ATTACHMENT E

CLOSED-PROFILE CONCRETE BRIDGE RAILING COSTS

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

Malcolm H. Ray, P.E., Ph.D.
Christine E. Carrigan, Ph.D.
T. Olaf Johnson
RoadSafe LLC
12 Main Street
Canton, Maine 04221

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

This project is focused on developing warranting guidelines for the selection of the appropriate test level bridge railing based on site conditions. In order to narrow the focus of the project somewhat, the objective of the current phase of the project is limited to closed-profile concrete barriers without top rail attachments. Bridge railings like the NJ safety shape, F shape, vertical wall and constant slope barrier are the most common members of this family of bridge railings. The barrier capacity, cost and crash experience are all based on (essentially) the same family of barrier in this phase of the project.

The barrier installation and repair cost data has been determined by a detailed examination of State bid price data for the states where crash data was collected and supplemented with additional cost data from other states when necessary. Personnel in the States where crash data was collected have been contacted to get more precise installation costs. These costs were then "normalized" to national average costs using a WSDOT study of construction bid costs discussed below. This report summarizes the findings of the installation and repair costs associated with concrete bridge railings addressed in this research.

COSTS

Conducting a B/C analysis requires a reasonable understanding of all the project costs. Some easily recognized project costs are the design, construction and maintenance costs of a bridge railing alternative, however, there may also be less obvious costs like environmental mitigation and right-of-way (ROW) costs associated with each alternative. Impacts to the environment, available ROW and their associated costs are routinely evaluated when considering improvement alternatives as these costs can be considerable for projects with alignment or cross-section changes. Construction costs, however, are generally the largest project related cost considered by the programming agencies and are used as the benchmark for other costs during the planning stage of a project. Many of the non-construction costs like traffic control, right-of-way, etc will "wash out" of the cost comparisons since they would appear in both alternatives. For example, the same traffic control would likely be required regardless of the test level of the barrier being constructed.

Construction Costs

The FHWA has continually compiled records of variations in contract bid prices from Federal-aid highway construction projects since 1922. This information was shared with interested parties through the Bid-Price Index. [NHCCI11] A recent report prepared and submitted in 2003 by the United States General Accounting Office (GAO) to the United State Senate Committee on Government Affairs Subcommittee on Financial Management compared the states in terms of highway construction costs using data collected by the Federal Highway Administration (FHWA). This review found "significant issues regarding the quality of the data that FHWA collects and reports." [USBUDG03] The review determined the comparison could not be made with the data FHWA collects and reports (i.e., Bid-Price index). Following this criticism of the Bid-Price Index, FHWA initiated a study in 2003 to replace the Bid-Price index and ultimately abandoned it in 2007 in favor of the National Highway Construction Cost Index (NHCCI). The NHCCI "is intended as a price index that can be used both to track pure price-changes associated with highway construction costs and to convert current-dollar expenditures on highway construction to real- or constant-dollar expenditures."[NHCCI11] The NHCCI has a base of one, relative to the first quarter of the first year of data collection (i.e., March 2003). When the index is higher than one, costs have increased by that multiple. When the index is less than one, costs have decreased by that multiple. Figure 1 shows the NHCCI index for 2003 through 2010. Costs in the last quarter of 2009, for example, are approximately the same as the costs in the second quarter of 2003, whereas costs in the third quarter of 2006 were about 1.4 times higher than in the first quarter of 2003.

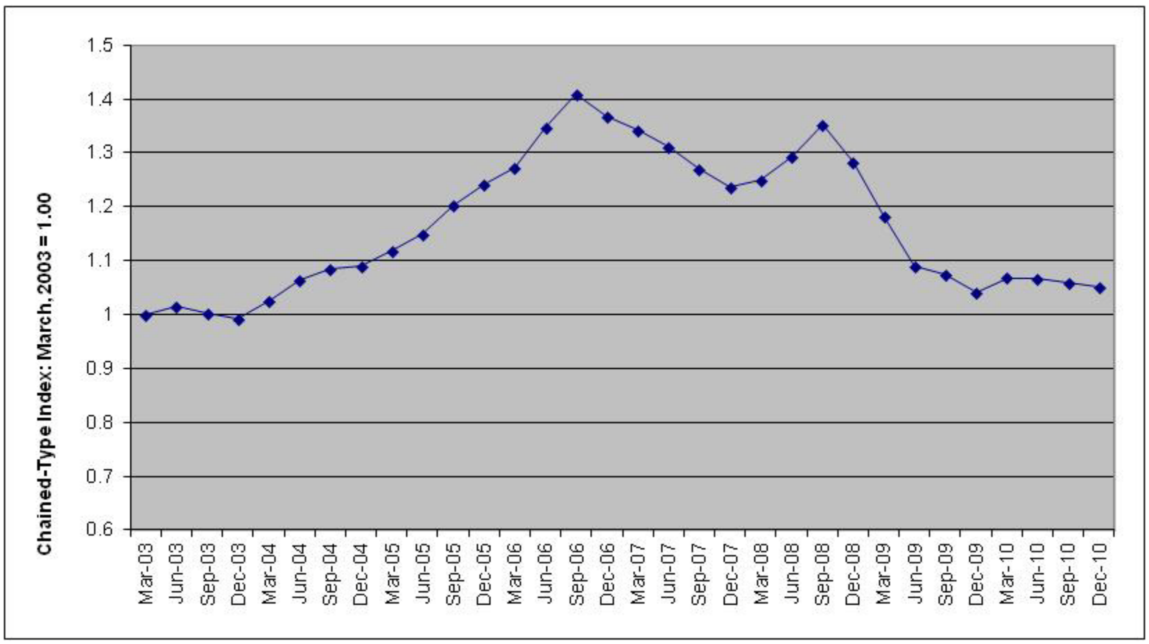

Figure 1. Quarterly Prices.

For many looking to use this information to compare costs between different years, the above graph is perhaps too precise. Oftentimes, weighted average construction costs are only available as an average for the entire fiscal year instead of for the individual quarters within that year. In this case, the individual quarters from Figure 1 are averaged together, giving a single NHCCI index for the year of interest. The calculated yearly index values can be seen Table 1, and are presented graphically in Figure 2. While the process of using a simple arithmetical mean between quarters to find the yearly index value is not explicitly mentioned on the NHCCI website, however, the values are listed on the second worksheet of the Excel spreadsheet that is downloadable at the aforementioned web address. [NHCCI11]

Table 1. Yearly NHCCI Indices.

Year	Index
2003	1.003
2004	1.066
2005	1.179
2006	1.349
2007	1.290
2008	1.295
2009	1.097
2010	1.062

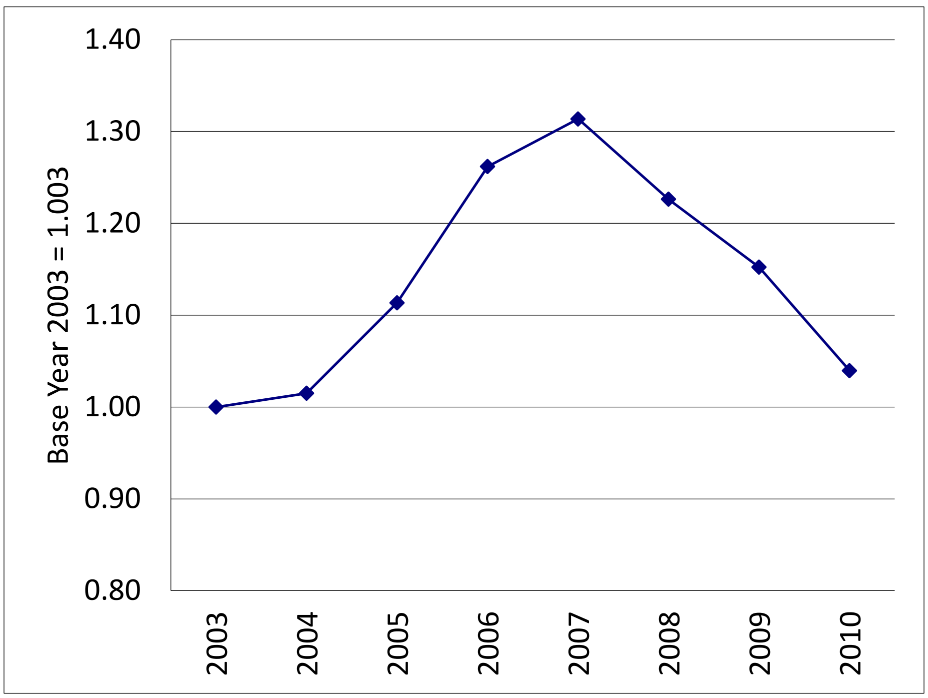

Figure 2. Graphical Trend of Yearly NHCCI Indices.

Using these indices, an analyst can convert the construction costs given for a certain year to a decided base year for comparison purposes. For example, if a particular barrier had a weighted average bid price of 132.86 USD in the year 2010, the cost in 2003 dollars would be: ———— , or 125.48 USD. Obviously, this simple equation can also be used to convert values from earlier years into values of more recent years. For comparison purposes in this report, all bridge rail costs were converted to 2003 dollars using this method. In some instances, the weighted average bid prices obtained spanned more than one year. In these cases, the inclusive years were averaged together to obtain a new index for the group of years needed. With the decrease of accuracy inherent in using multiple averages, this process was avoided whenever possible.

Some states list their weighted average bid prices as a running 12-month average, meaning they are continuously updated. In these instances the NHCCI index for 2010 was used, as it was the best estimate available of the currently unpublished 2011 index.

Once the NHCCI index has been used to convert all years to the 2003 baseline, construction costs in various geographical regions needed to be normalized to a national average cost. The Washington Department of Transportation (WSDOT) preformed a survey of highway agencies within the United States in 2002 to better understand all project related costs and to gauge how WSDOT costs relate to other states. Figure 3 is a summary of the study's findings for construction costs per lane mile of construction.

WSDOT found the average highway construction cost throughout the United States is roughly $2.3 million per lane mile of highway. This figure excludes "right of way, pre-construction environmental compliance, and construction environmental compliance and mitigation." [WSDOT09] These exclusions are quite variable by project and region, let alone state. A range of right-of-way (ROW) costs and costs related to environmental mitigation are summarized in Table 2 as a percentage of construction costs. As shown in Figure 3, the cost per lane mile of construction can vary by as much as a factor of about 8.5; meaning New York State's costs are almost 8.5 times higher than Mississippi. Regional variations in construction costs, therefore, are quite large.

Simple multipliers for each state can be calculated from Figure 3 to account for this regional variation. It is important to note that only 25 states are represented in the WSDOT study. Fortunately, these 25 states are fairly well distributed throughout the continental U.S. This allows the use of regional estimation for those states that are not directly represented. For instance, the state of Indiana is absent from the WSDOT study but it is bordered by three states that are; Illinois, Michigan and Ohio. An average is taken of these bordering states to estimate what the construction cost per lane mile is for the state in question. Quality judgment is a requisite when using this method as there are a few notable exceptions. One of these exceptions is New York. It is quite likely that New York City, the most populous city in the country, is responsible for the high lane-mile construction costs reported for New York State. It is highly unlikely that it costs as much to construct a lane-mile of highway in the more rural areas of the state.

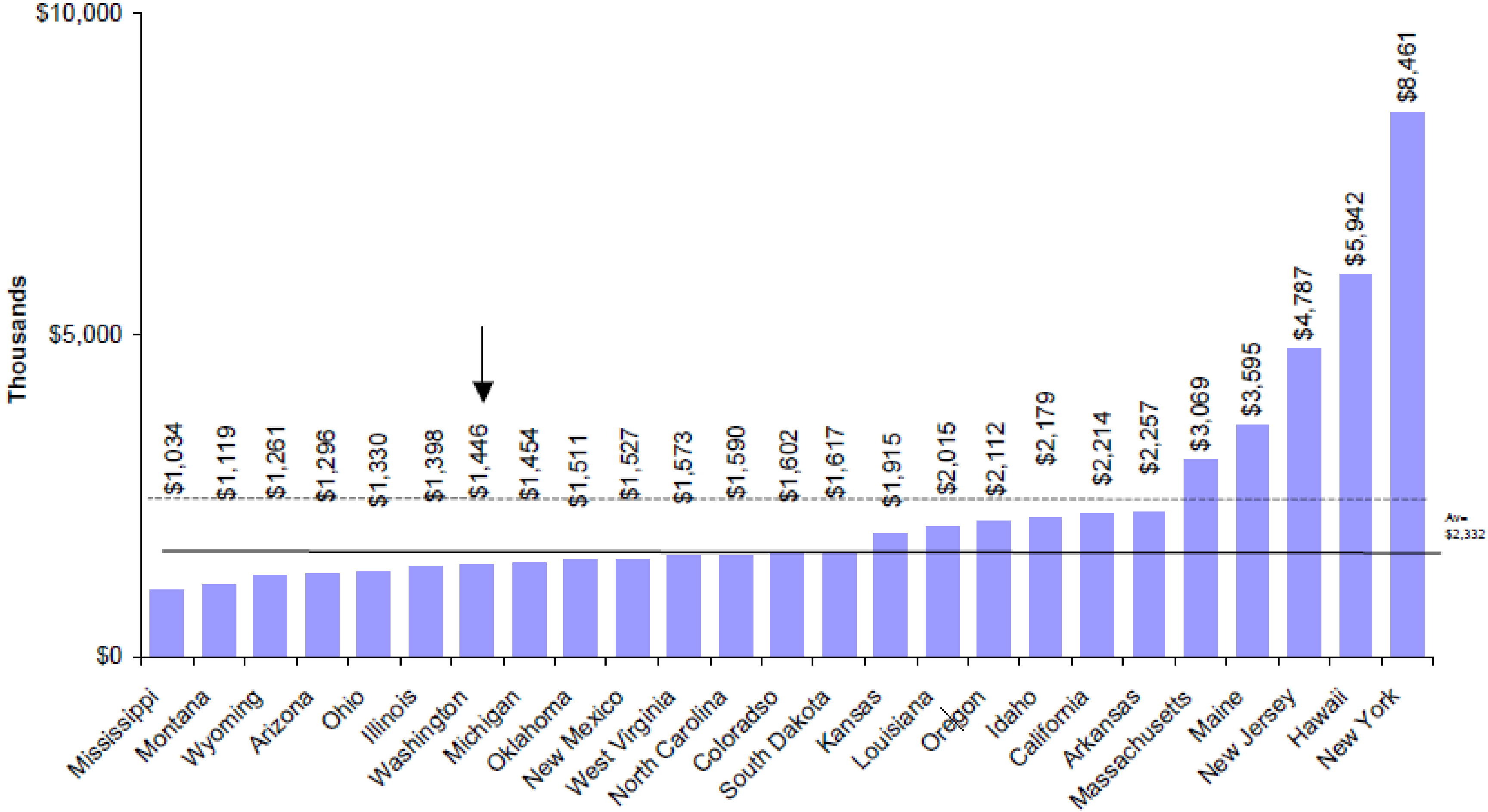

Figure 3. Lane Mile Cost Comparison by State. [WSDOT09]

Table 2. Summary of Project Related Costs. **[**WSDOT09**]**

State Name	Construction Cost	Right Of Way Variability	Environmental Documentation Variability	Environmental Mitigation Variability	State Prevailing Wage Law	PE %	CE %	Mob. %
Mississippi	$1,033,576	11 - 20%	0 - 10%	0 - 10%	No	No Data	5%	5%
Montana	$1,118,827	0 - 10%	0 - 10%	0 - 10%	Yes	<10%	10%	8%
Wyoming	$1,261,046	11 - 20%	0 - 10%	0 - 10%	Yes	10%	12%	8%
Arizona	$1,295,908	>30%	11 - 20%	11 - 20%	No	8%	15%	10%
Ohio	$1,330,176	11 - 20%	0 - 10%	0 - 10%	Yes	10%	8%	3%
Washington	$1,445,662	0 - 10%	0 - 10%	11 - 20%	Yes	15%	15%	10%
Illinois	$1,398,314	0 - 10%	0 - 10%	0 - 10%	Yes	10%	12%	3%
Michigan	$1,454,462	>30%	11 - 20%	11 - 20%	Yes	8%	0 - 15%	5%
New Mexico	$1,526,631	> 30%	0 - 10%	0 - 10%	Yes	8 - 10%	15 - 20%	10%
Oklahoma	$1,510,910	11 - 20%	0 - 10%	0 - 10%	No	5%	9%	3%
South Dakota	$1,616,581	0 - 10%	0 - 10%	0 - 10%	Yes	4%	10%	10%
North Carolina	$1,590,182	> 30%	0 - 10%	0 - 10%	Yes	10%	10%	5%
West Virginia	$1,572,946	11 - 20%	0 - 10%	0 - 10%	Yes	15%	18%	1%
Kansas	$1,914,917	11 - 20%	0 - 10%	0 - 10%	No	7%	10%	6%
Louisiana	$2,015,042	ROW costly item in urban areas	0 - 10%	0 - 10%	No	15%	4%	5%
Oregon	$2,112,486	11 - 20%	0 - 10%	0 - 10%	Yes	12%	No Data	10%
Idaho	$2,178,689	> 30%	0 - 10%	0 - 10%	No	10%	10%	10%
California	$2,213,519	0 - 10%	0 - 10%	0 - 10%	Yes	20%	15%	10%
Arkansas	$2,257,449	11 - 20%	0 - 10%	0 - 10%	Yes	10%	10%	10%
Massachusetts	$3,069,336	Varies Widely	0 - 10%	0 - 10%	Yes	10%	10%	0%
Maine	$3,594,823	0 - 10%	0 - 10%	0 - 10%	No	9%	10%	8%
New Jersey	$4,787,288	11 - 20%	0 - 10%	0 - 10%	Yes	15%	10%	10%
Hawaii	$5,942,278	11 - 20%	11 - 20%	0 - 10%	Yes	10%	15%	10%
New York	$8,461,288	No Data	No Data	No Data	Yes	5%	10%	4%
Colorado	$1,602,251	No Data	0-10%	11-20%	No	11%	11%	5%
Total Const. Cost	$58,304,586							
Average Const. Cost	$2,332,183							

A review of average bid prices from several state websites [WSDOT11; PennDOT11; INDOT11; TxDOT11; CalTrans11] and the New Jersey Turnpike Authority [NJTA11] was conducted to determine the typical range of bridge rail construction costs. These average bid prices were gathered by the states reviewed during construction and maintenance projects. The bid prices generally include the cost of materials, labor and forming, and do not include changes to the deck to accommodate the rail, traffic control, etc. To limit the effects of material cost variability, only concrete bridge rails without additional steel or aluminum rails on top were reviewed. Table 3 provides a summary of this review.

Table 3 shows the year and state factors that were calculated using Table 1 and Figure 3, and the final factored average cost values found when combining both year and state factors. The first column shows the test level of the bridge rail, the second column indicates the state, and the third column shows the year or years for the bid prices collected. The fourth column shows the exact description used by the states (or authority), while the fifth column is the weighted average bid price that was either posted or converted. In some cases, the unit of measure was posted as "per meter" and these have been converted to "per linear foot" for the purpose of comparison with other railings. The sixth column is the factor used for the year the data was collected and represents the value that the weighted average price should be multiplied by to convert it to 2003 dollars. It is calculated by dividing the NHCCI index for 2003 (1.003) by the NHCCI index for the year posted (Table 1). The seventh column is the factor used to normalize the individual state's cost to the national average cost. As with the factor for year, this is a simple unitless ratio. The last column is the final factored average. As previously stated, this represents the averaged cost in 2003 to construct one linear foot of the particular bridge rail.

Table 3. Weighted Average Bid Prices Per Linear Foot With Year and State Factors Applied.

Test Level	**State**	**Year**	**Description**	**Quantity (feet)**	**Weighted Avg Bid Price ($)**	**Year Factor**	**State Factor**	**Final Factored Avg**
TL-2	IA	2007	Vertical Wall Separation Barrier	Unavailable	64.90	0.778	1.547	78.06
TL-2	IN	2010	Vertical Wall, TX (Concrete, pedestrian)	3173	86.98	0.944	1.673	137.43
TL-3	TX	2011	Single Slope RAIL (TY SSTR)	260606	28.18	0.944	1.571	41.81
TL-3	TX	2011	Vertical Wall RAIL (TY T221)	340	69.01	0.944	1.571	102.40
TL-4	WS	2008-2011	Traffic Barrier (F-shape)	Unavailable	111.49	0.871	1.613	156.71
TL-4	TX	2011	Safety Shape Rail (TY T501)	17361	32.07	0.944	1.571	47.58
TL-4	TX	2011	Safety Shape Rail (TY T502)	6341	30.00	0.944	1.571	44.51
TL-4	TX	2011	Safety Shape Rail (TY T503)	2010	85.00	0.944	1.571	126.12
TL-4	CA	2009	Safety Shape Rail, Type 25	1228	85.00	0.914	1.053	81.84
TL-4	CA	2009	Safety Shape Rail, Type 25	545	44.20	0.914	1.053	42.55
TL-4	CA	2008	Safety Shape Rail, Type 25	207	106.68	0.775	1.053	87.00
TL-4	CA	2008	Safety Shape Rail, Type 25	331	60.00	0.775	1.053	48.93
TL-4	CA	2007	Safety Shape Rail, Type 25	5387	49.23	0.778	1.053	40.30
TL-4	CA	2006	Safety Shape Rail, Type 25	2769	87.97	0.744	1.053	68.87
TL-4	CA	2005	Safety Shape Rail, Type 25	3763	71.26	0.851	1.053	63.83
TL-4	CA	2004	Safety Shape Rail, Type 25	2228	50.77	0.941	1.053	50.30
TL-4	CA	2003	Safety Shape Rail, Type 25	2123	45.75	1.000	1.053	48.17
TL-5	IN	2010	Barrier, Concrete, 45 in. (F-shaped, used for bridge railing)	1981	132.86	0.944	1.673	209.93

TL-5	PA	2009-2011	Single Face Concrete Bridge Rail, 34" F-Shape	328	57.10	0.930	0.910	48.30
TL-5	PA	2009-2011	Single Face Concrete Bridge Rail, 41" F-Shape	1270	54.77	0.930	0.910	46.33
TL-5	NJTA	2007	Barrier Parapet (safety shape)	426	600.00	0.778	0.487	227.19
TL-5	NJTA	2008	Barrier Parapet (safety shape)	1422	456.68	0.775	0.487	172.25
TL-5	NJTA	2009	Barrier Parapet (safety shape)	4120	200.00	0.914	0.487	89.05

Four of the states used here for cost comparison were not in the WSDOT study and required regional averaging; Texas, Iowa, Indiana, and Pennsylvania. As stated previously, a judgment call had to be made in these instances as to which of the neighboring states should be used for each state's estimated cost per lane-mile. The following is the methodology for each state where this estimation was necessary.

The states used to estimate Texas's average cost per lane-mile were Arizona, New Mexico, Colorado and Oklahoma. Lane-mile costs for Louisiana and Arkansas (both of which border Texas) were available but it was decided to not include them in the estimation because the states chosen better represent the Southwest region of the United States. This is a common regional association and it is more probable that Texas's costs would be closer to those of its western neighbors.

Iowa's estimated lane-mile cost was determined by averaging together the costs for South Dakota, Illinois and Kansas. These are the closest states to Iowa and have lane-mile costs that are also comparable to each other. There does not seem to be much variation among states in the Midwest region.

Indiana is another state that is almost entirely surrounded by states that were part of the WSDOT study making the decision relatively straightforward. The average costs from Illinois, Michigan and Ohio were used for the lane-mile cost for Indiana.

Pennsylvania was not as straightforward as the other three states because of its location. Lane-mile cost data is available for Ohio, West Virginia, New Jersey and New York. It was decided to not use New York in the estimation process as it is an anomaly. The lane-mile cost for New York is much higher than any of its surrounding states', and it is likely that the high cost is associated with the inclusion of New York City. The omission of New Jersey was also considered but it was ultimately decided to use the state in the estimation as most of Pennsylvania's population is located in the south-east portion of the state, near the New Jersey border. [USCEN10]

Comparison of Barrier Test Levels

All bridges on the National Highway System (NHS) must use at least a test level 3 (TL-3) bridge railing. [FHWA97] Many states are now requiring bridge rails with higher test levels for new construction. Table 4 shows the average costs of the various tests levels as well as a comparison of those test levels to the TL-3 bridge rails. The “Low”, “Average” and “High” columns represent the comparison factors for the lowest, average, and highest bid prices as compared to the average bid price for a TL-3 barrier. As an example, the highest bid price for a safety-shape TL-4 railing costs 1.54 times that of the average TL-3 barrier. The least expensive TL-2 barrier costs more than the average TL-3 barrier, although not by much. The least expensive TL-4 barrier (a safety shape) is only 68% of the cost of an average TL-3 barrier, while the most expensive TL-4 barrier (an F-shape) costs 85% more. All of the values in Table 4 are using both the factor calculated to adjust for the year of purchase and the factor calculated for the state where it was installed.

Table 4. Comparison of Test Level Costs to TL-3, Using Factors.

		Qty. (feet)	# Instances	Average ($)	Low	Average	High
TL-2	**Vertical Wall**	> 3173	2	107.75	1.06	1.49	1.65
TL-3	**All**	260,946	2	**72.10**	0.70	1.00	1.30
	Single Slope	260,606	1	41.81		0.70	
	Vertical Wall	340	1	102.40		1.30	
TL-4	**All**	> 44,292	13	69.75	0.68	0.98	1.85
	F-Shape	Unavailable	1	156.71		1.85	
	Safety Shape	44,292	12	62.50	0.68	0.90	1.54
TL-5	**All**	9,547	6	132.18	0.74	1.60	2.55
	F-Shape	3,579	3	101.52	0.74	1.29	2.38
	Safety Shape	5,968	3	162.83	1.17	1.91	2.55

These costs indicate the national average cost to install bridge railing in the 2003 base year. These costs do not, however, reflect any changes needed to the bridge to accommodate the different railing choices. For example, a TL-5 concrete bridge railing is designed to resist a more demanding impact than a similar TL-3 bridge railing. The increase in railing strength must be matched by an increase in the deck strength and the connection between the deck and the railing. For example, the TL-4 F-shape concrete bridge railing is shown in the AASHTO-ARTBA-AGC Bridge Railing Guide to require a minimum thickness of eight inches whereas the TL-5 F-shape concrete bridge railing requires a 10-inch thick deck and heavier reinforcement. [Buth93] So, while Table 4 indicates that on average a TL-5 concrete bridge railing costs about 74 percent more than a similar TL-4 concrete bridge railing, these costs do not include any costs associated with a 25 percent thicker deck (i.e., 10 versus 8 inches) and heavier reinforcement. These not-so-obvious construction costs should be included in the true construction cost of the railing if they will be a part of the project.

Repair and Maintenance Costs

Repair costs for bridge railings can be significant even though many bridge railings are typically not damaged in most collisions. An estimate from one state of 54 $/ft was found, but repair costs are quite difficult to determine and often not tracked separately. A recent project from the State of Florida to enhance its bridge management software includes cost elements for all types of bridge construction and repair. [Sobanjo11] The contractor bid price for bridge railing repair and retrofit are included in Table 5.23 of the Sobanjo and Thompson report. The data contained 176 winning bids for work on bridge barrier repairs and retrofits. The average price was 601 $/ft with an extremely wide range going from a low of 0.01 $/ft to a high of almost 57,000 $/ft. The median cost was almost 90 $/ft. This would seem to suggest that the majority of the repairs and retrofits cost about 90 $/ft but there were a small number of very high repair costs which probably indicate a complete failure of the barrier and possibly bridge deck or structure that required extensive and costly repairs.

Many States prefer concrete bridge railings because for the vast majority of crashes there will be little important barrier damage. In the rare case of a major collision involving a heavy vehicle, however, concrete bridge railings can fail catastrophically. Such catastrophic damage may including the complete structural failure of the concrete barrier itself as well as failure of the bridge deck since many concrete bridge railings are constructed integral with the deck.

Kubbler reported on a recent crash testing program in Germany of six very high containment level bridge railings (i.e., EN 1317 containment level H4b). [Kubbler07] The bridge railings included a concrete safety shaped barrier, several steel post-and-beam barriers and an all-steel safety shaped barrier with an energy dissipating base attachment to the deck. All six barriers were tested with a large tractor trailer truck of containment level H4b (i.e., test TB-81). The test facility used a special instrumented bridge deck that was able to measure the forces and moments transmitted by the collisions to the deck. The all-steel safety shape barrier with the energy absorbing base attachment resulted in much lower deck loadings than any of the other barriers tested which would make major deck repairs unlikely. [Ray08]

The repair costs for rare penetration events, therefore, may have an important affect on the selection of a barrier and should be included in the assessment of costs in the benefit cost analysis. While, for example, a penetration of a concrete barrier may only occur in one percent of crashes, the cost of that one crash could erase the savings of the many no-repair crashes.

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