 percent.

Traditional language in AASHTO barrier guides indicating "that longitudinal barriers are hazardous and should be used only if absolutely necessary" should be softened to reflect a more realistic appraisal of their performance.

Severity indexes for barrier impacts used in benefit-to-cost models may be excessively severe, resulting in understating the benefit of installing a guardrail. These severity indexes should be carefully approached in light of the estimated number of unreported accidents. Severity indexes for barrier ends should distinguish whether the end is one of the newer crashworthy ends meeting the criteria outlined in *NCHRP Report 230* (*10*) or one of the older designs that does not meet these criteria.

Embankment warrant curves may be incorrect if the reporting rate of guardrail impacts is different from that of vehicles going down embankments. These warrant curves should be evaluated using estimates of unreported accidents.

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