Assessment of New Construction Market Pricing for Steel and Concrete Bridges

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6. Abstract

This report discusses the initial construction costs of structural steel and concrete vehicular bridges and the cost difference between these bridge types. It presents the methodology used to collect and analyze the data, results, and conclusions. The authors collected and analyzed costs from 789 bridge projects from 12 state Departments of Transportation (DOT) that were awarded between 2014 and 2019. Seventy-five bridge projects were excluded for various reasons, resulting in a total of 714 bridge projects included in the review.

The objective of this review was to analyze the initial construction costs of structural steel and concrete bridges that have been built across the United States in order to compare the in-place cost of these bridge types on national, regional, and state bases. All costs in this report are in Q2 2019 dollars.

7. Key Words Bridge Cost Estimating	8. Distribution Statement TBD

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Introduction

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Scope of This Review

Focus of the Review

The authors' review focused solely on new and total replacements of structural steel and concrete bridges let by state DOTs. Except for the three bridges described above, the bridges included in our review were let after 2014 and used a Design-Bid-Build (DBB) delivery methodology. These bridge projects were chosen because both detailed project cost information and project plan sets were generally available through online or other subscription-based sources. We excluded bridge projects that used other alternative delivery methodologies, such as Design-Build (DB) or Construction Manager–General Contractor (CMGC), because detailed bid tabs and/or plans are not commonly available for these types of projects. Additionally, we did not review bridge projects let by other agencies such as transit agencies, tollways, railroads, city or county agencies, or other government agencies.

Data Collected

To perform our review, we collected various pieces of information for each state DOT and bridge included in the analysis, including historical bid tabs, construction plans, cost escalation indices, and standard specifications. This information is considered public and is generally available; however, each DOT treats the records with varying levels of security. Some DOTs publish the information directly on their websites and make it available for free public consumption. Others publish the information online and share the links with those who request them. Still others subscribe to services that will share the information for a fee. Some DOTs will share the information in response to an open-records request. Some will not share at all. The ease of collecting the required information played a role in our ultimate selection of state DOTs to be included in the review.

Parameters of the Review

In general, the approach used for this review generates a single parametric value for each bridge included in the analysis, and this value relates the cost to build the bridge to the area in square feet of bridge deck. This is a common parameter used across the industry to communicate bridge construction costs at a high level. The cost of each bridge includes those items that are consistent across all bridges (items such as structure excavation, foundations, abutments, piers, beams, deck, and mobilization) but excludes items that can be highly variable (items such as demolition, aesthetics, lighting, drainage, barrier, and approach slabs). The area of bridge deck is calculated for each bridge as the length along the centerline of bridge (between the approach pavement notches) multiplied by the out-to-out width of the deck.

In addition to cost data, we also recorded various parameters for each bridge. These parameters allowed us to sort the bridges into groupings of similar characteristics for comparison, or to conduct more in-depth analysis of a particular characteristic. The parameters include general items such as state or region; layout characteristics such as: overall length, out-to-out width, span length, skew, alignment, and so on; service characteristics such as what type of facility uses the bridge and what the bridge is crossing; bridge type characteristics such as beam type and beam sub-type; physical characteristics such as size, grade, and weight of structural elements; and other characteristics such as funding source.

These parameters and characteristics are described in further detail in this report.

Acronyms and Definitions

Adj.	adjustment
BLS	Bureau of Labor Statistics
CCI	Construction Cost Index
CMGC	Construction Manager–General Contractor
DB	Design-Build
DBB	Design-Bid-Build
DOT	Department of Transportation
ENR	Engineering News-Record
I-90	Interstate 90
lf	linear feet
No	number
NSBA	National Steel Bridge Alliance
PPCB	precast, prestressed concrete box beam
PPCI	precast, prestressed concrete I-beam
PPCS	precast, prestressed concrete slab beam
PPI	Producers Price Index
Q2	second calendar quarter
Reg.	regional
RSB	rolled steel beam
sf	square feet
SPG	steel plate girder
Tot	total

Approach

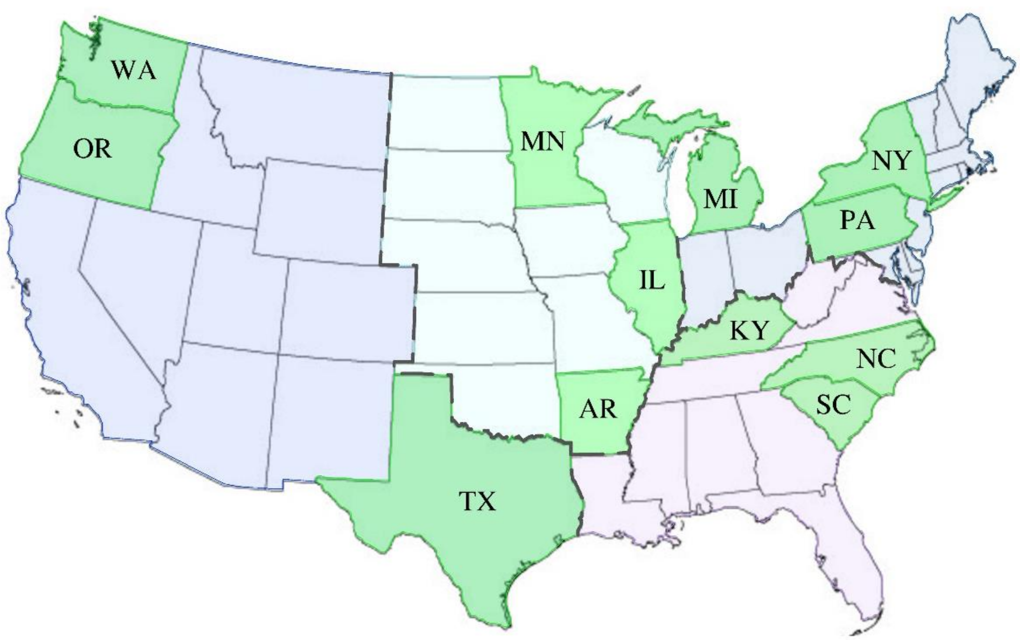
Our approach to the review consisted of the following steps: identifying states to be included in the review, gathering required information, taking off information from plan sets, organizing bid tab data into categories, calculating parametric cost information, and establishing key parameters.

Identify States Included in the Review

In selecting the states included in the review, the authors divided the United States into the four NSBA regions: West, Central, Southeast, and Northeast. Within those regions, NSBA staff selected 12 states—three states from each region, as shown in Figure 1. States were selected for a variety of reasons, including the following:

- Varying levels of concrete and steel usage
- Geographical spread of the selected states
- Availability of data within each state
- Balancing of review budget with a desire to collect data from all states

Figure 1: States Selected for Review



The 12 states shown in green are included in the review.

Gather Required Information

For each state, we collected information including standard specifications, bridge plans, historical bid tables, and construction cost indices (if available). Sources for this information included Bid Express, DOT websites, and American Institute of Steel Construction (AISC)/NSBA agency contacts. The data were collected starting with recent lettings and working backward chronologically until enough data were accumulated to provide statistically significant results.

Table 1 summarizes the quantity of bridge projects included in the review by state and year. As described previously, three bridges that were let in 2011 were included in the state of Washington to provide samples for comparison between bridge types in the state.

Table 1: Bridge Project Count by State and Year

Region	State	Steel								Concrete								Total
		11	14	15	16	17	18	19	Tot	11	14	15	16	17	18	19	Tot	
West	Oregon		2	1		1			4		6	7	8	2			23	**27**
	Texas				1	3	1	1	6						63	29	92	**98**
	Washington	2							2	1	9	8	10	4	3	5	40	**42**
Central	Arkansas				38	9	6		53									**53**
	Illinois						23	8	31						29	4	33	**64**
	Minnesota					2			2					42	8		50	**52**
Southeast	Kentucky				1	2			3				1	11	21	14	47	**50**
	North Carolina					12	5		17					25	29		54	**71**
	South Carolina						1	1	2		6	13	3	9	6	4	41	**43**
Northeast	Michigan			3	2	3	4	3	15			3	21	9	16	7	56	**71**
	New York				16	14	8		38				1	5	2		8	**46**
	Pennsylvania					6	1		7				30	27	33		90	**97**
Total		**2**	**2**	**4**	**58**	**52**	**49**	**13**	**180**	**1**	**21**	**31**	**74**	**134**	**210**	**63**	**534**	**714**

Excludes 16 projects considered to be outliers for each state. Outliers are discussed on page 10 of this report. Column headers refer to the year the bridge projects were let but have been truncated to show only the last two digits.

Take Off Information from Plan Sets

We then developed a list of information to be collected from each bridge plan set and used this information in the statistical analysis of the projects, or to sort projects based on similar features or parameters. This information included the following:

- **General Items** – region, state, bridge identification number, contract identification number, partial or rehab identifier, outlier identifier
- **Geometric Characteristics** – length, width, deck area, number of spans, span lengths, maximum span length, average span length, horizontal curvature, and skew
- **Service Characteristics –** what service uses the bridge (freeway, state highway, and rural road), and what the bridge is crossing (freeway, rural road, railroad, and waterway)
- **Bridge Beam Type Characteristics –** beam type category (concrete or steel), beam type subcategory (steel plate girder, rolled steel beam, precast prestressed concrete I-beam, precast prestressed concrete box beam, and precast prestressed concrete slab beam)
- **Physical Characteristics –** Size and/or grade of structural elements, weight of structural steel, total length of concrete beams, quantity of superstructure concrete and reinforcing steel, and coating system
- **Funding/Construction –** staged construction, delivery method, accelerated bridge construction (ABC), or other construction methodology

Organize Bid Tab Data into Categories

In the next step, we developed a set of categories to organize bid items into various components that make up a typical bridge project. These categories combined similar elements of work into a hierarchy that allowed us to analyze them at various levels of detail. Individual bid items were assigned to specific categories. Similar items across each state were assigned to the same categories, thereby giving us a consistent understanding of bridge costs across all projects in each state. Figure 2 lists the work categories.

Figure 2: Work Categories

Category	Group	Sub-group
General		
Civil		
Structures	Bridges	Bridge Removal
		Structure Excavation
		Foundations
		Substructure
		Beams
		Superstructure
		Aesthetics
		Temp. Works
		Maintenance
		Drainage
		Barrier
	Bridges Total	
	Retaining Walls	
	Overhead Signs	
	Minor	
	Removal	
Signals		
Lighting		
ITS		
Power		
Communications		
Water		
Sewer		
Environmental		
Miscellaneous		

The key bridge components are:

- **Bridge removal** – Demolition and removal of existing bridges (Excluded).
- **Structure excavation** – Excavation and backfill to provide access for foundation and substructure work including shoring and dewatering if required (Included).
- **Foundations** – Spread footings, piling, drilled shafts or other (Included).
- **Substructure** – Bridge abutments, piers and pier caps (Included).
- **Beams** – Structural steel or concrete girders, beams and/or precast slabs, bearings, and diaphragms or cross frames (Included).
- **Superstructure** – Concrete or asphalt decking and/or other components built with the deck, such as sidewalk or median flatwork (Included).
- **Aesthetics** – Decorative features that can be identified in the plan sets such as rock façades, decorative painting, decorative barrier and/or/rail treatment, or other features (Excluded).
- **Temporary works** – Installation and removal of temporary bridges or other structures that provide for phasing of construction. This does not include support for installation of steel girders. (Excluded).
- **Maintenance** – Work to restore elements on adjacent bridges or other bridge maintenance requirements (Excluded).
- **Drainage** – Deck drains and outlets (Excluded).
- **Barrier** – Median and edge barrier including metal guardrail, barrier rail, or concrete barrier installed on the bridge (Excluded).

- **Mobilization** – A portion of the overall project mobilization costs typically dedicated to a contractor getting ready to set up and ready to start a given project. If the bridge is included in a roadway project or as a package containing multiple bridges, mobilization costs are calculated based on the representative dollar-weighted portion of the bridge cost in relation to the other project costs (Included).
- **Approach Slab** – Roadway pavement beyond the abutments at both ends of the bridge (Excluded).

In many cases, there was not a one-to-one relationship between the bid items shown in the bid tabs and the work categories of each bridge project. Examples included situations in which the bid tabs aggregated concrete or reinforcing steel for both superstructure and substructure elements into single bid items. Through our analysis of the bridge plans, we broke apart the costs for these elements and assigned them to the appropriate work category. In cases where the bid price was a blended unit price for these elements and there was no way to identify whether a different unit price should have been used for the individual elements, we applied the blended unit price to the quantities found in each element.

Not all elements of a typical bridge project were included in the ultimate comparable price. Some bridge projects included items such as demolition and removal of existing structures, elaborate temporary works, and aesthetic treatments, whereas others did not. We reduced the overall list of work categories to a subset of comparable categories reflecting elements that a typical bridge would require. Table 2 provides the list of comparable categories and sample costs. The cost included in each of these six categories was summarized for each bridge and aggregated across the nation, regions, and states—so, our review compared not only the total bottom-line parametric cost, but also costs within each comparable sub-category.

Table 2: Comparable Work Categories

Group Name	Sub-group Name	Sample Parametric Cost		
		Low	Ave	High
Mobilization	Mobilization	$	$	$
Bridges	Structure Excavation	$	$	$
	Foundations	$	$	$
	Substructure	$	$	$
	Beams	$	$	$
	Superstructure	$	$	$
Total $/square foot of bridge deck		**$**	**$**	**$**

Calculate Parametric Cost Information

The primary output of our review was the cost of a bridge per square foot of bridge deck. As described previously in the Approach section, this parameter was calculated by taking the cost of all bid items associated with a given work category and dividing by the total area of bridge deck obtained during the take-off. This calculation was repeated for every bridge included in our review. This approach allowed us to understand how the individual bridge components make up the overall parametric bridge cost. We then made several adjustments to the raw parametric price before making any comparisons.

Exclude Outliers

Before analyzing the data at the state level, we identified bridges that could be considered outliers. An outlier could be a bridge that is extremely costly to build due to difficult site conditions, remote location, unique design or other unknown factors. The opposite is also true; an outlier could be a bridge that is far simpler than typical, resulting in lower costs than expected. However, none of these lower-bounded outliers were identified for this review.

Bridge projects that were found to have significantly lower parametric costs were explored in greater detail and were often found to be partial reconstructions that either reused all or part of the existing foundation, or included agency provided materials, and were ultimately excluded.

Major outliers were defined for this review as costs that were greater than 3 times the difference between the third quartile and first quartile. Sixteen bridge projects from both concrete and steel groupings were outside this boundary and were excluded from the results.

Escalate Project Costs

In order to compare bridge project costs from past years, it was necessary to escalate these project costs to a current base year. This report set the current base year to the end of the second quarter (Q2) of 2019.

Unfortunately, calculating escalation is an inexact science. Available data vary from state to state, and the methodologies each State uses to calculate the price escalation also vary. Attempting to apply these differing approaches from state to state could introduce undesired variability in the results. Therefore, we developed a nationwide approach to applying escalation to all projects. The approach explored potential differences between concrete and steel bridges. Since a large portion of the bridge cost is the structural steel or concrete beam elements, it is reasonable to conclude that variations in escalation in these components should affect the overall escalation factor applied to the overall bridge type.

We used the following process to calculate escalation:

1. **Identify a sample bridge project.** In early 2018, HDR was tasked with developing preliminary plans for a highway bridge crossing over a river in Montana. This task included preparing preliminary design plans and cost estimates for concrete and steel bridge alternatives over the same crossing. When developing the cost estimates, the authors used a production-based approach that builds up total cost from various cost components such as materials, labor, and equipment. This sample project is useful for this exercise because designs were developed for the same bridge, on the same roadway, over the same river crossing and were modified as needed to provide steel beams or concrete beams as called for with each alternative. This consistency eliminates site-specific differences such as ground conditions, haul lengths, weather impacts, and so on, that could affect the unit price of individual components of a bridge built at different locations or at different times.
2. **Break up the bridge project into components.** HDR then used the detailed cost information generated as part of the previously mentioned river crossing project to understand how costs associated with a typical bridge are broken into various cost components. These cost components are tied to nationally published databases that track cost escalation over time, databases such as Bureau of Labor Statistics (BLS), Producers Price Index (PPI), and Engineering News-Record (ENR) Construction Cost Index (CCI). Various cost components from the BLS and PPI were identified, and the project cost estimates were grouped into those components. Any costs not placed into a particular category were assigned to the ENR CCI index category. The cost categories used are:
    - Supervisors of construction and extraction workers
    - Construction trades workers
    - Construction machinery and equipment
    - Fabricated structural metal bar joists and concrete reinforcing bars for buildings
    - Fabricated structural metal for bridges
    - Ready-mix concrete
    - Prestressed concrete bridge beams and solid and hollow-cored slabs and panels
    - ENR CCI
3. **Research index rates and calculate escalation factor for each component.** Table 3 shows the raw escalation factors as downloaded for each component of the escalation calculation and the resulting 5-year compounded annual escalation factor that we applied to each component.

Table 3: Bridge Component Escalation Rate

Year	Supervisors of Construction and Extraction Workers	Construction Trades Workers	Construction Machinery and Equipment	Fabricated Structural Metal Bar Joists and Concrete Reinforcing Bars	Fabricated Structural Metal for Bridges	Ready-mix Concrete	Prestressed Concrete Bridge Beams	ENR CCI
	Median Wage Rate		PPI – Commodity					
2014	$60,380	$40,429	213.0	184.2	114.0	227.7	118.9	9,668
2015	$60,990	$41,275	216.6	189.8	113.4	239.5	122.3	9,936
2016	$62,070	$41,796	218.7	188.7	105.7	248.3	125.9	10,152
2017	$62,980	$43,028	220.2	199.0	100.7	257.2	129.7	10,530
2018	$64,070	$43,988	217.9	200.0	110.0	267.1	134.0	10,873
2019	$65,230	$45,338	231.1	217.4	109.5	272.5	140.3	11,186
Escalation	1.6%	2.3%	1.6%	3.4%	–0.8%	3.7%	3.4%	3.0%

4. **Determine escalation rate for each bridge component.** We then escalated the cost of each bridge component at a rate associated with the 5-year annual compounded rate for that component. Each component was summed to yield an overall escalated cost for each alternative. The escalated rates were divided by the base rate for each alternative, and the resulting factor was used as the escalation factor for all bridges within the project.

Table 4: Bridge Escalation Calculation

Bridge Alternative	Supervisors of Construction and Extraction Workers	Construction Trades Workers	Construction Machinery and Equipment	Fabricated Structural Metal Bar Joists and Concrete Reinforcing Bars	Fabricated Structural Metal for Bridges	Ready-mix Concrete	Prestressed Concrete Bridge Beams	ENR CCI	Total Cost	Annual Escalation
Base Cost ($ thousands)										
Steel	$2,143	$6,665	$3,699	$1,656	$9,897	$3,087		$2,395	$29,545	
Concrete	$2,143	$4,733	$3,985	$1,785	$314	$3,258	$8,392	$2,386	$26,998	
Escalation	1.6%	2.3%	1.6%	3.4%	–0.8%	3.7%	3.4%	3.0%		
Escalated Cost ($ thousands)										
Steel	$2,176	$6,819	$3,760	$1,712	$9,818	$3,200	$0	$2,465	$29,954	**1.40%**
Concrete	$2,176	$4,842	$4,050	$1,845	$311	$3,377	$8,675	$2,456	$27,737	**2.75%**

As shown in Table 4 above, this analysis resulted in our applying different escalation factors for steel and concrete bridges. Steel bridges were escalated at 1.4% compounded annually, whereas concrete bridges were escalated at 2.75% compounded annually. The variance is driven primarily by the difference in escalation factors for Fabricated Structural Metal for Bridges (-0.8%) and Prestressed Concrete Bridge Beams (+3.7%).

Adjust Costs by Location

In the final step, we developed a location factor and applied it to costs generated from individual states to allow us to compare costs across the states. We used the *City Cost Indexes – Year 2019 Base* as published by RS Means as the basis for this factor.

The approach involved calculating the average of the weighted average values for each city within a given state. The resulting value was used to escalate or deescalate the costs for any individual state as required based on the result of this calculation to a national average rate. The costs for each state were divided by the location factor shown in Table 5 to develop the national average cost for use in comparing costs across states.

Table 5: Location Factors

Region	State	Location Factor
West	Washington	0.9969
	Oregon	0.9889
	Texas	0.8293
Central	Minnesota	0.9820
	Illinois	1.0676
	Arkansas	0.8040
Southeast	North Carolina	0.8412
	South Carolina	0.8365
	Kentucky	0.8821
Northeast	Michigan	0.9303
	New York	1.1506
	Pennsylvania	0.9846

Establish Key Parameters

This review captured a large number of parameters that can be used to analyze bridge costs based on various characteristics. However, the results focused only on a small subset of these parameters. This section describes these key parameters in greater detail.

Bridge Type and Subtype

We assigned each bridge to a category that relates to the girder or beam material, either structural steel or concrete. Each bridge was further assigned to a subcategory so that we could compare cost profiles at a more granular level. The bridge types and subtypes are:

- Structural Steel
  - Steel plate girder (SPG)
  - Rolled steel beam (RSB)
- Concrete
  - Precast, prestressed concrete I-beam (PPCI)
  - Precast, prestressed concrete box beam (PPCB)
  - Precast, prestressed concrete slab beam (PPCS)

Other bridge subtypes such as steel truss, cast-in-place concrete post-tensioned, arch or cable-stayed bridges that were found in the data we collected were excluded from the comparison. In some cases a bridge was constructed utilizing multiple girder or beam material types, for example a steel girder main span with concrete approach spans. **In these instances, the bridge was categorized by the material type associated with the main span.**

Span Length Classification

This review defines the span length as the distance along the centerline of the bridge from one end of the bridge to the midpoint of the next adjacent pier, or the opposite end of the bridge for a single-span bridge; or as the distance from midpoint to midpoint of adjacent piers. **This review captured the length of each span associated with every bridge collected and assigned each bridge an overall span length based on the maximum span length of all spans associated with that bridge.**

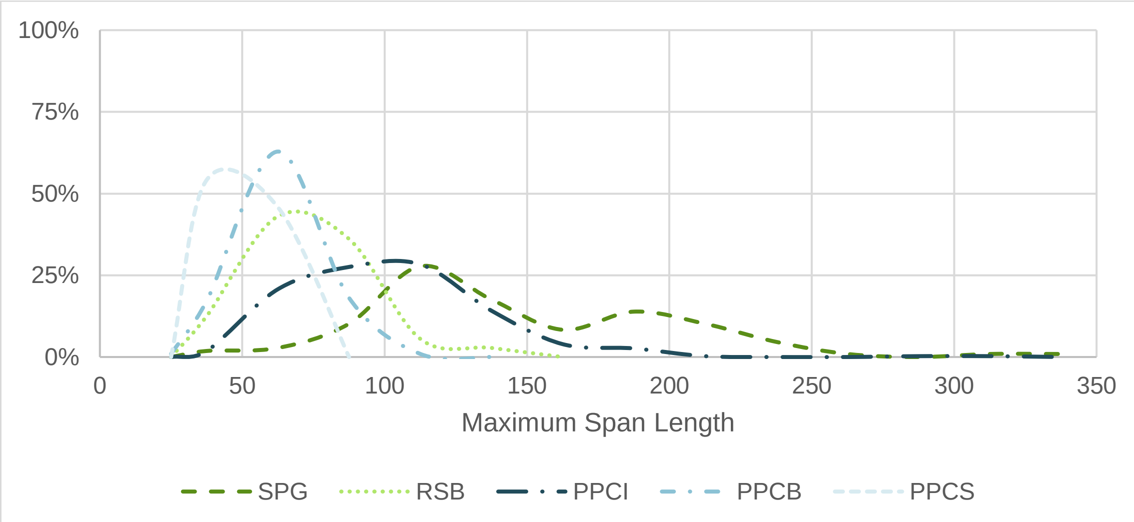
Figure 3 provides a histogram of maximum span length by bridge subtype along with the number of bridges that fall within various 50-foot span length ranges. The figure shows the range of spans over which each bridge subtype is typically built and provides the basis used to establish span length classifications that group bridges into similar lengths for comparison.

As shown in the figure, over 80% of PPCS bridges have a maximum span length between 25 and 50 feet, and none are longer than 65 feet. Nearly 85% of PPCB bridges have a maximum span length of less than 75 feet, and only a single bridge has a maximum span length greater than 100 feet. About 91% of RSB bridges have a maximum span length of 35 to 100 feet, and the absolute maximum span length is about 125 feet.

About 78% of PPCI bridges have a maximum span length between 50 and 125 feet, and an additional 13% are between 125 and 150 feet. The only PPCI bridge in the data collected for this review that had longer than an approximate 225-foot span length was let in Oregon and had a maximum span length of 290 feet. This bridge underwent a value engineering exercise during construction, and the 90-inch post-tensioned concrete bulb-T design was replaced with steel girders. This bridge is included in the study as let by the Oregon DOT.

Nearly a quarter of SPG bridges have a maximum span length between 150 and 200 feet, as compared to just over 5% for PPCI bridges in this span range, and an additional 12% have a maximum span length greater than 200 feet. This leaves 65% of SPG bridges with a maximum span length less than 150 feet and 57% in the 75-to-150-foot maximum span range.

Figure 3: Maximum Span Length



Span Classification (feet)	Maximum Span Length Range (feet)	Steel (number)		Concrete (number)		
		SPG	RSB	PPCI	PPCB	PPCS
< 100	< 50	2	9	7	19	26
	50 to 75	3	31	79	66	22
	75 to 100	11	26	105	19	0
100 to 150	100 to 125	30	4	108	1	0
	125 to 150	19	2	54	0	0
150 to 200	150 to 175	9	0	15	0	0
	175 to 200	15	0	10	0	0
> 200	200 to 225	11	0	1	0	0
	225 to 250	5	0	0	0	0
	> 250	3	0	2	0	0

We selected the four span classifications shown above in Figure 3 to form groups of bridges in order to compare construction cost based on similar maximum span length.

Skew Angle and Horizontal Curvature

We grouped bridges into categories for comparison based on horizontal curvature alignment and skew angle.

This review defines a horizontally curved bridge as any bridge where the centerline alignment is completely or partially on a radius, or simply any bridge that is not straight. The specific radius of curvature for horizontally curved bridges was not collected. We expect that span lengths for concrete curved bridges will generally be shorter than span lengths for steel bridges as concrete girders are not typically cast with a radius; in most cases, curved bridges constructed using concrete girders use chorded straight girders. For the same reason, we also anticipated that concrete bridges would generally have a larger radius of curvature, or would be straighter than steel bridges in this category, which would result in simpler concrete bridges being selected as compared to steel in this category.

This review defines skew angle as the angle in degrees between a line perpendicular to the centerline alignment of the bridge and a line along the centerline of the bridge abutments or piers. A single skew angle was collected for each bridge included in the review. If a particular bridge could be assigned multiple skew angles, the maximum skew angle was assigned to that bridge. The review further defines a highly skewed bridge as any bridge with a skew angle greater than or equal to 30 degrees.

Staging and Coatings

Construction staging and coating can have an impact on bridge costs. This information was collected but not considered within the results presented for this report.

Results

Where there is adequate samples within a given category, the results will display a median value rather than an average value. The median is used to represent a central number with the advantage of reducing the natural skew found in the data. However, as the results are filtered to finer degrees and less samples are available in each category, the median becomes more susceptible to wide swings. Thus, in these circumstances the average cost is displayed. In either case, the text describing the chart will indicate which is used.

National

Figure 4: Bridge Cost by Beam Subtype – National (All Span Lengths)[1]

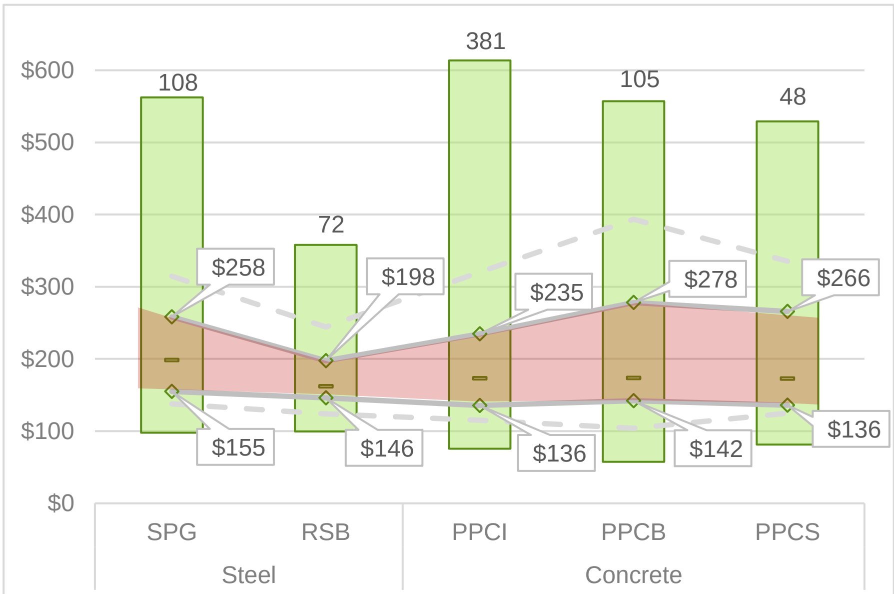


Figure 4 shows the combined results from the 12 states included in the review, 714 bridges total. All costs have been escalated from the year of letting to the base year of Q2 2019 and have been location-adjusted before being included in the figure.

The figure is divided into primary beam types of steel and concrete and is further divided by beam subtype (SPG/RSB, PPCI/PPCB/PPCS). The figure shows a colored bar chart that spans from the minimum to the maximum bridge costs within a given beam subtype. Also shown are the 10th-, 25th-, 50th-, 75th-, and 90th-percentile costs for each beam subtype. The total number of bridges of each beam type is indicated by the number at the top of each bar of the bar chart.

The 10th- and 90th-percentile costs are represented by the dashed line. The 25th- and 75th-percentile costs are represented by the solid line and include labels. The 50th-percentile or median cost is represented by a dash. The area shaded between the 25th and 75th percentiles represents the range of costs for the middle 50th percentile of projects built within each beam subtype. Similarly, the area between the two dashed lines, which is not shaded, represents the range of costs for the middle 80th percentile of projects.

[1] This figure has all span lengths and complexities and does not compare like structures. See the following pages and figures, which break down the cost into similar structures.

Figure 5 shows the range of cost per square foot of bridge deck for each beam subtype within the four span classifications. The figure shows a colored bar chart that spans from the minimum to the maximum bridge costs within a given beam subtype. The total number of bridges of each beam type is indicated by the number at the top of each bar of the bar chart. Also shown are the 25th-, 50th-, and 75th-percentile costs for each beam subtype. The 25th- and 75th-percentile costs are represented by the solid line and include labels where data is available. The 50th-percentile or median cost is represented by a dash.

Figure 5: Cost by Span Classification – National

Figure 6 shows the range of cost per square foot of bridge deck for each beam subtype within the straight, highly skewed, and horizontally curved alignment types. The figure shows a colored bar chart that spans from the minimum to the maximum bridge costs within a given beam subtype. The total number of bridges of each beam type is indicated by the number at the top of each bar of the bar chart. Also shown are the 25th-, 50th-, and 75th-percentile costs for each beam subtype. The 25th- and 75th-percentile costs are represented by the solid line and include labels where data is available. The 50th-percentile or median cost is represented by a dash.

Figure 6: Average Cost by Alignment Type – National

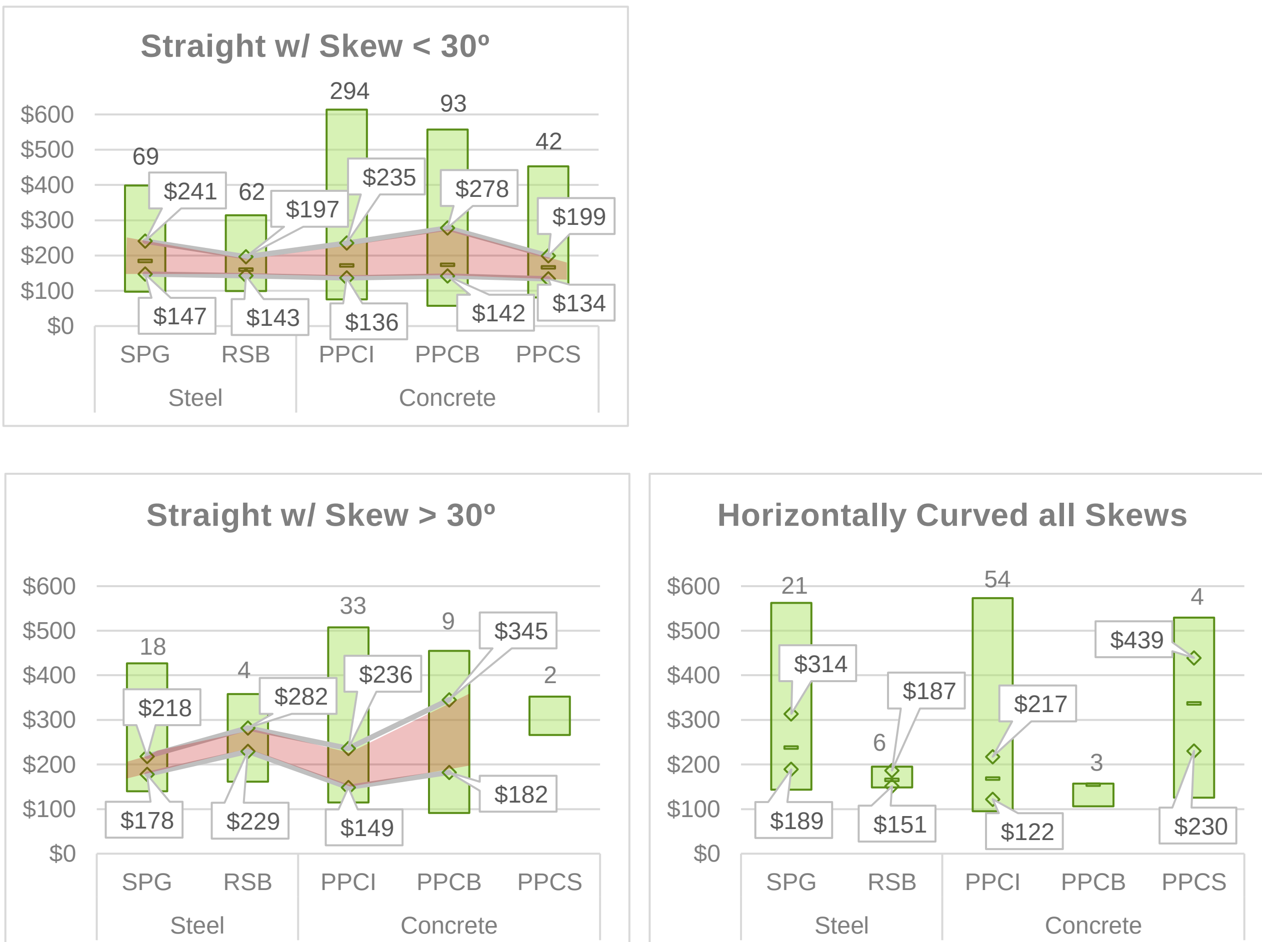


Figure 7 shows the range of cost per square foot of bridge deck for Straight and Skew < 30º bridges across different span ranges. The figure shows a colored bar chart that spans from the minimum to the maximum bridge costs within a given beam subtype. The total number of bridges of each beam type is indicated by the number at the top of each bar of the bar chart. Also shown are the 25th-, average, and 75th-percentile costs for each beam subtype. The 25th- and 75th-percentile costs are represented by the solid line and include labels where data is available. The 50th-percentile or median cost is represented by a dash.

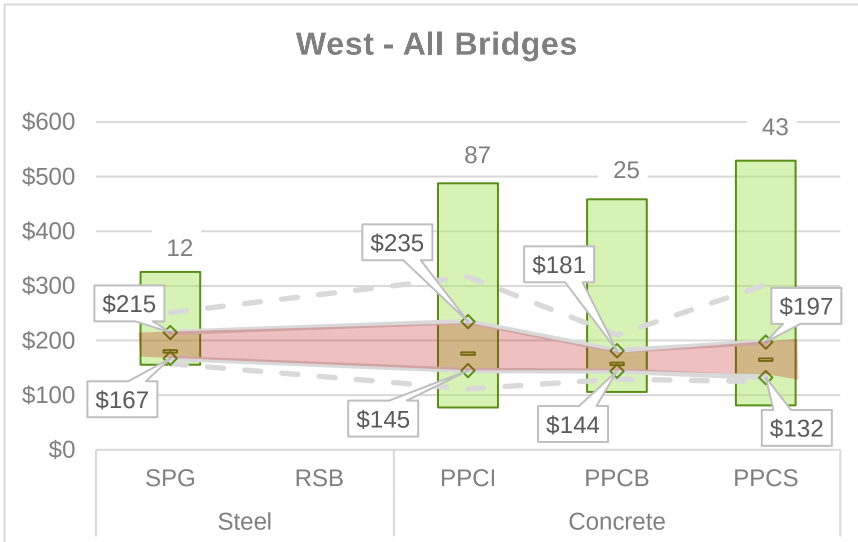
Figure 7: Average Cost by Span Length for Straight and Skew < 30º Bridges – National

Regional

West Region

Figure 9 shows the combined results from the three West Region states included in the review. All costs have been escalated from the year of letting to the base year of Q2 2019 and have been location adjusted before being included in the figure.

Figure 8: West Region Results[2]



The figure is divided into primary beam types of steel and concrete and is further divided by beam subtype (SPG/RSB, PPCI/PPCB/PPCS). The figure shows a colored bar chart that spans from the minimum to the maximum bridge costs within a given beam subtype. The total number of bridges of each beam type is indicated by the number at the top of each bar of the bar chart. Also shown are the 10th-, 25th-, 50th-, 75th-, and 90th-percentile costs for each beam subtype.

The 10th- and 90th-percentile costs are represented by the dashed line. The 25th- and 75th-percentile costs are represented by the solid line and include labels. The 50th-percentile or median cost is represented by a dash. The area shaded between the 25th and 75th percentiles represents the range of costs for the middle 50th percentile of projects built within each beam subtype. Similarly, the area between the two dashed lines, which is not shaded, represents the range of costs for the middle 80th percentile of projects.

Table 6: West Region Results Table

Beam Type		Washington Reg. Adj. – 0.9969			Oregon Reg. Adj. – 0.9989			Texas Reg. Adj. – 0.8293			Regional Total		
Primary	**Secondary**	**No**	**%**	**Avg $/sf**	**No**	**%**	**Avg $/sf**	**No**	**%**	**Avg $/sf**	**No**	**%**	**Avg $/sf**
Steel	SPG	2	4.8%	$189	4	14.8%	$197	6	6.1%	$206	12	7.2%	$200
Steel Total		**2**	**4.8%**	**$189**	**4**	**14.8%**	**$197**	**6**	**6.1%**	**$206**	**12**	**7.2%**	**$200**
Concrete	PPCI	33	78.6%	$257	19	70.4%	$207	35	35.7%	$135	87	52.1%	$197
	PPCB				4	14.8%	$302	21	21.4%	$157	25	15.0%	$180
	PPCS	7	16.7%	$358				36	36.7%	$159	43	25.7%	$191
Concrete Total		**40**	**95.2%**	**$274**	**23**	**85.2%**	**$224**	**92**	**93.9%**	**$150**	**155**	**92.8%**	**$193**

[2] This figure has all span lengths and complexities and does not compare like structures. See the following pages and figures, which break down the cost into similar structures.

Table 6 above summarizes the results for each state in the West Region. The table includes the number of bridge projects included in the review by beam type and subtype, the percentage that each beam type and subtype comprises of the overall bridge projects included, and the average parametric cost per square foot of bridge deck. As shown in the table, SPG bridges make up about 9% of the bridges in this region, and no RSB bridges were identified within the projects sampled. PPCI bridges make up the majority of the bridges in the region, with over 52% of the samples. For the state of Washington, we needed to pull data from 2011 in order to find the two steel bridges that are included in these results. A single PPCI bridge was let during the same period as the SPG bridges and is also included in the results.

Figure 9 shows the range of cost per square foot of bridge deck for each beam subtype within the four span classifications. The figure shows a colored bar chart that spans from the minimum to the maximum bridge costs within a given beam subtype, the number of bridges included, and a callout for the average cost within each beam subtype.

Figure 9: West Region Results by Span Length

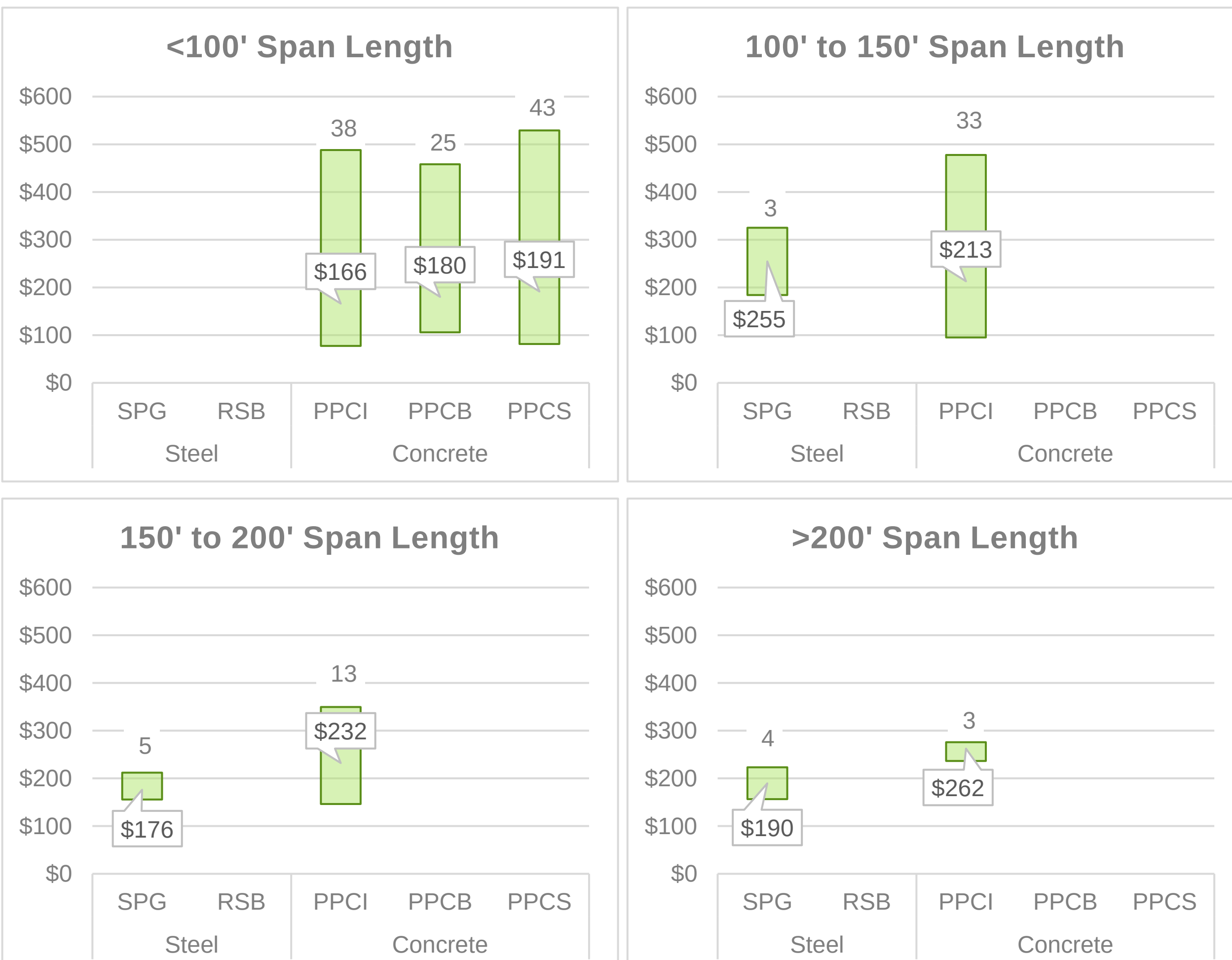
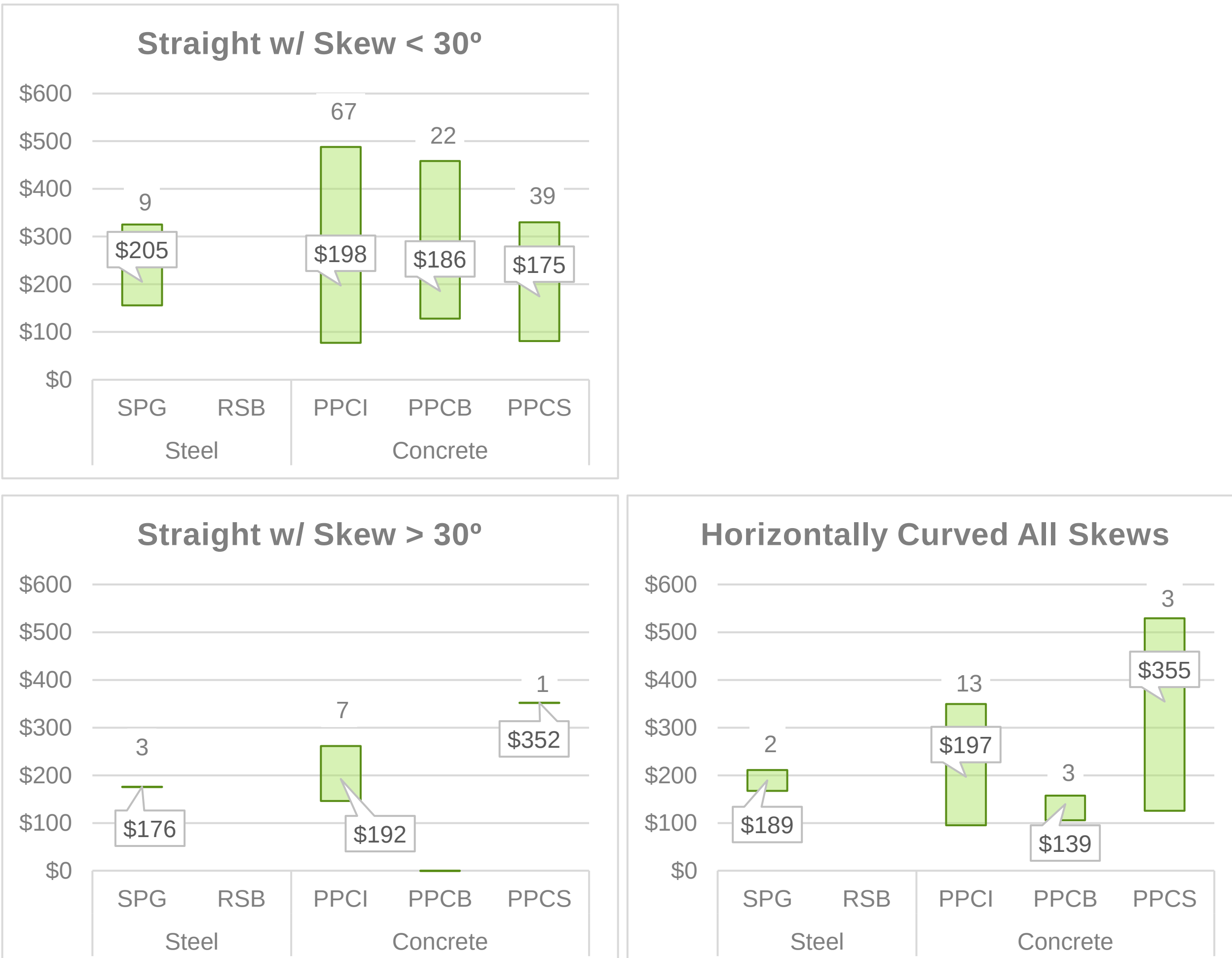


Figure 10 shows the range of cost per square foot of bridge deck for each beam subtype within the straight, highly skewed, and horizontally curved alignment types. The figure shows a colored bar chart that spans from the minimum to the maximum bridge costs within a given beam subtype, the number of bridges included, and a callout for the average cost within each beam subtype.

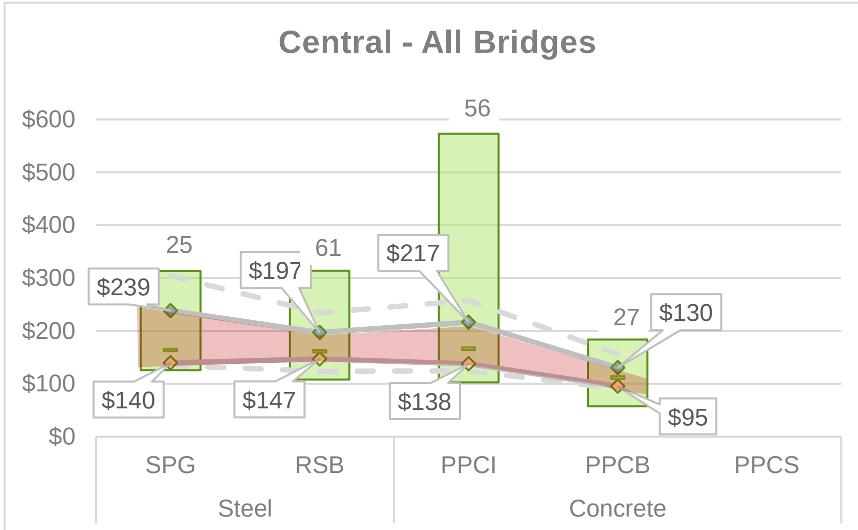
Figure 10: West Region Results by Alignment Type



Central Region

Figure 11 shows the combined results from the three Central Region states included in the review. All costs have been escalated from the year of letting to the base year of Q2 2019 and have been location adjusted before being included in the figure.

Figure 11: Central Region Results[3]



The figure is divided into primary beam types of steel and concrete and is further divided by beam subtype (SPG/RSB, PPCI/PPCB/PPCS). The figure shows a colored bar chart that spans from the minimum to the maximum bridge costs within a given beam subtype. The total number of bridges of each beam type is indicated by the number at the top of each bar of the bar chart. Also shown are the 10th-, 25th-, 50th-, 75th-, and 90th-percentile costs for each beam subtype.

The 10th- and 90th-percentile costs are represented by the dashed line. The 25th- and 75th-percentile costs are represented by the solid line and include labels. The 50th-percentile or median cost is represented by a dash. The area shaded between the 25th and 75th percentiles represents the range of costs for the middle 50th percentile of projects built within each beam subtype. Similarly, the area between the two dashed lines, which is not shaded, represents the range of costs for the middle 80th percentile of projects.

Table 7: Central Region Results Table

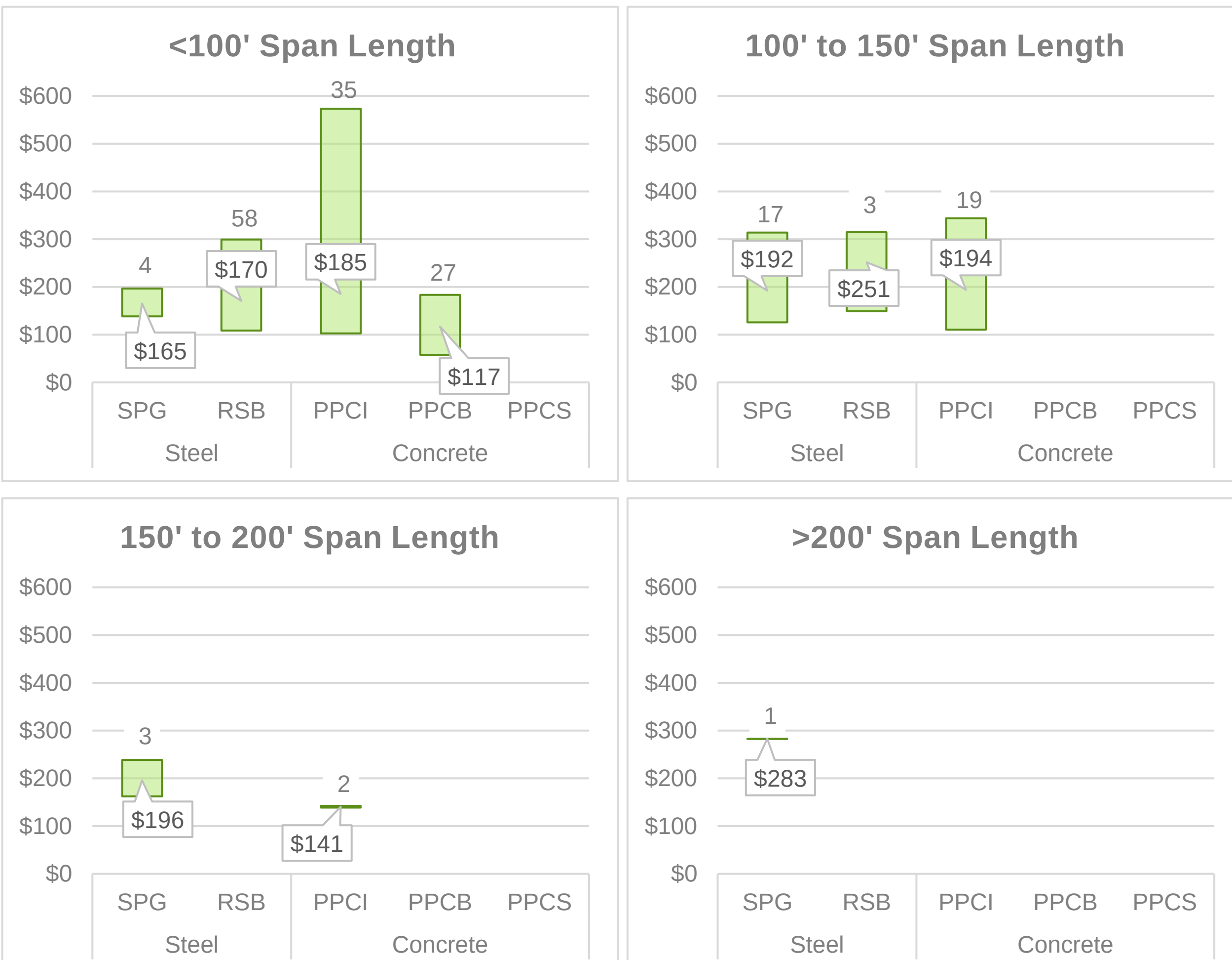
Beam Type		Minnesota Reg. Adj. – 0.9820			Illinois Reg. Adj. – 1.0676			Arkansas Reg. Adj. –0. 8040			Regional Total		
Primary	**Secondary**	**No**	**%**	**Avg $/sf**	**No**	**%**	**Avg $/sf**	**No**	**%**	**Avg $/sf**	**No**	**%**	**Avg $/sf**
Steel	SPG	2	3.8%	$229	13	20.3%	$174	10	18.9%	$207	25	14.8%	$192
	RSB				18	28.1%	$160	43	81.1%	$180	61	36.1%	$174
Steel Total		**2**	**3.8%**	**$229**	**31**	**48.4%**	**$166**	**53**	**100.0%**	**$185**	**86**	**50.9%**	**$179**
Concrete	PPCI	50	96.2%	$189	6	9.4%	$169				56	33.1%	$186
	PPCB				27	42.2%	$117				27	16.0%	$117
Concrete Total		**50**	**96.2%**	**$189**	**33**	**51.6%**	**$126**				**83**	**49.1%**	**$164**

[3] This figure has all span lengths and complexities and does not compare like structures. See the following pages and figures, which break down the cost into similar structures.

Table 7 above summarizes the bridge projects in the Central Region that were included in the review. As shown in the table, approximately equal shares of concrete and steel bridges have been built in the region. However, Minnesota's preference for PPCI bridges is counterbalanced by Arkansas' preference for RSB bridges. The majority of bridge projects from Arkansas were from 2016, from Minnesota 2017, and from Illinois 2018 and the first quarter of 2019. In Arkansas, the combination of escalation and regional adjustment resulted in the greatest cost adjustment out of all 12 states, at about a 25% positive adjustment.

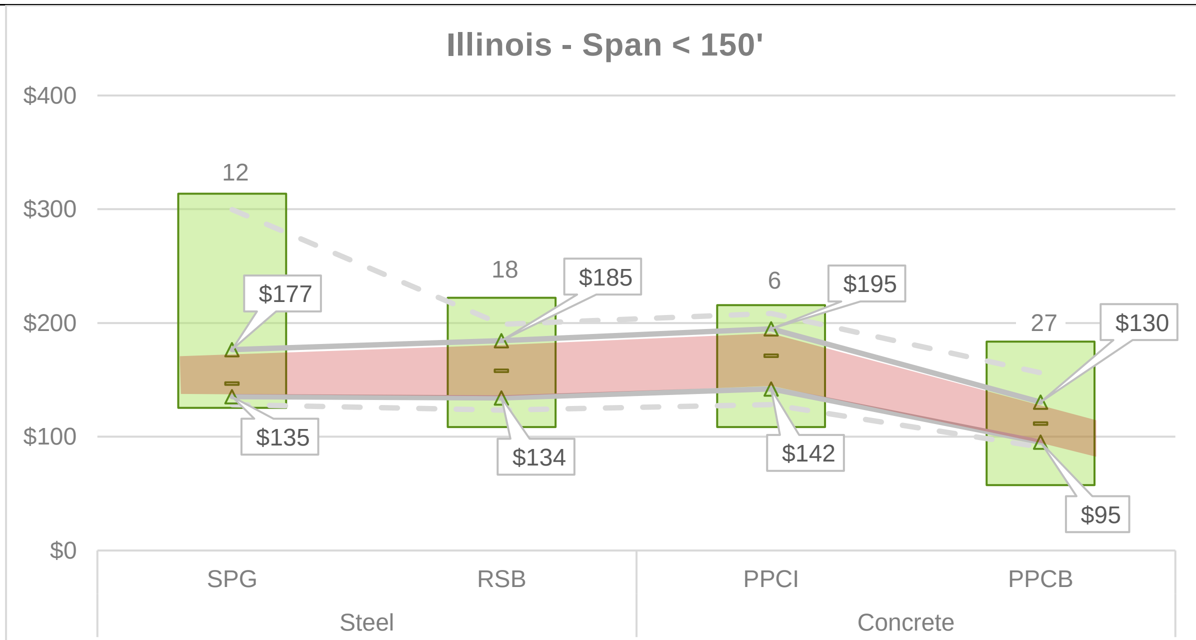
Figure 12 shows the range of cost per square foot of bridge deck for each beam subtype within the four span classifications. The figure shows a colored bar chart that spans from the minimum to the maximum bridge costs within a given beam subtype, the number of bridges included, and a callout for the average cost within each beam subtype.

Figure 12: Central Region Results by Span Length



Within the Central Region and as shown in Figure 13, Illinois offers an opportunity to compare bridge cost within the same state because there are adequate and roughly equal numbers of steel and concrete samples available within the combination of less-than-100-foot and 100-to-150-foot-span categories. The figure shows a colored bar chart that spans from the minimum to the maximum bridge costs within a given beam subtype. The total number of bridges of each beam type is indicated by the number at the top of each bar of the bar chart. Also shown are the 25th- and 75th-percentile costs for each beam subtype represented by the grey line with labels calling out the 25th- and 75th-percentile values. The area shaded between the 25th and 75th percentiles represents the range of costs for the middle 50th percentile of projects built within each beam subtype. Also shown is the 50th percentile or median cost. Below the graph is a table that shows the average bridge cost by detailed category.

Figure 13: Illinois Results – Less-than-150-foot Span Length



Average Bridge Cost – Detailed

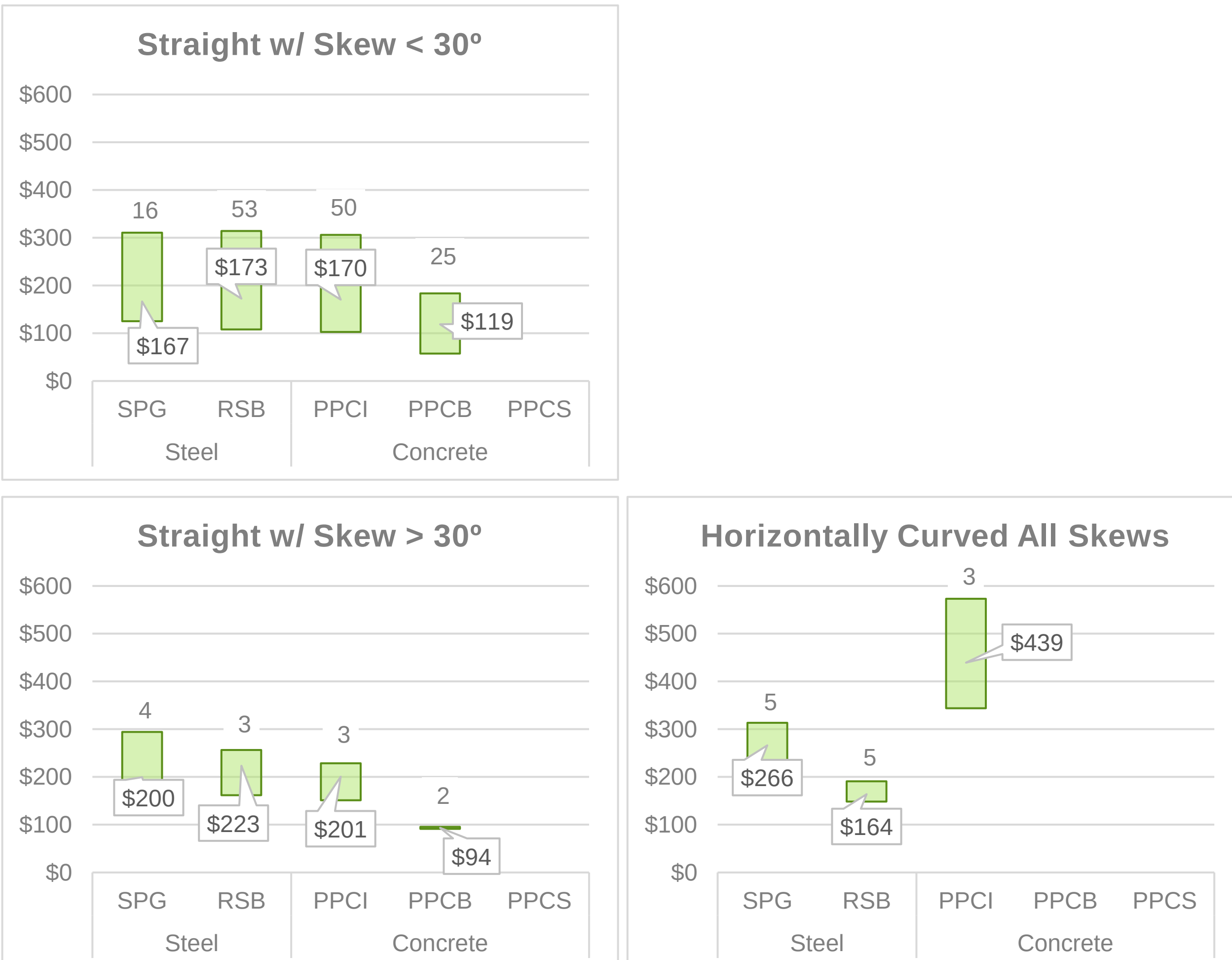
Category	SPG	RSB	PPCI	PPCB
Mobilization	$13.66	$13.76	$17.04	$4.26
Structure Excavation	$3.94	$6.27	$14.05	$8.15
Foundations	$23.46	$25.58	$17.14	$18.88
Substructure	$22.18	$27.49	$18.44	$20.71
Beams	$66.65	$40.37	$48.04	$65.86
Superstructure	$47.27	$48.39	$54.59	$2.34
Total	**$177.15**	**$161.87**	**$169.30**	**$120.19**

The information provides some insight into the data. For example, the superstructure cost for PPCB bridges is about $50 per square foot less than the other bridge types shown. The designs for these bridges typically use the top slab of the box beam as the wearing surface and therefore do not call for placement of a deck as part of the bridge project. This design approach is not typically being used currently on freeway or major roadway application and raises the question whether these bridges are truly comparable.

In addition, the average cost shown in the table for SPG bridges is nearly equal to the 75th-percentile cost. This result occurs because two bridges are significantly more complex than the remaining 10 bridges in the sample set and drive the average cost up. Excluding these two bridges results in an average cost of $158/sf. This result illustrates the potential flaw in using average bridge costs from large sample sets to develop estimated costs for future bridge projects.

Figure 14 shows the range of cost per square foot of bridge deck for each beam subtype within the straight, highly skewed, and horizontally curved alignment types. The figure shows a colored bar chart that spans from the minimum to the maximum bridge costs within a given beam subtype, the number of bridges included, and a callout for the average cost within each beam subtype.

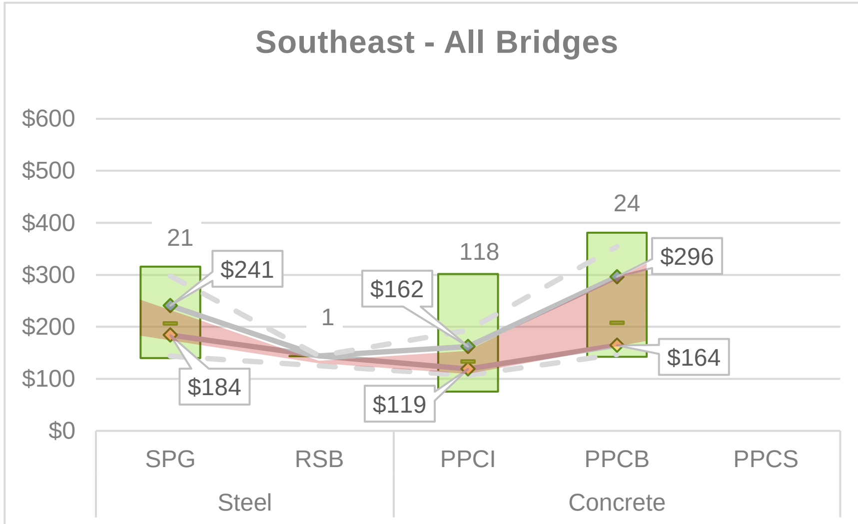
Figure 14: Central Region Results by Alignment Type



Southeast Region

Figure 15 shows the combined results from the three Southeast Region states included in the review. All costs have been escalated from the year of letting to the base year of Q2 2019 and have been location adjusted before being included in the figure.

Figure 15: Southeast Region Results[4]



The figure is divided into primary beam types of steel and concrete and is further divided by beam subtype (SPG/RSB, PPCI/PPCB/PPCS). The figure shows a colored bar chart that spans from the minimum to the maximum bridge costs within a given beam subtype. The total number of bridges of each beam type is indicated by the number at the top of each bar of the bar chart. Also shown are the 10th-, 25th-, 50th-, 75th-, and 90th-percentile costs for each beam subtype. The 10th- and 90th-percentile costs are represented by the dashed line.

The 25th- and 75th-percentile costs are represented by the solid line and include labels. The 50th-percentile or median cost is represented by a dash. The area shaded between the 25th and 75th percentiles represents the range of costs for the middle 50th percentile of projects built within each beam subtype. Similarly, the area between the two dashed lines, which is not shaded, represents the range of costs for the middle 80th percentile of projects

Table 8: Southeast Region Results Table

Beam Type		North Carolina Reg. Adj. – 0.8412			South Carolina Reg. Adj. – 0.8365			Kentucky Reg. Adj. – 0.8821			Regional Total		
Primary	**Secondary**	**No**	**%**	**Avg $/sf**	**No**	**%**	**Avg $/sf**	**No**	**%**	**Avg $/sf**	**No**	**%**	**Avg $/sf**
Steel	SPG	16	22.5%	$202	2	4.7%	$242	3	6.0%	$260	21	12.8%	$214
	RSB	1	1.4%	$144							1	0.6%	$144
Steel Total		**17**	**23.9%**	**$199**	**2**	**4.7%**	**$242**	**3**	**6.0%**	**$260**	**22**	**13.4%**	**$211**
Concrete	PPCI	54	76.1%	$129	41	95.3%	$166	23	46.0%	$141	118	72.0%	$144
	PPCB							24	48.0%	$234	24	14.6%	$234
Concrete Total		**54**	**76.1%**	**$129**	**41**	**95.3%**	**$166**	**47**	**94.0%**	**$188**	**142**	**86.6%**	**$159**

[4] This figure has all span lengths and complexities and does not compare like structures. See the following pages and figures, which break down the cost into similar structures.

Table 8 above summarizes the bridge projects in the Southeast Region that were included in the review. As shown in the table, the states in this region focus primarily on PPCI bridges, with 72% of the total samples being this bridge type. Bridge projects from North Carolina and Kentucky were taken primarily after 2016, whereas projects from South Carolina are spread more evenly between 2014 and 2018.

Figure 16 shows the range of cost per square foot of bridge deck for each beam subtype within the four span classifications. The figure shows a colored bar chart that spans from the minimum to the maximum bridge costs within a given beam subtype, the number of bridges included, and a callout for the average cost within each beam subtype.

Figure 16: Southeast Region Results by Span Length

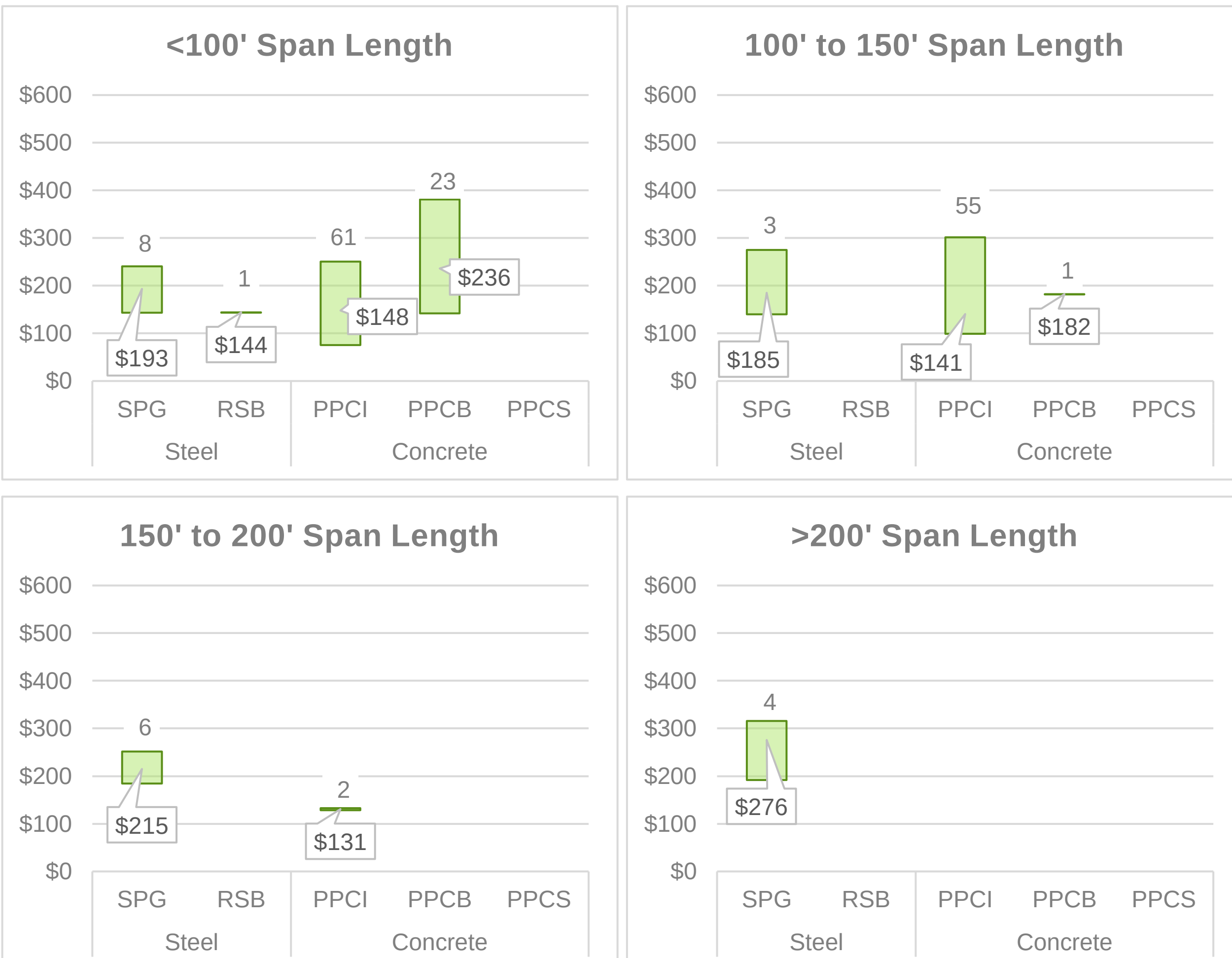


Figure 17 shows the range of cost per square foot of bridge deck for each beam subtype within the straight, highly skewed, and horizontally curved alignment types. The figure shows a colored bar chart that spans from the minimum to the maximum bridge costs within a given beam subtype, the number of bridges included, and a callout for the average cost within each beam subtype.

Figure 17: Southeast Region Results by Alignment Type

Northeast Region

Figure 18: Northeast Region Results[5]

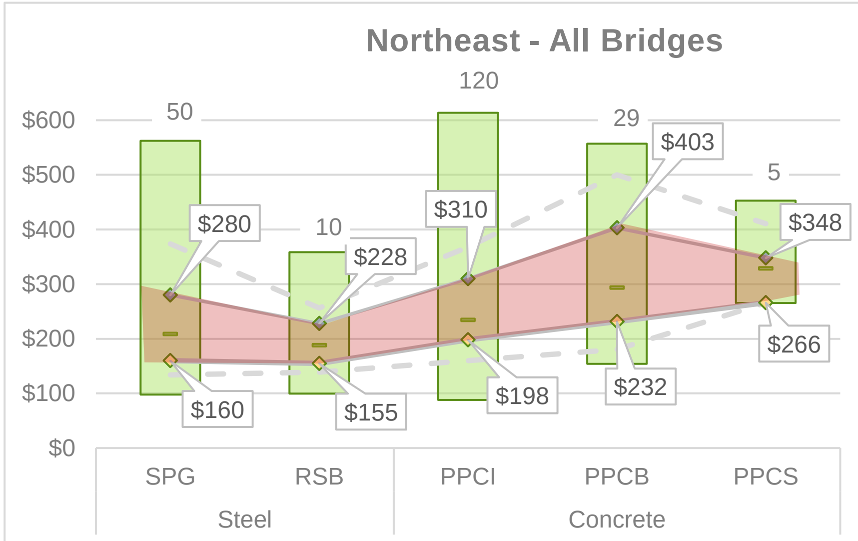


Figure 18 shows the combined results from the three Northeast Region states included in the review. All costs have been escalated from the year of letting to the base year of Q2 2019 and have been location adjusted before being included in the figure.

The figure is divided into primary beam types of steel and concrete and is further divided by beam subtype (SPG/RSB, PPCI/PPCB/PPCS). The figure shows a colored bar chart that spans from the minimum to the maximum bridge costs within a given beam subtype. The total number of bridges of each beam type is indicated by the number at the top of each bar of the bar chart. Also shown are the 10th-, 25th-, 50th-, 75th-, and 90th-percentile costs for each beam subtype.

The 10th- and 90th-percentile costs are represented by the dashed line. The 25th- and 75th-percentile costs are represented by the solid line and include labels. The 50th-percentile or median cost is represented by a dash. The area shaded between the 25th and 75th percentiles represents the range of costs for the middle 50th percentile of projects built within each beam subtype. Similarly, the area between the two dashed lines, which is not shaded, represents the range of costs for the middle 80th percentile of projects.

Table 9: Northeast Region Results Table

Beam Type		Michigan Reg. Adj. – 0.9303			New York Reg. Adj. – 1.1506			Pennsylvania Reg. Adj. – 0.9846			Regional Total		
Primary	**Secondary**	**No**	**%**	**Avg $/sf**	**No**	**%**	**Avg $/sf**	**No**	**%**	**Avg $/sf**	**No**	**%**	**Avg $/sf**
Steel	SPG	15	21.1%	$275	28	60.9%	$190	7	7.2%	$338	50	23.4%	$237
	RSB				10	21.7%	$197				10	4.7%	$197
Steel Total		**15**	**21.1%**	**$275**	**38**	**82.6%**	**$192**	**7**	**7.2%**	**$309**	**60**	**28.0%**	**$230**
Concrete	PPCI	41	57.7%	$253	2	4.3%	$278	77	79.4%	$258	120	56.1%	$257
	PPCB	15	21.1%	$243	1	2.2%	$182	13	13.4%	$422	29	13.6%	$321
	PPCS				5	10.9%	$332				5	2.3%	$332
Concrete Total		**56**	**78.9%**	**$250**	**8**	**17.4%**	**$300**	**90**	**92.8%**	**$282**	**154**	**72.0%**	**$271**

[5] This figure has all span lengths and complexities and does not compare like structures. See the following pages and figures, which break down the cost into similar structures.

Table 9 above summarizes the bridge projects in the Northeast Region that were included in the review. As shown in the table, concrete bridges were built nearly three out of four times, with PPCI bridges leading the way at over 56% across the region. The trend was driven by Michigan and Pennsylvania, while New York showed the opposite trend, building steel bridges over 82% of the time. The bridge samples taken throughout the region were spread relatively evenly throughout the period from 2016 to 2018. The regional adjustment factor applied to projects in New York is 115.06, which results in the greatest negative price adjustment and joins Illinois as the only two states with negative location adjustments.

From a regional perspective, the results indicate that the average cost per square foot of bridge deck for both SPG and RSB bridges is more cost-competitive than for all of the concrete options. This trend is driven primarily based on the results from New York, where the majority of steel bridges in the region are found and where the cost is significantly lower than in the other states.

In Pennsylvania, the cost for SPG bridges is higher than expected. As shown in Table 10, the costs of Bridges 26898 and 26906 are significantly higher than the costs of other SPG bridges in the state, and the cost of Bridge 36A22 is somewhat higher. The costs of Bridges 26898 and 26906 are driven by a combination of substructure and beam costs, whereas the superstructure costs are driving the costs for Bridge 36A22. These three bridges are on the lower end of the spectrum with regard to the overall deck area, and this lower value can increase the unit price per square foot of bridge deck.

Table 10: SPG Bridge Cost Detail

Sub-group	26898	26906	27048	27051	32135	35232	36A22
Mobilization	$42.35	$35.78	$15.16	$9.45	$18.35	$10.75	$22.80
Structure ex	$117.45	$68.56	$10.74	$3.27	$15.74	$11.74	$75.56
Foundations	$44.02	$51.28	$13.54	$29.48	$49.87	$28.42	$48.42
Substructure	$134.04	$121.28	$30.91	$17.92	$39.49	$27.64	$80.82
Beams	$153.84	$210.50	$129.44	$57.68	$91.99	$54.00	$82.06
Superstructure	$70.53	$67.85	$71.00	$34.50	$72.71	$31.91	$61.12
Total	**$562**	**$555**	**$271**	**$152**	**$288**	**$164**	**$371**
Deck area (sf)	7,131	7,646	51,571	164,274	128,385	90,772	9,104
Service type	Freeway	Freeway	Freeway	Freeway	Freeway	Freeway	Rural
Crossing type	Freeway /Railroad	Freeway /Railroad	Rural	Rural	Rural	Rural	Railroad
Staged	Y	Y	Y	Y	Y	Y	Y
Bridge alignment	Curved	Curved	Curved	Straight	Curved	Curved	Skewed
Length (lf)	202	183	765	993	1,232	531	105
Width (lf)	35.4	41.9	67.4	165.4	104.2	171.0	86.7
Max span length	106	183	184	250	143	180	105
Str steel/deck sf	50.9	67.5	41.3	22.3	35.2	19.9	36.4

Bridges 26898 and 26906 are somewhat similar in complexity. Both are narrow ramps providing access from one freeway to the next. They provide crossings over a combination of freeway ramps and existing railroad lines, and building such bridges requires complex staging and work under freeway traffic conditions. Both bridges called primarily for Grade 50 steel with a small amount of galvanized steel at a bid unit price of $3/lb. The weight of steel per area of bridge deck appears to be higher than what would be expected based on the span length.

Bridge 36A22 is a less-complex bridge to build but also provides a crossing over an active railroad line. Based on the complex location and staging and the limited work windows that are often associated with bridge construction around active railroad lines, it is not surprising that the substructure and beam elements of these bridges are more expensive than those of a simpler bridge in a simpler location. If these bridges were removed from the analysis, the average unit cost of SPG bridges in Pennsylvania would be about $249/sf, which would result in SPG bridges becoming the most cost-competitive in the state.

The cost for PPCB bridges is also higher than expected, however similar analysis shows that these bridges are well distributed with the middle 50th percentile between $364 and $500.

Figure 19 shows the range of cost per square foot of bridge deck for each beam subtype within the four span classifications. The figure shows a colored bar chart that spans from the minimum to the maximum bridge costs within a given beam subtype, the number of bridges included, and a callout for the average cost within each beam subtype.

Figure 19: Northeast Region Results by Span Length

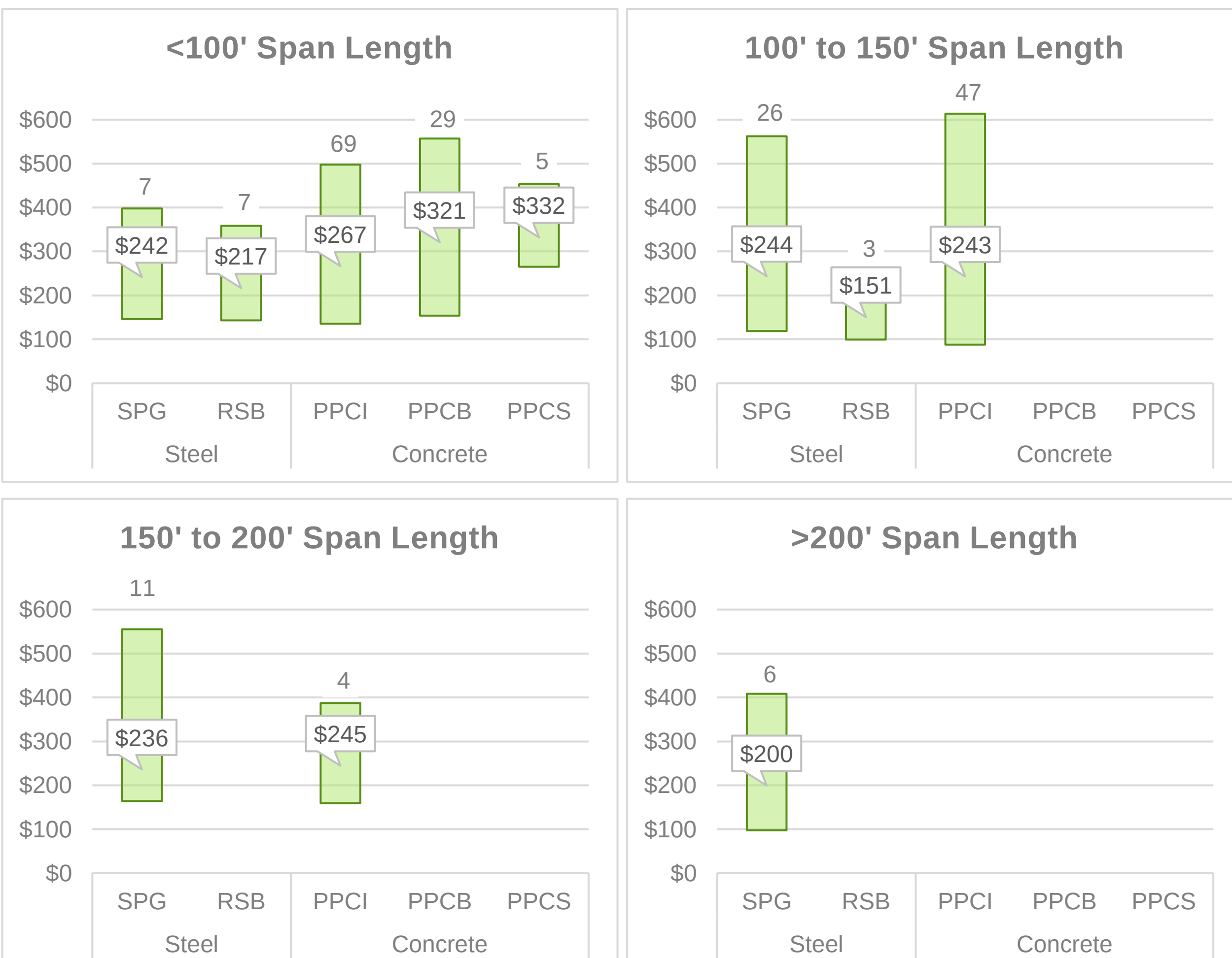
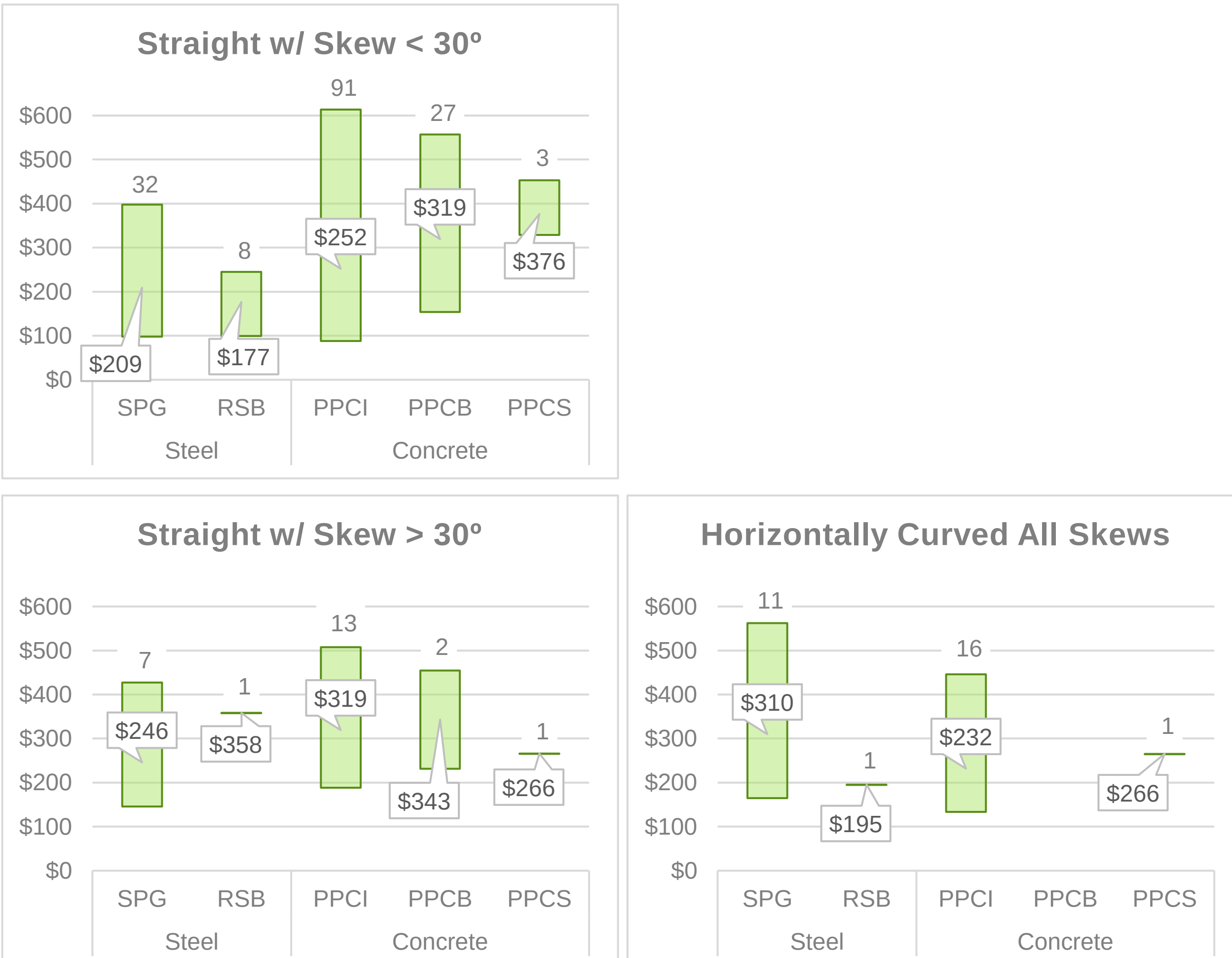


Figure 20 shows the range of cost per square foot of bridge deck for each beam subtype within the straight, highly skewed, and horizontally curved alignment types. The figure shows a colored bar chart that spans from the minimum to the maximum bridge costs within a given beam subtype, the number of bridges included, and a callout for the average cost within each beam subtype.

Figure 20: Northeast Region Results by Alignment Type



State

Table 11 summarizes the average parametric bridge cost by state, beam subtype, and span length. The costs shown include escalation as described previously but exclude the regional adjustment factor.

Table 11: Statewide Average[6] Bridge Cost by Span Category (without Regional Adjustment)

Region	State	Beam Type	Beam Subtype	Cost ($/SF) by Span Length (feet) <100	100 to 150	150 to 200	>200	All Spans ($/SF)
West	Washington	Steel	SPG				189	189
		Concrete	PPCI	315	262	239	255	256
			PPCS	357				357
	Oregon	Steel	SPG		182	187	221	194
		Concrete	PPCI	266	169		273	205
			PPCB	298				298
	Texas	Steel	SPG		240	139	130	171
		Concrete	PPCI	112	107	121		112
			PPCB	130				130
			PPCS	132				132
Central	Minnesota	Steel	SPG		216	234		225
		Concrete	PPCI	185	190	138		185
	Illinois	Steel	SPG	165	194	173		186
			RSB	171				171
		Concrete	PPCI	174	215			181
			PPCB	125				125
	Arkansas	Steel	SPG	158	161	150	228	167
			RSB	141	202			145
Southeast	North Carolina	Steel	SPG	165	156	175	213	171
			RSB	121				121
		Concrete	PPCI	113	106	110		109
	South Carolina	Steel	SPG			202		202
		Concrete	PPCI	133	149			139
	Kentucky	Steel	SPG			162	263	229
		Concrete	PPCI	128	118			124
			PPCB	208	161			206
Northeast	Michigan	Steel	SPG	201	285	195	380	256
		Concrete	PPCI	245	223			235
			PPCB	226				226
	New York	Steel	SPG	290	205	220	183	219
			RSB	249	173			226
		Concrete	PPCI	320				320
			PPCB	209				209
			PPCS	382				382
	Pennsylvania	Steel	SPG		401	325	150	333
		Concrete	PPCI	264	241	241		254
			PPCB	415				415

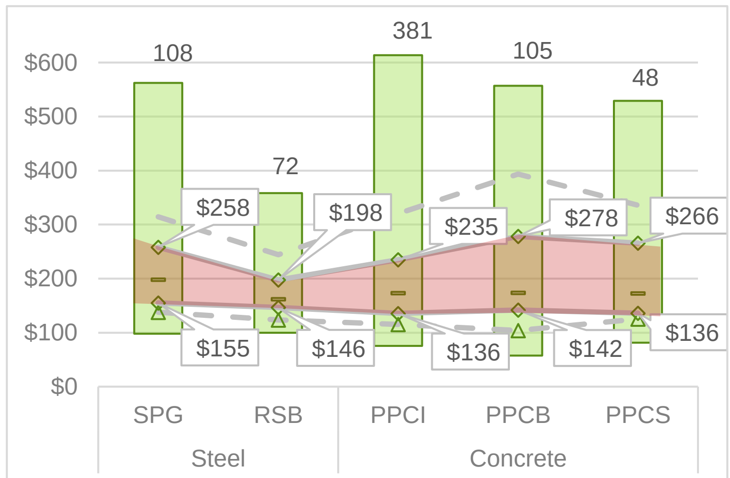
6 This table presents average bridge costs. The actual expected cost for any given bridge is based on specific site conditions and may vary greatly from the average. Therefore, the use of average cost during the type selection process can lead to selecting a more expensive bridge. We recommend that cost ranges presented elsewhere in this report are used to make informed selection decisions.

Conclusions

The objective of this review was to analyze the initial construction costs of structural steel and concrete bridges that have been built across the United States in order to compare the in-place cost of these bridge types on national, regional, and state bases.

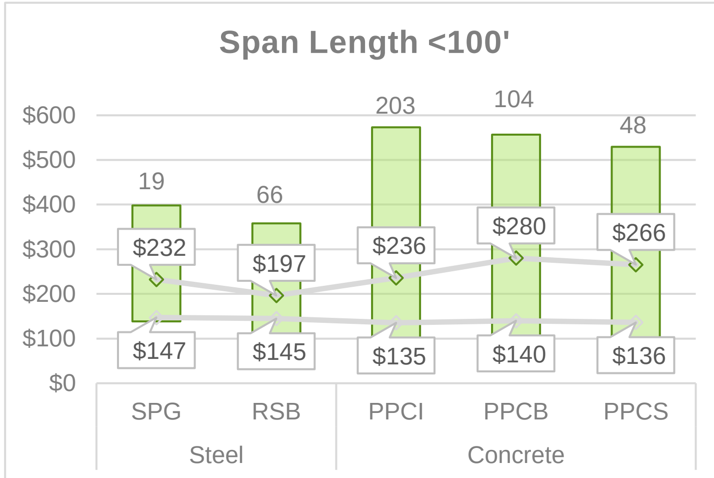
The Results section of this report provides various quantitative summaries of the results, while this Conclusions section presents the authors' findings and interpretations based on those quantitative summaries.

1. **Overall, steel bridges are cost-competitive with concrete bridges.**



This conclusion is drawn from our review of the results published in this report and other statistical analyses conducted as part of developing this report. There is significant overlap in bridge cost among the beam subtypes included in this review, especially within the middle 50th-percentile or median range of cost. Figure 4 (which is reproduced at right) illustrates this result on the national level; however, the trend is common for results at the regional and state levels and is repeated throughout various span length ranges and alignment types. This overlap indicates that, from a cost-competiveness perspective, any of the bridge types could potentially be the most cost-competitive type for a given set of circumstances. Therefore, no bridge type should be eliminated from the type selection process based on a historical average unit price comparison. State DOTs might want to consider publishing bridge costs as ranges as opposed to discrete average prices to avoid eliminating bridge types from consideration that might be the lowest overall cost. State DOTs might also want to consider publishing bridge costs based on other factors such as span length or complexity to provide a more complete picture of potential bridge cost ranges.

2. At the 75th percentile, RSB bridges are most cost-competitive, and PPCB bridges are least cost-competitive.



This conclusion is drawn from our review of the various results published in this report. Figure 4 (which is reproduced above) illustrates this result on the national level for all span lengths, and Figure 5 (which is reproduced at right) illustrates this result on the national level for span lengths less than 100 feet. The trend is common for results at the regional levels, but note that only four states in our review used RSB bridges. This conclusion indicates that DOTs that have adopted RSB bridges could experience lower initial costs across their structures program, especially in the short-span market where RSB bridges compete directly with PPCB bridges.

3. States exhibit distinct trends in the use of particular bridge types, and more States tend to use concrete than steel.

Table 1 (which is provided in summary form at right) illustrates that concrete bridges were built 75% of the time over all states included in our review. It also illustrates trends that individual States exhibit toward using particular bridge types. Nine out of the 12 States included in the review showed a significant trend toward using concrete bridges, with 6 of these 9 States selecting concrete bridges in over 9 out of 10 cases. Conversely, 2 out of the 12 States included in the review showed a trend toward using steel bridges, with Arkansas selecting steel bridges exclusively over the review's time period. Only 1 out of 12 States included in the review appeared to show no distinct trend, with Illinois selecting concrete and steel bridges at roughly equal numbers.

Region	State	Steel	Concrete
West	Oregon	15%	85%
	Texas	6%	94%
	Washington	5%	95%
Central	Arkansas	100%	0%
	Illinois	48%	52%
	Minnesota	4%	96%
Southeast	Kentucky	6%	94%
	North Carolina	24%	76%
	South Carolina	5%	95%
Northeast	Michigan	21%	79%
	New York	83%	17%
	Pennsylvania	7%	93%
	Total	**25%**	**75%**

The scope of this report does not include attempting to understand the type selection process used by DOTs to choose which type of bridge to build; however, the data collected suggest that, within the parameters of this review, concrete beam types are generally selected three out of four times. DOTs might choose concrete beam types more often because many DOTs publish expected budgetary bridge costs for their state and often list concrete bridges as a more cost-competitive option, or they might make this choice for other reasons or a combination of reasons not presented in this report.

Limitations of this Report

HDR reiterates that this report does not include all bridges built in any given state. DOTs in many states are turning to alternative approaches such as Design-Build, CMGC, and Public-Private Partnerships (P3) to deliver projects, and these costs are typically not available in the historical databases and are therefore not included in this review. Additionally, this report focused on bridges contracted through DOTs only and did not attempt to collect samples from other agencies such as transit, tollway, or ports of authority. Therefore, the results of this review should not be compared to other studies based on the National Bridge Inventory or other national sources of information.

Authors Comments

These conclusions come as a surprise to the authors, who assumed that concrete bridges would be more cost-competitive than steel bridges. In fact, when developing preliminary cost estimates that include both concrete and steel bridges, the authors have traditionally set the parametric price for concrete bridges lower than steel bridges, and this assumption is nearly always accepted as a matter of fact. Additionally, several bridge engineers from around the country helped with the data collection and analysis for this review, and most echoed the assumption that concrete bridges would be cheaper than steel bridges. However, the results do not lead to this conclusion.

Statistical Analysis of Beam Subtype Mean Price Differences

INTRODUCTION

The results described within the report have demonstrated how the middle 50 percent of unit prices varied among the five different beam subtypes, and how these ranges changed depending on whether all bridges were evaluated or sub-sets of bridges were studied. Key bridge characteristics such as regional location, maximum span length and skew angle were used to drill down into the data set to study bridges with shared features so as to conduct an ‘apples-to-apples’ comparison of unit prices by beam subtype material.

This comparative analysis showed that unit prices in the mid-range levels for SPG and RSB bridges tended to share values with the unit prices in the mid-range levels observed in PPCI, PPCB and PPCS bridges when studying bridges with shared characteristics. While the comparative analysis based on all 714 bridges did show that SPG bridges tended to have a higher sample mean and 75th percentile for unit prices compared to the other beam subtypes (see Figure 4), this trend was not consistently repeated when conducting the ‘apples-to-apples’ comparisons within sub-sets of bridges with shared features. The overlap in mid-range prices across the five different beam subtypes opened the door to further testing of bridge unit price assumptions based on whether or not a bridge’s beam was constructed from steel versus concrete.

This study used a type of statistical analysis called regression analysis to objectively test whether there are predictable differences in unit prices among the five beam subtypes from a statistical perspective. The statistical testing process evaluates whether the observed differences in group means are materially different from zero while simultaneously controlling for shared bridge characteristics such as regional location, skew angle, crossing type and other variables.

Regression analysis uses statistical theory to test if differences in group sample means could have occurred by chance or due to the attributes of the samples in each group being tested. For example, the groups in this analysis are the five different beam subtypes. This study is interested in testing if the sample mean prices for SPG and RSB bridges are different than the sample mean prices for PPCI, PPCB and PPCS bridges. Differences in mean prices could happen just by chance or they could be due to a measurable quality of the bridge samples (e.g., beam subtype material) that influences price trends in a systematic, non-random fashion.

If the statistical test results indicate that observed differences are random in nature, then the test result is described as being *not statistically significant*; otherwise, it is *statistically significant*. This study used the 1 percent significance level as the threshold to determine if differences in sample means were statistically significant or not. If the probability associated with observing a difference in mean prices between two beam subtypes is less than 1 percent, then there is only a 1 percent probability that the differences happened by chance. With such a low probability, the observed differences are considered to be non-random in nature and can be attributed to differences in the materials used to fabricate the beams (i.e., steel versus concrete).

DATA DESCRIPTION

This statistical analysis used 712 bridges to conduct the regression analysis. These are the same bridges used in the earlier analysis with the exception of two bridges belonging to the pedestrian service type category which were dropped. Given the extremely low numbers in this category, there was not enough sample variability in these groups to add to the regression analysis.

Table 12 below characterizes the bridges by beam subtype. Based on the simple statistics, SPG bridges have the highest means and medians of the sets. RSB bridges have the lowest such statistics. The most popular beam subtype is PPCI with 379 out of the 712 of bridges or 53 percent having this particular subtype. Its mean unit price of $198 per square foot of deck falls in the middle of the five subtypes. Its median unit price of $173 per square foot of deck is similar to the other concrete subtypes, PPCB and PPCS.

Table 12: Descriptive Statistics of Bridge Unit Prices ($)

	Statistic				
Beam Subtype Name	**Count**	**Mean**	**Median**	**Minimum**	**Maximum**
Steel Plate Girder	108	$ 218	$ 198	$ 98	$ 562
Rolled Steel Beam	72	$ 177	$ 162	$ 100	$ 358
Precast Prestressed Concrete I Beam	379	$ 198	$ 173	$ 75	$ 614
Precast Prestressed Concrete Box Beam	105	$ 215	$ 174	$ 58	$ 557
Precast Prestressed Concrete Slab	48	$ 206	$ 173	$ 81	$ 529
All Bridge Types	712	$ 202	$ 175	$ 58	$ 614

The same data used to construct Table 12 is displayed graphically in Figure 21. In this figure, one can see where the bulk of the unit prices is situated per subtype. The black line in the middle of each box represents the median unit price. The dotted line follows the trends in mean unit prices. The lower and upper boundaries of the boxes capture the 25th and 75th percentiles of unit prices, respectively. The lower and upper whiskers represent the values derived by multiplying the inter-quartile range (difference between the 75th and 25th percentiles) with a factor of 1.5, and then subtracting that value from the 25th percentile to produce the lower whisker and adding that value to the 75th percentile to produce the upper whisker. The green dots represent unit prices that are outside this range.

Figure 21: Box and Whiskers Plots of Unit Prices by Beam Subtype

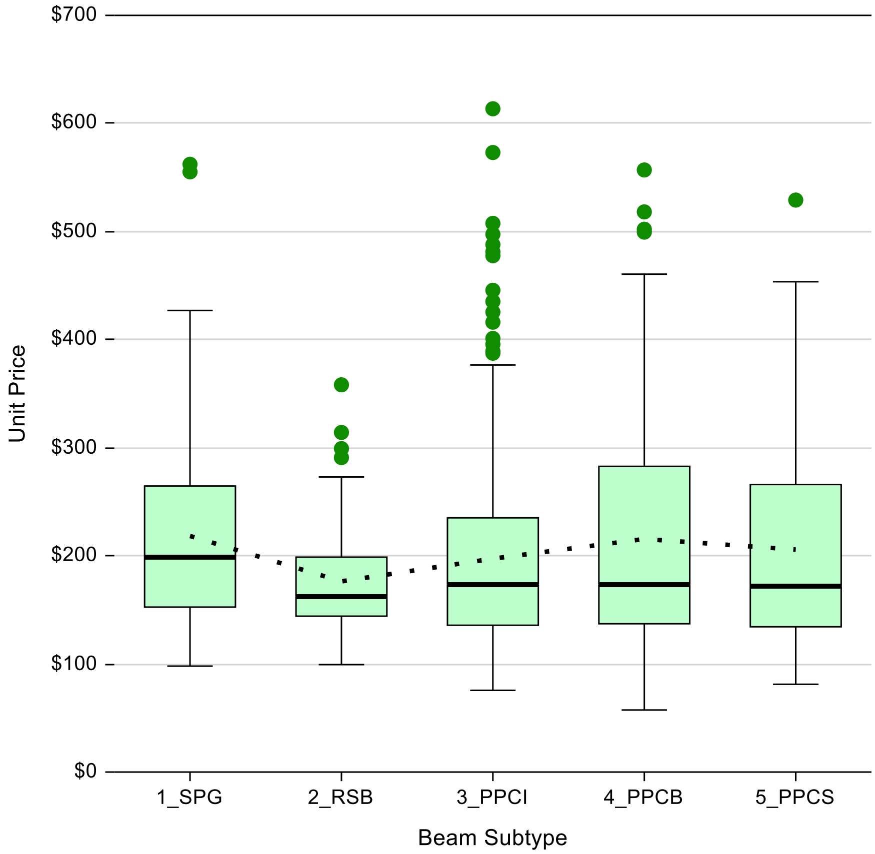


Figure 21 shows that there is a tendency for unit prices to be higher for SPG bridges compared to the remaining four subtypes. However, with the bulk of the unit prices per subtype covering similar price ranges with each other, and with many bridges having unit prices in the PPCI data set much higher than the 75th percentile of unit prices for SPG bridges, an objective evaluation is required to assess in an unbiased manner whether there is a systematic bias in bridge unit prices introduced solely to using steel beams rather than concrete beams. This evaluation is based on a regression analysis and modelling approach. The approach introduces the notion of control factors to enable an unbiased comparison of mean prices between sets of beam subtypes while simultaneously controlling for other factors (that is, bridge characteristics) that are known and accepted by industry to impact prices. In this manner, if mean prices differences are observed to be statistically significant, then the differences can be attributed to type of material used to construct the beam rather than to other bridge characteristics such as location, service type, crossing type, among others.

REGRESSION ANALYSIS

Regression analysis is done to produce a mathematical equation that relates the unit price per bridge as a function of other variables believed to best explain the trends and variability in unit prices. It is a statistical means to relate the variability in bridge prices per square foot of deck as a function of bridge characteristics. The following equation is a simplification of the regression analysis conducted. The equation models the mean unit price per bridge as represented by $\boldsymbol{E}[\boldsymbol{Price_i}]$ as a function of variables. The first five terms on the right-hand side of the equation indicate whether a given bridge has PPCI, SPG, RSB, PPCB or PPCS beam subtypes. If a bridge does not use SPG, RSB, PPCB or PPCS beam subtypes, the coefficient $\boldsymbol{\beta_0}$ captures the effect of PPCI bridge on unit price levels. The functional form of the model treats PPCI as the reference group for testing purposes. The coefficients $\boldsymbol{\beta_1}$to $\boldsymbol{\beta_4}$ capture the mean differences between a given beam subtype indicated in the term relative to the PPCI subtype.

$$\boldsymbol{E}[\boldsymbol{Price_i}] = \boldsymbol{\beta_0} + \boldsymbol{\beta_1 SPG_i} + \boldsymbol{\beta_2 RSB_i} + \boldsymbol{\beta_3 PPCB_i} + \boldsymbol{\beta_4 PPCS_i} + \sum \boldsymbol{X_{ij}\,\beta_i}$$

The summation term in the equation, that is $\sum \boldsymbol{X_{ij}\beta_j}$, captures key bridge characteristics which play a vital role in unit price trends and account for the majority of unit price variability across the bridges in the sample. By including them in the analysis, they can control for apparent price differences in bridges. The factors or characteristics this study found to be significant in explaining unit price trends and variability are as follows:

- Region: west, southeast, central, northeast
- Crossing type: railroad, waterway, freeway, rural road
- Bridge alignment: skewed, straight, horizontally curved
- Service type: rural, freeway
- Number of spans, maximum span length
- Deck area and deck width to length ratio.

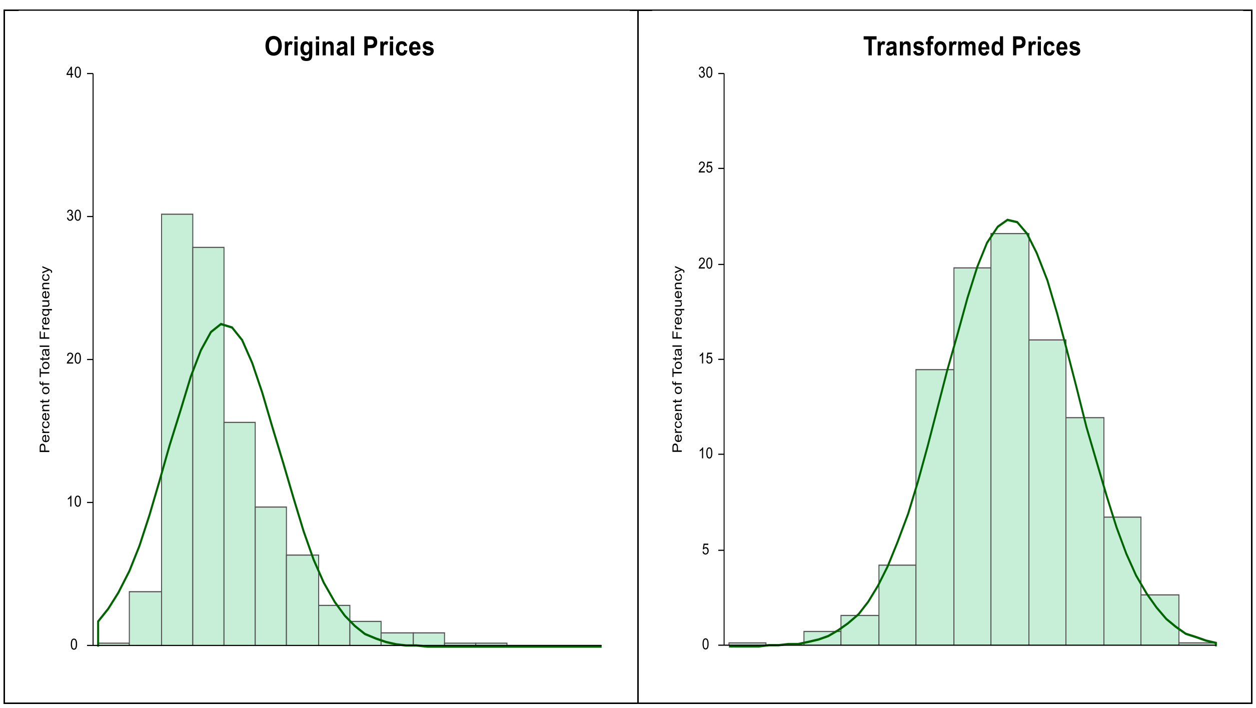
The remaining variability which cannot be explained by the above key factors is left to the beam subtypes to explain provided one or more of the subtypes has a coefficient value that is *statistically significant.* If the coefficient happens to be positive, then its respective beam subtype has a mean unit price that is higher than the PPCI mean unit price. If it is negative, the converse is true. If the difference in mean unit price per subtype with that of the PPCI subtype is *not statistically significant*, then observed differences in mean unit prices are a result of random fluctuations generated from the sample of bridges.

MODELING ASSUMPTIONS

In order to have confidence in the test results from regression analysis, key data assumptions should be validated. The key assumptions are that the observations from a sample follow a known distribution (for example, the normal distribution), are independent of each other, and have a constant variance across the observations. The authors studied the patterns in the unit prices from the sample of bridges and found that the data were not normally distributed, nor did the data follow any of the other main distributions such as lognormal, exponential, or gamma. The study assumed sample unit prices were independent of each other given sampled bridges are widely dispersed.

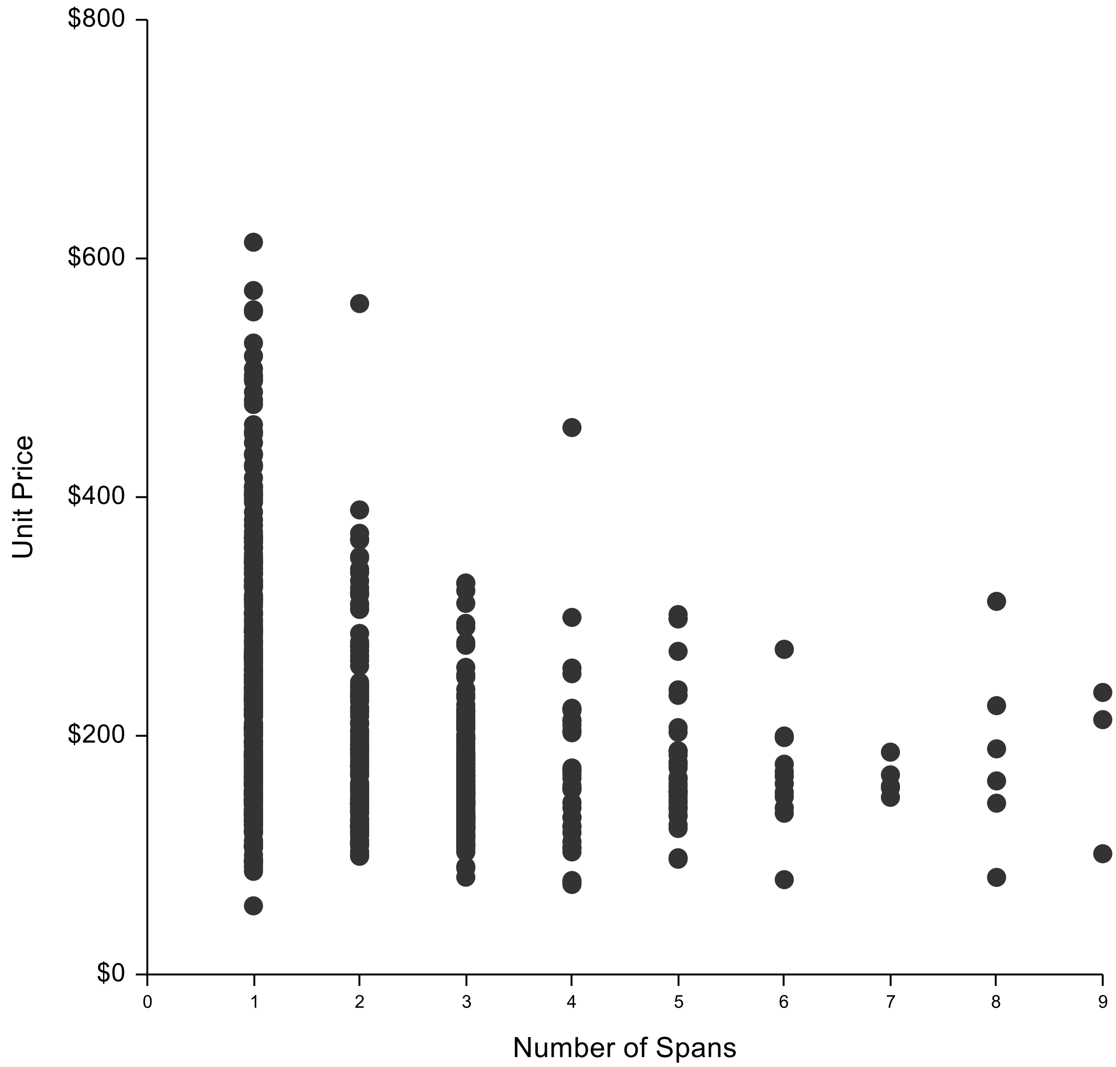
Figure 22a shows that the empirical distribution of unit prices is skewed to the right and that its shape deviates from the familiar normal bell shaped curve overlaid on the sample distribution. Prior to performing the statistical modeling used for this study, a transformation is required to remove this skew and normalize it. The authors tested many types of transformation on unit prices and were able to find a function which transformed the data to resemble a normal type distribution. Tests for goodness-of-fit showed that the transformed data did follow a normal distribution and was suitable for regression analysis. The distribution in Figure 22b demonstrates the result of the transformation and the distribution's approximation to the normal distribution.

Figure 22: Original and Transformed Distributions of Unit Prices



The particular type of regression analysis used for the analysis of the bridge sample is a generalized linear model (GLM).[7] It is an extension of the more common ordinary least squares (OLS) regression model. Among its added features over and above the OLS regression model, GLMs control for non-constant variance of the variable being modeled or tested. The evaluation noted that the variance of unit prices markedly changes by the number of spans. See Figure 23. As the number of spans increases, the variability range per span number becomes systematically smaller. (For the purpose of demonstrating the trends, the plot only tracks up to 9 spans. The maximum number of spans is 66.) To stabilize the variance of prices over the data, the authors used the number of spans as a weighting factor in the regression analysis.

Figure 23: A Plot of Unit Prices by Number of Bridge Spans



[7] McCullagh,P., and J.A. Nelder. 1989. Generalized Linear Models. London: Chapman & Hall.

REGRESSION RESULTS

The statistical output from the regression analysis is summarized in . The authors tested many bridge characteristics which could explain trends in unit price variability, but not all were statistically significant. Some of the bridge characteristics were functions of other variables and it would be redundant to include them in the model. For example, the total length of the bridge is correlated to the square foot of total bridge deck. Only one of these two variables can be used as an explanatory variable in the regression model. The qualifying variables (i.e., bridge characteristics) are listed in and are statistically significant at the 1 percent significance level. Bridge characteristics which were tested but found to be not statistically significant at the 1 percent significance level were staged construction (yes or no), coating system (painted, not painted, not applicable), and primary structural steel grade (50, 70) and weathering (weathered, not weathered, not applicable).

The main objective of the statistical analysis was to evaluate if differences in mean unit prices between different sets of beam subtypes were statistically significant or not. The results in show that Table 12 differences in mean unit prices for each of the beam subtypes SPG, RSP, PPCB and PPCS in relation to PPCI are not statistically significant at the 1 percent significance level. The authors re-ran the regression analysis switching PPCI with PPCB and then with PPCS. Results still showed that there were no statistically significant differences in mean unit prices between each of the beam subtypes and the reference groups.

Table 13: Coefficient Statistical Test Results

Bridge Characteristic		Sign	Significant
Beam Subtype	SPG	+	No
	RSB	+	No
	PPCB	-	No
	PPCS	+	No
	PPCI		
Region	West	-	No
	Southeast	-	Yes
	Northeast	+	Yes
	Central		
Service Type	Rural Road	-	Yes
	Freeway		
Crossing Type	Waterway	-	Yes
	Rural Road	-	Yes
	Railroad	-	Yes
	Freeway		
Alignment Classification	Straight	-	Yes
	Highly Skewed	-	Yes
	Horizontally Curved		
Span Length		+	Yes
Deck Area		-	Yes
Width to Length Ratio		+	Yes
Skew Angle		+	Yes

The sign of the coefficient associated with each factor is also included in . A positive coefficient sign indicated that the mean unit price for a characteristic in relation to its reference group is higher. A negative coefficient indicates it is lower. The blank cells indicate the reference category. However, the interpretation of whether those differences are material or not is left to the outcome of the statistical tests of significance. With respect to the beam subtype bridge characteristic, the mean differences are not statistically significant, and hence differences are simply due to random variation within the sample.

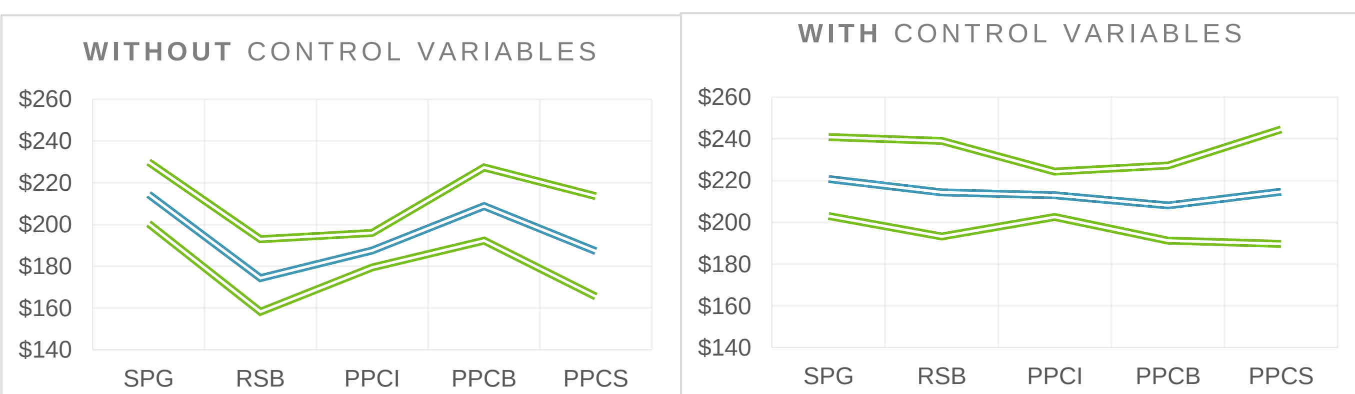
When a characteristic is statistically significant such as bridge service type, then the differences in mean unit prices between the two different service types is statistically significant holding all other bridge characteristics constant. For example, the coefficient for the rural service type bridges is negative and is statistically significant. This demonstrates that the mean unit price for rural service type bridges relative to freeway service type bridges is lower on average holding all other bridge characteristics constant. The bridge characteristics that are measured such as deck area or skew angle can be interpreted to mean that as the characteristic increases in value, the unit price per bridge either increases (positive coefficient) or decreases (negative coefficient) at the rate estimated by its respective coefficient.

IMPORTANCE OF CONTROL VARIABLES

The authors repeated the same regression analysis to assess the impact on testing for mean differences in unit prices by beam subtypes when bridge characteristics are not included as control variables in the analysis. The estimated mean price modeled from this regression analysis per beam subtype is plotted in Figure 24a. The mean prices are bounded by lower and upper values which denote the 95 percent confidence interval for the mean prices. A 95 percent confidence interval for a mean unit price estimated from the sample represents a probable range of values that one can be 95 percent certain contains the true mean unit price of the population.

The trend in the mean prices enveloped within their confidence intervals shows notable deviations in unit prices and ranges. The statistical tests at the 1 percent significance level for the effects of beam subtype on price differences without controlling for other key bridge characteristics showed that there are statistically significant differences. The mean unit price for SPG bridges is higher than PPCI bridges, but not for PPCB or PPCS bridges. The mean unit price for RSB bridges is not statistically different from PPCI or PPCS bridges. The mean unit price for RSB bridges is statistically different and lower than for PPCB bridges. However, when key bridge characteristics are included in the regression model, they are able to explain the majority of the variation in price trends. This is graphically demonstrated by the flattening of the confidence interval band across the five beam subtypes in Figure 24b. As discussed in the previous section, the observed differences in mean unit prices between SPG or RSB bridges relative to PPCI, PPCB and PPCS bridges are not statistically significant. Differences in the estimated means per subtype while simultaneously holding key bridge characteristics constant at their sample averages are slight and substantially lower than the same analysis done without control variables.

*Figure 24: 95 Percent Confidence Interval of Mean Unit Prices **without** and **with** Control Variables*



FINDINGS

The outcomes from the statistical analysis using regression modeling approaches showed that observed differences in mean prices between bridges that use SPG or RSB beam subtypes relative to bridges that use beam subtypes PPCI, PPCB or PPCS are not statistically significant at the 1 percent significance level while holding other bridge characteristics constant. Mean unit price differences are better explained by regional location, service type, crossing type, bridge alignment and skew angle, span length (ft), deck area (sf), and width to length ratio of deck.