ATTACHMENT D

CLOSED-PROFILE CONCRETE BRIDGE RAILING VALIDATION DATA

N C H R P 22-12(3)

Recommended Guidelines for the Selection of Test Levels 2 through 5 Bridge Railings

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INTRODUCTION

Unfortunately, the literature review and survey did not uncover much in the way of in-service studies or even crash studies of bridge railings so it was necessary to look for other sources of data for bridge railing performance. There are some existing databases like the 22-08 and FHWA Narrow Bridge databases but these are now very old and, at least in the case of the 22-08 Texas data, have been determined to have serious coding problems. In any case, a great deal has changed in the types of bridge railings that are available today in comparison with the early 1990s as reflected in the NCHRP 22-08 report.[Mak94]

Like bridge railings, there are median barriers at the higher test levels (i.e., TL-4 and TL-5) and there are many more miles of median barrier than there are of bridge railing. There is little difference between the impact performance of concrete bridge rails and similarly shaped concrete median barriers. Similarly, most rigid median barriers are used with relatively narrow shoulders that are similar to the shoulders available on most bridges. In fact, the most widely used median barriers and the most widely used bridge railings incorporate a New Jersey or F shape profile. Median barrier crash databases, therefore, have been utilized in addition to bridge rails to identify the severity and outcome of crashes of common bridge rail shapes. This report details the crash data that was gathered and the analysis steps taken for use in the development of the project's objective guidelines.

PROBABILITY OF INJURY METHOD

The development of the guidelines for bride rails will include the cost/benefit analysis of bridge rails using the updated Roadside Safety Analysis Program (RSAPv3). RSAPv3 has incorporated the Probability of Injury (POI) method as a technique for estimating crash severity. The POI method is based on observed police reported crashes which are then adjusted for any unreported crashes and scaled to account for speed affects. The general process for developing a POI look-up table (LUT) for a particular hazard involves four steps as outlined below.

1. Calculate the equivalent fatal crash cost ratio (EFCCR),
2. Adjust for unreported crashes,
3. Adjust for speed affects by determining the baseline equivalent fatal crash cost ratio for a baseline impact speed of 45 mi/hr (i.e., $EFCCR_{45}$) for a bridge rail or median barrier, and
4. Develop the POI lookup table.

POI LUTs were created from the crash data collected for this project.

Equivalent Fatal Crash Cost Ratio

The first step in developing a POI LUT is to calculate the Equivalent Fatal Crash Cost Ratio (EFCCR) using police-reported crash data. Police reports generally categorize crash severity using the KABCO scale where K represents a fatal crash through O which represents a property-damage-only crash. A severity distribution by outcome (i.e., vehicle was contained or redirected, rolled over, or penetrated) for a particular type of hazard should be determined. Depending on the structure of the police reported data the crash outcome or performance may be more or less difficult to determine. There are some important considerations for collecting the data:

1. The data collection must be a census meaning all police reported crashes of a particular type must be collected. If the data collection is *ad hoc* the result will be an unrealistic distribution of severities which are probably weighted toward the more "interesting" higher severity crashes.
2. The geographical and temporal distribution of the census needs to be large enough so that cases in all five of the severity categories (i.e., K through O) are collected. Fatal crashes with roadside hardware, for example, typically represent only one or two percent of all police reported cases so it is important to collect enough cases such that there are at least a few fatal crashes available. Ideally there should be cases of each of the five severities for each outcome being analyzed. If an insufficient number of cases are collected the results will probably be biased toward less severe crashes since they are much more common. That said, however, it is believed that fatal crashes should be quite rare for crash tested roadside hardware when the outcome is smooth redirection without rollover.
3. The cases should be restricted to one of three types of outcomes:
    a. Containment/redirection/stopped-in-contact,
    b. Rollover as a result of interaction with the bridge rail/median barrier or
    c. Penetration through the bridge rail/median barrier (i.e., penetration in this context means any means of crossing the barrier line – roll over the barrier, penetrate through the barrier or vault over the barrier).
4. If possible, the data should be collected on roadways with the same posted speed limit – this information will be useful later. If not possible, the posted speed limit should at least be recorded so the data can be categorized by posted speed limit.

Separating the police reported data into the three types of outcomes listed above (i.e., contained, rollover, penetration) and further examining crashes by Posted Speed Limit (PSL), a severity distribution of the contain/redirected crashes can be obtained and the percent of penetrations and rollovers can be determined. The severity distribution for contained/redirected crashes should be adjusted to account for unreported crashes, however, the percent of penetrations and rollovers should not be adjusted.[NCHRP22-27]

After determining the adjusted severity distribution, the EFCCR for the contained/redirected crashes at each posted speed limit (PSL) can be found by calculating the average crash cost and dividing by the fatal crash cost. Now the $EFCCR_{45}$ for each PSL group can be calculated using this equation [NCHRP22-27]:

$$EFCCR = \left[\frac{EFCCR_{45}}{4{,}017}\right] PSL^2$$

The $EFCCR_{45}$ is a single, dimensionless value at an assumed base impact speed of 45 mi/hr which corresponds to a base posted speed limit of 65 mi/hr. This adjustment to a base speed removes any unintentional speed bias in the data collection. This value allows for direct comparison of hazard severity between different roadside hazards for the same impact speed base condition.

The EFCCR for the total collision including all its events is the sum of all EFCCRs during the trajectory.

Percent of Penetrations and Rollovers

The POI table has three parts based on the possible outcomes of the crash: the $EFCCR_{45}$ for cases involving redirection or containment or stopping in contact with the hazard, the percent of vehicles that cross the hazard line by penetrating the barrier, rolling over the barrier or vaulting over the barrier and the percent of cases resulting in a rollover after redirection or separation from the bridge rail/median barrier. Therefore, individual hazard POI LUTs do not contain an $EFCCR_{45}$ for penetrations or roll overs. There are separate POI LUTs for these outcomes. Rollovers, for example, have a separate POI table regardless of the cause of the rollover (i.e., terrain or barrier) and if a vehicle enters another roadway or falls into a body of water there are separate $EFCCR_{45}$ for those events.

The severity of a crash after a penetration has occurred is determined by the next event (i.e., vehicle crosses median, lands in water, lands on interstate, etc.) RSAPv3 has a default POI LUT for "cross-median" events, however, that POI LUT is not appropriate for bridge rail penetrations. POI LUTs for bridge rail penetrations for different environmental factors (i.e., bridge over embankment, over river, over highway etc.) are being generated.

CRASH DATA

The collected crash data was used to (1) develop POI LUTs for several concrete bridge rail/median barrier shapes and (2) develop POI LUTs for penetration of any bridge rails over hazards (i.e., roads, water, etc.). The data was therefore divided into two sub-sets. Crashes with concrete median barriers were reviewed to determine the severity distribution of these crashes and develop the POI LUTs for striking the bridge rails. Concrete median barrier was chosen because there is a good deal more median barrier installed than bridge rail, which increases the exposure rate and allows for a larger data sample. Concrete median barriers and concrete bridge rails are essentially the same shape; therefore, these roadside devices are expected to perform similarly.

Bridge rail crashes were analyzed next to determine the severity distribution after penetrating bridge rails. All types of bridge rails were considered in this analysis because the analysis was focused on the result of penetration, not the probability of penetration. The type of bridge rail would not impact the outcome after penetration. The following sections briefly describe the data used in these analyses. The results of the analyses are shown at the end of this report.

Concrete Median Barrier Crash Review

New Jersey Turnpike Median Barriers

Crash records for the New Jersey Turnpike were requested for 2003 through 2009 from Rutgers University. Rutgers maintains a database of crashes throughout New Jersey which are linked to road geometrics.[Plan4Safety11] The ADT and percent of trucks for the New Jersey Turnpike were requested from the Turnpike directly. There is a 105 mile long section of the New Jersey Turnpike where Safety Shape [NJTA1] TL-5 concrete median barrier is used exclusively and continuously where the speed limit is either 55 or 65 mi/hr. A total of 1,816 crashes within the 65 mi/hr zone and 241 crashes within the 55 mi/hr zone were reviewed. The severity distributions were calculated and adjusted for the unreported crashes by 77 percent [Fitzpatrick99] and the $EFCCR_{45}$s were determined. The distributions and the $EFCCR_{45}$ values are presented in Table 1. The percentage of penetrations and rollovers was also determined and are presented in Table 2. Narratives of the crashes for which the vehicles appear to have penetrated or rolled over the barrier were requested and subsequently reviewed to verify that a PRV had occurred.

Table 1. New Jersey Turnpike Crash Severity Distribution and EFCCRs

Barrier	**K**	**A**	**B**	**C**	**PDO/UNK**	**Unreported**	**Total**
Crash Cost	$2,600,000	$180,000	$36,000	$19,000	$2,000	$1,000	
Contained, Stopped or Redirected on 55 mi/hr Segments							
No.	0	1	12	35	193	807	1048
%	0.00	0.10	1.15	3.34	18.42	77.00	100
Crash Cost	$0	$172	$412	$635	$368	$770	$2,357
						EFCCR	0.0009
						$EFCCR_{45}$	0.0012
Contained, Stopped or Redirected on 65 mi/hr Segments							
No.	0	11	103	307	1395	6080	7896
%	0.00	0.14	1.30	3.89	17.67	77.00	100
Crash Cost	$0	$251	$470	$739	$353	$770	$2,582
						EFCCR	0.0010
						$EFCCR_{45}$	0.0009

Table 2. NJTA After Barrier Contact Behavior Percentages

Behavior	**55 mi/hr**		**65 mi/hr**	
	#	**%**	**#**	**%**
Contained/Redirected				
Reported	241	99.34	1,816	99.35
Unreported	807		6,080	
Reported PRV	2	0.19	11	0.14
Reported Rollover After Redirection	5	0.47	41	0.52

As can be seen in Table 2, two instances of barrier PRV in the 55 mi/hr zone. One of these resulted in a possible injury (i.e., C), while the other resulted in property damage only. There were 11 instances of barrier PRV in the 65 mi/hr zone. Two of these resulted in visible injuries, one in a possible injury, five in property damage only, and the injury level is unknown for three of the cases. The percentage of PRV crashes was between 0.14 in the 65 mi/hr set and 0.19 in the 55 mi/hr set.

The number of instances where the vehicle rolled over after being redirected by the barrier are also shown in Table 2 for both of the speed zones. In the 55 mi/hr zone, five instances of this occurred; two had visible injuries, two had possible injuries, and one resulted in property damage only. In the 65 mi/hr zone, 41 instances occurred; 1 fatality, 1 incapacitating injury, 19 visible injuries, 11 possible injuries, 4 resulted in property damage only, and 5 cases where the injury level was unknown. For both speed limit set, the percent of redirection rollovers was about 0.5%.

Massachusetts Median Barriers

The Massachusetts DOT crash database was also examined for 2006-2009 to identify median barrier collisions on specific sections of roadways where median barriers were recently constructed (i.e., within the past five or six years). A subsequent field review was conducted to isolate sections of roadway where 32-inch tall and 42-inch tall concrete F-shape median barriers exist absent of other types of barriers. This field review was conducted to eliminate the possibility of reviewing crash records where the reporter may have confused the type of barrier struck. After this review, 154 crashes with 32-inch barrier and 34 crashes with 42-inch barrier were identified. All of these crashes occurred on roads with posted speed limits of either 55 or 65 mi/hr. The severity distribution was determined and was adjusted for unreported crashes by 77 percent. [Fitzpatrick99] The $EFCCR_{45}$ was calculated for each barrier height within each speed zone. The results and distributions are shown in Table 3. The percentages of penetrations and rollovers were determined and confirmed using available narratives of the police reports. These percentages are presented in Table 4.

From Table 4 it can be seen that the 32 inch F-shape barrier had two reported instances where the vehicle penetrated, rolled, or vaulted over the barrier in the 55 mi/hr speed zones. Both of these crashes resulted in non-incapacitating injuries. This same barrier had six instances of PRV failure in the 65 mi/hr zone as well, two of which were non-incapacitating injuries and four resulted in property damage only. The 42 inch F-shape barrier had two instances of PRV failure in the 55 mi/hr zone (which was the only zone the 42 inch F-shape was installed), and both instances resulted in property damage only.

Also in Table 4 is the rollover after redirection information for the different barriers within the different speed zones. No rollover after redirection cases were reported for the 32 inch F-shape barrier within the 55 mi/hr speed zones, but five were reported in the 65 mi/hr zones. Of these five crashes, three resulted in non-incapacitating injuries, one in property damage only, and one crash had an unknown level of injury. Only one occurrence of a rollover after redirection was reported for the 42 inch F-shape barrier in the 55 mi/hr zones (again, this was the only speed zone where crashes were analyzed for this F-shape barrier). Unfortunately, this single rollover resulted in a fatality.

Table 3. Massachusetts Crash Severity Distribution and EFCCRs

Barrier	K	A	B	C	PDO/UNK	Unreported	Total
Crash Cost	$2,600,000	$180,000	$36,000	$19,000	$2,000	$1,000	
Contained, Stopped or Redirected on 55 mi/hr Segments, 32" F-Shape							
No.	0	0	4	4	14	74	96
%	0.00	0.00	4.17	4.17	14.58	77.08	100
Crash Cost	$0	$0	$1,500	$792	$292	$771	$3,354
						EFCCR	0.0013
						$EFCCR_{45}$	0.0017
Contained, Stopped or Redirected on 65 mi/hr Segments, 32" F-Shape							
No.	3	4	36	17	72	442	574
%	0.52	0.70	6.27	2.96	12.54	77.00	100
Crash Cost	$13,589	$1,254	$2,258	$563	$251	$770	$18,685
						EFCCR	0.0072
						$EFCCR_{45}$	0.0068
Contained, Stopped or Redirected on 55 mi/hr Segments, 42" F-Shape							
No.	0	0	6	4	24	114	148
%	0.00	0.00	4.05	2.70	16.22	77.03	100
Crash Cost	$0	$0	$1,459	$514	$324	$770	$3,068
						EFCCR	0.0012
						$EFCCR_{45}$	0.0016

Table 4. Massachusetts After Barrier Contact Behavior Percentages

Behavior	32" @ 55 mi/hr		32" @ 65 mi/hr		42" @ 55 mi/hr	
	#	%	#	%	#	%
Contained/Redirected						
Reported	22	97.96	132	98.12	34	98.01
Unreported	74		442		114	
Reported PRV	2	2.04	6	1.03	2	1.32
Reported Rollover After Redirection	0	0.00	5	0.85	1	0.66

Washington Concrete Median Barriers

The Washington State crash data was examined for I-90 and I-5 with posted speed limits of 60 mi/hr where 32-inch New Jersey safety shaped and 34-inch single-slope concrete median barriers were used. The severity distribution of 549 cases involving 32-inch safety shape barriers and 178 cases involving single-slope barriers was calculated and adjusted for unreported crashes by 77 percent.[Fitzpatrick99] The $EFCCR_{45}$ was calculated for both and can be seen in Table 5, along with the severity distributions. The percent of penetrations and rollovers were determined for both barriers and are presented in Table 6.

Table 5. Washington State Crash Severity Distribution and EFCCRs

Barrier	K	A	B	C	PDO/UNK	Unreported	Total
Crash Cost	$2,600,000	$180,000	$36,000	$19,000	$2,000	$1,000	
Contained, Stopped or Redirected on 60 mi/hr Segments, 32" Safety Shape							
No.	2	4	62	112	369	1838	2387
%	0.08	0.17	2.60	4.69	15.46	77.00	100
Crash Cost	$2,178	$302	$935	$891	$309	$770	$5,386
						EFCCR	0.0021
						$EFCCR_{45}$	0.0023
Contained, Stopped or Redirected on 60 mi/hr Segments, 34" Single Slope							
No.	0	3	20	28	127	596	774
%	0.00	0.39	2.58	3.62	16.41	77.00	100
Crash Cost	$0	$698	$930	$687	$328	$770	$3,413
						EFCCR	0.0013
						$EFCCR_{45}$	0.0015

Table 6. Washington State After Barrier Contact Behavior Percentages

Behavior	32" Safety Shape		34" Single Slope	
	#	**%**	**#**	**%**
Contained/Redirected				
Reported	549	99.29	178	99.10
Unreported	1,838		596	
Reported PRV	3	0.12	1	0.13
Reported Rollover After Redirection	14	0.58	6	0.77

Table 6 shows the numbers and percentages of reported crashes that resulted in a penetration, roll or vault over the barrier (PRV). For the 32 inch safety shape barrier, three of these crashes occurred. One of these crashes resulted in a non-incapacitating injury, while the other two resulted in property damage only. For the 34" single slope barrier, the only crash of this type resulted in property damage only.

Table 6 also shows the number of reported crashes that resulted in a rollover after being redirected by the two barrier types. The 32 inch safety shape barrier had 14 of these crashes; including one that resulted in a fatality. Of the remaining 13 crashes, six resulted in non-incapacitating injuries (level B), three resulted in possible injuries (level C), and four resulted in property damage only. The 34 inch single slope barrier had six crashes where the vehicle rolled over after being redirected by the barrier. Two of these crashes resulted in non-incapacitating injuries, one resulted in a possible injury, and three resulted in property damage only.

Kansas Median Barrier

An existing Kansas median barrier database was examined to determine its appropriateness for use in the current study. Approximately 4,200 median barrier crashes are included in the database. The vast majority of these, almost 4,000, involved 32-inch tall New Jersey shape concrete barriers (i.e., Report 350 TL-4). A quick review of the nine fatal crashes included in this database indicated that none these crashes involve a vehicle going through or over the barrier. Four of the fatal crashes occurred when a vehicle struck the safety shaped barrier and rolled over back into its original direction of travel. Two crashes involved unbelted occupants being ejected from the vehicle, two more appear to be related to extremely high angle impacts and the final fatality was a motorcyclist. A thorough analysis of this crash database could provide another source of both vehicle penetration rates and crash severity rates for 32-inch high safety shaped barriers.

[Note: The crash data for Kansas median barriers is still being reviewed by the research team. The results will be presented as soon as possible.]

Texas Crash Data

The Texas crash data has improved significantly since NCHRP 22-08 was performed and the TTI members of the research team have direct access to the Texas data. The new TX DOT Crash Records Information System (CRIS) goes back to 2003 and the most recent year available is 2009; therefore, seven years of data is available. The Texas crash data is geo-located using latitude and longitude although the geocodes for some of the earlier years in the database were derived from mile point, control section data and is thus associated with the nearest 0.1 mile marker from crash location. More recent years have true latitude/longitude data collected on-the-scene by police officers. TTI also has access to hard copy reports which can be used to spot-check and validate the data to be sure that coding errors do not corrupt the final results. TTI researchers have also done a lot of work mapping crashes and roadway data into GIS. There are layers of information in this GIS database that correspond to crashes, bridge locations, and traffic data including truck volumes on the Texas highway network. Proximity or buffer analyses can be performed whereby all crashes within a certain specified distance (e.g., 0.2 miles) of a bridge structure are selected. This may be useful for identifying and helping to narrow down the crashes of interest. The traffic data is bi-directional for divided highways. A study of TL-4 and TL-5 concrete safety shaped median barriers and bridge railings in Texas could provide crash severities and penetration rates for similar bridge railings. Texas DOT and has adopted widespread application of TL-5 median barriers. A large section of I-35 between Austin and Dallas incorporates a TL-5 concrete median barrier. As discussed before, there are also a number of TX bridge railings that have already had their yield-line capacities calculated. There are, therefore, a number of States where specific long projects with concrete safety shaped median barriers and bridge railings at the TL-4 and TL-5 level can be identified and crash data collected.

[Note: The crash data for Texas median barriers is still being reviewed by the research team. The results will be presented as soon as possible.]

Bridge Railing Crash Review

Pennsylvania Interstate Bridges

PennDOT requires “bridge railings that meet the requirements of Test Level 5 (TL-5) of NCHRP Report 350, unless another test level is authorized by the District Executive.” [PennDOT11] PennDOT generally specifies a 42 inch concrete F-shape barrier as the TL-5 railing, however other PennDOT adopted railings may also be used. A TL-4 32 inch concrete F-shape barrier is also a common barrier used and was also analyzed.

Crash records were reviewed from 2006 to 2010 for bridge rail crashes on interstates highways. Traffic volumes for the interstates and the roads which crossed under the interstates were found online.[PA11] Unfortunately, the percentage of trucks in the traffic was not available. The environmental features surrounding each bridge were reviewed using Google Earth.[Google11]

Table 8 shows the reported PRV failures for the two heights of the F-shape bridge rail in both the 55 and 65 mi/hr speed limit zones. For the 32” F-shape bridge rail in the 55 mi/hr zone, two PRVs occurred. The first of these involved a tractor-trailer, where the trailer portion rolled over and stayed on the bridge but the tractor portion broke through the barrier and dropped off the bridge. The tractor fell approximately 90 ft. and landed on its passenger side on a small island in the middle of Maiden Creek, resulting in a possible (C) injury. Witnesses say the truck was travelling at or around the speed limit at the time of the crash.

The second 32 inch bridge rail crash that occurred in the 55 mi/hr zone involved a passenger car that vaulted over the rail and fell approximately 80 ft. and came to rest on its roof in a wooded area next to a river. This crash resulted in property damage only.

The same bridge rail in the 65 mi/hr zone experienced five PRVs. The first of these involved a tractor-trailer truck where the tractor portion stayed in the traveled way of the highway, but the trailer portion broke through the bridge rail and ended up hanging over the bridge but did not fall off. This resulted in an incapacitating injury. This bridge crosses Pulaski Mercer Rd. (State Route 468), which experiences a 400 vehicle per day traffic volume.

Table 7. Pennsylvania Crash Severity Distribution and EFCCRs

Barrier	K	A	B	C	PDO/UNK	Unreported	Total
Crash Cost	$2,600,000	$180,000	$36,000	$19,000	$2,000	$1,000	
Contained, Stopped or Redirected on 55 mi/hr Segments, 32" F-Shape Bridge Rail							
No.	3	1	6	14	33	191	248
%	1.21	0.40	2.42	5.65	13.31	77.02	100
Crash Cost	$31,452	$726	$871	$1,073	$266	$770	$35,157
						EFCCR	0.0135
						$EFCCR_{45}$	0.0180
Contained, Stopped or Redirected on 65 mi/hr Segments, 32" F-Shape Bridge Rail							
No.	1	0	7	28	71	358	465
%	0.22	0.00	1.51	6.02	15.27	76.99	100
Crash Cost	$5,591	$0	$542	$1,144	$305	$770	$8,353
						EFCCR	0.0032
						$EFCCR_{45}$	0.0031
Contained, Stopped or Redirected on 55 mi/hr Segments, 42" F-Shape Bridge Rail							
No.	1	0	1	3	5	33	43
%	2.33	0.00	2.33	6.98	11.63	76.74	100
Crash Cost	$60,465	$0	$837	$1,326	$233	$767	$63,628
						EFCCR	0.0245
						$EFCCR_{45}$	0.0325
Contained, Stopped or Redirected on 65 mi/hr Segments, 42" F-Shape Bridge Rail							
No.	0	0	4	9	33	154	200
%	0.00	0.00	2.00	4.50	16.50	77.00	100
Crash Cost	0	0	720	855	330	770	$2,675
						EFCCR	0.0010
						$EFCCR_{45}$	0.0010

The second 32 inch bridge rail crash that occurred in the 65 mi/hr zone involved a passenger car riding on top of the rail for 30 ft. before falling off the bridge and dropping 60 ft. and coming to rest on its roof, resulting in an incapacitating (A) injury. According to witnesses, this vehicle was travelling somewhere between 50 and 55 mi/hr when the incident occurred, which is below the posted speed limit. It was later discovered that a vehicle defect caused the vehicle to hit the bridge rail. The vehicle landed in an unused area under the bridge; a fortunate occurrence as this bridge spans South Fork Tenmile Creek, Route 188 (a 5,000 vehicle per day state route), and a set of railroad tracks.

The third PRV incident for this barrier in the 65 mi/hr speed zone also involved an incapacitating injury. In this crash, the vehicle had rolled over onto its passenger side prior to coming in contact with the bridge rail. As the vehicle hit the bridge rail it rolled over the barrier and landed in a grassy area next to Bullfrog Rd. (unknown average daily traffic).

Table 8. Pennsylvania Bridge Rail After Barrier Contact Behavior Percentages

Behavior	**32" @ 55 mi/hr**		**32" @ 65 mi/hr**		**42" @ 55 mi/hr**		**42" @ 65 mi/hr**	
	#	%	#	%	#	%	#	%
Contained/Redirected								
Reported	57	96.88	107	98.10	10	93.48	46	99.50
Unreported	191		358		33		154	
Reported PRV	2	0.78	5	1.05	0	0.00	0	0.00
Reported Rollover After Redirection	6	2.34	4	0.84	3	6.52	1	0.50

The fourth crash involving the 32 inch F-Shape bridge rail in the 65 mi/hr zone resulted in a non-incapacitating (B) injury. The vehicle struck the bridge rail and then rolled over, landing on the centerline of the road passing below the bridge. This road, Route 374, experiences roughly 1,500 vehicles per day.

The last crash involving the 32 inch F-Shape bridge rail in the 65 mi/hr zone involved a bus filled with 42 passengers and resulted in a single non-incapacitating (B) injury. The bus struck the barrier and rode up onto the top of the barrier and balanced there before falling approximately 100 ft. into the Lehigh River below. The bus was able to be evacuated entirely while it was balancing on top of the bridge rail.

The 42” F-shape bridge rail had zero PRV failures for both the 55 mi/hr and 65 mi/hr speed zones.

In Table 8 are also the number of incidents for each bridge rail and speed zone where a vehicle rolled over after being redirected by the bridge rail. For the 32 inch rail in the 55 mi/hr speed zone 6 incidents were reported. Of these six incidents, two resulted in fatalities two resulted in non-incapacitating injuries and two resulted in possible injuries. For the same size rail in the 65 mi/hr speed zone, four incidents occurred. One of these incidents resulted in a fatality while the remaining three resulted in only possible injuries. The 42 inch bridge rail experienced four cases where the vehicle was reported as rolling over after being redirected; three in the 55 mi/hr zone and one in the 65 mi/hr zone. Of the three incidents in the 55 mi/hr zone, one resulted in a non-incapacitating injury and two resulted in possible injuries. The one reported case where a rollover occurred in the 65 mi/hr zone resulted in a non-incapacitating injury.

Nebraska Bridge Rails

The Nebraska DOR crash database was examined for 2007 through 2009 to identify bridge rail collisions on state and local highways, freeways and interstates in Nebraska. The review contained all rail types, include concrete rails and metal rails. These crashes occurred on roads with a variety of posted speed limits. The review of the Nebraska data includes 1,525 crashes on roadways with a variety of posted speed limits. This review includes 18 vehicles that penetrated the bridge rail, 42 that rolled over after redirection, seven that rolled over the barrier and eight that vaulted the barrier.

[Note: The crash data involving Nebraska bridge rails is still being reviewed by the research team. The results will be posted as soon as they are available.]

Ohio Bridges

The research team has also acquired crash data for bridges in Ohio. This data includes bridge railing crashes for five years of data (i.e., 2005 through 2010) and includes police-level data on about 430 bridge railing crashes.

Ohio installs TL-3 bridge rail on "all bridge structures on the National Highway System (NHS) or the State System…as defined by NCHRP report 350," effective October 1, 1998. The Twin Steel Tube Bridge Guardrail (Standard Bridge Drawing TST-1-99) should be used for side draining structures, which shall not be used over highways and railroads. "For bridges with heights of 25 feet or more above the lowest groundline or normal water, concrete deflector parapets should be used." [OH11; OH11a] Therefore, the barrier shown in Figure 1 is the TL-3 concrete barrier which is typically installed on NHS roadways which cross over highways.

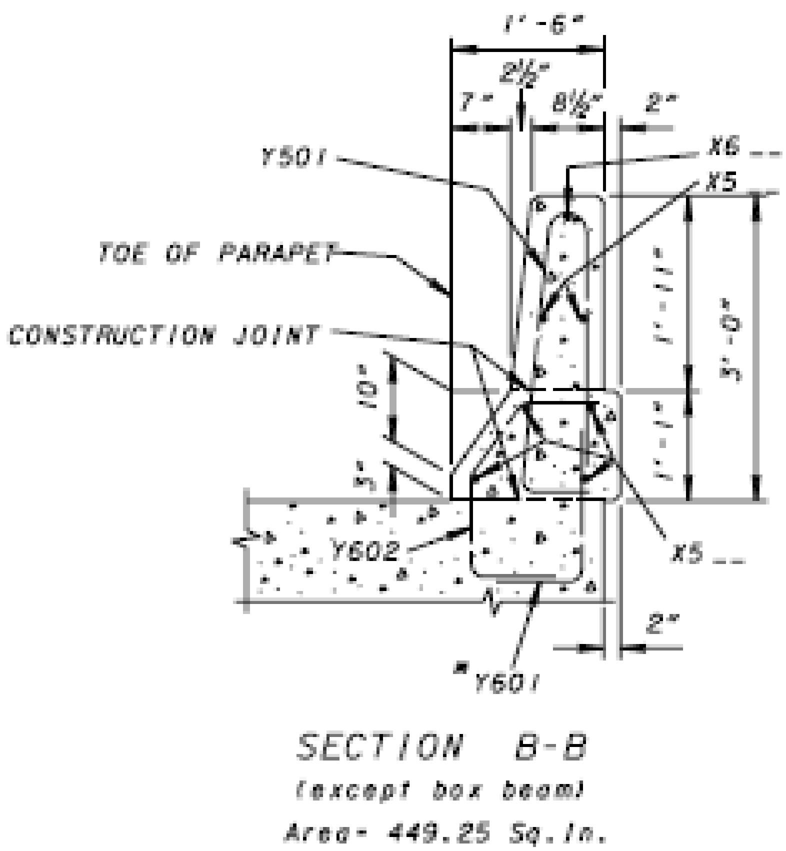

Figure 1. Ohio Standard Drawing BR-1 [OH11a]

[Note: The crash data involving Ohio bridge rails is still being reviewed by the research team. The results will be posted as soon as they are available.]

RESULTS

There are many different types and test levels of concrete barrier currently installed on the nation's highways. While much is understood about the differences in the structural performance of these barriers, little is understood about the distribution of crash severities or crash outcomes (e.g., redirected, penetration, rollover) between these different concrete barriers. Crash data has been collected from several states for different barriers with very different exposure rates (i.e., ADT and percent trucks). This variety will provide insight into the crash outcomes of these different barriers under different scenarios. The results of the POI analysis are shown in **Error! Reference source not found.**.

Median Barriers

A summary of the $EFCCR_{45}$ values from all of the median barriers analyzed is shown in Table 9. [Note: The results from Kansas and Texas are currently not in the table, but will be added when the analyses are completed.]

Table 9. $EFCCR_{45}$ Comparison for Median Barriers

State	Hazard	Number of Cases	Contained, Redirected, In-Contact $EFCCR_{45}$	Penetration Breakaway Vault %	Rollover After Redirection %
Median Barriers					
NJ	TL-5 Safety Shape (55 mi/hr zone)	241	0.0012	0.19	0.47
NJ	TL-5 Safety Shape (65 mi/hr zone)	1816	0.0009	0.14	0.52
WA	32" Safety Shape (60 mi/hr zone)	549	0.0023	0.12	0.58
WA	34" Single Slope (60 mi/hr zone)	178	0.0015	0.13	0.77
MA	32" F-Shape (55 mi/hr zone)	22	0.0017	2.04	0.00
MA	32" F-Shape (65 mi/hr zone)	132	0.0068	1.03	0.85
MA	42" F-Shape (55 mi/hr zone)	34	0.0016	1.32	0.66

The TL-5 Safety Shape barriers from New Jersey have $EFCCR_{45}$s that are relatively close to one another, but the 32 inch Safety Shape $EFCCR_{45}$ from Washington is almost twice the value. This could be due to a number of reasons, including the height of the barrier. The values range from 0.0012 to 0.0023. Both of the percent PRV failure and rollover after redirection values for the different barriers are relatively close to each other.

Washington State 34 inch Single Slope barrier was the only instance of the single slope barrier observed in this analysis, with an $EFCCR_{45}$ value of 0.0015.

The $EFCCR_{45}$ for the 32 inch F-Shape barrier in Massachusetts in the 65 mi/hr zone (0.0068) is four times that of the exact same barrier in the 55 mi/hr zone (0.0017). The $EFCCR_{45}$ for the 42 inch barrier in the 55 mi/hr zone (0.0016) is almost identical with the $EFCCR_{45}$ for the 32 inch barrier in the same speed zone (0.0017).

Bridge Railings

A summary of the EFCCR45s for bridge rails is shown in Table 10. For now, only the Pennsylvania Interstate bridges are listed. The Nebraska and Ohio bridge rail data will be listed after the analyses are completed.

Table 10. $EFCCR_{45}$ Comparison for Bridge Rails

State	Hazard	Number of Cases	Contained, Redirected, In-Contact	Penetration Breakaway Vault	Rollover After Redirection
			$EFCCR_{45}$	%	%
Bridge Railings					
PA	32" F-Shape (55 mi/hr zone)	57	0.0180	0.78	2.34
PA	32" F-Shape (65 mi/hr zone)	107	0.0031	1.05	0.84
PA	42" F-Shape (55 mi/hr zone)	10	0.0325	0.00	6.52
PA	42" F-Shape (65 mi/hr zone)	46	0.0010	0.00	0.50

Both the 32 inch and the 42 inch F-Shape barriers had higher $EFCCR_{45}$s calculated from the 55 mi/hr zones than those that were calculated from the 65 mi/hr zones. In both instances, the difference is substantial.

Rollover after Redirection

The following is a severity comparison between different types of barriers with respect to when a vehicle rolls over after being redirected by the barrier. In each of these cases the vehicle did not penetrate or roll over the barrier, only cases where the vehicle stayed on the same side of the barrier were analyzed. Barriers used in the median of a divided highway and barriers used as bridge rails were combined for this analysis. The three types currently being examined are the New Jersey Safety Shape barrier, the Single Slope barrier, and the F-Shape barrier.

Table 11. Comparison of Rollover after Redirection EFCCRs by Barrier Type

State	Hazard	Posted Speed Limit (mi/hr)	# of Cases	K	A	B	C	O	Unk	EFCCR	$EFCCR_{45}$
Median Barriers and Bridge Railings				**$2,600,000**	**$180,000**	**$36,000**	**$19,000**	**$2,000**	**$2,000**		
NJ	TL-5 Safety Shape	55	5			2	2	1		0.0086	0.0114
NJ	TL-5 Safety Shape	65	41	1	1	19	11	4	5	0.0346	0.0329
WA	32" Safety Shape	60	14	1		6	3	4		0.0791	0.0883
Total Safety Shape			60	2	1	27	16	9	5	0.0428	
WA	34" Single Slope	60	6			2	1	3		0.0062	0.0069
MA	32" F-Shape	65	5			3		1	1	0.0086	0.0082
MA	42" F-Shape	55	1	1						1.0000	1.3279
PA	32" F-Shape	55	6	2		2	2			0.3404	0.4520
PA	32" F-Shape	65	4	1			3			0.2555	0.2429
PA	42" F-Shape	55	3			1	2			0.0095	0.0126
PA	42" F-Shape	65	1			1				0.0138	0.0132
Total F-Shape			20	4	0	7	7	1	1	0.2075	

With a combined total of 60 cases, the Safety Shape barrier has an EFCCR of 0.0428, which is a value in between those of the Single Slope barrier and the F-Shape barrier. The 34” Single Slope barrier had the lowest EFCCR at 0.0062, while the F-Shape barrier had the highest EFCCR at 0.2075. One of the reasons the EFCCR value is so high for the F-Shape barrier is that the three barriers within this group that had fatalities did not have many lower severity crashes to counterbalance the value. For instance, the Massachusetts 42” F-Shape severity distribution consists of a single fatality only and no other crashes. As a result, the EFCCR for this one barrier is 1.0000. Only 20 cases in total were able to be used for the EFCCR calculation and it is quite possible that both the Single Slope and the F-Shape barrier could have EFCCR values that are closer to the EFCCR value calculated for the Safety Shape barrier if more crash data were available.

After Penetration Hazards

The Highway Safety Information System (HSIS) is a multistate database that contains crash, roadway inventory, and traffic volume data for a select group of states. [HSIS01] The research team reviewed crash data from embankments and water hazards from this database for Washington State. The data was organized by posted speed limits, ranging from 25 mi/hr to 70 mi/hr in five mi/hr increments. Certain speed zones from within these data subsets were chosen for analysis. Only those speed zones that contained full severity distributions were used. The purpose of this method is to ensure that every level of severity has been represented for calculation of the EFCCR for each hazard. Currently, information is available for embankments in 55 and 70 mi/hr speed zones and water hazards in 55 mi/hr speed zones. Table 12 shows the results of the analyses for after penetration hazards.

Table 12. Severity Distributions and EFCCRs for After Penetration Hazards

Hazard	K	A	B	C	PDO/UNK	Total
Crash Cost	$2,600,000	$180,000	$36,000	$19,000	$2,000	
Embankment in 55 mi/hr Speed Zones						
No.	7	10	42	33	93	185
%	3.78	5.41	22.70	17.84	50.27	100.00
Crash Cost	$98,378	$9,730	$8,173	$3,389	$1,005	$120,676
					EFCCR	0.0464
					$EFCCR_{45}$	0.0616
Embankment in 70 mi/hr Speed Zones						
No.	3	3	16	5	25	52
%	5.77	5.77	30.77	9.62	48.08	100
Crash Cost	$150,000	$10,385	$11,077	$1,827	$962	$174,250
					EFCCR	0.0670
					$EFCCR_{45}$	0.0549
Water in 55 mi/hr Speed Zones						
No.	1	2	6	4	37	50
%	2.00	4.00	12.00	8.00	74.00	100
Crash Cost	$52,000	$7,200	$4,320	$1,520	$1,480	$66,520
					EFCCR	0.0256
					$EFCCR_{45}$	0.0340

CONCLUSIONS

The Probability of Injury approach adopted in RSAPv3 for predicting the severity of the crashes was applied to the crash data reviewed. This approach capitalized on police-level crash data to accurately represent the severity distribution of actual crash events. The POI table developed will be used in conjunction with RSAPv3 to generate bridge rail guidelines.

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