ADVANCING EMBODIED CARBON REDUCTION IN INFRASTRUCTURE PROJECTS (BRIDGES)

FINAL PRESENTATION

COLUMBIA | CBIPS
Center for Buildings, Infrastructure and Public Space

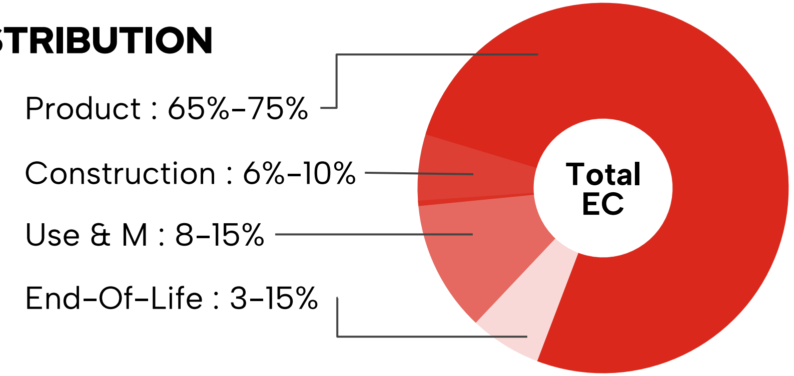
01 INTRODUCTION

EMBODIED CARBON

DEFINITION

- **Embodied Carbon (EC)** refers to the total greenhouse gas emissions associated with the materials and processes involved in a project's **lifecycle.**
- Critical metric in assessing the **environmental impact** of infrastructure projects

DISTRIBUTION

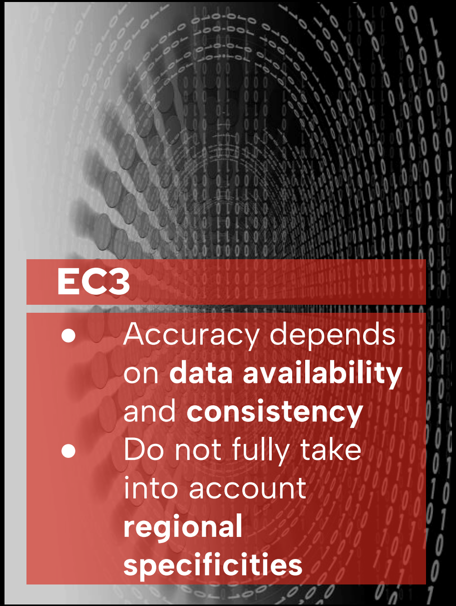


SCOPE : LIFE-CYCLE ASSESSMENT PHASES

PRODUCT A1-A3 → **CONSTRUCTION A4-A5** → **USE AND MAINTENANCE B1-B7** → **END-OF-LIFE C1-C4**

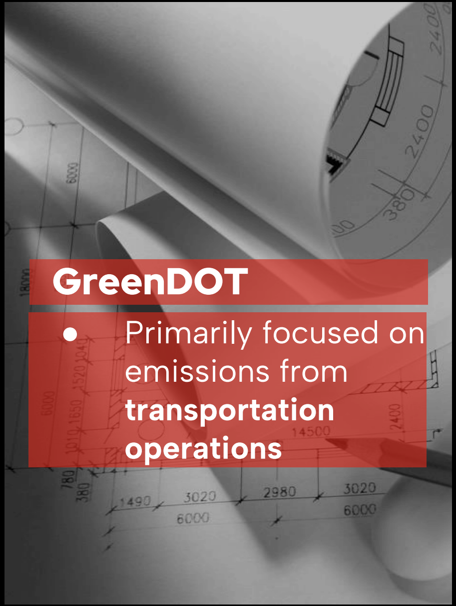
Embodied Carbon

TOOLS AND LIMITATIONS



EC3

- Accuracy depends on **data availability** and **consistency**
- Do not fully take into account **regional specificities**

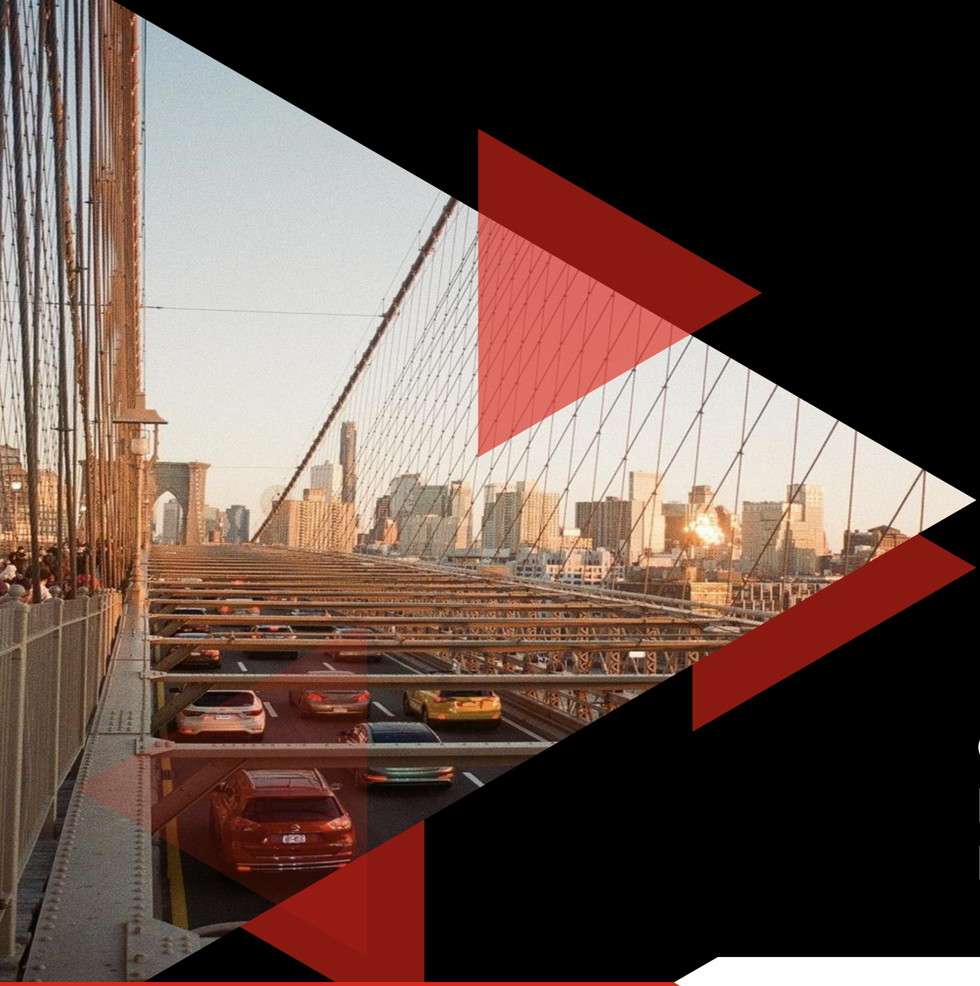


GreenDOT

- Primarily focused on emissions from **transportation operations**

AsPECT

- Specialized for **asphalt** : its utility is limited to **specific types** of projects
- Do not include a **detailed LCA**



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CASE STUDY 1

Carbon Impact Assessment of the Bridge Construction based on Resilience Theory

KEY APPROACHES

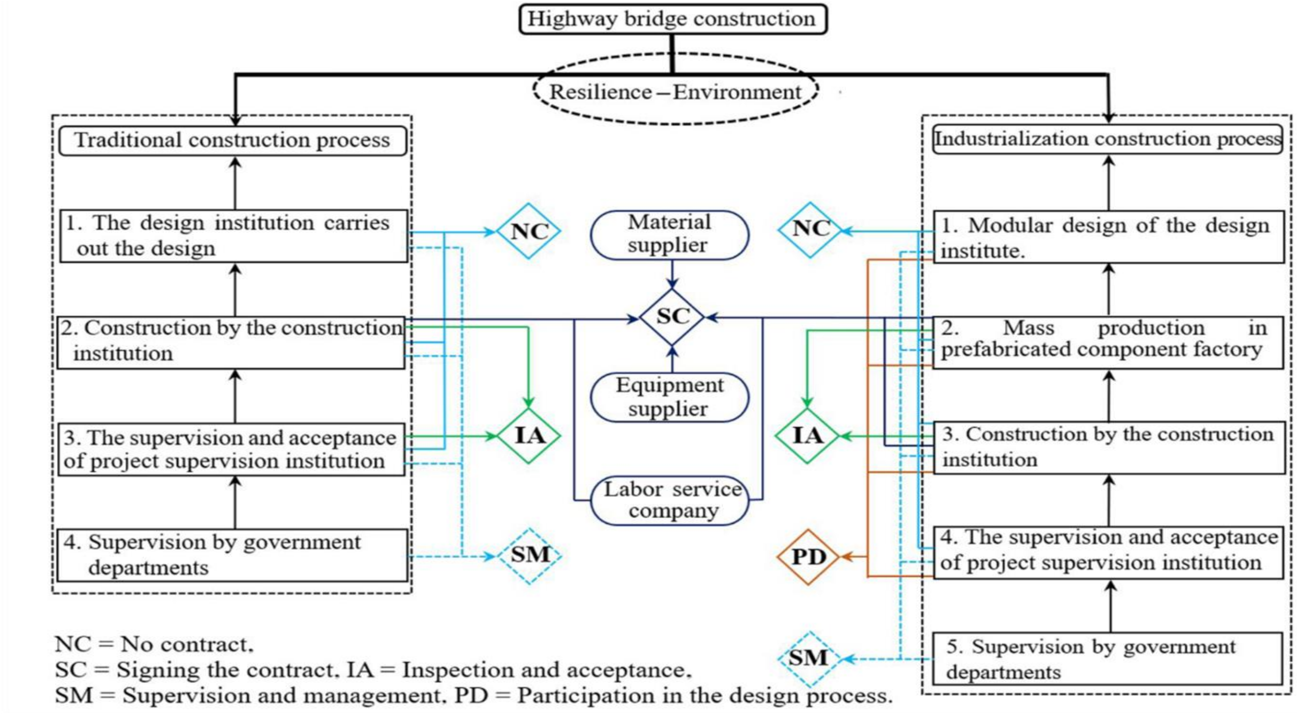
1. Industrialized Construction
2. Green Building Practices
3. Energy Efficiency
4. Recycling and Waste Management

INDUSTRIALIZED CONSTRUCTION

Industrialized construction significantly reduces material waste and energy consumption. For instance, industrialized bridge construction can save 56.31% of materials compared to traditional methods

It also reduces pollution discharge, with emissions from industrialized construction being 143.4 times lower than cast-in-place construction

TRADITIONAL VS INDUSTRIALIZED CONSTRUCTION



Source: Carbon Impact Assessment of Bridge Construction based on Resilience Theory

GREEN BUILDING PRACTICES

Using sustainable materials and construction methods helps reduce the carbon footprint. The focus should be on materials with lower embodied energy and emissions

Life cycle assessment (LCA) can be used to evaluate environmental impact throughout the bridge's life cycle, guiding the selection of sustainable materials

RECYCLING AND WASTE MANAGEMENT

Implementing recycling practices for construction waste helps reduce emissions. For example, recycling concrete and steel from bridge construction can significantly lower the environmental impact

Effective waste management strategies reduce the overall carbon footprint by minimizing the need for new materials

STATISTICAL ANALYSIS

01 MATERIAL IMPACT

The materials used in bridge construction contribute significantly to environmental impact. Reducing this impact involves using sustainable materials and recycling where possible

02 ENERGY CONSUMPTION

Energy used in construction processes can be minimized by adopting energy-efficient practices and machinery

03 EMISSION REDUCTION

The emissions from vehicles and machinery used in construction can be mitigated through the use of clean energy sources and efficient logistics

ENERGY EFFICIENCY

Reducing energy consumption in construction processes contributes to decarbonization. This includes using energy-efficient machinery and optimizing construction schedules to minimize energy use

Utilizing renewable energy sources where possible can further reduce the carbon footprint

NEED AND IMPORTANCE OF THIS CASE STUDY

Reduction in Material Usage with Industrialized Construction:

- Industrialized bridge construction can save 56.31% of materials compared to traditional methods, indicating a significant reduction in the carbon footprint due to material usage

Lower Emissions with Industrialized Methods:

- Industrialized and prefabricated construction results in much lower emissions. The emissions from industrialized construction are 1/143 of the emissions from traditional construction methods. This dramatic reduction contributes to the goal of sustainable construction

Environmental Impact Assessment:

- The research model assesses the environmental resilience impact of bridge construction, providing a framework for evaluating the resilience change during project management. This model uses life cycle assessment (LCA) to measure environmental impacts throughout the bridge's lifecycle

Resilience Factor Differences:

- Traditional bridge construction has a quadratic parabola resilience, while industrialized construction has a non-isosceles trapezoid resilience. This difference in resilience shapes the environmental impact assessment

CONSTRUCTION STAGES AND ENVIRONMENTAL IMPACT

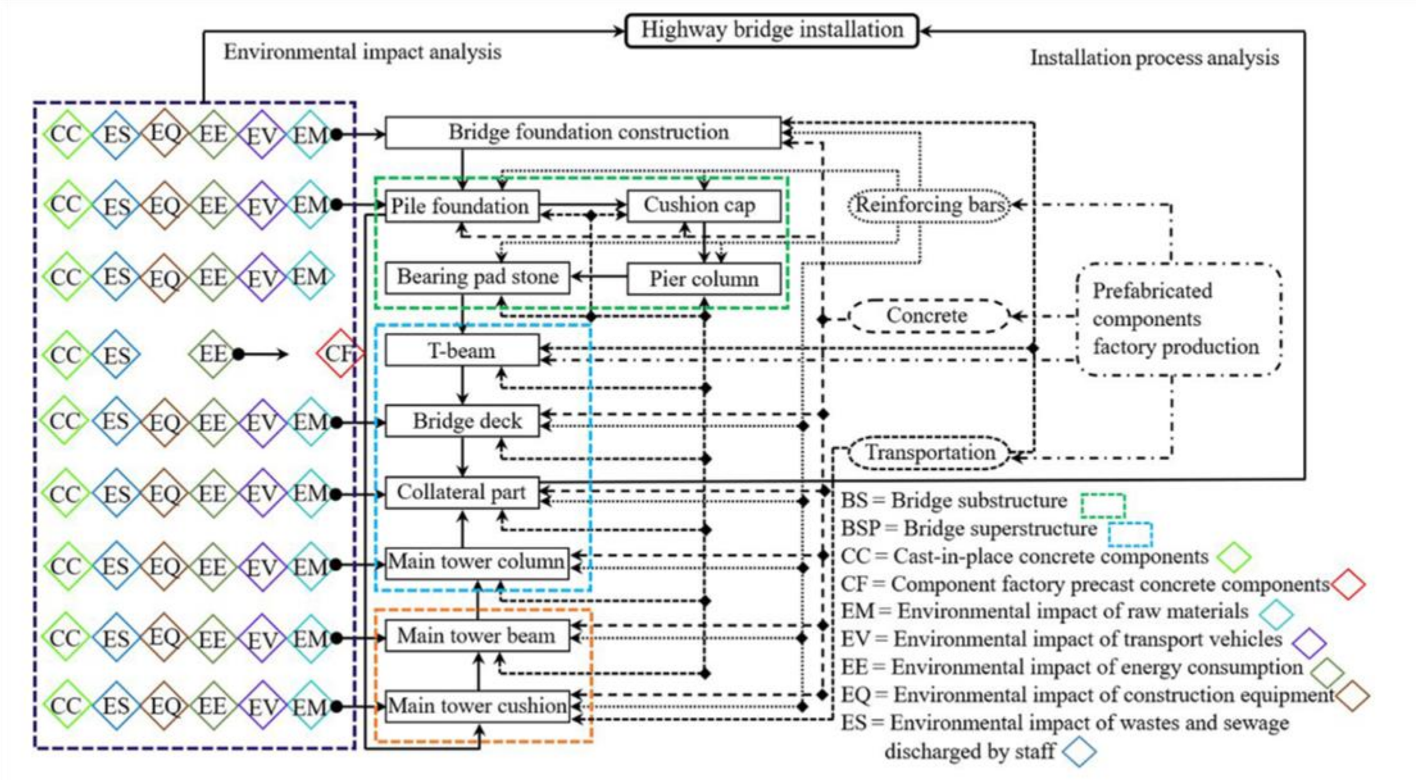
Material Usage:

- The materials used during construction are a major contributor to environmental impact. The emissions caused by manufacturing reinforcement bars, steel, and anti-corrosion coatings account for 93.7% of the total emissions

Concrete Mixing and T-Beam Production:

- Emissions from concrete mixing and T-beam production contribute significantly to the overall carbon footprint. The concrete used for T-beam production accounted for 48.9% of the total emissions in the beam yard

INSTALLATION PROCESS AND ENVIRONMENTAL IMPACT MODEL ANALYSIS OF THE ENTIRE NETWORK BRIDGE



Source: Carbon Impact Assessment of Bridge Construction based on Resilience Theory

GENERAL LAYOUT DESCRIPTION OF THE CONSTRUCTION PLAN OF EACH DISTRIBUTION STRUCTURE OF TPB

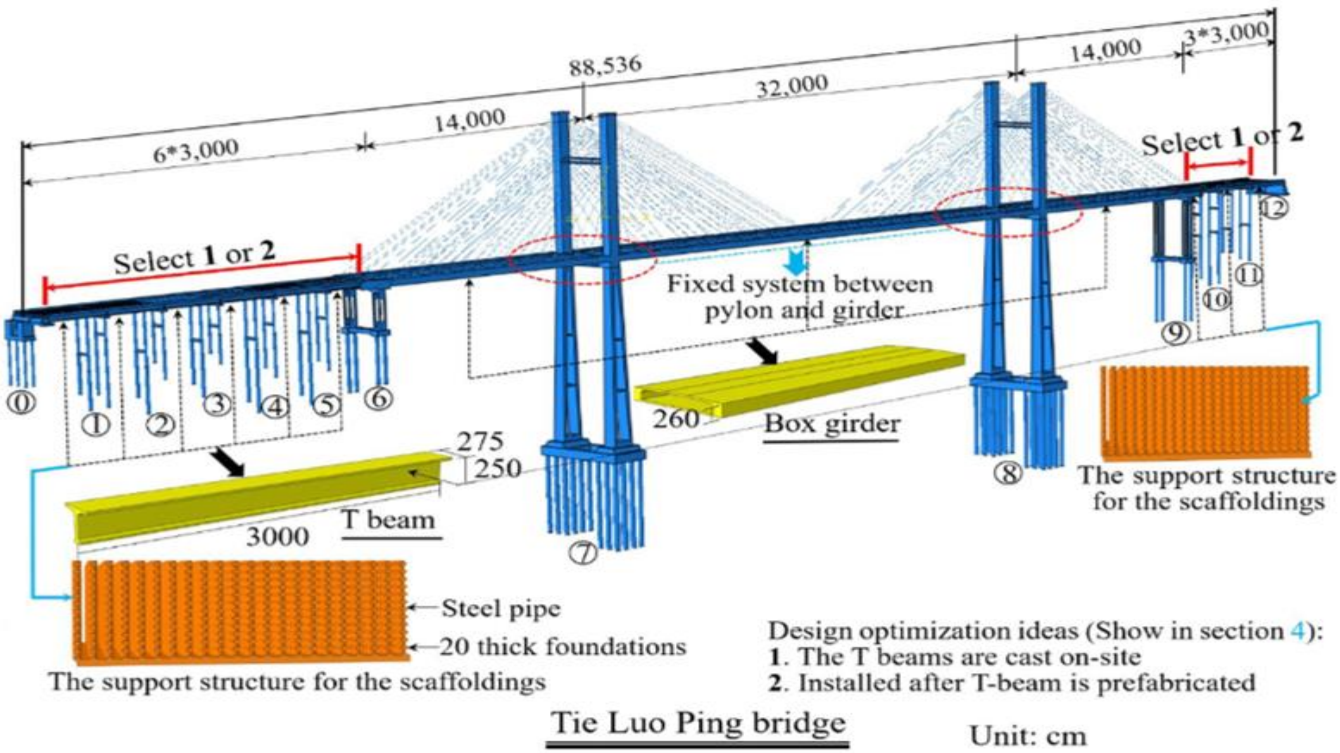


Fig: Tie Luo Ping Bridge, Source: Wikipedia

Source: Carbon Impact Assessment of Bridge Construction based on Resilience Theory

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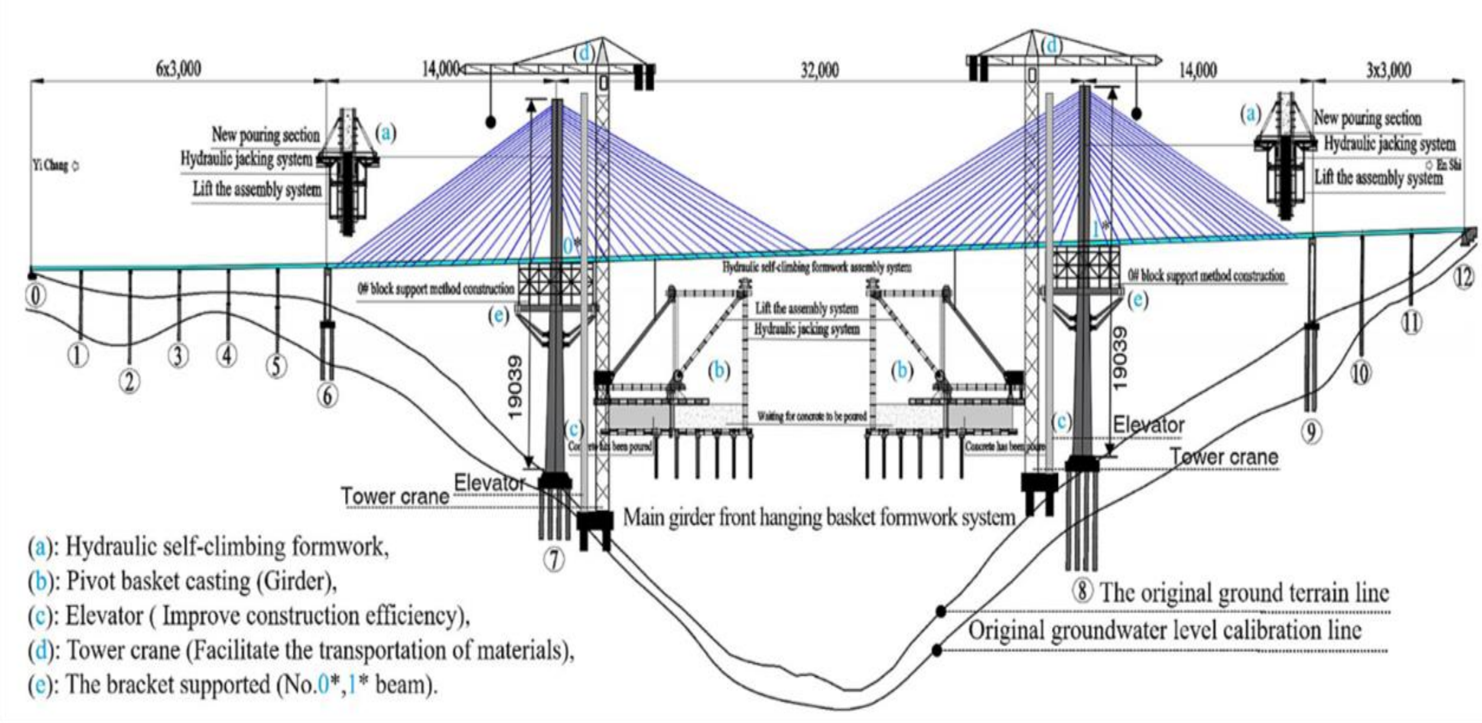
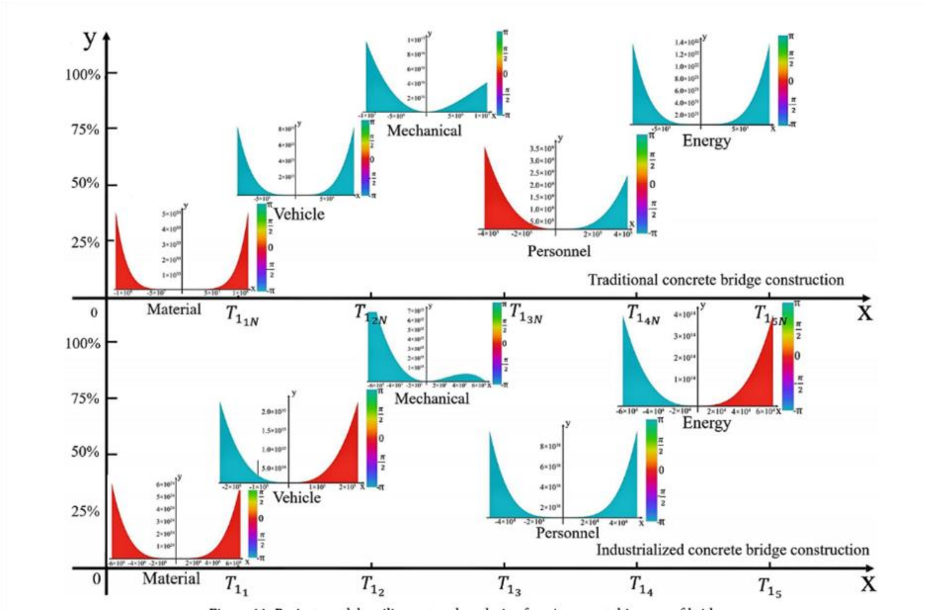


Source: Carbon Impact Assessment of Bridge Construction based on Resilience Theory

PROJECT MODEL RESILIENCE TREND ANALYSIS OF ENVIRONMENTAL IMPACT OF BRIDGES



Source: Carbon Impact Assessment of Bridge Construction based on Resilience Theory

PROJECT MODEL RESILIENCE TREND ANALYSIS OF ENVIRONMENTAL IMPACT OF BRIDGES

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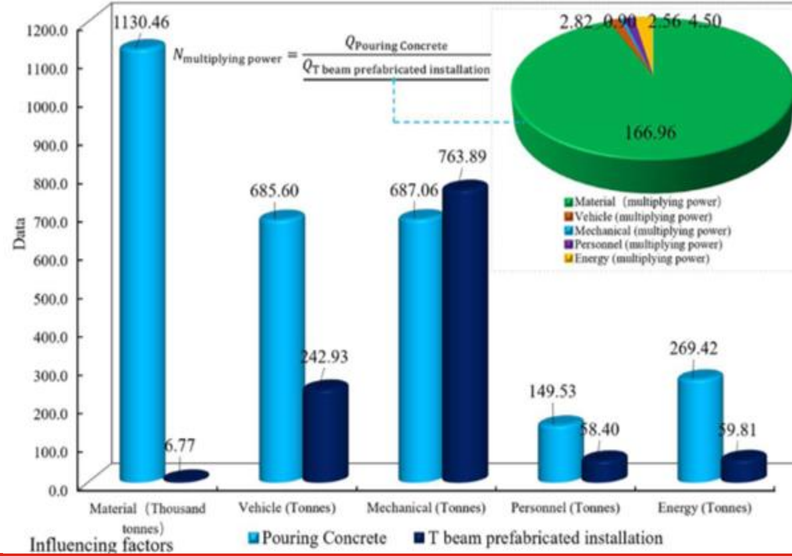
Table 2. Statistical table of environmental impact data of bridges

Name	GWP	AP	FEP	PMFP	WP
Traditional concrete bridge construction (kg)					
Material	113,332,299.20	1,384,340.77	858,833.61	3,916,441.55	7,607,602.73
Vehicle	903,056.32	257.84	59.29	33.38	2.10
Mechanical	9,651,674.47	65.50	19.67	40.46	68.39
Personnel	405,158.40	0.00	18,288.40	0.00	70,340.00
Energy	887,301.91	3.65	1.32	178.95	676.40
Total	125,179,490.30	1,384,667.75	877,202.28	3,916,694.35	7,678,689.62
Industrialized concrete bridge construction (kg)					
Material	6,503,188.61	25,206.08	16,735.60	86,163.10	139,431.85
Vehicle	242,918.58	4.52	1.50	3.08	3.90
Mechanical	763,869.54	6.23	1.92	3.95	6.20
Personnel	53,245.66	0.09	1,047.84	15.80	4,089.79
Energy	59,805.83	0.27	0.09	0.29	1.02
Total	7,623,028.22	25,217.20	17,786.95	86,186.22	143,532.77



Source: Carbon Impact Assessment of Bridge Construction based on Resilience Theory

03

CASE STUDY 2

An Environmental Comparison Of Bridge Forms

A Comparative Analysis of 3 Bridge Types, Costs, and Environmental Footprints

	Relative cost	Relative env. burden
Cantilever	1.0	1.0
Cable stay	1.2	1.3
Arch	2.0	1.9

Table 1. Bridge Type vs Cost and Env. Burden

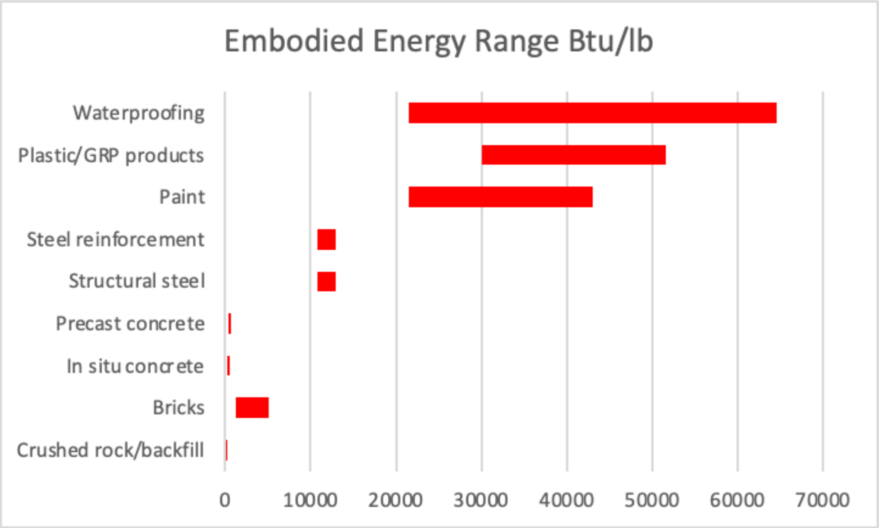
Conclusion: The preliminary environmental impact of a bridge is expected to correlate closely with its associated cost.

- Case study: major creek crossing in the Middle East
- Material quantities and cost estimates prepared for **three bridge options**
- Concrete cantilever, concrete cable stay and steel arch are considered
- Estimate of **embodied energy and CO2 emissions** are assessed from the principal material quantities
- A bridge that utilizes **fewer materials** and employs a **repetitive construction** technique is expected to have a l**ower embodied energy**, resulting in **minimized** CO2 emissions.

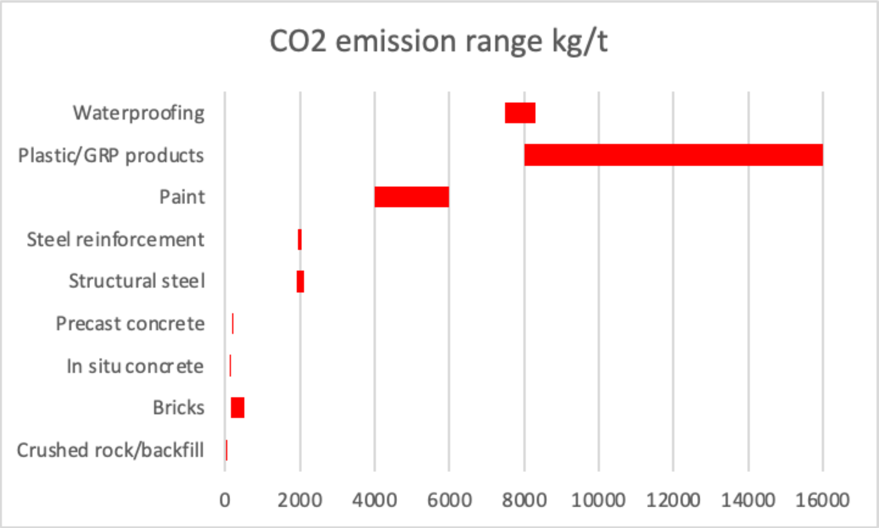
Case study by David Collins, Tech. Director, Benaim, London UK

- **Moderate length** river bridge
- River width of ≈ 120 meters and approach spans of 66 meters on each side
- The total deck area was ≈ 4300 m2
- This configuration enables the evaluation of both the **shorter span structures** on the approaches and the **main river span**
- Embedded **energy** and **CO2 emission** during **construction** phase
- **4 types:** Viaduct, Girder, tied arch and cable stayed
- **Material:** Steel, Concrete, Steel–Concrete composite
- **Data:** From actual projects and estimates

GRAPHICAL REPRESENTATION



Graph 1. Embodied energy during construction (GJ/m2) for various structural forms and materials



Graph 2. CO2 emission range (kg/t) for various structural forms and materials

Embodied Energy During Construction (GJ/m^2) For Various Structural Forms and Materials

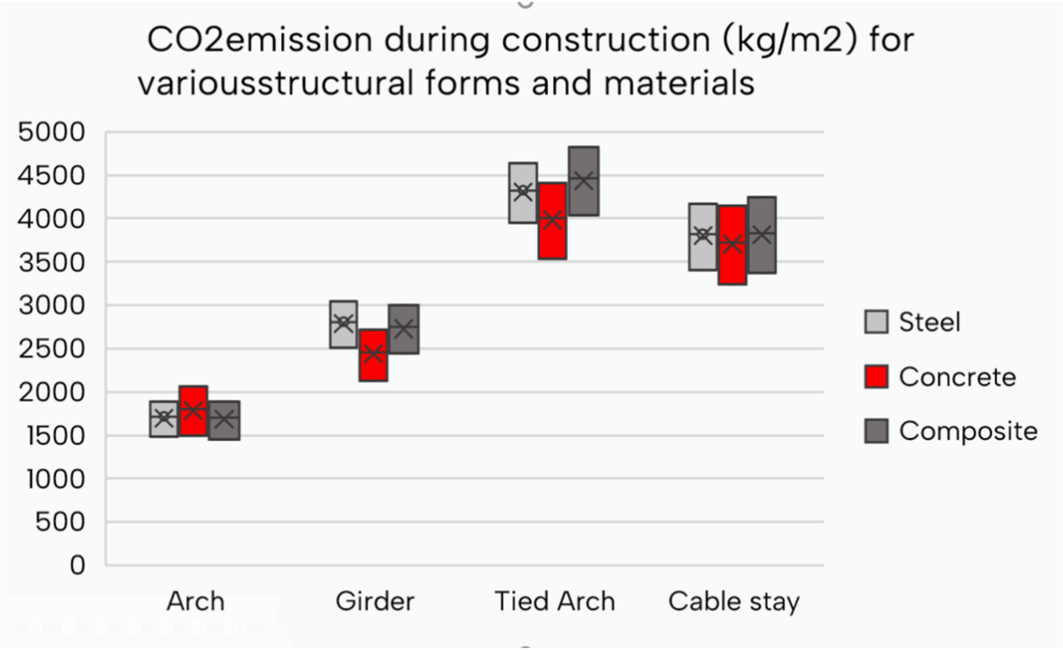
Energy	Type	Steel	Concrete	Composite
Minimum	Arch	17.8	**15.7 / 16.6**	16.6
	Girder	30.9	23.6	29.1
	Tied Arch	49.8	38.8	48.8
	Cable stay	40.3	34.3	37.7
Average	Arch	23.5	21.1 / 22.1	22.1
	Girder	39.3	30.6	37
	Tied Arch	61.9	49.1	60.8
	Cable stay	50.6	43.9	47.7
Maximum	Arch	30.8	28.1 / 28.6	29.2
	Girder	49.3	39.1	46.6
	Tied Arch	**75.6**	60.9	74.4
	Cable stay	62.6	54.8	59.3

- The **maximum** and **minimum** values were employed to delineate the **probable range** of **embodied energy** and CO2 for **each structural form** and **material**.
- **Lowest** – short-span concrete structure
- **Highest** – all-steel or composite, longer span structure
- **Shorter-span** structures – **insignificant** difference between concrete and steel-concrete composite

Table 3. Embodied energy during construction (GJ/m2) for various structural forms and materials

CO2 Emission During Construction (kg/m2) For Various Structural Forms and Materials

CO2 Range	Type	Steel	Concrete	Composite
Minimum	Arch	1484	1445/1499	1453
	Girder	2513	2132	2440
	Tied Arch	3952	3536	4036
	Cable stay	3406	3242	3372
Average	Arch	1719	1710/1883	1702
	Girder	2810	2457	2750
	Tied Arch	4326	4005	4459
	Cable stay	3822	3726	3830
Maximum	Arch	1891	1912/2066	1893
	Girder	3043	2718	2998
	Tied Arch	4637	4410	4820
	Cable stay	4174	4146	4244



Graph 3.Table 4. CO2 emission during construction (kg/m2) for various structural forms and materials

CASE STUDY 2

Variation In Embodied Energy With Span And Material Type

- The embodied energy vs **span** and **material** type.
- **Greater** embodied energy in **longer spans**.
- Variation of **form and material** can have a significant **effect** on the environmental burden.
- A **well-designed longer-span** bridge that incorporates local materials, recycled steel, and cement produced through the dry process, with some cement replacement, can approach the environmental friendliness of a **shorter-span** structure with no considerations
- **Architectural solutions** tend to impose a **higher** environmental burden across **all** materials.

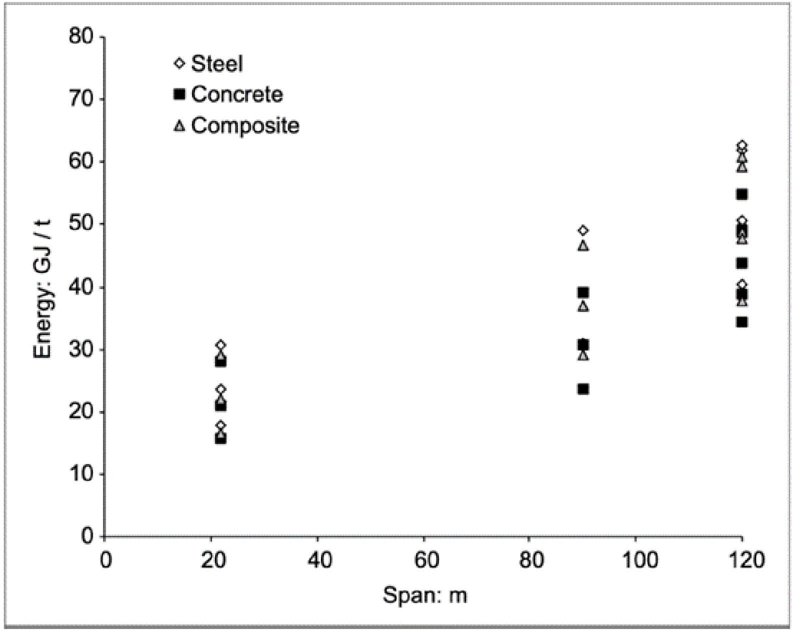
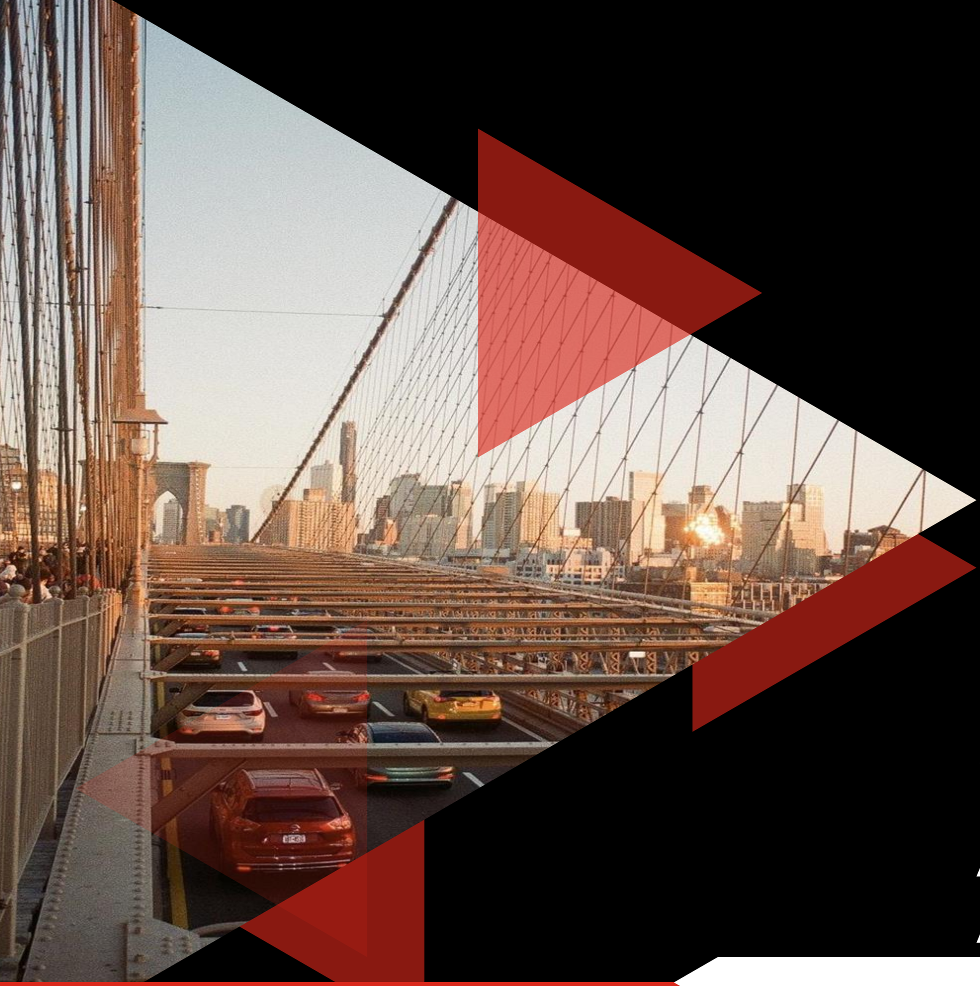


Figure 4. Variation in embodied energy with span and material type

CONCLUSION

- More **architectural** forms – **higher environmental burden**, reflected in the cost.
- For **shorter** span – **little difference** between the popular precast concrete beam and the steel girder with a concrete slab.
- For **longer spans** – **concrete** fridges are marginally better than steel—concrete composites or all-steel structures.
- Choosing **materials wisely** is crucial to lowering the environmental impact of bridges. For example, using concrete for compression elements like towers and arches, and steel for tension elements like ties, proves effective.
- While CO_2 emissions during the bridge's life from **repair and maintenance** are slightly **higher**, they are **similar** to those during **construction**. Designers can reduce environmental impact by opting for **minimal material** structures based on proven principles. To make a more significant difference, designers should actively choose materials from l**ow-energy production processes and local sources**.
- To further minimize ongoing environmental impact, follow good practices like **reducing joints and avoiding high-energy products** like paints and plastics that need frequent replacement.



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CASE STUDY 3

Assessment of Embodied Carbon in a Tied Arch Bridge

NEED AND IMPORTANCE OF THIS CASE STUDY

Global Impact and Targets:

- The built environment and **construction sector contribute 39% of global carbon emissions** and **50% of raw material use**.

Bridge Infrastructure Challenges:

- Bridges, crucial for modern infrastructure, often use **carbon-intensive materials like steel and concrete**. Sustainable design practices are crucial to mitigate environmental impact.

Focus on Steel Tied-Arch Bridges:

- The research centers on steel tied-arch bridges, emphasizing a specific case study to assess the total embodied carbon in an optimized superstructure.

Net-Zero Design Strategies:

- Achieving net-zero bridge design requires **minimizing material use**, especially carbon-intensive materials, and **offsetting remaining embodied carbon through complementary techniques**.

TIED-ARCH BRIDGES IN EUROPE

Tied-Arch Bridges in Europe:

- Tied-arch bridges are prevalent in Europe, with 57.9% constructed since 2000.

Database Analysis and Categorization:

- Approximately **60%** of these bridges serve as **road bridges, with spans ranging from 26m to 285m.**

Evolution and Popularity:

- The first steel tied-arch bridge in Europe was completed in 1904, and their numbers steadily increased until 1988, with a **significant surge from 1999 to 2014**.

Figure 11 – **Bicycle bridge at Tessenderlo, Belgium**
Anker. (n.d.). Bicycle Bridge Tessenderlo, Belgium. Anker.

EMBODIED IMPACT - A CASE STUDY

Optimization and Mass Reduction:

- Conducted a parametric study on individual components (main girders, stiffeners, arch, bracing, and hangers) of a steel tied-arch bridge, resulting in an optimized design with a total steel mass of 3452 tonne

Carbon Neutral Superstructure Strategies:

- Explored achieving carbon neutrality by using renewable energy for EAF steel production, potentially saving over 673 t CO2 eq. SSAB's innovations, including the world's first fossil-free steel and SSAB Zero, offer carbon emissions-free options.

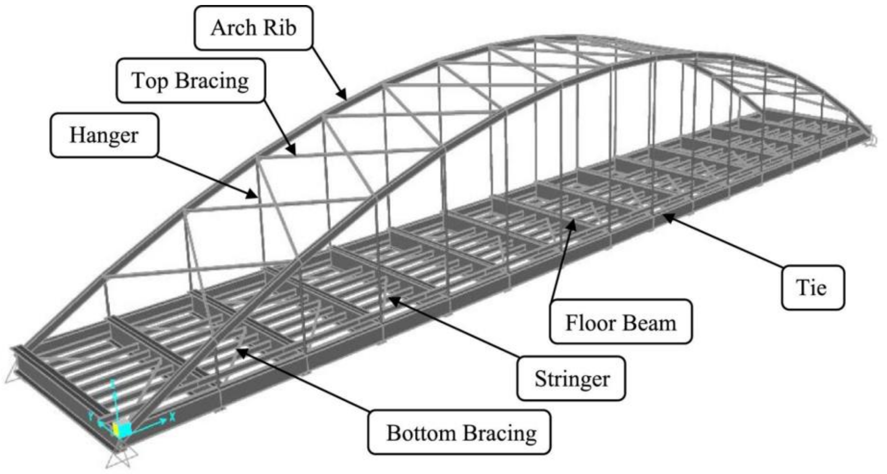

Figure 12 - **Tied-Arch Bridge components**
Allan, J (2022), Operational and embodied emissions associated with urban neighbourhood densification strategies

CASE STUDY 3

EMBODIED IMPACT - A CASE STUDY

ATERIALS:

oncrete Emission Reduction:

- Use alternative cementitious materials to decrease concrete GWP by over 60%, with options like Portland fly ash cement and blast furnace cement

nnovative Carbon Utilization Technologies:

- Explore CarbiCrete (carbicrete.com) and CarbonCure (carboncure.com) for carbon-neutral groundwork, where CarbiCrete, being carbon-negative, removes more CO2 (e.g., 998 kg emitted, 1,000 kg removed), and CarbonCure reduces cement use by 7%, saving 15 kg CO2 eq. /m3.

oncrete Carbon Sequestration:

- Implement techniques like CarbiCrete and CarbonCure for active CO2 sequestration and mineralization in concrete.

Component	Material	Total Mass
Central Girder	S460	450
Edge Girder	S460	571
Transversal Stiffeners	S460	73
Arch	S355	2107
Bracing	S355	133
Longitudinal Stiffeners	S275	118

Table 6 – **Bridge components and their material specifications**

CASE STUDY 3

CONCLUSION

Carbon Neutrality Focus:

- Addressing global warming, the paper targets tangible carbon neutrality actions in modern infrastructure, specifically steel tied-arch bridges.

Optimization for Carbon Reduction:

- Optimizing design focuses on **minimizing steel mass**, **exploring materials**, and alternative techniques, showing potential GWP reductions.

Assessing Global Warming Potential:

- Embodied carbon calculations post-optimization assess the design's global warming potential, considering **green electricity, lower carbon steel, and cement alternatives**.

SSAB Zero Impact:

- SSAB Zero usage can **reduce GWP by 40.4%**, and incorporating SSAB plates for closed sections **achieves an impressive 94% reduction** in GWP.

05

CASE STUDY 4

Gordie Howe Cable Stayed Bridge

GORDIE HOWE BRIDGE

CANADIAN BRIDGE TOWER DIMENSIONS

- Canadian Bridge Tower – 220 M High
- Elevator (Kyle bar net) – 200 ft/min
- 5 Platforms – bottom level deck, road deck, P5 – post tensioning and iron works, and jump form (temporary column moves up the column)
- Takes about 5 min 15 sec to reach top from bottom

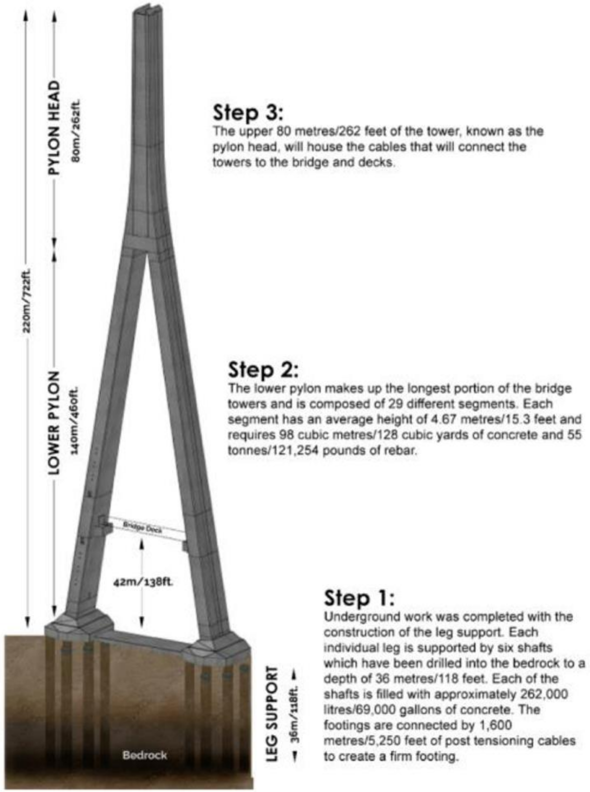

Figure 13. Pylon Dimensions

Figure 14. Construction of Gordie Howe Bridge

CASE STUDY 4

GORDIE HOWE BRIDGE - Construction Process

- Concrete is pumped from the ground and for rebar is inserted using tower frame.
- First installing the steel box on the upper pylon as anchors for cables
- Passive anchors for cables at deck level and active anchors for cables on the pylon
- Architectural Head to prevent snow or water accumulation

Figure 17. Anchors at pylon for cables

Figure 18. Architectural Head

Figure 19. Prefabricated Girder panels

GORDIE HOWE BRIDGE – Construction Process

stv

- Excavation about 30m, 100 ft to find solid rock. Then building footings for the legs, struts between the footings and then leg construction is done.
- For leg construction the same system is used which is combined coming around 140 m (450ft) above the ground. Then upper pylon is constructed where all the cables go.
- The jump form jumps 4.5m at the time and 25 jumps in leg and 22 jumps on the upper pylon. The jump form is 4 storey tall.
- Jump form can hold on 30 workers – 10 hours a day and 6 days in a week – ironworkers, laborers, and operating engineers.
- Grade 60 Mpa concrete. High yield steel rebar and stainless steel for some areas for durability purposes. Some steel boxes in upper pile.

Figure 15. Steel boxes in upper pylon

Figure 16. Erection process

KEY MATRIX DETERMINING EC FOR BRIDGES

- **Span** of the Bridge
- **Type** of the bridge - Arched / Cable-stayed / Beam / Tied-Arch
- **Material Use** - Concrete / Steel / Composite / Recycled Materials
- **Material Waste** - Waste Management Method Data
- **Intensity of use of equipment** - Impact on EC due to Precasting

EMBODIED CARBON FACTOR – REFERENCE

Table 7 – Suggested embodied carbon factors (ECFA1–A3,i) for common secondary bridge elements

ELEMENTS	SUBDIVISION 1	SUBDIVISION 2	EMBODIES CARBON A1-3 (tCO_2e/t)	UNIT OF MEASURE
BEARINGS	Steel rocket/roller	Vertical load capacity <400 tonnes	2	No.
	Electronic	Vertical load capacity <100 tonnes	0.2	No (per bearing)
		Vertical load capacity 100 t< X < 200t tonnes	0.8	No (per bearing)
	Spherical	Vertical load capacity <100 tonnes	1.21	No (per bearing)
		Vertical load capacity 100 t< X < 200t tonnes	5.63	No (per bearing)
		Vertical load capacity 200 t< X < 300t tonnes	10.26	No (per bearing)
		Vertical load capacity 300 t< X < 400t tonnes	15.75	No (per bearing)
		Vertical load capacity 400 t< X < 500t tonnes	21.57	No (per bearing)
	Pot	Vertical load capacity <100 tonnes	0.97	No (per bearing)
		Vertical load capacity 100 t< X < 200t tonnes	5.09	No (per bearing)
		Vertical load capacity 200 t< X < 300t tonnes	9.29	No (per bearing)
		Vertical load capacity 300 t< X < 400t tonnes	14.28	per bearing
		Vertical load capacity 400 t< X < 500t tonnes	18.07	No

EMBODIED CARBON FACTOR – REFERENCE

Table 7 – Suggested embodied carbon factors (ECFA1–A3,i) for common secondary bridge elements

Expansion joints	All types	Movement range low <99mm	0.14	Length of Joint (m)
		Movement range Medium 100mm < X < 120mm	0.37	Length of Joint (m)
		Movement range High >120mm	0.61	Length of Joint (m)
Protective treatment	Polymer based paint	Solvent based typical	0.0018	Applied surface area (m2)
		Solvent based marine	0.0041	Applied surface area (m2)
	Hot dip galvanizing	Zinc coating only	0.0031	Applied surface area (m2)
Services	Pvc pipe	<150mm diameter	0.01	Length of pipe (m)
	Cast iron pipe	<150mm diameter	0.08	Length of pipe (m)
	Vitrified clay pipe	<150mm diameter	0.01	Length of pipe (m)
Surfacing	Waterproofing	Flexible sheeting/ spray applied	0.012	Area of waterproofing (m2)
		bituminous layer	0.005	

EMBODIED CARBON FACTOR – REFERENCE

Table 8 – Mode of transport carbon factors

MODE OF TRANSPORT	TYPE	CARBON EMISSION FACTOR	UNITS
Road	HGV (diesel) - 0% laden	0.642	Kg CO2e/km
Road	HGV (diesel) - 50% laden	0.119	kgCO2e/(tonne.km)
Road	HGV (diesel) - 100% laden	0.0722	kgCO2e/(tonne.km)
Sea	Average bulk carrier	0.00353	kgCO2e/(tonne.km)
Sea	Average container ship	0.0161	kgCO2e/(tonne.km)
Rail		0.0278	kgCO2e/(tonne.km)

EMBODIED CARBON FACTOR

Table 11. GORDIE HOWE BRIDGE Calculations

GORDIE HOWE BRIDGE					
EQUIPMENTS	**Dimensions**	units	**Carbon Factor**	**Carbon Emission**	**units**
Elevator	200 ft/min - 5 mins 15 sec				
CONSTRUCTION					
Excavation	30	meter	15.2	456	kgCO2e/m
Footings					
Canadian Bridge Tower	220	meter	7.6	1672	kgCO2e/m
Lower Pylon	240	meter	19.1	4584	kgCO2e/m
Pylon Head	80	meter	19.1	1528	kgCO2e/m

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