Analysis of Bridge Railing Accidents

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As part of a study to evaluate and validate the performance-level selection criteria contained in the 1989 AASHTO *Guide Specifications for Bridge Railings*, it was found that the Benefit Cost Analysis Program (BCAP), which was used to develop the performance-level selection criteria, was dominated by the frequency and severity of accidents involving trucks penetrating or rolling over the bridge railings. Contrary to results of previous accident studies, BCAP predicted a very high incidence of penetration or rolling over the bridge railings. In an effort to better estimate the extent of bridge railing accidents in which impacting vehicles penetrated or went over the bridge railings, Texas accident data for the years 1988 through 1990 were analyzed. Also, the dates of construction or latest reconstruction were determined for a sample of the bridge accidents so that the performances of bridge railings designed to the current specifications and older bridge railings might be differentiated. Finally, hard copies of accident reports for those bridge railing accidents involving trucks penetrating or going over the bridge railings were manually reviewed. Results of the analysis indicate that passenger cars and light trucks accounted for more than three-quarters of the accidents in which vehicles went through or over the bridge railings. Also, the incidence of going through or over the bridge railing happened mostly on rural highways. For bridge railings constructed to current specifications, the proportion of accidents involving single-unit and combination trucks going through or over bridge railings was found to be 4.4 percent, which is in line with that found in previous studies. There is a significant difference in performance between bridge railings constructed after 1965 that met current design specifications and those constructed before 1965. A review of hard copies of the accident reports of the accidents involving heavy trucks going through or over bridge railings indicated that the magnitude of the problem with trucks going through or over bridge railings is much smaller than that indicated by the accident data. Only 6 of the 53 accidents actually involved heavy trucks going through or over bridge railings, and only 1 of the 6 accidents involved a bridge railing constructed after 1965. The remaining accidents were miscodes on object struck, vehicle type, or bridge railing performance.

In 1989 AASHTO adopted the *Guide Specifications for Bridge Railings* (hereinafter referred to as the Guide Specifications) (*1*). Two of the key new features of the Guide Specifications were the incorporation of the multiple performance-level concept and the requirement that future bridge railing designs be crash tested to confirm impact performance. Although the concept of multiple performance levels is very appealing and worthy of implementation, it is important to make sure that the procedures and selection criteria promulgated in the Guide Specifications are appropriate and valid. A study was sponsored by NCHRP and conducted by the Texas Transportation Institute to evaluate the performance-level selection criteria for bridge railings (*2*).

In the course of evaluating the multiple performance levels and the selection procedures contained in the Guide Specifications, it was found that the performance-level selection criteria were dominated by the frequency and severity of accidents involving trucks that either went through or rolled over the bridge railings. The Benefit Cost Analysis Program (BCAP) used to generate the performance-level selection criteria predicted a very high incidence of bridge railing penetration by trucks. For example, for a Performance Level 2 bridge railing, such as the widely used concrete safety-shaped bridge railing, BCAP predicted that 28.6 percent of the truck impacts would result in bridge railing penetrations but no trucks rolling over a bridge railing (*2*). Based on a previous study by the California Department of Transportation and preliminary investigations, it was anticipated that the rate at which trucks go through or over bridge railings would be on the order of 3 to 4 percent. There was clearly a large discrepancy between what BCAP predicts and observations made from real-world accident data.

The objectives of this analysis of bridge railing accidents were therefore to obtain better estimates of the extent of accidents involving penetration or rolling over bridge railings and to validate BCAP and the performance-level selection guidelines contained in the Guide Specifications. A summary of the accident analysis and the results are presented in this paper.

STUDY APPROACH

Accident data from the state of Texas for the 3 years from 1988 to 1990 were used in the analysis. Accidents involving bridge railings were identified from the accident data file by keying on the variable "object struck," which has "side of bridge" as one of the codes for object struck. The performance of the bridge railing was identified from another variable, "bridge detail," which indicates if the vehicle was retained on the bridge, went through the bridge railing, or went over the bridge railing. The following screening criteria were used to select bridge railing accidents for study:

1. Only accidents on state-maintained highways were included (i.e., no city streets or county roads). The variable bridge detail was not coded for city streets or county roads, and therefore, bridge railing accidents on these roadways had to be eliminated.
2. Only single-vehicle accidents were included. When more than one vehicle was involved in an accident, it is not possible to determine which vehicle struck the bridge railing without reviewing the hard copy of the accident report. This criterion excluded all multivehicle accidents to eliminate any question as to which vehicle struck the bridge railing.
3. Only accidents with object struck coded as side of bridge were included.
4. Only accidents with the variable bridge detail coded as vehicle retained on bridge, vehicle went through bridge rail, or vehicle went over bridge rail were included.

These screening criteria reduced the data set to include only single-vehicle accidents occurring on state-maintained highways

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with the object struck coded as side of bridge and bridge detail coded as vehicle retained on bridge, vehicle went through bridge rail, or vehicle went over bridge rail. For the years 1988 to 1990, a total of 4,552 accidents were identified as meeting the screening criteria and were included in the analysis. The breakdown of the sample accidents by year is as follows: 1,217 in 1988, 1,754 in 1989, and 1,581 in 1990. Of the 4,552 vehicles that struck bridge railings, 4,323 (95.0 percent) were retained on the bridge, 70 (1.5 percent) went through the bridge railing, and 159 (3.5 percent) went over the bridge railing, as shown in Table 1.

The design specifications for bridge railings were substantially revised in 1964. Current bridge railings are required to meet specific geometric criteria and must be capable of resisting applied static loads without exceeding allowable stresses in any of their component members. Bridge railings constructed before 1964 were not designed to specific geometric criteria or loading capacities and are less likely to contain and redirect the impacting vehicles. To differentiate the performances of bridge railings constructed to current specifications from those of the older bridge railings, the date of construction or the latest date of reconstruction for all 229 (70 + 159) bridges with vehicles going through or over the bridge railings and a 10 percent sample (432 bridges) of the bridges with vehicles retained by the bridge railings were manually determined by matching the accidents to the individual bridges by using the bridge inventory file. Of the 661 (229 + 432) bridges checked, only 541 (81.9 percent) were successfully matched to bridges in the bridge inventory file, including 171 bridges with vehicles going through or over the bridge railings and 370 bridges with vehicles retained on the bridges. The discrepancy can be attributed to errors in the coding of the object struck (i.e., bridge railing was incorrectly coded) and in the reported locations of the accidents. This accident sample was analyzed separately in an effort to determine the difference in impact performances of bridge railings constructed to current specifications and those of the older bridge railings.

Finally, hard copies of accident reports for all 53 accidents involving single-unit trucks (24 accidents) or combination trucks (29 accidents) going through or over bridge railings were acquired from the Texas Department of Public Safety. These accident reports were manually reviewed to obtain some insights into these accidents.

ANALYSIS RESULTS

Slightly less than half (2,148 of 4,552, or 47.2 percent) of the bridge railing accidents occurred on rural highways (including towns with populations of less than 5,000), as shown in Table 2. The most significant result is that most of the accidents involving vehicles going through or over bridge railings occurred on rural highways. Of the 229 accidents involving vehicles going through (70 accidents) or over (159 accidents) bridge railings, 188 (82.1 percent) occurred on rural highways and only 41 (17.9 percent) occurred on urban highways. In comparison, slightly more than half (2,404 of 4,552, or 52.8 percent) of the bridge railing accidents occurred on urban highways. The highest proportion of accidents in which vehicles (15.1 percent) went through or over bridge railings occurred on rural farm-to-market-type roadways, which are typically two-lane, two-way highways with low traffic volumes. The bridge railings on these farm-to-market highways are likely to be constructed before 1965 and are not up to current design specifications. For rural Interstate and U.S. and state highways, the proportions of vehicles going through or over bridge railings are 7.4 and 7.3 percent, respectively. In comparison, only 1.7 percent of the bridge railing accidents on urban highways resulted in vehicles going through or over the bridge railings.

Approximately half (48.1 percent) of the bridge railing accidents occurred during the hours of darkness, and the proportion remained similar regardless of the bridge railing performance, as shown in Table 3. It is interesting to note that for accidents involving vehicles going through or over bridge railings that occurred during the hours of darkness, the overwhelming majority (97 of 115 accidents, or 84.4 percent) occurred in unlighted areas. In comparison, only 60

TABLE 1 Distribution of Accidents by Bridge Railing Performance

Bridge Railing Performance	Number	%
Vehicle Retained on Bridge	4,323	95.0
Vehicle Went Through Bridge Railing	70	1.5
Vehicle Went Over Bridge Railing	159	3.5
Total	4,552	100.0

TABLE 2 Bridge Railing Performance by Highway Type

Highway Type	Vehicle Retained on Bridge No.	%	Vehicle Went Through or Over Bridge Railing No.	%	Total No.	%
RURAL						
Rural Interstate	587	92.6	47	7.4	634	100.0
Rural US & State	1,036	92.7	81	7.3	1,117	100.0
Rural Farm to Market	337	84.9	60	15.1	397	100.0
Rural Subtotal	1,960	91.3	188	8.7	2,148	100.0
URBAN						
Urban Interstate	1,303	98.1	25	1.9	1,328	100.0
Urban US & State	972	98.5	15	1.5	987	100.0
Urban Farm to Market	88	98.9	1	1.1	89	100.0
Urban Subtotal	2,363	98.3	41	1.7	2,404	100.0
Total	4,323	95.0	229	5.0	4,552	100.0

TABLE 3 Bridge Railing Performance by Light Condition

Light Condition	Vehicle Retained on Bridge No.	%	Vehicle Went Through or Over Bridge Railing No.	%	Total No.	%
Daylight	2,075	48.0	105	45.8	2,180	47.9
Dawn	124	2.9	6	2.6	130	2.9
Dark, Not Lighted	1,236	28.6	97	42.4	1,333	29.3
Dark, Lighted	836	19.3	18	7.9	854	18.8
Dusk	52	1.2	3	1.3	55	1.2
Total	4,323	100.0	229	100.0	4,552	100.0

percent (1,236 of 2,072) of those accidents in which the vehicles were contained by the bridge railings occurred in unlighted areas. This again reflects the fact that most of the accidents involving vehicles going through or over bridge railings occurred on rural highways.

Bridge railing performance by surface conditions is shown in Table 4. Slightly more than half (53.3 percent) of the bridge railing accidents occurred on dry pavements. Another 27.9 percent of the bridge railing accidents occurred under snowy conditions, which is not surprising because bridges tend to freeze more readily. The percentage of accidents involving vehicles going through or over bridge railings was lower under wet or snowy pavement surface conditions, probably the result of lower traffic speeds during adverse weather and under adverse surface conditions.

Bridge railing performance by vehicle type is shown in Table 5. Vehicle types are categorized as passenger car, pickup truck, single-unit truck, combination truck, and other. The pickup truck category includes all light trucks (i.e., pickup trucks, vans, and utility vehicles). Single-unit trucks are medium-size trucks in which the beds or cargo-carrying areas are rigidly attached to the frames of the trucks. Combination trucks are commonly referred to as tractor-trailers. The other vehicle type is mostly motorcycles. Single-unit trucks and combination trucks (i.e., tractor-trailers) accounted for 516 (11.3 percent) and 184 (4.0 percent) of the 4,552 bridge railing accidents, respectively. As may be expected, combination trucks had the highest proportion (15.8 percent) of accidents in which the vehicle went through or over the bridge railing. However, it is somewhat surprising that the proportion of vehicles going through or over the bridge railing for single-unit trucks (4.6 percent) was actually lower than that for pickup trucks (6.7 percent), although it was higher than that for passenger cars (3.6 percent). A possible explanation is that single-unit trucks are operated under totally different conditions than the other vehicle types. For example, single-unit trucks are mostly used for local transport of goods during business hours, which would reduce their exposure to single-vehicle-type accidents and would keep operating speeds relatively low, thereby reducing the potential for penetrating a bridge railing.

As already mentioned, bridge railings constructed up through 1964 were not designed to current specifications and are less likely to contain and redirect impacting vehicles. Note that even though the bridge railing specifications changed in 1964, most bridge railings completed in 1965 would have been designed under the old specifications. Therefore, bridge railings completed in 1965 were considered to have been designed under the old specifications, whereas railings completed in 1966 and later were considered to be designed to meet the modern criteria.

To differentiate the performances of bridge railings designed to current standards from those of the older bridge railings, the sample of 541 accidents in which the date of construction or the latest date of reconstruction for the bridges was determined was analyzed further. Bridge railing performance by vehicle type and the data are broken down by date of construction or latest reconstruction is shown in Table 6. It is evident that bridges constructed after 1965 had a lower incidence of vehicles going through or over bridge railings than bridges constructed in 1965 or earlier. For all vehicle types, the proportion of vehicles going through or over bridge railings dropped from 5.9 percent for bridge railings constructed in 1965 or earlier to 3.0 percent (49.1 percent reduction) for bridge railings constructed after 1965. The differences are even more pronounced for combination trucks. The proportion of combination trucks going through or over bridge railings for railings constructed in 1965 or earlier is 24.5 percent. The corresponding proportion for bridge railings constructed after 1965 dropped to 7.7 percent (68.6 percent reduction).

Shown in Table 7 is a breakdown of highway type by date of bridge construction or latest reconstruction. It is interesting to note that rural highways have a higher proportion of bridge railings con-

TABLE 4 Bridge Railing Performance by Surface Condition

	Vehicle Retained on Bridge		Vehicle Went Through or Over Bridge Railing		Total	
Surface Condition	No.	%	No.	%	No.	%
Dry	2,270	52.5	155	67.7	2,425	53.3
Wet	826	19.1	33	14.4	859	18.9
Snowy	1,227	28.4	41	17.9	1,268	27.9
Total	4,323	100.0	229	100.0	4,552	100.0

TABLE 5 Bridge Railing Performance by Vehicle Type

	Vehicle Retained on Bridge		Vehicle Went Through or Over Bridge Railing		Total	
Vehicle Type	No.	%	No.	%	No.	%
Passenger Car	2,518	96.4	94	3.6	2,612	100.0
Pickup Truck	1,136	93.3	81	6.7	1,217	100.0
Single Unit Truck	492	95.4	24	4.6	516	100.0
Combination Truck	155	84.2	29	15.8	184	100.0
Other	22	95.7	1	4.3	23	100.0
Total	4,323	95.0	229	5.0	4,552	100.0

TABLE 6 Bridge Railing Performance by Vehicle Type and Year of Construction

	Vehicle Retained on Bridge		Vehicle Went Through or Over Bridge Railing		Total	
Vehicle Type	No.	%	No.	%	No.	%
	1965 AND EARLIER					
Passenger Car	1,070	95.6	49	4.4	1,119	100.0
Pickup Truck	470	92.3	39	7.7	509	100.0
Single Unit Truck	210	94.6	12	5.4	222	100.0
Combination Truck	40	75.5	13	24.5	53	100.0
Total	1,790	94.1	113	5.9	1,903	100.0
	AFTER 1965					
Passenger Car	1,230	97.9	27	2.1	1,257	100.0
Pickup Truck	350	95.4	17	4.6	367	100.0
Single Unit Truck	210	97.7	5	2.3	215	100.0
Combination Truck	120	92.3	10	7.7	130	100.0
Total	1,910	97.0	59	3.0	1,969	100.0

For accidents in which vehicles were retained on the bridges, only a 10 percent sample was checked for year of construction or latest reconstruction.

TABLE 7 Highway Type by Year of Construction

Highway Type	Year of Construction: 1965 and Earlier No.	%	After 1965 No.	%	Total No.	%
RURAL						
Rural Interstate	240	42.9	319	57.1	559	100.0
Rural US & State	447	54.1	379	45.9	826	100.0
Rural Farm to Market	320	87.9	44	12.1	364	100.0
Rural Subtotal	1,007	57.6	742	42.4	1,749	100.0
URBAN						
Urban Interstate	460	38.6	731	61.4	1,191	100.0
Urban US & State	365	42.4	496	57.6	861	100.0
Urban Farm to Market	71	100.0	0	0.0	71	100.0
Urban Subtotal	896	42.2	1,227	57.8	2,123	100.0
Total	1,903	49.2	1,969	50.8	3,872	100.0

For accidents in which vehicles were retained on the bridges, only a 10 percent sample was checked for year of construction or latest reconstruction.

TABLE 8 Accident Severity by Vehicle Type and Bridge Railing Performance

Vehicle Type	No Injury No.	%	Minor to Moderate Injury No.	%	Severe to Fatal Injury No.	%	Total No.	%
VEHICLE RETAINED ON BRIDGE								
Passenger Car	1,390	55.2	931	37.0	197	7.8	2,518	100.0
Pickup Truck	659	58.0	375	33.0	102	9.0	1,136	100.0
Single Unit Truck	281	57.1	169	34.4	42	8.5	492	100.0
Combination Truck	90	58.1	53	34.2	12	7.7	155	100.0
Other	4	18.2	6	27.3	12	54.6	22	100.0
Total	2,424	56.1	1,534	35.5	365	8.4	4,323	100.0
VEHICLE WENT THROUGH OR OVER BRIDGE RAILING								
Passenger Car	26	27.7	37	39.3	31	33.0	94	100.0
Pickup Truck	24	29.6	35	43.2	22	27.2	81	100.0
Single Unit Truck	8	33.3	3	12.5	13	54.2	24	100.0
Combination Truck	8	27.6	9	31.0	12	41.4	29	100.0
Other	0	0.0	1	100.0	0	0.0	1	100.0
Total	66	28.8	85	37.1	78	34.1	229	100.0

structed in 1965 or earlier (57.6 percent), whereas the opposite is true for the urban highways (42.2 percent). This finding is a further explanation for the dramatic differences between the rates that vehicles go through or over bridge railings in urban and rural areas. For bridge railings on farm-to-market-type highways, only 44 of 435 (360 + 71), or 10.1 percent, were constructed after 1965. This confirms the earlier contention that bridge railings on farm-to-market-type highways are likely to be constructed before 1965 and are not up to current design specifications, thereby explaining the high percentage of vehicles going through or over bridge railings on these roads.

The severity of accidents by vehicle type by bridge railing performance is shown in Table 8. As may be expected, the severity of accidents involving vehicles going through or over bridge railings was very high. The proportion of severe to fatal (percent $A + K$) injury accidents increased from 8.4 percent for vehicles retained on bridges to 34.1 percent for vehicles that went through or over the bridge railings. The severities of the accidents in which the vehicles were contained were similar for all vehicle types except for the "other" vehicle type, which was mostly motorcycles. For vehicles that went through or over the bridge railings, the proportion of $A + K$ injury accidents was highest for single-unit trucks (54.2 percent), followed closely by combination trucks (41.4 percent), and both of these proportions were considerably higher than those for passenger cars and pickup trucks (33.0 percent and 27.2 percent, respectively).

Finally, manual review of hard copies of the 53 accident reports involving single-unit or combination trucks going through or over bridge railings revealed significant problems with the police-reported accident data. As shown in Table 9, only 17 of the 53 (32.1 percent) accidents actually involved bridge railings. The other 36 accidents were miscoded and involved approach guardrails or ends of guardrails and bridge railings. As for vehicle type, all 29 accidents involving combination trucks were coded correctly. However, for the 24 accidents involving single-unit trucks, only 6 (25 percent) were coded correctly. Of the remaining 18 accidents miscoded as involving single-unit trucks, 16 involved pickup trucks or utility vehicles and 2 involved combination trucks. Also, of the 17 accidents involving bridge railings, only 10 (58.8 percent) involved vehicles actually going through or over the bridge railings. In the other seven accidents the vehicles were actually retained on the bridges. Of the six accidents involving combination trucks going through or over bridge railings, only one involved a bridge railing constructed after 1965. These findings clearly indicate that the magnitude of the problem with trucks going through or over bridge railings is much smaller than that indicated by the accident data.

SUMMARY OF FINDINGS

A summary of the findings from this accident analysis is presented as follows.

- Passenger cars and light trucks (i.e., pickup trucks, vans, and utility vehicles) accounted for 175 of the 229 accidents (76.4 percent) in which vehicles went through or over the bridge railings.
- The accident data indicated a very low incidence of going through or over the bridge railing on urban highways. Whereas more than half (52.8 percent) of the bridge railing accidents occurred on urban highways, only 41 of 229 (17.9 percent) accidents resulting in the vehicle going through or over the bridge railing occurred on urban highways.
- The accident data from this study indicate a higher incidence of trucks (4.6 percent of single-unit trucks and 15.8 percent of combination trucks) going through or over bridge railings than was previously believed, which is on the order of 3 to 4 percent. However, when only bridge railings constructed after 1965 are considered, the proportion dropped to 2.3 percent for single-unit trucks and 7.7 percent for combination trucks, for a combined percentage of 4.4 per-

TABLE 9 Breakdown of 53 Accidents Coded as Single-Unit or Combination Trucks Going Through or Over Bridge Railings

OBJECT STRUCK

Object Struck	Number	%
Bridge Railing	17	32.1
Bridge Railing End	3	5.7
Guardrail	26	49.1
Guardrail End	5	9.4
Other	2	3.8
Total	53	100.0

VEHICLE TYPE

	Actual Vehicle Type			
Coded Vehicle Type	Combination Truck	Single Unit Truck	Pickup Truck	Total
Combination Truck	29	0	0	29
Single Unit Truck	2	6	16	24
Total	31	6	16	53

BRIDGE RAILING PERFORMANCE

	Combination Truck		Single Unit Truck		Pickup Truck		Total	
Bridge Railing Performance	No.	%	No.	%	No.	%	No.	%
Vehicle Retained on Bridge	4	40.0	1	100.0	2	33.3	7	41.2
Vehicle Went Through or Over Bridge Railing	6	60.0	0	0.0	4	66.7	10	58.8
Total	10	100.0	1	100.0	6	100.0	17	100.0

cent. These percentages are more in line with those found in previous studies.

- There is a significant difference in performance between bridge railings constructed after 1965 that met current design specifications and those constructed before 1965.
- A review of hard copies of the accident reports of the 53 accidents involving heavy trucks going through or over bridge railings indicated that the magnitude of the problem with trucks going through or over bridge railings is much smaller than that indicated by the accident data. Only 6 of the 53 accidents actually involved heavy trucks going through or over bridge railings, and only 1 of the 6 accidents involved a bridge railing constructed after 1965. The remaining accidents were miscodes on object struck, vehicle type, or bridge railing performance.

DISCUSSION OF RESULTS

Results from this accident analysis bring out a number of interesting points, which are discussed as follows.

- This analysis of bridge railing accident data confirmed previous findings that the incidence of heavy trucks going through or over bridge railings constituted at most 3 or 4 percent of reported bridge railing accidents. It should be borne in mind that this analysis was biased toward the more severe impacts, thus representing the upper-bound values. The screening criteria would favor the more severe impacts by including only single-vehicle accidents on state-maintained highways. Furthermore, there is the problem with accidents that, for whatever reason, were not reported to police agencies. Even if the ratio of reported to unreported accidents is assumed conservatively to be 1 to 1, the proportion of trucks going through or over bridge railings for bridge railings constructed after 1965 would drop to only 2.2 percent, or half of 4.4 percent.
- The results of this analysis indicated that BCAP, which was used to develop the performance-level selection guidelines contained in the 1989 AASHTO *Guide Specifications for Bridge Railings*, was in error in overpredicting the incidence of trucks penetrating bridge railings while not predicting any occurrence of trucks rolling over bridge railings. Further review of BCAP identified serious problems with its penetration and rollover algorithms. First, the structural capacities of the bridge railings used to develop the performance-level selection guidelines were severely understated, which led to the high predicted penetrations rates. Second, the rollover algorithm in BCAP was found to have grossly overpredicted the speed at which a truck would roll over a bridge railing, thus resulting in the program not predicting any occurrence of rolling over a bridge railing. Third, BCAP totally ignores the possibility that passenger cars and light trucks (i.e., pickup trucks, vans, and utility vehicles) will roll over bridge railings. Accidents involving these vehicles were found to comprise more than 75 percent of the accidents in which the impacting vehicles went through or over bridge railings. The penetration and rollover algorithms of BCAP were then modified, and the modified BCAP was used to

revise the performance-level selection guidelines under NCHRP Project 22-8 (*2*).

- The results of this analysis confirmed some of the problems associated with the use of police-level accident data (i.e., incorrect coding of accident location, object struck, accident outcome, and vehicle type). For example, only 81.9 percent of the bridge railing accidents were successfully matched to bridges, which suggests that there are errors in the coding of object struck or in the reported locations of the accidents. Results of the manual review of hard copies of accident reports are even more alarming. Only 17 of 53 (32.1 percent) reported bridge railing accidents actually involved bridge railings. Of these 17 accidents, only 10 (58.8 percent) were coded correctly in terms of the vehicle going through or over the bridge railings. Furthermore, only 6 of the 24 (25 percent) single-unit trucks were identified correctly, whereas all 29 combination trucks were correctly coded. In light of these coding problems, great care should be taken in using the accident statistics presented in this paper.

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