Historical Life Cycle Costs of Steel & Concrete Girder Bridges

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Steel Bridge Essentials
Summer Webinar Series
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SSSBA, Short Span Economic

Overview

The Short Span Steel Bridge Alliance (SSSBA)

Initial Costs

- County & State Case Studies

Life Cycle Costs

Short Span Steel Bridge Alliance – Who We Are

*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**.*

Rolled Beam & Plate

Buried Bridges

Truss

Press Brake & Folded Plate

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

County Crew Built Bridges

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:

19.3% Total Cost Savings w/ 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/ft^2)**

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/ft^2)**

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

25.8% Superstructure Cost Savings

Concrete:

- Superstructure total cost of $50.61 per ft^2

<u>Same bridge conditions:</u>

- *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

Superstructure	Steel						Concrete				
Bridge Number	061	140	149	152	710	AVG	028	057	069	520	AVG
Year Built	2008	2008	2008	2009	2010	AVG	2009	2010	2011	2006	AVG
Span Length	50	50	40	62	64	**53.2**	36	36	38	40	**37.5**
Skew	0	0	0	30	35	**13**	0	15	20	30	**16.25**
Cost Summary											
- Labor	$14,568	$21,705	$15,853	$24,765	$31,949	**$21,768**	$12,065	$15,379	$14,674	$19,044	**$15,291**
- Material	$56,676	$53,593	$46,282	$92,821	$69,357	**$63,746**	$51,589	$54,450	$50,576	$46,850	**$50,866**
- Rock	$6,170	$6,216	$3,694	$8,235	$6,501	**$6,163**	$5,135	$7,549	$5,378	$3,621	**$5,421**
- Equipment	$7,487	$12,026	$7,017	$19,579	$15,266	**$12,275**	$5,568	$10,952	$11,093	$14,742	**$10,589**
- Guardrail	$4,715	$7,146	$3,961	$7,003	$7,003	**$5,966**	$4,737	$4,663	$5,356	$3,323	**$4,520**
Construction Cost	$89,616	$100,686	$76,807	$152,403	$130,076	**$109,918**	$79,094	$92,993	$87,077	$87,580	**$86,686**
CONST. COST PER FT^2	**$74.68**	**$83.91**	**$80.01**	**$102.42**	**$84.68**	**$86.09**	**$91.54**	**$107.63**	**$95.48**	**$91.23**	**$96.32**

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

Letting Date 5/27/2011					
1800	206-10.00	Class 1 Excavation	85	CUYD	$1,700.00
1810	702-10.12	Structural Steel Piles (12 in.)	737	LF	$33,533.50
1820	702-60.00	Pre-Bore for Piling	240	LF	$9,600.00
1830	702-70.00	Pile Point Reinforcement	22	EA	$2,420.00
1840	703-20.03	Class B Concrete (Substructure)	76.2	CUYD	$45,339.00
1850	703-42.13	Slab on Concrete I-Girder	630	SQYD	[illegible]
1860	703-42.15	Safety Barrier Curb	[illegible]	[illegible]	[illegible]
1870	705-60.03	Type 6 (54in.), Prestre[illegible]	[illegible]	[illegible]	[illegible]
1880	706-10.60	[illegible]	[illegible]	[illegible]	[illegible]
				Total Bridge Cost =	$440,632.50
				Cost/ft² =	$77.71

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

Letting Date 9/28/2007					
1560	206100	Class 1 Excavation	130	CUYD	[illegible]
1580	7021012	Structural Steel Piles (12 in.)	[illegible]	[illegible]	[illegible]
~~1570~~	~~6071066~~	~~Pedestrian Fence~~	[illegible]	[illegible]	[illegible]
1590	7027000	Pile Poi[illegible]	[illegible]	[illegible]	[illegible]
1600	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	$2,400.00
[illegible]	[illegible]	[illegible]	2	EA	$4,000.00
[illegible]	[illegible]	[illegible] Bearing Pad	9	EA	$10,800.00
[illegible]	[illegible]	Laminated Neoprene Bearing Pad (Tapered)	18	EA	$6,750.00
1730	7251000	Corrugated Metal Pipe Pile Spacers	20	EA	$5,000.00
1670	7125365A	Intermediate Field Coat (System G)	22100	SQFT	$30,940.00
1680	7125370A	Finish Field Coat (System G)	2800	SQFT	$3,220.00
~~1690~~	~~7129911~~	~~Misc. Fab. Struc. Low Alloy Steel (Aesthethics~~	~~24330~~	~~LB~~	~~$54,742.50~~
				Total Bridge Cost =	$1,057,538.80
				Cost/ft² =	$64.04
				Cost/ft² with ENR CCI Adjustment of 1.139 =	$72.94

Using ENR CCI Index Increase of 2.7%/yr

For 2017

Concrete = $ 91.18/ft²

Steel = $ 85.58/ft²

Summary on Initial Costs

<u>Preconception is Wrong</u>

Steel & Concrete Bridges Are Competitive

Both Steel & Concrete Bridges Should Be Considered for Bridge Projects

What About Life Cycle Costs?

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

Historical life Cycle Costs of Steel & Concrete Bridges

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

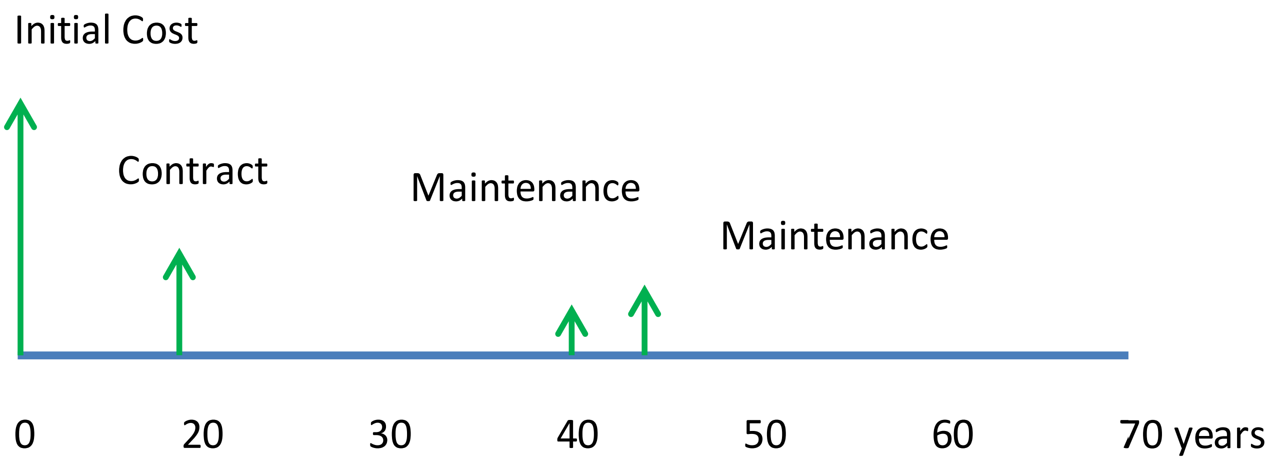
Report on www.ShortSpanSteelBridges.org

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/ft^2**

Bridges with known initial costs

Bridges with complete and accurate external contractor maintenance and rehabilitation

PennDOT Database Development

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

Bridge Type	Number of Bridges that Meet All criteria	Percentage of 1960 – 2010 database
Steel I Beam	82	14.9%
Steel I Girder	230	22.6%
P/S Box - Adjacent	400	27.8%
P/S Box - Spread	581	26.5%
P/S I Beam	412	29.8%
Total	1705	25.9%

PennDOT Database Bridge Life Model

Bridge Life Model uses Average Deterioration Rates of Total PennDOT Inventory

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

Super Structure Condition Rating Used

Assume Bridge Replacement at Condition Rating = 3

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

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

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

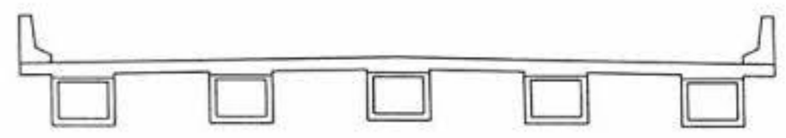
↑ Steel Rolled Precast Box Spread

All are "similar" with None "Way Out" of Balance

Agency Life Cycle Costs – An Example

Precast Spread Box-Beam Bridge

BrKey:	30570
Bridge Type:	P/S, Box Beam (Spread)
County:	Schuykill
Location:	0.75 mi. N of Exit 107(33)
Year Built:	1969
Spans:	3
Length:	176 ft
Deck Area:	7621 ft^2
Super Cond Rating:	5



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

$$Remaining\ Life = \frac{(3-5)}{-0.07988} = 25\ years$$

$$Bridge\ Life = 2014 + 25 - 1969 = 70\ years$$

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

$$2014\ Dollars = \frac{CCI\ 2014}{CCI\ 19XX} 19XX\ Dollars$$

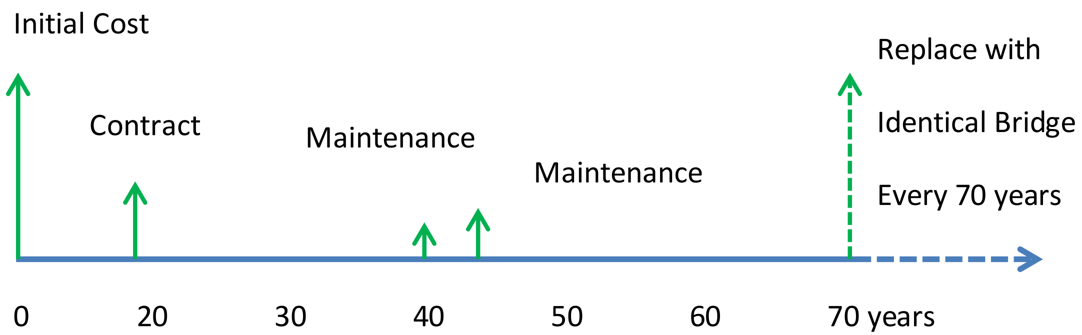
Transform the costs to constant 2014 dollars using Construction Cost

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

OMB Circular A-94 2011 30 yr Discount Rate = 2.3%



Present Value Cost for 1 Cycle

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

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

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

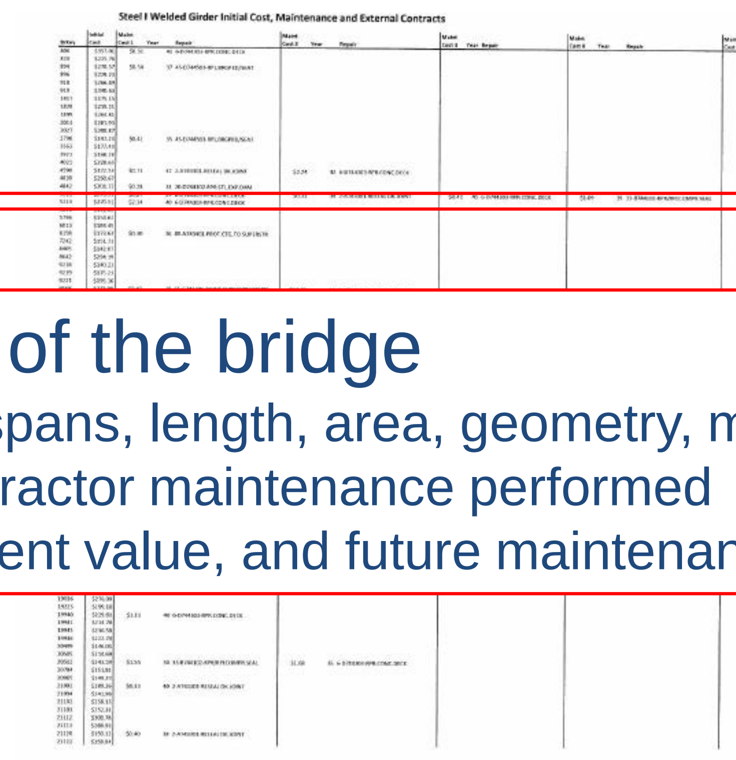
Bridge Type	Number of Bridges in Table 11 Database	Number of Bridges in LCC Study Database
Steel I Beam	**82**	**54**
Steel I Girder	**230**	**144**
P/S Box - Adjacent	**400**	**282**
P/S Box - Spread	**581**	**397**
P/S I Beam	**412**	**309**
	1705	**1186**

Life Cycle Costs Analysis Database

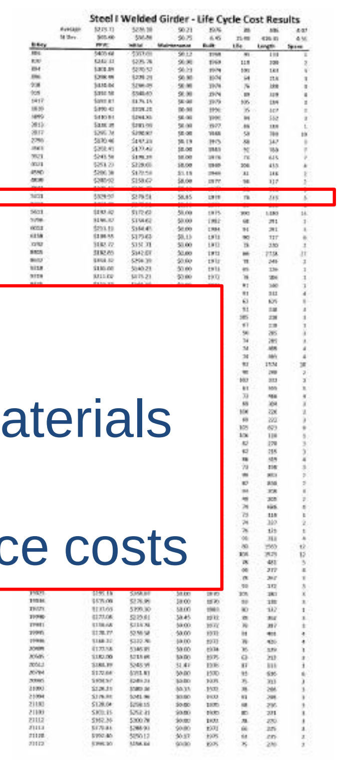
The Steel Plate Girder Bridge Data Base

General Information

Maintenance & Contract Work



Initial & LCC



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

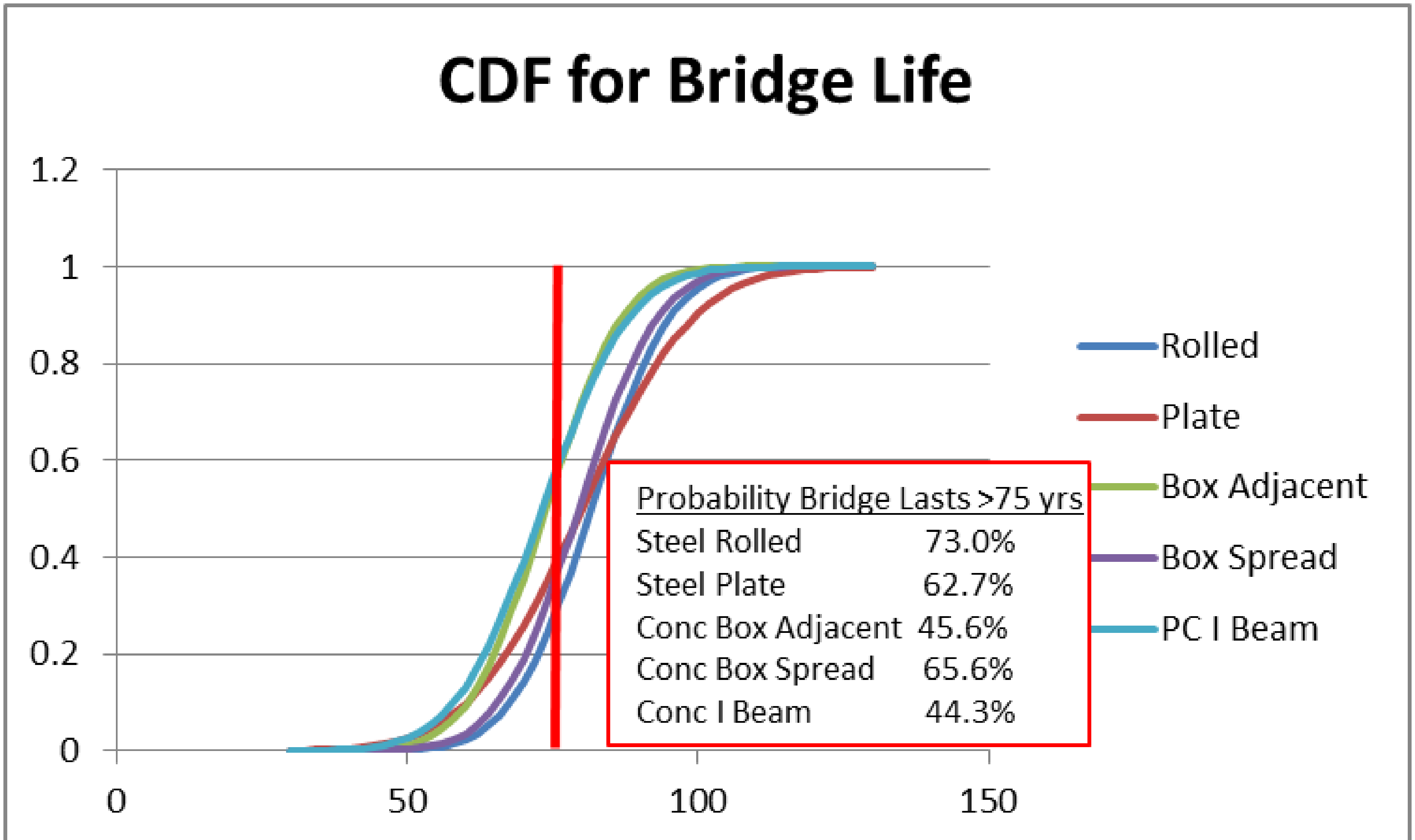
Bridge Type	Number of Bridges in Final LCC Database	Average Year Built	Average Bridge Life (years)
Steel I Beam	82	1981	81.3
Steel I Girder	230	1977	79.2
P/S Box - Adjacent	400	1985	74.0
P/S Box - Spread	581	1984	79.9
P/S I Beam	412	1984	74.5

↑

Steel Rolled
Precast Box - Spread

All are "similar" with None "Way Out" of Balance

Cumulative Density Function on Bridge Life



Capitalized Costs (Perpetual Present Value) – All Bridges

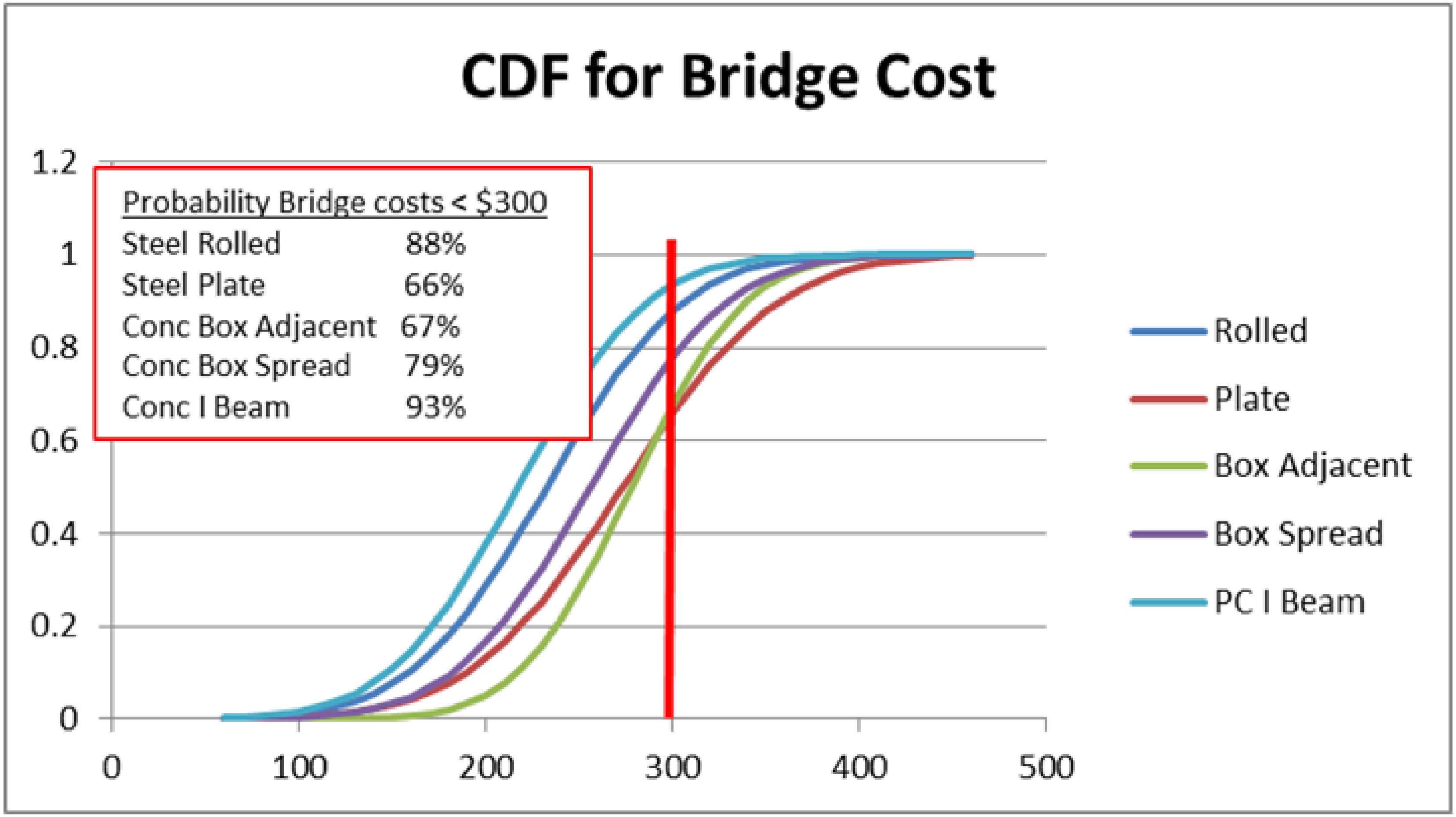
	# Bridges	PPVC	Initial Cost	Future Cost	Avg Length	Avg # Spans	Avg Year Built	Avg Life
Steel I Beam	54	$232.78	$194.78	$0.42	166	2.19	1980	82
Steel I Girder	144	$273.71	$226.10	$0.21	406	4.07	1976	80
P/S Box - Adjacent	282	$278.30	$223.74	$0.96	89	1.31	1987	74
P/S Box - Spread	397	$256.11	$210.65	$2.06	89	1.56	1986	79
P/S I Beam	309	$217.50	$174.10	$0.20	212	2.43	1985	73

↑

Precast I Beam
Steel Rolled

All are "similar" with None "Way Out" of Balance

Cumulative Density Function – Capitalized Costs – All Bridges



Capitalized Costs (Perpetual Present Value) – Short Span

Perpetual Present Value Cost – Length<140 ft

Short Length Bridges for Short Span Steel Bridge Alliance

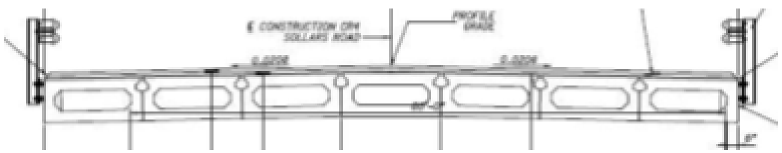
	# Bridges	PPVC	Initial Cost	Future Cost	Avg Length	Avg # Spans	Avg Year Built	Avg Life
Steel I Beam	27	$266.24	$222.08	$0.16	84	1.26	1978	82
Steel I Girder	18	$311.26	$257.19	$0.29	119	1.00	1977	81
P/S Box - Adjacent	240	$292.38	$235.03	$0.95	69	1.09	1987	74
P/S Box - Spread	325	$272.20	$225.14	$2.16	64	1.23	1986	81
P/S I Beam	98	$281.64	$231.20	$0.05	104	1.08	1987	77

↑

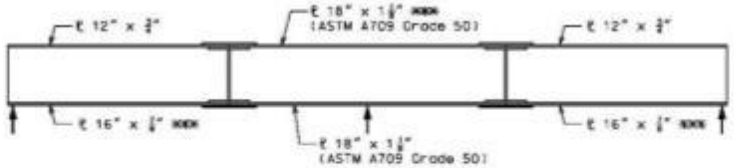
Steel Rolled
Precast Box Spread

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

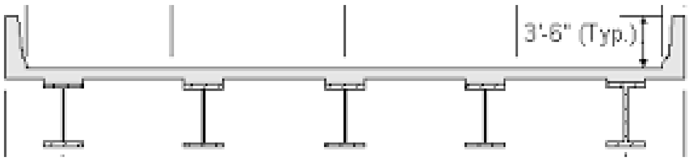
Which Type of Bridge is Best?



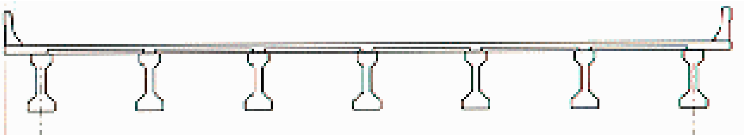
Precast Box Adjacent



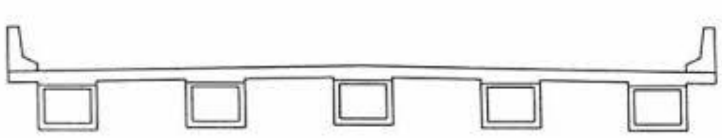
Steel Plate Girder



Steel Rolled Beam



Precast I Beam



Precast Box Spread

Which Type of Bridge is Best?

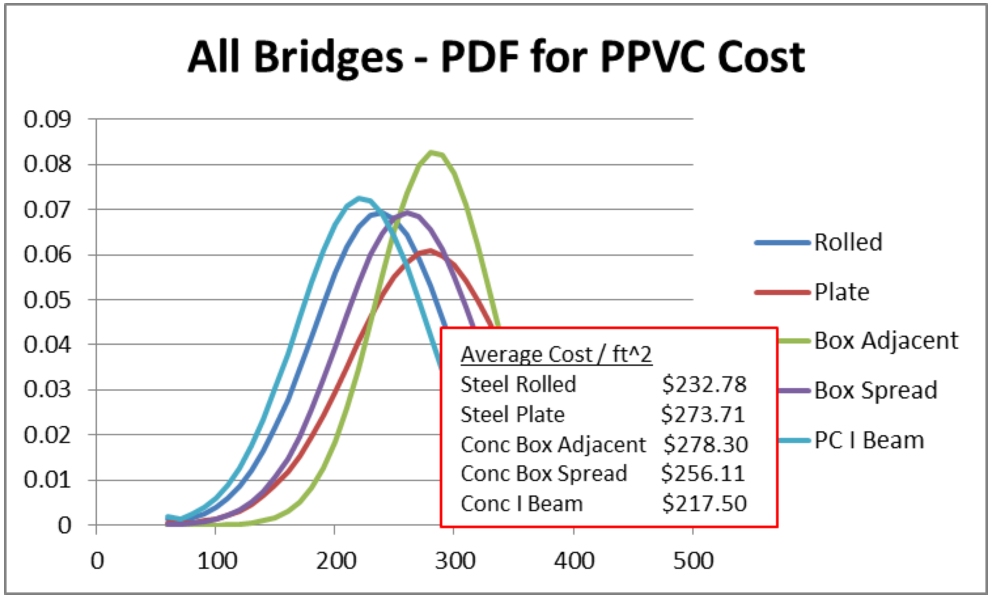
All are "similar" with None "Way Out" of Balance

Overall Weighted Average PPVC = $252.40/ft^2 – Capitalized Costs

Bridge Types within 14% of Weighted Average

Standard Deviation Range $48.02/ft^2 - $65.60/ft^2 [COV ≈ 20% - 25%]

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



Probability Density Function Capitalized Costs

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

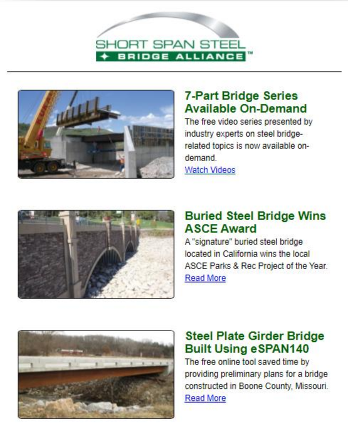
For any Given Bridge Project, Concrete or Steel Bridge Types May Be the Most Economical

Preconception that Concrete is Always Less Expensive is a Misconception

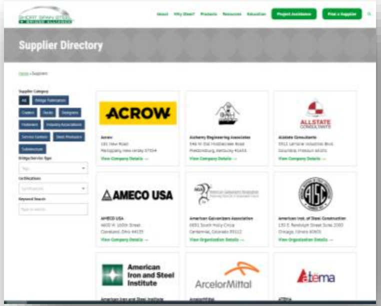
Owners Should Consider Both Steel and Concrete Alternatives for Individual Bridge Projects

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

eSPAN140™

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