Sustainability of Rural Steel and Concrete Bridges

Steel Bridge Essentials: Designing Cost-Effective & Resilient Bridges

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Objectives

- Life Cycle Sustainability Assessment (Cradle to Grave) of Two Nearly Identical, Functionally Equivalent, Two-Lane Bridges from Whitman County, WA
  - Steel – Seltice-Warner
    - Built 2020, 35 ft – 8 in, Modular Steel, 7 Rolled Beams, Corrugated Gravel Deck, County Crew Built
  - Concrete – Thornton Depot
    - Built 2019, 34 ft – 0 in, Precast Prestressed Beams, 8 Beams, Concrete Deck, County Crew Built
- Develop Procedures for Owners or Society that Considers Sustainability Benefits for the Design of Bridges

Bridges – Life Cycle

Steel Seltice-Warner

- Superstructure
- Construction
- Maintenance
- Demolition

Concrete Thornton Depot

- Superstructure
- Construction
- Maintenance
- Demolition

Superstructure Only

Bridge Lifes 75 yrs

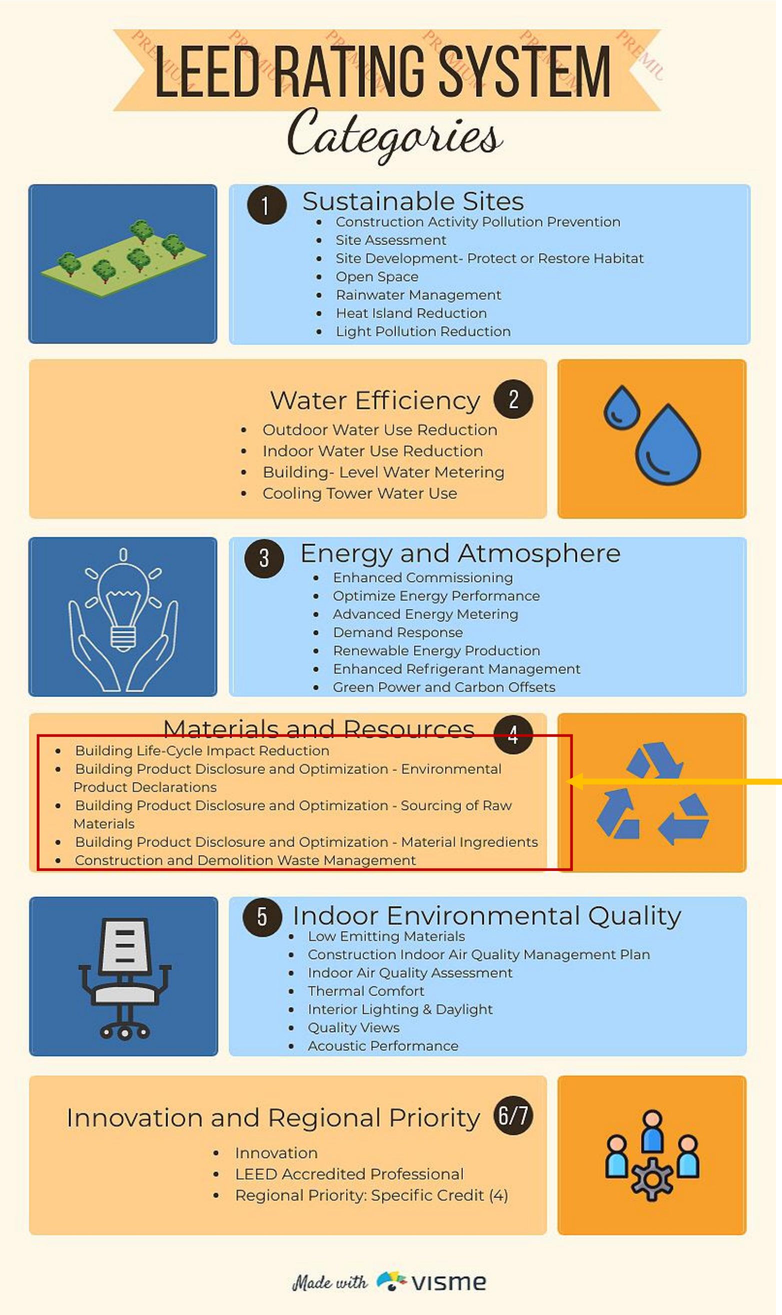
Prefabricated Bridges and Installation Equipment and Costs

Maintenance Assumed Identical for Both Bridges (none for 25 yrs, yearly for 50 yrs)

Demolition Equipment and Costs Different for the Two Bridges

Process

- Life Cycle Sustainability Assessment
  - Establish Criteria and Benchmarks
  - GHG, Energy, Recycling & Wastestream Metrics
  - Life Cycle Bridge Results
- Procedure that Considers Sustainability Benefits for the Design of Bridges
  - Monetizing Sustainability Benefits
  - Equivalent Cost Decision Making



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SUSTAINABILITY CRITERIA

EMISSIONS

ENERGY CONSUMPTION

RECYCLABILITY AND WASTE MANAGEMENT

LIFECYCLE COST

Superstructure Materials and Fabrication

Construction Equipment

Maintenance Equipment

Demolition Equipment

Emissions and Energy Consumption Benchmarks

Recyclability and Waste Management Benchmarks

- Use of recycled materials
- Recovery of recyclable materials during demolition
- Material to the landfill

Lifecycle Cost Benchmarks

- Life Expectancy of the Project
- Initial Cost
- Maintenance Cost
- Demolition and Salvage/Landfill Cost
- Present Value Life Cycle Cost

Emissions and Energy Consumption Metrics

- Fabricated Material and Component Emissions & Energy Consumption Metrics from Environmental Product Declarations (EPDs).
- Equipment Emissions & Energy Consumption Metrics from Analysis

Material	Description	Emissions (kgCO2e/ton)	Energy Consumption (MJ/ton)
Concrete	Precast Concrete Component	310.3	3268
	Grout	614.2	4545
Steel	Hot Rolled Steel Shapes	1106.8	16840
	Plates	1569.4	20804
	Steel Tubes	2168.2	25611
	Steel Deck	2150.0	27208
	Guardrail*	2150.0	27208
Other	#7 Gravel (1/2" x #4)	1.41	30.8

Construction Equipment	Description	Emissions (kgCO2e/hr)	Energy Consumption (MJ/hr)
Equipment	Light Equipment	50.8	724.5
	Heavy Equipment	71.1	1014.3

Superstructure Emissions and Energy Consumption

Steel Seltice-Warner

Bridge Component:	Weight (tons):	Emissions (kgCO2e/ton)	Energy (MJ/ton)	Length Factor	Emissions (kgCO2e)	Energy (MJ)
Stringers	9.337	1,106.8	16,840.1	0.953	9,851	149,892
Diaphragm	0.916	1,106.8	16,840.1	1.000	1,013	15,418
Tubes	0.308	2,168.2	25,610.8	0.953	637	7,523
Center Splice Plate	0.152	1,569.4	20,803.6	1.000	239	3,172
Side Dam	0.244	1,569.4	20,803.6	0.953	365	4,838
End Angle	0.274	1,106.8	16,840.1	1.000	304	4,621
Bridge Deck	4.699	2,150.0	27,208.3	0.953	9,631	121,880
Guardrail	0.360	2,150.0	27,208.3	0.953	737	9,328
Bridge Rail Post	0.578	1,106.8	16,840.1	1.000	639	9,725
Post Block	0.096	1,106.8	16,840.1	1.000	107	1,621
Gravel	22.655	1.4	30.8	0.953	30	665
Steel Weight	**16.96**			**Sub-Total Superstructure**	**23,554**	**328,683**
Reinf Concrete Weight	**-**					

Concrete Thornton Depot

Bridge Component:	Weight (tons):	Emissions (kgCO2e/ton)	Energy (MJ/ton)	Length Factor	Emissions (kgCO2e)	Energy (MJ)
Precast Elements	103.840	310.3	3,267.7	1.000	32,217	339,316
Misc. Steel Detail Items	0.338	2,150.0	27,208.3	1.000	727	9,196
Grout	0.999	614.2	4,545.0	1.000	614	4,540
Guardrail	0.360	2,150.0	27,208.3	1.000	773	9,785
Bridge Rail Post	0.387	1,106.8	16,840.1	1.000	428	6,517
Steel Weight	**1.08**			**Sub-Total Superstructure**	**34,759**	**369,355**
Reinf Concrete Weight	**103.84**					

Equipment Emissions and Energy Consumption

Steel Seltice-Warner

Construction Equipment	Hours on Site	Emissions (kgCO2e/hr)	Energy (MJ/hr)	Usage Factor	Emissions (kgCO2e)	Energy (MJ)
Heavy Equipment	130	71.1	1,014.3	0.30	2771	39558
Light Equipment	105	50.8	724.5	0.30	1599	22822
				Sub-Total Construction	**4,370**	**62,379**

Maintenance	Hours on Site/yr	Emissions (kgCO2e/hr)	Energy (MJ/hr)	Usage Factor	EoL Yrs of Maint	Emissions (kgCO2e)	Energy (MJ)
Heavy Equipment	3	71.1	1,014.3	1.00	50	10658	152145
Light Equipment	3	50.8	724.5	1.00	50	7613	108675
				Sub-Total Maintenance		**18,270**	**260,820**

Demolition	Hours on Site	Emissions (kgCO2e/hr)	Energy (MJ/hr)	Usage Factor	Emissions (kgCO2e)	Energy (MJ)
Heavy Equipment	20	71.1	1,014.3	0.50	711	10143
Light Equipment	15	50.8	724.5	0.50	381	5434
				Sub-Total Yearly Demolition	**1,091**	**15,577**

Concrete Thornton Depot

Construction Equipment	Hours on Site	Emissions (kgCO2e/hr)	Energy (MJ/hr)	Usage Factor	Emissions (kgCO2e)	Energy (MJ)
Heavy Equipment	128	71.1	1,014.3	0.30	2728	38949
Light Equipment	134	50.8	724.5	0.30	2040	29125
				Sub-Total Construction	**4,768**	**68,074**

Maintenance	Hours on Site/yr	Emissions (kgCO2e/hr)	Energy (MJ/hr)	Usage Factor	EoL Yrs of Maint	Emissions (kgCO2e)	Energy (MJ)
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				Sub-Total Maintenance		**18,270**	**260,820**

Demolition	Hours on Site	Emissions (kgCO2e/hr)	Energy (MJ/hr)	Usage Factor	Emissions (kgCO2e)	Energy (MJ)
Heavy Equipment	40	71.1	1,014.3	0.50	1421	20286
Light Equipment	20	50.8	724.5	0.50	508	7245
				Sub-Total Yearly Demolition	**1,929**	**27,531**

Life Cycle Emissions and Energy Consumption

Emissions

Emissions (kgCO2e)					
	Superstructure	Construction	Maintenance	Demolition	Total
Steel	23554	4370	18270	1091	47284
Concrete	34759	4768	18270	1929	59726

Steel 68% Less Same Less 79%

Energy Consumption

Energy (MJ)					
	Superstructure	Construction	Maintenance	Demolition	Total
Steel	328683	62379	260820	15577	667459
Concrete	369355	68074	260820	27531	725780

Steel 89% Less Same Less 92%

RESULTS – Steel Bridge Has Sustainability Advantages

Recycling, Surplus and Landfill

- Recycling Surplus or Cost
  - 98% Steel Recycled at Surplus of $100/ton
  - 80% of Concrete Recycled at Cost of $4.10/ton
- Landfill Cost $75/ton

Bridge	Steel Weight (tons)	% Steel Recycled	Concrete Weight	% Concrete Recycled	Steel Recycled (tons)	Concrete Recycled (tons)	Steel to Landfill (tons)	Concrete to Landfill (tons)
Steel	16.96	98%	-	80.0%	16.62	0.00	0.34	0
Concrete	1.08	98%	103.84	80.0%	1.06	83.07	0.02	20.768

Seltice-Warner Salvage Payback and Landfill Costs	
Tons of Steel Recycled	16.62
Tons of Steel to Landfill	0.34
Recycling Payback	$1,662.49
Landill Cost	$25.45

Thornton Depot Salvage Payback and Landfill Costs	
Tons of Steel Recycled	1.06
Tons of Steel to Landfill	0.02
Tons of Concrete Recycled	83.07
Tons of Concrete to Landfill	20.77
Recycling Cost	$234.30
Landill Cost	$1,559.23

Present Value of Costs (OMB Discount Rate 1.70%)

Steel Seltice-Warner

Bridge Component:	Costs	Length Factor	Adjusted Costs	Present Value Cost
Prefabricated Bridge	$ 60,134.00	0.953	$ 57,323.95	$ 57,323.95
Labor	$ 8,750.00	1.000	$ 8,750.00	$ 8,750.00
Equipment	$ 8,255.00	1.000	$ 8,255.00	$ 8,255.00
Materials	$ 3,491.00	0.953	$ 3,327.87	$ 3,327.87
		Sub-Total Superstructure	**$ 77,656.81**	**$ 77,656.81**

Demolition	Costs	Length Factor	Adjusted Costs	Present Value Cost
Labor	$ 5,000.00	1.000	$ 5,000.00	$ 1,412.21
Equipment	$ 1,110.00	1.000	$ 1,110.00	$ 313.51
Salvage	$ (1,662.49)	0.953	$ (1,584.81)	$ (447.61)
Landfill	$ 25.45	0.953	$ 24.26	$ 24.26
		Sub-Total Demolition	**$ 4,549.45**	**$ 1,302.36**

Maintenance	Costs / yr	Length Factor	EoL Yrs Maint	Life (yrs)	Adjusted Costs/ yr	Present Value Cost
Labor	$ 375.00	1.00	50.00	75	$ 375.00	8243
Equipment	$ 375.00	1.00	50.00	75	$ 375.00	8243
				Sub-Total Maintenance	**$ 750.00**	**$ 16,485.34**

Concrete Thornton Depot

Bridge Component:	Costs	Length Factor	Adjusted Costs	Present Value Cost
Prefabricated Bridge	$ 73,569.00	1.000	$ 73,569.00	$ 73,569.00
Labor	$ 11,800.00	1.000	$ 11,800.00	$ 11,800.00
Equipment	$ 10,444.00	1.000	$ 10,444.00	$ 10,444.00
Materials	$ 1,032.00	1.000	$ 1,032.00	$ 1,032.00
		Sub-Total Superstructure	**$ 96,845.00**	**$ 96,845.00**

Demolition	Costs	Length Factor	Adjusted Costs	Present Value Cost
Labor	$ 7,500.00	1.000	$ 7,500.00	$ 2,118.31
Equipment	$ 2,040.00	1.000	$ 2,040.00	$ 576.18
Salvage	$ 234.30	1.000	$ 234.30	$ 66.18
Landfill	$ 1,559.23	1.000	$ 1,559.23	$ 1,559.23
		Sub-Total Demolition	**$ 11,333.53**	**$ 4,319.90**

Maintenance	Costs / yr	Length Factor	EoL Yrs Maint	Life (yrs)	Adjusted Costs/ yr	Present Value Cost
Labor	$ 375.00	1.00	50.00	75	$ 375.00	$ 8,242.67
Equipment	$ 375.00	1.00	50.00	75	$ 375.00	$ 8,242.67
				Sub-Total Maintenance	**$ 750.00**	**$ 16,485.34**

Life Cycle Costs

Life Cycle Cost					
	Superstructure	Tot Initial	PV Maint	PV Demo	Total LCC
Steel	$ 57,324	$ 77,657	$ 16,485	$ 1,302	$ 95,445
Concrete	$ 73,569	$ 96,845	$ 16,485	$ 4,320	$ 117,650

Steel 78% 80% Same Less 81%

RESULTS – Steel Bridge Has Lower Initial & Life Cycle Costs

Considering Sustainability in Design Decisions

Monetizing Sustainability Benefits

- Sustainable design is predicated on the idea that society is willing to pay extra for reducing harmful effects on the environment.

  For these Two Bridges, This Decision is Trivial

  Steel has Higher Sustainability Benefits

  AND Steel has Lower Costs

  No Decision Required

  But, What if the Steel Bridge Cost More than the Concrete Bridge?

- Considering sustainability in the design of a bridge entails answering the question, “what additional cost would society or the owner be willing to pay to increase sustainability benefits?”

- Suppose Society is Willing to Pay:

  $0.20 per kg of CO_2e Reduced

  $0.04 per MJ of Energy Reduced

  $50 per ton of Landfill Reduced

Considering Sustainability in Design Decisions

Monetizing Sustainability Benefits

- Then, an Equivalent Cost can be Determined for Any Number of Design Alternatives. Basis of Analysis on the Lowest Cost Alternative.

Equivalent Cost = [Initial or Life Cycle Cost]
- [Reduced kg CO2e]*($0.20/kg CO2e)
- [Reduced MJ]*($0.04/MJ)
- [Reduced Landfill tons]*($50/ton)

- The Lowest Equivalent Cost Alternative is Chosen Considering the Sustainability Benefits and Cost of the Alternative.
- This is Actually an Incremental Benefit-Cost Analysis "Hidden" in Terms Owners and Society Understand (Similar to Initial or Life Cycle Costs)

Considering Sustainability in Design Decisions

Equivalent Cost = [Initial or Life Cycle Cost] - [Reduced kg CO2e]*($0.20/kg CO2e) - [Reduced MJ]*($0.04/MJ) - [Reduced Landfill tons]*($50/ton)

Bridge	Initial or Life Cycle Cost	Initial or Life Cycle Total			Reduction			Cost Benefit			Total Cost Benefit	**Equivalent Cost**
		kg CO2e	MJ Consumed	Landfill (tons)	kg CO2e	MJ Consumed	Landfill (tons)	kg CO2e	MJ Consumed	Landfill (tons)		
Alt 1	$ 100,000	59726	725780	21	0	0	0	$0	$0	$0	$0	**$100,000**
Alt 2	$ 105,000	70000	720000	10	-10274	5780	11	-$2,055	$231	$540	-$1,284	**$106,284**
Alt 3	$ 105,000	47284	667459	1	12442	58321	20	$2,488	$2,333	$1,000	$5,821	**$99,179**
Alt 4	$ 107,000	45000	664000	10	14726	61780	11	$2,945	$2,471	$540	$5,956	**$101,044**
Alt 5	$ 107,000	44000	750000	1	15726	-24220	20	$3,145	-$969	$1,000	$3,176	**$103,824**

- Alt 3 has lowest Equivalent Cost at $99179 (Initial Cost – Total Cost Benefit)
  - Alt 1 is Lowest Cost with a Basis Total Cost Benefit of Zero
  - Alt 4 has highest Sustainability Benefits with $5956 more benefits than Alt 1, but Costs $7000 more than Alt 1 (Incremental B/C < 1) – the Sustainability Benefits are not Worth the Extra Cost
  - Alt 3 has $5821 more Sustainability Benefits than Alt 1 and costs only $5000 more (Incremental B/C = 1.16) – the Sustainability Benefits Outweigh the Additional Costs
  - Alts 2 & 4 additional sustainability benefits (if any) do not outweigh the additional costs
- Alt 3 costs $5000 more, but has a Societal Accepted Rate of Return of $5821
- This is Incremental Benefit Cost Analysis with Monetized Sustainability Benefits
- Owner or Society Determines the Acceptable Cost for Sustainability Benefits
- Owners Understand Equivalent Cost: Compare Similar to Initial Costs or Life Cycle Costs

Summary & Conclusions

Results of Steel Seltice-Warner and Concrete Thornton Depot Bridges

- For the Installed Bridge
  - Steel had 30% less Emissions
  - Steel had 11% less Energy Consumed
- For the Life Cycle
  - Steel had 21% less Emissions (31300 equivalent vehicle miles)
  - Steel had 8% less Energy Consumed (0.6 homes for a year)
- Costs
  - Steel had 22% less Prefabricated Bridge Costs
  - Steel had 20% less Installed Initial Costs
  - Steel had 19% less Life Cycle Costs

Summary & Conclusions

Equivalent Cost Procedure

- Similar to Initial Cost or Life Cycle Cost Decision Making
- Owner or Society Driven with Acceptable Sustainability Benefit Costs
- Flexible in Analysis Details
    - Structure Only or Structure and Equipment
    - Initial Costs or Life Cycle Costs
    - Fabricated Bridge, Installed Bridge, or Life Cycle Bridge with or without Maintenance and Demolition
    - Any Combination of Emissions, Energy Consumed and Landfill Use (Others Could be Added)
    - Consider Total Energy or Only Non-Renewable Energy

Equivalent Cost = [Initial or Life Cycle Cost]

- [Reduced kg CO2e]*(Acceptable $/kg CO2e)

- [Reduced MJ]*(Acceptable $/MJ)

- [Reduced Landfill tons]*(Acceptable $/ton)

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