Historical Life Cycle Costs of Steel & Concrete Girder Bridges

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Director of Education, SSSBA

Steel Bridge Essentials
Summer Webinar Series
June 23, 2021
Overview
The Short Span Steel Bridge Alliance (SSSBA)
Initial Costs
   County & State Case Studies
Life Cycle Costs
A group of bridge and buried soil structure industry leaders who have joined together to provide educational information on the design and construction of short span steel bridges in installations up to 140 feet in length.
SSSBA – Our Members

- Producers
- Fabricators
- Fasteners
- Coaters
- Service Centers
- Trade Organizations
- Design Firms
- Contractors
- Bridge Owners
- Universities

SSSBA - Our Members
Initial Costs – Steel vs Concrete

Preconception that Concrete is Less Expensive than Steel for Typical Bridges

Many Times Steel is Not Even Considered
Owners Paying More Than They Could for Bridges
Unwarranted Lack of Competition Not Good

Case Studies from County & State Bridges
Case Study Bridges: Audrain County, MO

MO Bridge 411
- Built 2012
- 4 Steel Girders
- 47.5 ft Span
- 24 ft Roadway Width
- 2 ft Structural Depth + Slab

MO Bridge 336
- Built 2012
- 6 Precast Hollowcore Slabs
- 50.5 ft Span
- 24 ft Roadway Width
- 2 ft Structural Depth + Slab
Side-by-Side Comparison of Total Cost of Bridge

Steel:

- Total Bridge Costs:
  - Material = $41,764
  - Labor = $24,125
  - Equipment = $21,521
  - Guardrail = $7,895
  - Rock = $8,302
  - Engineering = $8,246
  - TOTAL = $111,853

  ($97.48/ft²)

Concrete:

- Total Bridge Costs:
  - Material = $67,450
  - Labor = $26,110
  - Equipment = $24,966
  - Guardrail = $6,603
  - Rock = $7,571
  - Engineering = $21,335
  - TOTAL = $154,035

  ($120.83/ft²)

19.3% Total Cost Savings w/ Steel
Superstructure Only Cost Comparison

**Steel:**

- **Superstructure Only:**
  - Time = 10 days
  - Girders = $21,463
  - Deck Panels = $7999
  - Reinf. Steel = $3135
  - Concrete = $4180
  - Labor = $5522
  - Equipment* = $500
  - TOTAL = $42,799

  $37.54 / ft$^2$

**Concrete:**

- **Superstructure Only:**
  - Time = 13 days
  - Slab Girders = $50,765
  - Deck Panels = $0
  - Reinf. Steel = $724
  - Concrete = $965
  - Labor = $4884
  - Equipment* = $4000
  - TOTAL = $61,338

  $50.61 / ft$^2$

**Material Considerations:**
- Added cost to use galvanized steel ≈ $0.22/lb (includes est. 10% fabrication fee)
- Added cost to use weathering steel ≈ $0.04/lb (already included in cost in example)

**Equipment Considerations:**
- County crane (30-ton) used for steel; Larger rented crane required for concrete
  - Equivalent county crane cost is $1520 (would result in steel cost of $38.88 / ft$^2$)
True Steel vs Concrete Cost Comparison

Steel:

- Superstructure total cost of $37.54 per ft$^2$

Concrete:

- Superstructure total cost of $50.61 per ft$^2$

25.8% Superstructure Cost Savings

Same bridge conditions:
- Structural Depth = 2 ft + Slab (No Difference in Approaches)
- Roadway Width = 24 ft
- Same Abutments for Both Can be Used (Steel Could Use Lighter)
- Same Guard Rail System
- Same Work Crew
Advantages of Steel Bridge

Lighter cranes required
  – Owner cranes can save costs
Advantages of Steel Bridge

Lighter abutments possible for steel bridges
Efficiencies of Steel Bridge

Cast-in-place deck on prestressed concrete deck panels or corrugated metal decking
Efficiencies of Steel Bridge

Simple and practical details
Efficiencies of Steel Bridge

Elastomeric bearings and integral abutments
Efficiencies of Steel Bridge

Use of weathering steel
## Case Study Bridges: Additional Bridges in MO

<table>
<thead>
<tr>
<th>Superstructure</th>
<th>Steel</th>
<th>Concrete</th>
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</thead>
<tbody>
<tr>
<td>Bridge Number</td>
<td>061</td>
<td>140</td>
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<tr>
<td>Span Length</td>
<td>50</td>
<td>50</td>
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<tr>
<td>Skew</td>
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<td>0</td>
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<tr>
<td>Cost Summary</td>
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<tr>
<td>- Labor</td>
<td>$14,568</td>
<td>$21,705</td>
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<tr>
<td>- Material</td>
<td>$56,676</td>
<td>$53,593</td>
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<tr>
<td>- Rock</td>
<td>$6,170</td>
<td>$6,216</td>
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<td>- Equipment</td>
<td>$7,487</td>
<td>$12,026</td>
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<td>- Guardrail</td>
<td>$4,715</td>
<td>$7,146</td>
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<td>Construction Cost</td>
<td>$89,616</td>
<td>$100,686</td>
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<tr>
<td>CONST. COST PER FT²</td>
<td>$74.68</td>
<td>$83.91</td>
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</table>
Two Near Identical MoDOT State Bridges Crossing US 63

Concrete P/S: 92 ft – 92 ft
Route H (Columbia Airport)
Built 2011

Steel Plate Girder: 98 ft – 98 ft
Discovery Parkway (Columbia)
Built 2007
### Costs for Concrete & Steel Bridges

**Concrete P/S: 92 ft – 92 ft**  
Route H (Columbia Airport)  
Built 2011

**Steel Plate Girder: 98 ft – 98 ft**  
Discovery Parkway (Columbia)  
Built 2007

<table>
<thead>
<tr>
<th>Letting Date 5/27/2011</th>
<th>Letting Date 9/28/2007</th>
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<tr>
<td><strong>Class 1 Excavation</strong></td>
<td><strong>Class 1 Excavation</strong></td>
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<td>1800 206-10.00</td>
<td>1560 206100</td>
</tr>
<tr>
<td>Class 1 Excavation</td>
<td>Class 1 Excavation</td>
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<tr>
<td>1810 702-10.12</td>
<td>1580 7021012</td>
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<td>Structural Steel Piles (12 in.)</td>
<td>Structural Steel Piles (12 in.)</td>
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<td>1820 702-60.00</td>
<td>1850 7021012</td>
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<td>Pre-Bore for Piling</td>
<td>Pile Point Reinforcement</td>
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<tr>
<td>1830 702-70.00</td>
<td>1870 7027000</td>
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<tr>
<td>Pile Point Reinforcement</td>
<td>Pile Point Reinforcement</td>
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<td>1840 703-20.03</td>
<td>1880 703-42.15</td>
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<td>Class B Concrete (Substructure)</td>
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<td>1850 703-42.13</td>
<td>1890 703-42.15</td>
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<tr>
<td>Slab on Concrete I-Girder</td>
<td>Safety Barrier Curb</td>
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<tr>
<td>1860 703-42.15</td>
<td>1890 703-42.15</td>
</tr>
<tr>
<td>Safety Barrier Curb</td>
<td>Safety Barrier Curb</td>
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<tr>
<td>1870 705-60.03</td>
<td>1900 703-42.15</td>
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<tr>
<td>Type 6 (54in.), Prestressed</td>
<td>Type 6 (54in.), Prestressed</td>
</tr>
<tr>
<td>1880 706-10.60</td>
<td></td>
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<tr>
<td>Pedestrian Fence</td>
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</table>

**Concrete P/S: 92 ft – 92 ft**  
Route H (Columbia Airport)  
Built 2011

**Steel Plate Girder: 98 ft – 98 ft**  
Discovery Parkway (Columbia)  
Built 2007

**Total Bridge Cost = $440,632.50**  
Cost/ft² = $77.71

**Total Bridge Cost = $1,057,538.80**  
Cost/ft² = $64.04

Cost/ft² with ENR CCI Adjustment of 1.139 = $72.94

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Using ENR CCI Index Increase of 2.7%/yr For 2017

Concrete Steel = $ 91.18/ft²

Concrete Steel = $ 85.58/ft²
Preconception is Wrong
Steel & Concrete Bridges Are Competitive

Both Steel & Concrete Bridges Should Be Considered for Bridge Projects
As owners replace their bridge infrastructure, the question of Life Service and Life Cycle Costs routinely comes up between concrete and steel bridge options.

The bridge industry does not have a good answer:
- Both steel and concrete bridge advocates claim an advantage
- Anecdotal information is not convincing
Examine Historical Life Service (Performance and Maintenance) and Agency Life Cycle Costs (True Agency Costs for a Bridge) of Steel and Concrete Bridges in Pennsylvania

Report on www.ShortSpanSteelBridges.org

Thank You to PennDOT professionals for their participation. Thanks to SMDI, NSBA and AGA for supporting the work.
Life Cycle Cost Data Collection

Start with a Comprehensive Inventory of Bridges

Initial Costs & Date Built
Maintenance Costs and Date Performed
End of Service Date – End of Life Model
PennDOT Database Development

Criteria to Develop LCC Bridge Database

Modern typical bridge structures
  Precast I-Beam, Box Adjacent, and Box Spread bridges
  Steel Rolled Shape and Welded Plate Girder bridges

Bridges built between 1960 and 2010

Bridges with complete and accurate department maintenance records
  Consider any maintenance cost that is equal to or greater than $0.25/ft²

Bridges with known initial costs

Bridges with complete and accurate external contractor maintenance and rehabilitation
All Bridges in PennDOT Inventory = 25,403
Number of Type Bridges in Inventory = 8,466
Number of Types Built 1960-2010 = 6,587

Bridges that Meet All Criteria

<table>
<thead>
<tr>
<th>Bridge Type</th>
<th>Number of Bridges that Meet All criteria</th>
<th>Percentage of 1960 – 2010 database</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel I Beam</td>
<td>82</td>
<td>14.9%</td>
</tr>
<tr>
<td>Steel I Girder</td>
<td>230</td>
<td>22.6%</td>
</tr>
<tr>
<td>P/S Box - Adjacent</td>
<td>400</td>
<td>27.8%</td>
</tr>
<tr>
<td>P/S Box - Spread</td>
<td>581</td>
<td>26.5%</td>
</tr>
<tr>
<td>P/S I Beam</td>
<td>412</td>
<td>29.8%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1705</strong></td>
<td><strong>25.9%</strong></td>
</tr>
</tbody>
</table>
Bridge Life Model uses Average Deterioration Rates of Total PennDOT Inventory

Super Structure Condition Rating Used
Assume Bridge Replacement at Condition Rating = 3

Deterioration Rate = \( \frac{(2014 \text{ Condition Rating}) - 9}{2014 - (\text{Year Built})} \)

Remaining Life = \( \frac{3 - (2014 \text{ Condition Rating})}{(\text{Average Deterioration Rate})} \)

Bridge Life = 2014 - (Year Built) + Remaining Life

<table>
<thead>
<tr>
<th>Bridge Type</th>
<th>Number of Bridges 1960 - 2010</th>
<th>Deterioration Rate (Condition Rating Loss/Year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel I Beam</td>
<td>550</td>
<td>-0.07114</td>
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<tr>
<td>Steel I Girder</td>
<td>1017</td>
<td>-0.08144</td>
</tr>
<tr>
<td>P/S Box - Adjacent</td>
<td>1440</td>
<td>-0.08125</td>
</tr>
<tr>
<td>P/S Box - Spread</td>
<td>2196</td>
<td>-0.07988</td>
</tr>
<tr>
<td>P/S I Beam</td>
<td>1384</td>
<td>-0.08383</td>
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</table>

All are “similar” with None “Way Out” of Balance

Steel Rolled Precast Box Spread
Agency Life Cycle Costs – An Example

Precast Spread Box-Beam Bridge

BrKey: 30570  
Bridge Type: P/S, Box Beam (Spread)  
County: Schuylkill  
Location: 0.75 mi. N of Exit 107(33)  
Year Built: 1969  
Spans: 3  
Length: 176 ft  
Deck Area: 7621 ft²  
Super Cond Rating: 5

Average Precast Box Beam – Spread bridge deterioration rate = -0.07988

\[
\text{Remaining Life} = \frac{(3 - 5)}{-0.07988} = 25 \text{ years}
\]

\[
\text{Bridge Life} = 2014 + 25 - 1969 = 70 \text{ years}
\]
Costs for the Life Cycle Cost Analysis

Example Bridge Costs

Initial Cost: Year = 1969 Cost = $141475 ($18.56/ft$^2$) Work: Bridge Construction

External Contract: Year = 1988 Cost = $58401 ($7.66/ft$^2$) Work: Latex Overlay

Maintenance 1: Year = 2009 Cost = $1891 ($0.25/ft$^2$) Work: Repair Concrete Deck

Maintenance 2: Year = 2013 Cost = $2510 ($0.33/ft$^2$) Work: Repair Concrete Deck

ENR Construction Cost Indices

\[
2014 \text{ Dollars} = \frac{CCI \ 2014}{CCI \ 19XX} \times 19XX \text{ Dollars}
\]

Transform the costs to constant 2014 dollars using Construction Cost

Initial Cost: Year = 0 Cost = $18.56/ft$^2$(9806/1269) = $143.45/ft$^2$

External Contract: Year = 19 Cost = $7.66/ft^2$(9806/4519) = $16.63/ft$^2$

Maintenance 1: Year = 40 Cost = $0.25/ft^2$(9806/8570) = $0.28/ft$^2$

Maintenance 2: Year = 44 Cost = $0.33/ft^2$(9806/9547) = $0.34/ft^2$
**Life Cycle Costs**

**Example Bridge Life Cycle**

![Bridge Life Cycle Diagram]

Present Value Cost for 1 Cycle

\[
PV_C = 143.45 + 16.63(1.023)^{-19} + 0.28(1.023)^{-40} + 0.34(1.023)^{-44} = 154.49/ft^2
\]

Perpetual Present Value Cost = Capitalized Cost

\[
PPVC = 154.49 \left[ \frac{(1 + 0.023)^{70}}{(1 + 0.023)^{70} - 1} \right] = 1.256(154.49) = 193.97/ft^2
\]

With Capitalized Costs, Can Compare Bridges Directly

OMB Circular A-94 2011 30 yr Discount Rate = 2.3%
**Typical Bridge Life Cycle Costs**

**Additional Bridges Removed Based on PPVC/Capitalized Costs**

To Consider “Typical” Bridges, Keep Bridges with PPVC within +/- 1 Standard Deviation of Overall Average

**Bridges in the Life Cycle Cost Analyses**

<table>
<thead>
<tr>
<th>Bridge Type</th>
<th>Number of Bridges in Table 11 Database</th>
<th>Number of Bridges in LCC Study Database</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel I Beam</td>
<td>82</td>
<td>54</td>
</tr>
<tr>
<td>Steel I Girder</td>
<td>230</td>
<td>144</td>
</tr>
<tr>
<td>P/S Box - Adjacent</td>
<td>400</td>
<td>282</td>
</tr>
<tr>
<td>P/S Box - Spread</td>
<td>581</td>
<td>397</td>
</tr>
<tr>
<td>P/S I Beam</td>
<td>412</td>
<td>309</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1705</strong></td>
<td><strong>1186</strong></td>
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</tbody>
</table>
The full history of the bridge
Location, year built, spans, length, area, geometry, materials
Department and contractor maintenance performed
Initial, perpetual present value, and future maintenance costs
Life Cycle Cost Report

Analysis and Variables Examined in Report

Bridge Life
PPVC/Capitalized Costs
  Number of Spans
  Bridge Length
PVC Future Costs
Department Maintenance
External Contracts

For the entire report:
www.ShortSpanSteelBridges.org

Additional LCC report on Galvanizing:
www.ShortSpanSteelBridges.org

For Steel Bridges
Curved vs. Straight
Fracture-Critical
Protection (Painted, Weathering, Galvanized)
Results for Bridge Life

<table>
<thead>
<tr>
<th>Bridge Type</th>
<th>Number of Bridges in Final LCC Database</th>
<th>Average Year Built</th>
<th>Average Bridge Life (years)</th>
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<tr>
<td>Steel I Beam</td>
<td>82</td>
<td>1981</td>
<td>81.3</td>
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<td>Steel I Girder</td>
<td>230</td>
<td>1977</td>
<td>79.2</td>
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<tr>
<td>P/S Box - Adjacent</td>
<td>400</td>
<td>1985</td>
<td>74.0</td>
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<tr>
<td>P/S Box - Spread</td>
<td>581</td>
<td>1984</td>
<td>79.9</td>
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<tr>
<td>P/S I Beam</td>
<td>412</td>
<td>1984</td>
<td>74.5</td>
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Steel Rolled Precast Box - Spread

All are “similar” with None “Way Out” of Balance
Cumulative Density Function on Bridge Life

CDF for Bridge Life

- Rolled
- Plate
- Box Adjacent
- Box Spread
- PC I Beam

<table>
<thead>
<tr>
<th>Material</th>
<th>Probability Bridge Lasts &gt;75 yrs</th>
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<tbody>
<tr>
<td>Steel Rolled</td>
<td>73.0%</td>
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<tr>
<td>Steel Plate</td>
<td>62.7%</td>
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<tr>
<td>Conc Box Adjacent</td>
<td>45.6%</td>
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<tr>
<td>Conc Box Spread</td>
<td>65.6%</td>
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<tr>
<td>Conc I Beam</td>
<td>44.3%</td>
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### Capitalized Costs (Perpetual Present Value) – All Bridges

<table>
<thead>
<tr>
<th># Bridges</th>
<th>PPVC</th>
<th>Initial Cost</th>
<th>Future Cost</th>
<th>Avg Length</th>
<th>Avg # Spans</th>
<th>Avg Year Built</th>
<th>Avg Life</th>
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<tbody>
<tr>
<td>Steel I Beam</td>
<td>54</td>
<td>$232.78</td>
<td>$194.78</td>
<td>166</td>
<td>2.19</td>
<td>1980</td>
<td>82</td>
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<td>Steel I Girder</td>
<td>144</td>
<td>$273.71</td>
<td>$226.10</td>
<td>406</td>
<td>4.07</td>
<td>1976</td>
<td>80</td>
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<td>P/S Box - Adjacent</td>
<td>282</td>
<td>$278.30</td>
<td>$223.74</td>
<td>89</td>
<td>1.31</td>
<td>1987</td>
<td>74</td>
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<td>P/S Box - Spread</td>
<td>397</td>
<td>$256.11</td>
<td>$210.65</td>
<td>89</td>
<td>1.56</td>
<td>1986</td>
<td>79</td>
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<td>P/S I Beam</td>
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<td>$217.50</td>
<td>$174.10</td>
<td>212</td>
<td>2.43</td>
<td>1985</td>
<td>73</td>
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All are “similar” with None “Way Out” of Balance
CDF for Bridge Cost

<table>
<thead>
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<th>Material</th>
<th>Probability</th>
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<tr>
<td>Steel Rolled</td>
<td>88%</td>
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<tr>
<td>Steel Plate</td>
<td>66%</td>
</tr>
<tr>
<td>Conc Box Adjacent</td>
<td>67%</td>
</tr>
<tr>
<td>Conc Box Spread</td>
<td>79%</td>
</tr>
<tr>
<td>Conc I Beam</td>
<td>93%</td>
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Capitalized Costs (Perpetual Present Value) – Short Span

Perpetual Present Value Cost – Length<140 ft

Short Length Bridges for Short Span Steel Bridge Alliance

<table>
<thead>
<tr>
<th># Bridges</th>
<th>PPVC</th>
<th>Initial Cost</th>
<th>Future Cost</th>
<th>Avg Length</th>
<th>Avg # Spans</th>
<th>Avg Year Built</th>
<th>Avg Life</th>
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<tbody>
<tr>
<td>Steel I Beam</td>
<td>27</td>
<td>$266.24</td>
<td>$222.08</td>
<td>$0.16</td>
<td>84</td>
<td>1.26</td>
<td>1978</td>
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<td>Steel I Girder</td>
<td>18</td>
<td>$311.26</td>
<td>$257.19</td>
<td>$0.29</td>
<td>119</td>
<td>1.00</td>
<td>1977</td>
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<td>$292.38</td>
<td>$235.03</td>
<td>$0.95</td>
<td>69</td>
<td>1.09</td>
<td>1987</td>
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<td>P/S Box - Spread</td>
<td>325</td>
<td>$272.20</td>
<td>$225.14</td>
<td>$2.16</td>
<td>64</td>
<td>1.23</td>
<td>1986</td>
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<tr>
<td>P/S I Beam</td>
<td>98</td>
<td>$281.64</td>
<td>$231.20</td>
<td>$0.05</td>
<td>104</td>
<td>1.08</td>
<td>1987</td>
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</tbody>
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Steel Rolled Precast Box Spread

All are “similar” with None “Way Out” of Balance
Which Type of Bridge is Best?

- Precast Box Adjacent
- Steel Rolled Beam
- Precast I Beam
- Steel Plate Girder
- Precast Box Spread
Which Type of Bridge is Best?

All are “similar” with None “Way Out” of Balance

Overall Weighted Average PPVC = $252.40/ft² – Capitalized Costs

Bridge Types within 14% of Weighted Average

Standard Deviation Range $48.02/ft² - $65.60/ft² [COV ≈ 20% - 25%]

Any One Type of Bridge May Be Most Economical for a Given Bridge Project

There is No One Type of Bridge That Clearly Beats the Others
Conclusions

Typical Concrete and Steel Bridges are Competitive on Initial Cost, Future Costs, Life Cycle Costs and Bridge Life

For any Given Bridge Project, Concrete or Steel Bridge Types May Be the Most Economical

Preconception that Concrete is Always Less Expensive is a Misconception

Owners Should Consider Both Steel and Concrete Alternatives for Individual Bridge Projects
5 Ways to Keep Learning About Steel Bridges

1. Subscribe to the Weekly Newsletter
2. Find a Supplier
3. Design a Bridge in 5 Minutes
4. Receive Free Project Assistance
5. Schedule a Workshop/Webinar

www.ShortSpanSteelBridges.org

Questions? Dan Snyder, Director, SSSBA, dsnyder@steel.org, (301) 367-6179

Website: ShortSpanSteelBridges.org
Twitter: @ShortSpanSteel
Facebook: Short Span Steel Bridge Alliance