Bridge Economy & Life Cycle Costs of Steel & Concrete Bridges

Missouri TEAM
March 14, 2019

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University of Wyoming & SSSBA Bridge Technology Center

Today’s Presentation

Initial Cost Case Studies & Life Cycle Cost Study of Typical Steel and Concrete Bridges

Problem Statement – Why This Presentation?

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

Problem Statement – Why This Presentation?

Preconception that Concrete is Less Expensive than Steel for Typical Bridges

Today's Presentation
Initial Costs – A Summary of Case Studies
Life Cycle Costs – A Look at Capital Costs

To Break That Preconception

SHORT SPAN STEEL
BRIDGE ALLIANCE

UNIVERSITY OF WYOMING

First Costs: Steel & Concrete Bridges

Case Studies

The New Steel

Missouri County Bridges – Where the SSSBA Began

Steel

Audrain County, MO Bridge 411

Built 2012

Steel 4 Girders

47.5 ft. Span

24 ft. Roadway Width

2 ft. Structural Depth

No Skew

Concrete

Audrain County, MO Bridge 336

Built 2012

Precast 6 Hollowcore Slab Girders

50.5 ft. Span

24 ft. Roadway Width

2 ft. Structural Depth

20º Skew

Case Study Bridges:
Side-by-Side Comparison Total Cost of Structure

Steel

19.3% Total Bridge Cost Savings with Steel

Total Bridge Costs	
Material	= $41,764
Labor	= $24,125
Equipment	= $21,521
Guard Rail	= $ 7,895
Rock	= $ 8,302
Engineering	= $ 8,246
TOTAL	**= $111,853 ($97.48 / sq. ft.)**

Concrete

Total Bridge Costs	
Material	= $67,450
Labor	= $26,110
Equipment	= $24,966
Guard Rail	= $ 6,603
Rock	= $ 7,571
Engineering	= $21,335
TOTAL	**= $154,035 ($120.83 / sq. ft.)**

Case Study Bridges: Superstructure Only Comparison

(Remove Site Prep, Abutment, Grading & Finishing, Guardrail, Engineering, Rock, Etc)

Steel

Superstucture Costs

Material	
Girders	= $21,463
Deck Panels	= $ 7,999
Reinf Steel	= $ 3,135
Concrete	= $ 4,180
Labor	= $ 5,522
Equipment*	= $ 500
SUPER TOTAL	**= $42,799**
SUPER TOTAL	**= $37.54 / sq. ft.**

Concrete

Superstucture Costs

Material	
Slab Girders	= $50,765
Deck Panels	= $ 0
Reinf Steel	= $ 724
Concrete	= $ 965
Labor	= $ 4,884
Equipment*	= $ 4,000
SUPER TOTAL	**= $61,338**
SUPER TOTAL	**= $50.61 / sq. ft.**

Added cost to use galvanized steel = $5,453.80 or $0.22 / lb. (includes est. 10% fabrication fee)
***** Cost to use weathering steel is approximately $0.04 / lb. (already included in cost in example)***

***County Crane (30 Ton) used for Steel, Larger Rented Crane (100 Ton) Required for Concrete (Equivalent County Crane Cost is $1520, would result in Steel Cost of $38.88 / sq. ft.)**

Case Study Bridges: Audrain County, MO

Steel: Superstructure $37.54 per sq. ft.

Concrete: Superstructure Cost $50.61 per sq. ft.

25.8% superstructure cost savings

Same bridge conditions:

- Structural Depth = 2 ft. (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

Case Study Bridges: Other Bridges in Audrain County

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**

County Bridge (Designed by eSPAN140)

- **Boone County, Missouri (Local)**
  - High Point Lane Bridge
  - 102 feet (2 lane rural road plate girder bridge)
  - 44” weathering steel plate girders (4 lines)
  - Constructed in summer 2013

State Bridge (Designed by eSPAN140)

Kansas Department of Transportation

- Shawnee County
- 112 feet (5 plate girder bridge)
- Competitive bid process (steel vs. concrete)
- DOT used eSPAN140 for preliminary design
- Constructed in summer 2014

1 Steel Bridge Bid

3 Concrete Bridge Bids

Steel = $ 1.240 mil

Concrete = $ 1.243 – $ 1.425 mil

Two MoDOT State Bridges Crossing US 63 in Boone County

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

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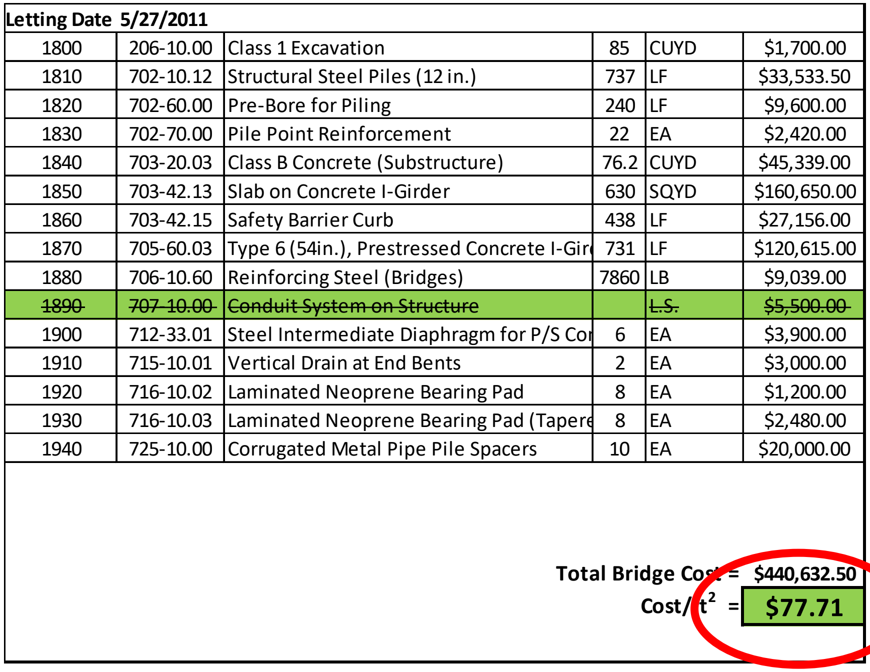


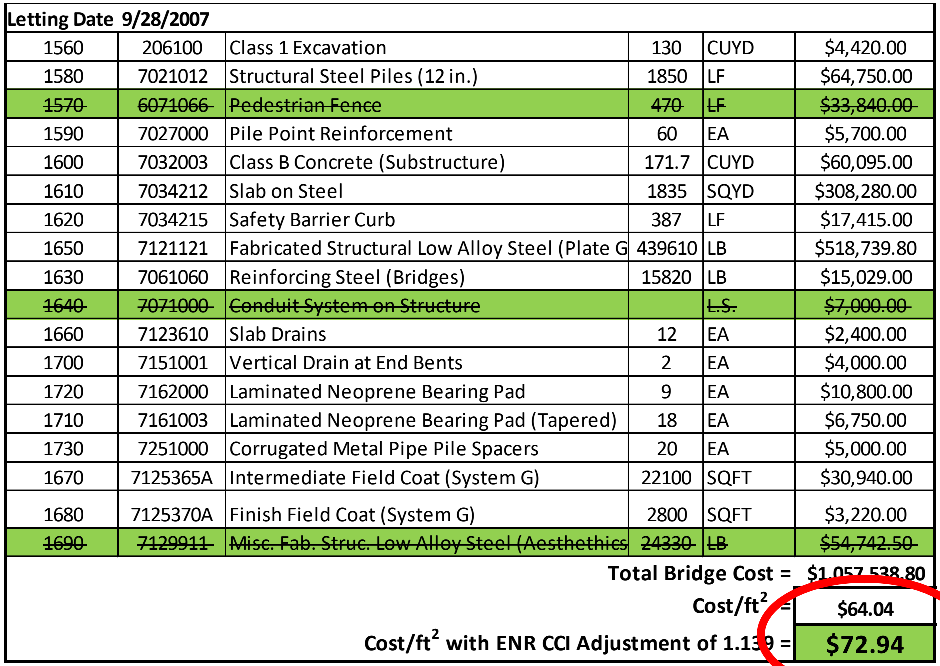
Letting Date 5/27/2011

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	$160,650.00
1860	703-42.15	Safety Barrier Curb	438	LF	$27,156.00
1870	705-60.03	Type 6 (54in.), Prestressed Concrete I-Gir	731	LF	$120,615.00
1880	706-10.60	Reinforcing Steel (Bridges)	7860	LB	$9,039.00
~~1890~~	~~707-10.00~~	~~Conduit System on Structure~~		~~L.S.~~	~~$5,500.00~~
1900	712-33.01	Steel Intermediate Diaphragm for P/S Co	6	EA	$3,900.00
1910	715-10.01	Vertical Drain at End Bents	2	EA	$3,000.00
1920	716-10.02	Laminated Neoprene Bearing Pad	8	EA	$1,200.00
1930	716-10.03	Laminated Neoprene Bearing Pad (Tapere	8	EA	$2,480.00
1940	725-10.00	Corrugated Metal Pipe Pile Spacers	10	EA	$20,000.00

Total Bridge Cost = $440,632.50

Cost/ft^2 = $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	$4,420.00
1580	7021012	Structural Steel Piles (12 in.)	1850	LF	$64,750.00
~~1570~~	~~6071066~~	~~Pedestrian Fence~~	~~470~~	~~LF~~	~~$33,840.00~~
1590	7027000	Pile Point Reinforcement	60	EA	$5,700.00
1600	7032003	Class B Concrete (Substructure)	171.7	CUYD	$60,095.00
1610	7034212	Slab on Steel	1835	SQYD	$308,280.00
1620	7034215	Safety Barrier Curb	387	LF	$17,415.00
1650	7121121	Fabricated Structural Low Alloy Steel (Plate G	439610	LB	$518,739.80
1630	7061060	Reinforcing Steel (Bridges)	15820	LB	$15,029.00
~~1640~~	~~7071000~~	~~Conduit System on Structure~~		~~L.S.~~	~~$7,000.00~~
1660	7123610	Slab Drains	12	EA	$2,400.00
1700	7151001	Vertical Drain at End Bents	2	EA	$4,000.00
1720	7162000	Laminated Neoprene Bearing Pad	9	EA	$10,800.00
1710	7161003	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/ft^2 = $64.04

Cost/ft^2 with ENR CCI Adjustment of 1.139 = $72.94

Concrete P/S: 92 ft – 92 ft
Route H (Columbia Airport)
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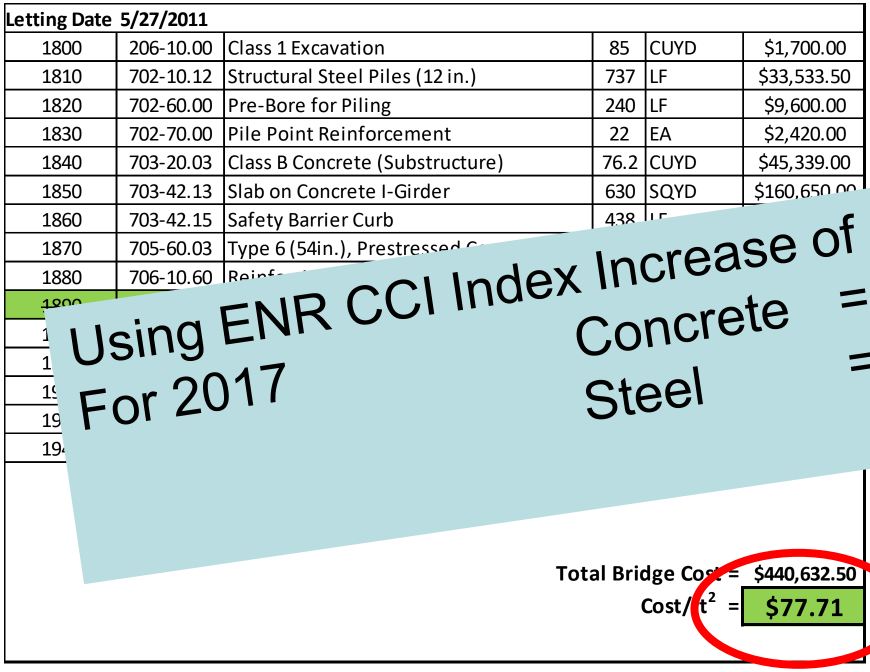
Using ENR CCI Index Increase of 2.7%/yr
For 2017

Concrete = $ 91.18/ft^2
Steel = $ 85.58/ft^2



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1870	705-60.03	Type 6 (54in.), Prestressed [illegible]	[illegible]	[illegible]	[illegible]
1880	706-10.60	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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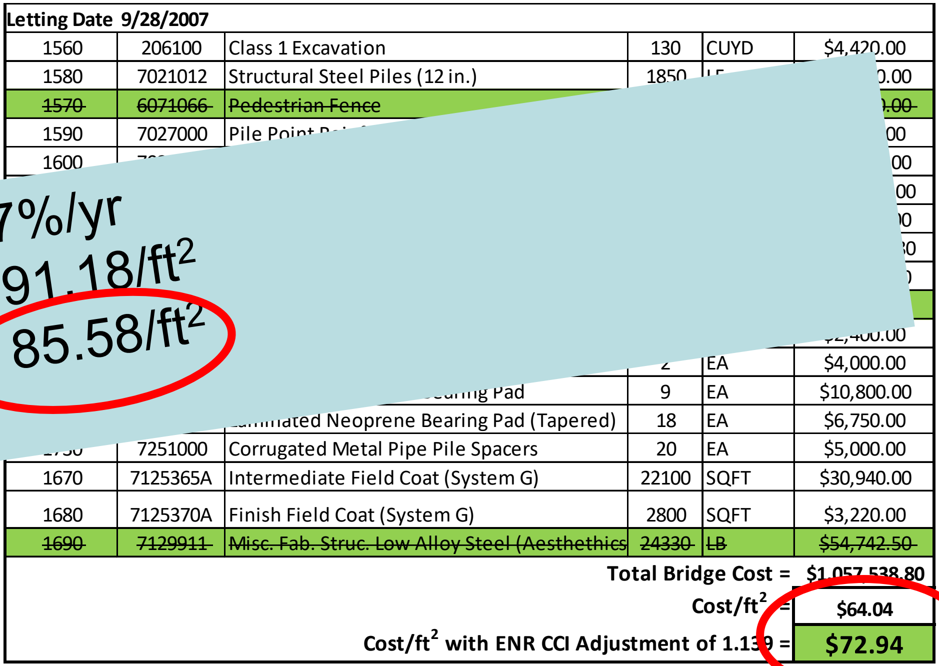

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1600	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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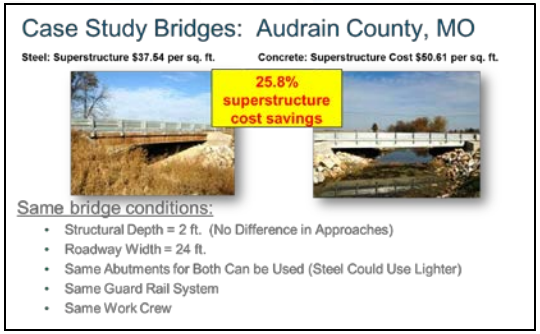
Summary on Initial Costs

- Case Studies of County Bridges
- Competitive Bids
- Bridges over US 63
- **Others Not Shown Here**



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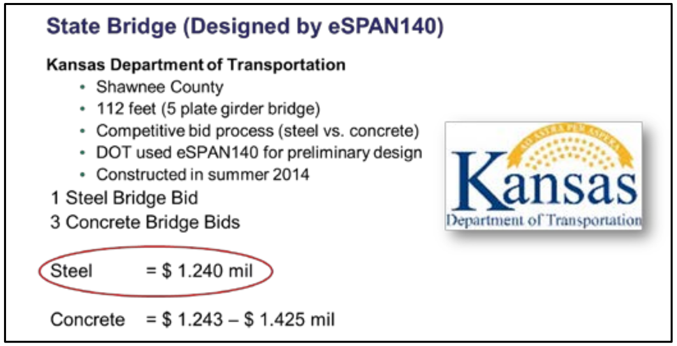

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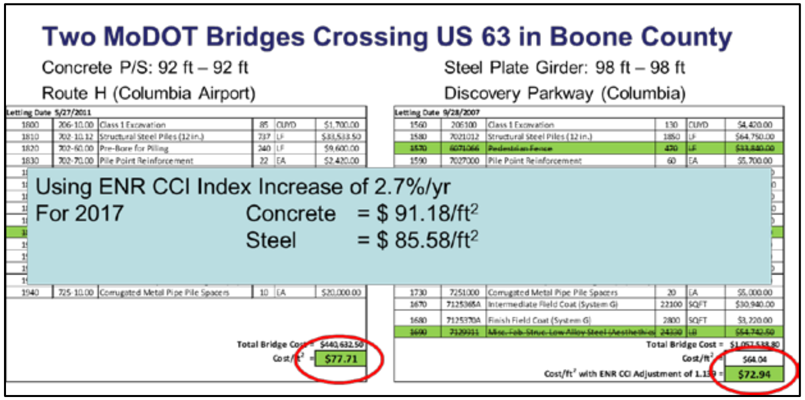

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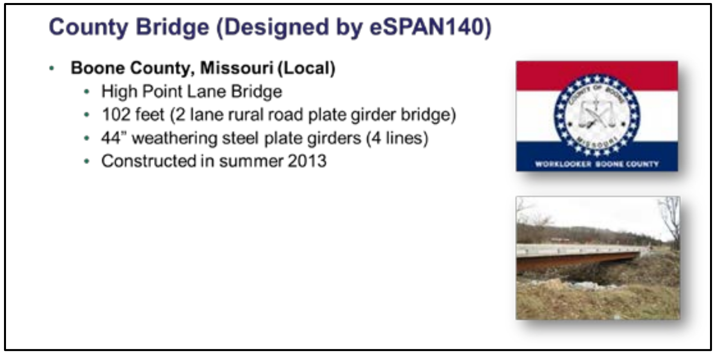

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Steel Bridges Compete and Win!

Preconception is Wrong

Steel & Concrete Bridges Are Competitive

SHORT SPAN STEEL
BRIDGE ALLIANCE

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What About Life Cycle Costs?

Historical Life Cycle Costs of Steel & Concrete Girder Bridges

Report on ShortSpanSteelBridges.org

Thank You to PennDOT professionals for their participation.
Thanks to SMDI, NSBA and AGA for supporting the work.

The New Steel

Why the Study?

As owners replace their bridge infrastructure, the question of Life Service and Life Cycle Costs routinely comes up between concrete and steel bridge options.

This is especially true for typical and short span bridge replacement projects.

The bridge industry does not have a good answer:

Both steel and concrete bridge advocates claim an advantage.
Anecdotal information is not convincing.

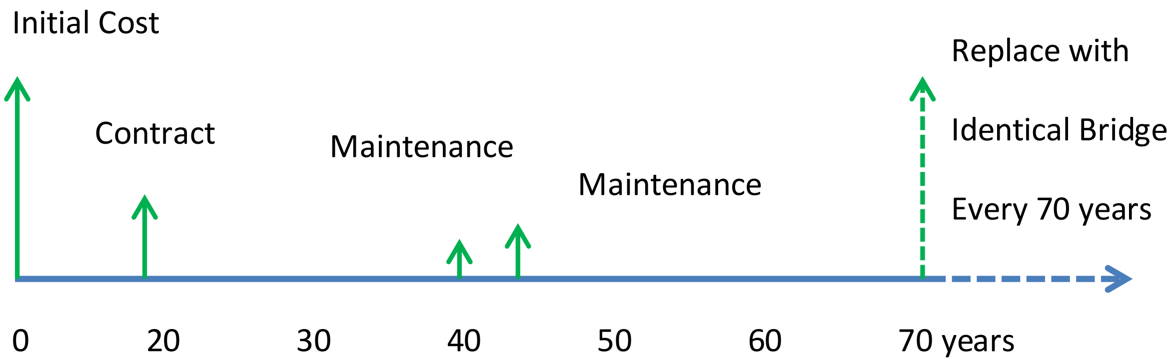
Study Objective

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

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



Initial Cost

Contract

Maintenance

Maintenance

Replace with

Identical Bridge

Every 70 years

0 20 30 40 50 60 70 years

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

Issues: *Availability of Historical Data*

Large Amount of Time & Resources to Collect Data

PennDOT Stepped Up to Participate

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

Initial cost limitation to bridges with initial cost less than $\$500/ft^2$ and greater than $\$100/ft^2$

Note: Total Recorded Initial and Maintenance Costs Used

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

Table 8: Final LCC Database that Meets 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%

NEEDED Notes on Limitations

Database Contains Only 25.9% of Eligible 1960 - 2010 Bridges

Large Percentage of Bridges Not Included
Bridges Removed Due To:

- Unknown Dates and/or Costs of Department Maintenance
- Unknown Dates and/or Costs of Contractor Maintenance

Therefore,

- Database is “Skewed” Towards Bridges with Lower Amounts of Maintenance

NEEDED Notes on Limitations

The Systematic Nature of the Study Used

Total 1960-2010 PennDOT Database Average Deterioration Rates Based on Condition Ratings

The Study Does Not Predict Any Future Maintenance

Therefore,

Results, Comparisons & Conclusions

Must Be Taken In Context to

the Database and the Database Limitations

PennDOT Database Bridge Life Model

Bridge Life Model uses Average Deterioration Rates of Total PennDOT Inventory

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

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

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

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

Table 9: Average Deterioration Rates

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**

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P/S Box - Spread	**2196**	**-0.07988**
P/S I Beam	**1384**	**-0.08383**

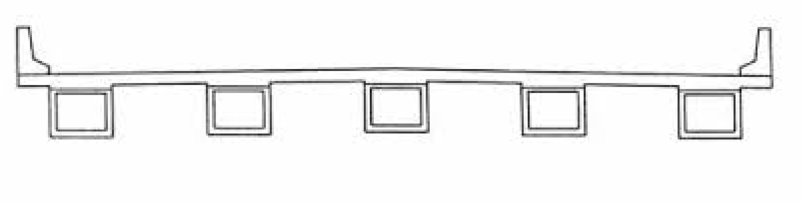
↑ Steel Rolled
Precast Box Spread

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:	Shuylkill
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

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

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

Life Cycle Costs

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

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

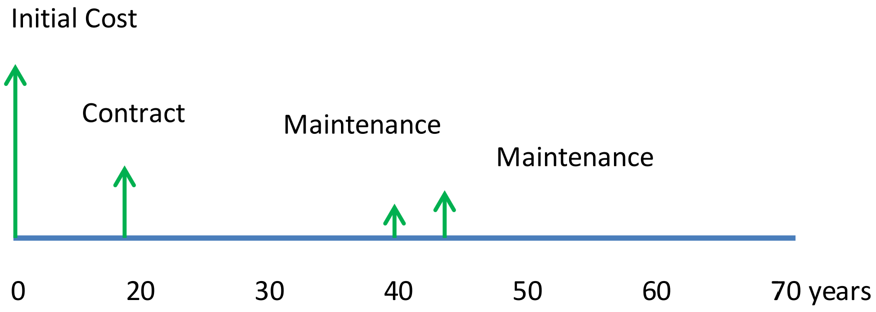
Transform the costs to constant 2014 dollars using Construction Cost

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

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

Example Bridge Life Cycle



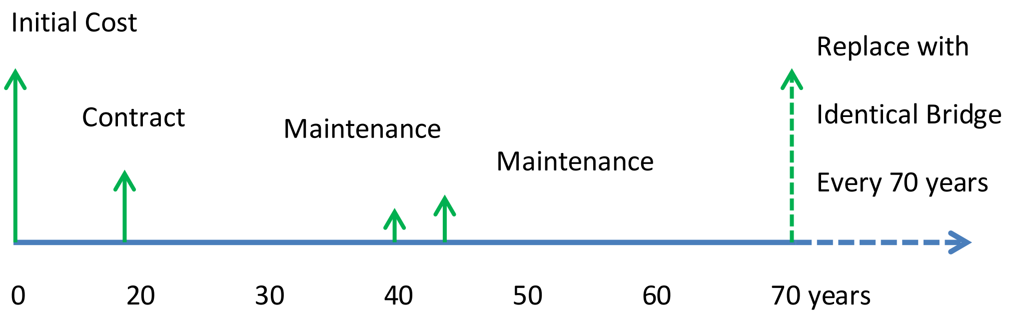
Present Value Cost for 1 Cycle

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

Life Cycle Costs

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

Example Bridge Life Cycle



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

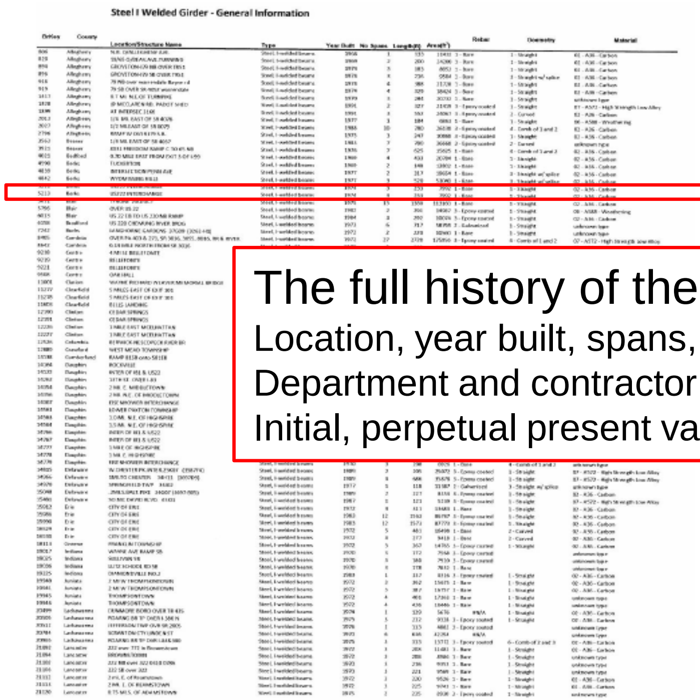
$$PPVC = \$154.49\left[\frac{(1+0.023)^{70}}{(1+0.023)^{70}-1}\right] = 1.256(\$154.49) = \$193.97/ft^2$$

With PPVC, Can Compare Bridges Directly

Life Cycle Cost Analyses

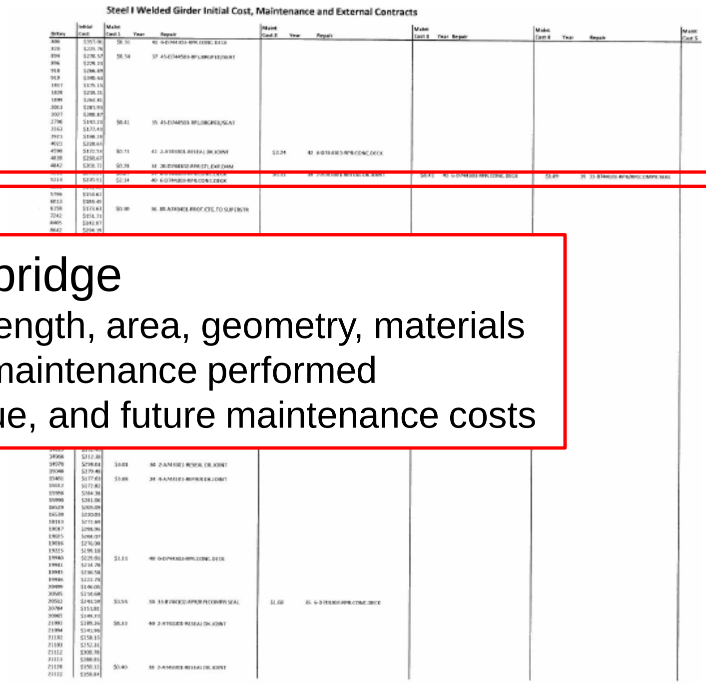
The Steel Plate Girder Bridge Data Base

General Information



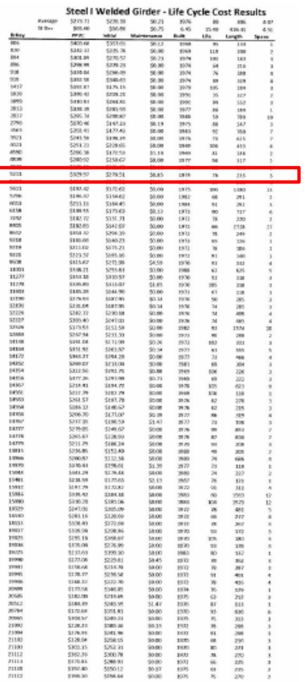
Steel I Welded Girder - General Information

Maintenance & Contract Work



Steel I Welded Girder Initial Cost, Maintenance and External Contracts

Initial & LCC



Steel I Welded Girder - Life Cycle Cost Results

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 Analyses

Additional Bridges Removed Based on PPVC

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

Bridges in the Life Cycle Cost Analyses

Table 13: Final Life Cycle Cost Database

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**

LCC Report

Analysis and Variables Examined in Report
- Bridge Life
- PPVC
  - Number of Spans
  - Bridge Length
  - PVC Future Costs
  - Department Maintenance
  - External Contracts

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

For the entire report:
www.ShortSpanSteelBridges.org

Additional LCC report on Galvanizing:
www.ShortSpanSteelBridges.org

Bridge Life

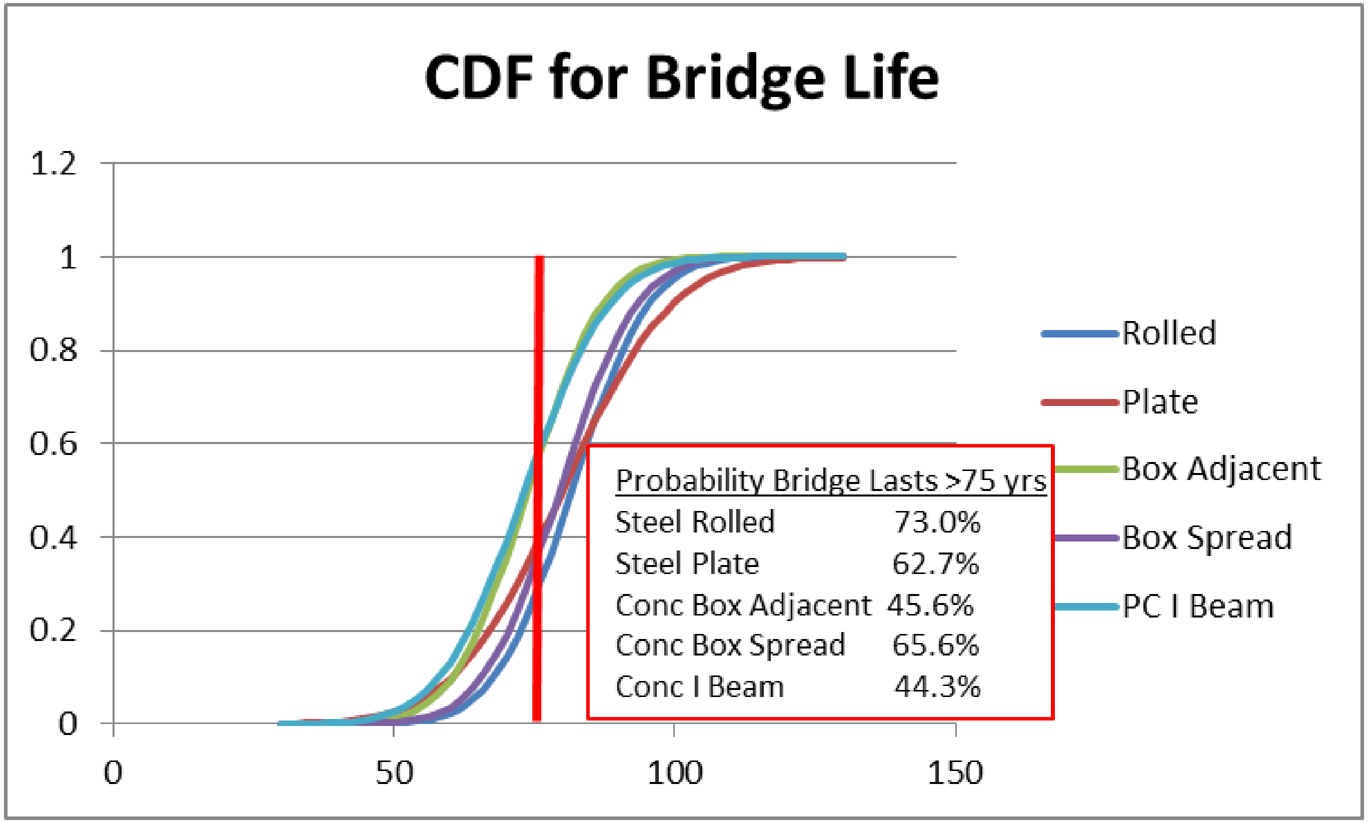
Table 10: Final LCC Database that Meets All Criteria

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

Bridge Life



Probability Bridge Lasts >75 yrs	
Steel Rolled	73.0%
Steel Plate	62.7%
Conc Box Adjacent	45.6%
Conc Box Spread	65.6%
Conc I Beam	44.3%

Perpetual Present Value Cost – All Bridges

Table 14: Life Cycle Cost Results Using Total Database

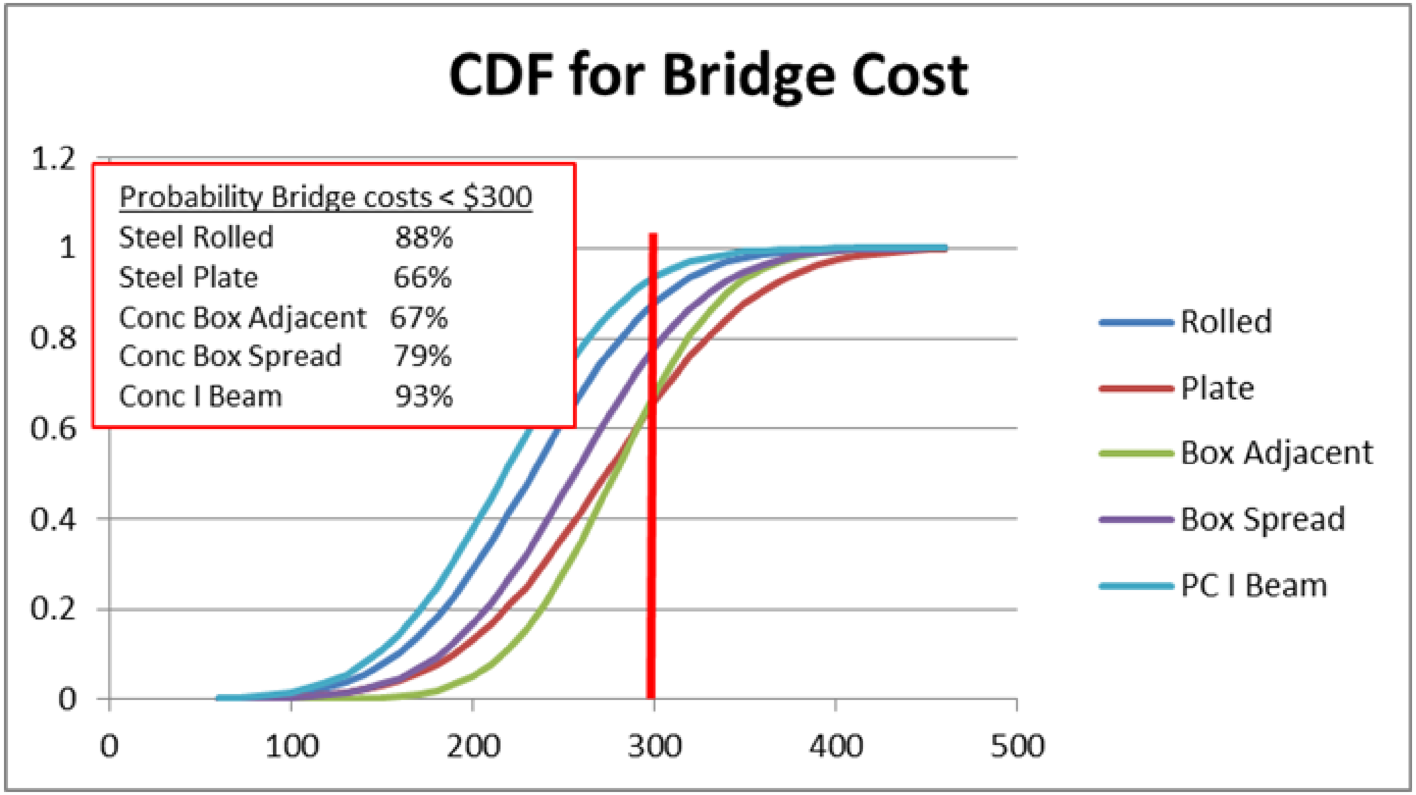
	# Bridges	PPVC	Initial Cost	Future Cost	Avg Length	Avg # Spans	Avg Year Built	Avg Life
Steel I Beam	54	$232.78	$194.78	$0.42	166	2.19	1980	82
Steel I Girder	144	$273.71	$226.10	$0.21	406	4.07	1976	80
P/S Box - Adjacent	282	$278.30	$223.74	$0.96	89	1.31	1987	74
P/S Box - Spread	397	$256.11	$210.65	$2.06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

Perpetual Present Value Cost – All Bridges



Probability Bridge costs < $300	
Steel Rolled	88%
Steel Plate	66%
Conc Box Adjacent	67%
Conc Box Spread	79%
Conc I Beam	93%

Perpetual Present Value Cost – Length<140 ft

Short Length Bridges

Table 20: Life Cycle Cost Results for Bridge Length Maximum = 140 ft

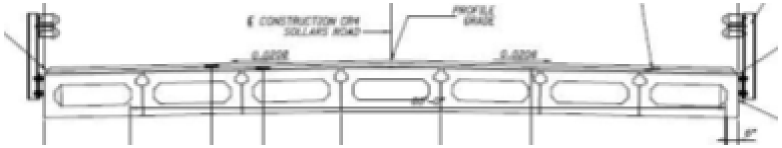
	# Bridges	PPVC	Initial Cost	Future Cost	Avg Length	Avg # Spans	Avg Year Built	Avg Life
Steel I Beam	27	$266.24	$222.08	$0.16	84	1.26	1978	82
Steel I Girder	18	$311.26	$257.19	$0.29	119	1.00	1977	81
P/S Box - Adjacent	240	$292.38	$235.03	$0.95	69	1.09	1987	74
P/S Box - Spread	325	$272.20	$225.14	$2.16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

↑

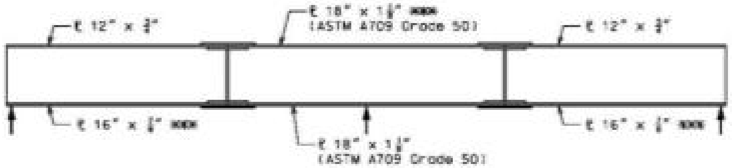
Steel Rolled
Precast Box Spread

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

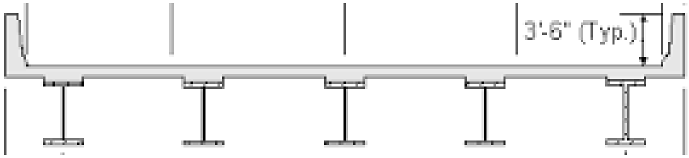
Which Type of Bridge is Best?



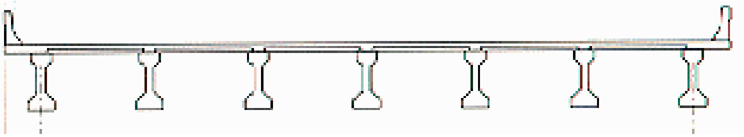
Precast Box Adjacent



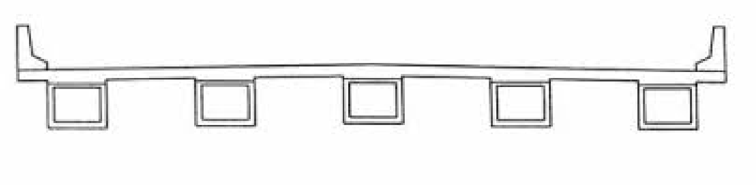
Steel Plate Girder



Steel Rolled Beam



Precast I Beam



Precast Box Spread

Which Type of Bridge is Best?

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

Which Type of Bridge is Best?

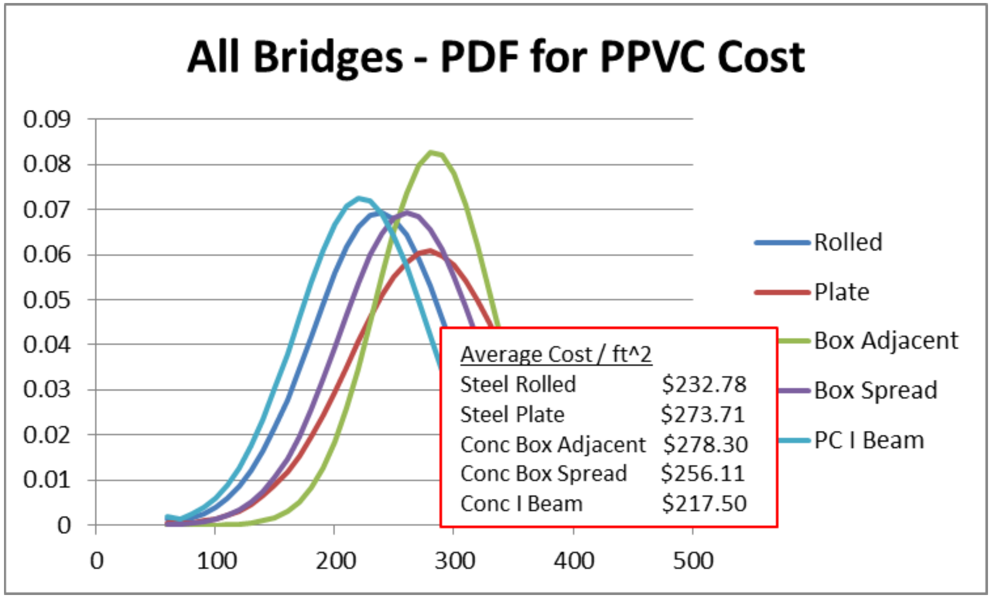
All are "similar" with None "Way Out" of Balance

Overall Weighted Average PPVC = $\$252.40/\text{ft}^2$ – Capitalized Costs

Bridge Types within 14% of
Weighted Average

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

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



Average Cost / ft^2	
Steel Rolled	$232.78
Steel Plate	$273.71
Conc Box Adjacent	$278.30
Conc Box Spread	$256.11
Conc I Beam	$217.50

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

SHORT SPAN STEEL
BRIDGE ALLIANCE

UNIVERSITY OF WYOMING

Need More Information?

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Thank You