Historical Life Cycle Costs of Steel & Concrete Girder Bridges

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Introduction

This Infrastructure Week Webinar will Examine the Historical Life Cycle Costs of Steel and Concrete Bridges in Pennsylvania

Background

Past work in Bridges – Michael Barker

Education:
Masters at Purdue in Concrete & PhD at Minnesota in Steel Bridge Research

At U of Missouri & U of Wyoming:
Concrete & Steel Bridge Rating Research
Steel Bridge AASHTO Design Provisions
Concrete & Steel Bridge Field Testing
Concrete Bridge FRP Strengthening
Concrete & Steel Bridge Serviceability Research
Work with Counties and County Built Bridges

Disclaimer

This work was supported by the steel industry
SMDI, NSBA & AGA

As a sabbatical project at the University of Wyoming

BUT….. This study was not influenced by the Steel Industry

I am First and Foremost a Bridge Engineer

And

This is a **Systematic** & **Honest** study of Life Cycle Costs for a database of Steel & Concrete bridges in Pennsylvania

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

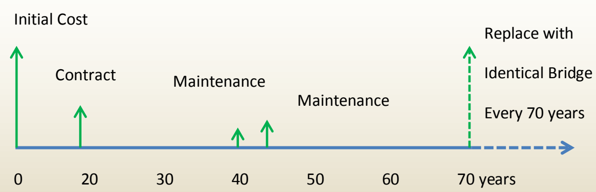
Also, Questions Remain Within Material Type

Different PC Concrete Bridge Types
Steel Bridge Construction Techniques & Coatings
Deck System & Rebar

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



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

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

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

Table 9: Average Deterioration Rates

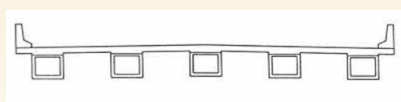
Bridge Type	Number of Bridges 1960 - 2010	Deterioration Rate (Condition Rating Loss/Year)
Steel I Beam	**550**	**-0.07114**
Steel I Girder	**1017**	**-0.08144**
P/S Box - Adjacent	**1440**	**-0.08125**
P/S Box - Spread	**2196**	**-0.07988**
P/S I Beam	**1384**	**-0.08383**

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

ENR Construction Cost Indices

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

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

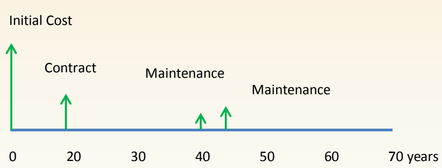
Transform the costs to constant 2014 dollars using Construction Cost

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



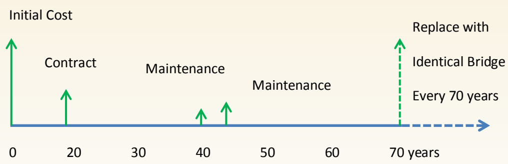
Present Value Cost for 1 Cycle

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

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

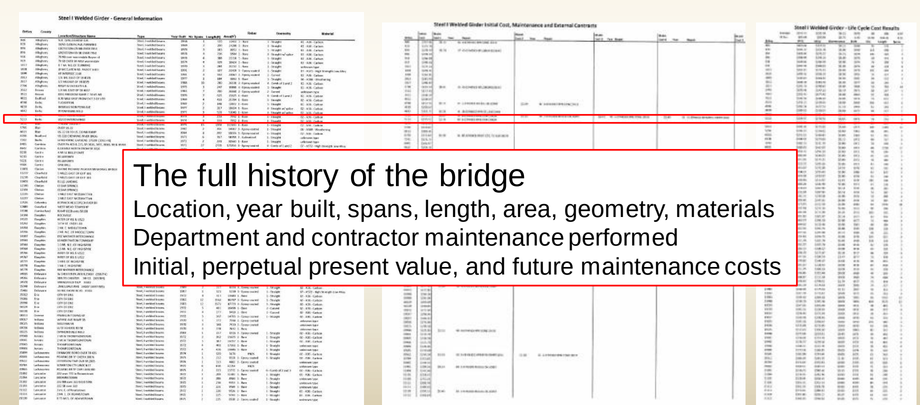
$$PPVC = \$154.49\left[\frac{(1+0.023)^{70}}{(1+0.023)^{70}-1}\right] = 1.256(\$154.49) = \$193.97/ft^2$$

With PPVC, Can Compare Bridges Directly

Life Cycle Cost Analyses

The Steel Plate Girder Bridge Data Base

General Information | 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 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 Study

Analysis and Variables Examined
- Bridge Life
- PPVC
  - Number of Spans
  - Bridge Length
- PVC Future Costs
  - Department Maintenance
  - External Contracts
- Type of Steel Bridge (curved & straight, fracture critical)
- Steel Protection (painted, weathering & galvanized)

Bridge Life

Table 10: Final LCC Database that Meets All Criteria

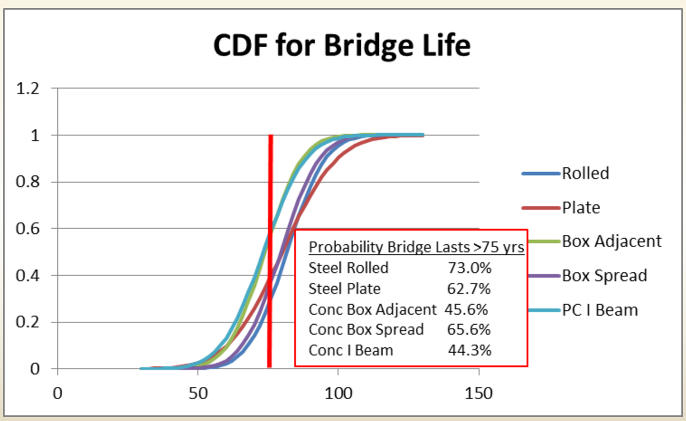
Bridge Type	Number of Bridges in Final LCC Database	Average Year Built	Average Bridge Life (years)
Steel I Beam	82	1981	81.3
Steel I Girder	230	1977	79.2
P/S Box - Adjacent	400	1985	74.0
P/S Box - Spread	581	1984	79.9
P/S I Beam	412	1984	74.5

↑

Steel Rolled
Precast Box - Spread

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

Bridge Life



Perpetual Present Value Cost – All Bridges

Table 14: Life Cycle Cost Results Using Total Database

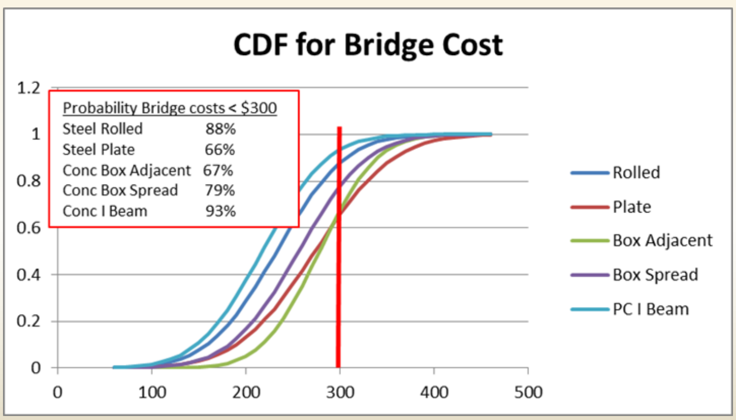
	# Bridges	PPVC	Initial Cost	Future Cost	Avg Length	Avg # Spans	Avg Year Built	Avg Life
Steel I Beam	54	$232.78	$194.78	$0.42	166	2.19	1980	82
Steel I Girder	144	$273.71	$226.10	$0.21	406	4.07	1976	80
P/S Box - Adjacent	282	$278.30	$223.74	$0.96	89	1.31	1987	74
P/S Box - Spread	397	$256.11	$210.65	$2.06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



Perpetual Present Value Cost – Length<140 ft

Short Span Bridges

Table 20: Life Cycle Cost Results for Span 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

Future Costs

Future Costs Compared to Initial Costs

Table 22: Life Cycle Costs and PPVC/Initial Cost for Total Database

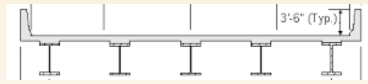
	# Bridges	PPVC	Initial Cost	Future Cost	Avg Life	PPVC/Initial Cost
Steel I Beam	54	$232.78	$194.78	$0.42	82	1.20
Steel I Girder	144	$273.71	$226.10	$0.21	80	1.21
P/S Box - Adjacent	282	$278.30	$223.74	$0.96	74	1.24
P/S Box - Spread	397	$256.11	$210.65	$2.06	79	1.22
P/S I Beam	309	$217.50	$174.10	$0.20	73	1.25

↑

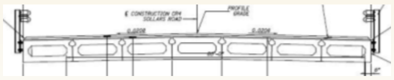
Steel Rolled
Steel Girder

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

Which Type of Bridge is Best?

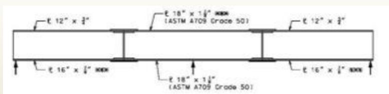


Steel Rolled Beam

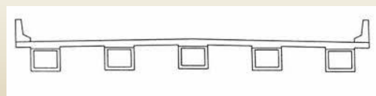


Precast Box Adjacent

Precast I Beam



Steel Plate Girder



Precast Box Spread

Which Type of Bridge is Best?

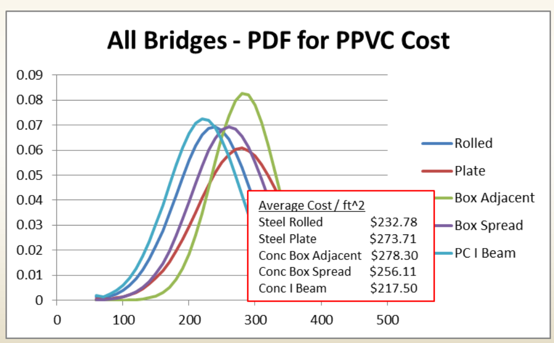
All are “similar” with None “Way Out” of Balance

Overall Average PPVC = \$252.40/ft^2

Bridge Type Range within 14%

Standard Deviations Range
\$48.02/ft^2 - \$65.60/ft^2

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

Summary

The report examines the Initial Costs, Life Cycle Costs, and Future Costs of the Bridges in the PennDOT Database

The database is limited to bridges that met the Criteria – It is Not as Comprehensive as Desired and Results must be Taken In Context of the Database and the Database Limitations

PennDOT expended resources to collect the required data and now have information on the Life Cycle Costs of their bridges. A template of what is required and how to handle the data has been developed. Other owners may be interested in the performance of their bridge inventories.

Possible Benefits of Life Cycle Cost Analyses

Concrete and Steel Bridges

Different Types of Concrete and Steel Bridges

Others Superstructure Issues:

- Rebar – Black, Epoxy, Galvanized & Stainless
- Decks – Joints, Integral abutments & Overlays
- Protective Systems – Paint, Weathering, Galvanizing
- Maintenance Programs – Washing, Clearing & Touch-Ups
- Service Programs – Salting, Cinders & Sanding

PennDOT Database 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

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

Closing

Thank You to PennDOT professionals, especially Tom Macioce, Bridge Engineer, and Katherine Schopman, Civil Engineer, for their participation.

Thanks to SMDI, NSBA and AGA for supporting the work.

Report currently under final review with the American Iron & Steel Institute, Steel Market Development Institute

The opinions, findings and conclusions in this work are not necessarily those of SMDI, NSBA or the AGA

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