SOIL-STEEL BRIDGES vs CONVENTIONAL REINFORCED CONCRETE BRIDGES - ENVIRONMENTAL IMPACT ISSUES

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Introduction

Life Cycle Assessment (LCA) is a tool used to evaluate the environmental aspects of a product or process. All used materials, energy and waste that are involved in every phase of the product life cycle, starting from raw material extraction to recycling or final disposal are mapped out. LCAs measure key environmental impacts including Global Warming Potential, toxicity and resource depletion. The results are used to gain insight into the most significant effects of a product. Then, by comparing with results of other LCAs, improvements are sought in order to achieve a lower environmental impact.

The truth is that today's bridge constructions rely on the non-renewable resources, the consumption of fossil fuels, and the intensive usage of concrete. This pushes designers to explore the new design options to mitigate the associated environmental burdens [1].

In the Americas, steel is widely used as a raw material for bridges and culverts under and over roads and railway lines, and has been in use in North America since 1896. In Europe, the corrugated steel construction method, used for soil-steel bridges, established since the mid-1950s, in many of European countries is still considered a niche product. On the other hand, flexible buried structures made of corrosion-protected steel offer numerous advantages over conventional concrete structures for road and railway infrastructure as well as for many other industrial applications. Fast and easy assembly makes corrugated steel structures more economical. The installation time for culverts and bridges made of corrugated steel is considerably shorter than for concrete structures due to several factors i.e: the light material, fewer elements, limited concrete curing. The simple and quick installation contributes to shortening the time needed for the construction of the bridge or culvert, and also to making it more economical. In the further course of time, buried corrugated steel structures stand out as particularly low-maintenance constructions. Renovations, expansions or extensions can also be implemented more quickly and flexibly with corrugated steel structures [1]. In this paper authors will summarize the total costs of the bridge facility, not only the direct ones, but also those that are incurred in a structure life time i.e repairs, renovations reconstruction, demolition/recycling, and are usually not taken into account when choosing the construction technology.

LCA and EPD certification

To be able to calculate environmental impact of the product and solution, Environmental Product Declaration (EPD) can be very useful where the life cycle assessment (LCA) is spread into stages of product life. There are the life stages named A, B, C, D and environmental impact from each stage is provided. The LCA covers "Product Stages" from "Cradle to Gate" in accordance with PN-EN 15804+A1:2014-04, but EPD can be done with selected, the most relevant stages and not always with full range of LCA.

Production Stage			Con-struction Stage		Use Stage							End-of-life Stage				Benefits and loads from re-cycling
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
Raw materila supply	Transport	Manufacturig	Transport	Construction Installation	Use	Maintenece	Repair	Replacement	Refurbishment	Operational energy	Operational water use	Deconstruction,	Transport	Waste processing	Disposal	Potential net benefits from recycling beyond the system boundary
Included			Included		Included	Excluded						Included				Included

Table 1. Life cycle stages

In terms of corrugated steel structures, used for soil-steel bridges, EPD covers following stages A, C and D. A1 and A2 stages covers raw materials supply and transport of such components as: steel plates, bolts, wood, chemicals, additives, ancillary materials, packaging materials and transport. A3 stage covers production process. All materials and energy consumption inventoried in factories includes in the calculations. In the assessment, all significant parameters from gathered production data are considered, i.e. all material used per formulation, utilized thermal energy, internal fuel and electric power consumption, direct production waste, and all available emission measurements.

At the end of life, stage C, the steel structures can be deconstructed with the use of heavy machinery. It is assumed that 98% of the resulting steel scrap undergo recycling after cutting and shredding, while the remaining 2% is forwarded to landfill in the form of mixed construction and demolition wastes. Waste processing (stage C3) includes impacts associated with collecting of the steel scrap, transport to scrap-yard, sorting and pressing to blocks. Benefits and loads beyond the system boundary (D) are calculated using a net scrap formulation proposed by World Steel Association, where the net scrap is determined as a difference between the amount of steel recycled at end-of-life and the scrap input from previous product life cycle (assumed 70%).

To be able to calculate environmental impact, of soil-steel bridges with use of corrugated steel plates product, and compare it with other product and solution, the same LCA stages need to be taken into calculation.

Environmental impacts: (DU) 1 tonne								
Indicator	**Unit**	**A1**	**A2**	**A3**	**A1-A3**	**C3**	**C4**	**D**
Global warming potential	kg CO_2 eq.	1.79E+03	2.81E+01	5.00E+01	1.86E+03	2.78E+01	3.31E+01	-1.26E+03
Depletion potential of the stratospheric ozone layer	kg CFC 11 eq.	4.03E-08	0.00E+00	0.00E+00	4.03E-08	2.68E-06	4.27E-06	-2.25E-08
Acidification potential of soil and water	kg SO_2 eq.	9.04E+00	2.05E-01	5.62E-02	9.30E+00	1.72E-01	1.98E-01	-7.29E+00
Formation potential of tropospheric ozone	kg Ethene eq.	1.14E+00	1.50E-02	5.38E-03	1.16E+00	9.93E-03	1.13E-02	-8.87E-01
Eutrophication potential	kg $(PO_4)^{3-}$ eq.	8.18E-01	3.62E-02	5.36E-03	8.60E-01	7.23E-02	8.23E-02	-2.16E-01
Abiotic depletion potential (ADP-elements) for non-fossil resources	kg Sb eq.	4.55E-04	0.00E+00	1.85E-04	6.40E-04	5.17E-03	5.34E-03	-8.12E-05
Abiotic depletion potential (ADP-fossil fuels) for fossil resources	MJ	1.81E+04	2.33E+02	4.84E+02	1.88E+04	3.86E+02	5.05E+02	-1.23E+04

Table 2. An example of environmental indicators of corrugated steel structure product

An environmental impact within selected indicators with conventional concrete bridge, similar data for concrete bridge solutions could be taken from global database Ecoinvent as the life cycle inventory database that support environmental assessments of products and processes.

Corrugated steel pipe vs concrete pipe - environmental impact comparison

In 2020 Canadian organization Groupe AGĒCO completed the comparative Life Cycle Assessment (LCA) study of corrugated steel pipes (CSP) with reinforcement concrete pipes (RCP), on behalf of the commissioning organization, the Corrugated Steel Pipe Institute (CSPI) [2].
The CSPI produced an EPD certificate, which is a snapshot in time of CSP carbon footprint. It was based upon 1 metric ton of steel and produced results in GHG emissions, Ozone depletion, Smog, Acid Rain, Eutrophication (induces excessive green algae) & depletion of fossil fuels.

The purpose of this project was a comparison of environmental impact of CSP to RCP using the 1800mm diameter pipe, 75-year service life sensitized for regional water and soil disparities. This was later extrapolated to produce any other diameter.

Overall, when compared to RCP in North America, CSP has lower potential impacts on all studied indicators.

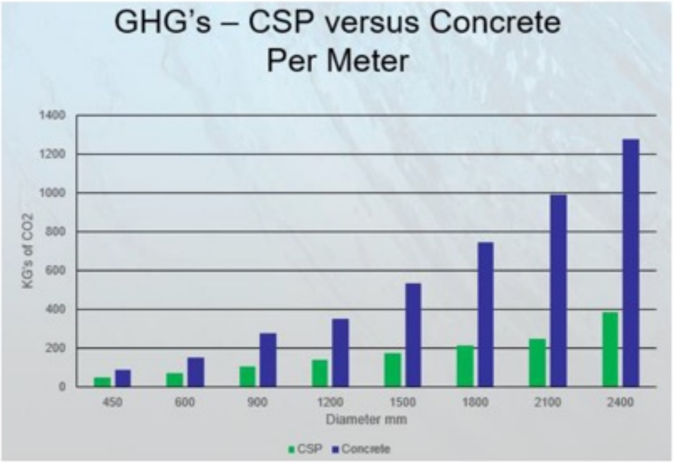


Fig 1. Carbon footprint of CSP with compare to RCP per diameter [2]

The main advantage of CSP over the RCP is the lower mass of the product. The stages contributing the most to the potential impacts of CSP are hot deep galvanize coils production. The net recycling benefits, which acknowledge the value of steel scrap, enable CSP to significantly reduce its impacts.

The analysis based of European area shows similar result and provide to the same conclusions.
Last year improvement of durability coating for CSP makes this solution durable of the same live time like solutions with RCP. The biggest environmental impact of CSP comes from hot deep galvanization process of steel coils as raw material for those pipes. Some improvement in this area is crucial to be able to improve environmental indicators of CSP [2].

Soil-steel bridges (SSB) vs reinforced concrete bridges (RCB) - environmental impact comparison

In 2022, polish institution The Instytut Techniki Budowlanej prepared environmental impact calculator, based on LCA analysis, that enables the comparison of selected environmental indicators associated with the production of soil-steel bridge (SSB) made of corrugated steel sheets and reinforced concrete bridge (RCB), in accordance with the guidelines of EN 15804 Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products. This comparison can be done for a few chosen environmental indicators.

INDICATORS

Parameter	Abbreviation	Unit	Method	Description
Global Warming Potential	GWP	ton ekw. Co□	CML	A measure of greenhouse gases emissions. These emissions increase the absorption of radiation emitted by the earth, intensifying the natural greenhouse effect. The GWP components can come from fossil or biogenic sources, such as the combustion of fossil fuels or wood.
Renewable primary energy	RPER	MJ	cumulative energy demand	Total consumption of renewable primary energy resources
Non-renewable primary energy	NRPER	MJ	cumulative energy demand	Total consumption of non-renewable primary energy resources
Total primary energy	TPE	MJ	cumulative energy demand	Total consumption of primary energy resources
Water	W	m^3	ReCiPe	Net consumption of fresh water resources

Table 3. Main environmental indicators as a subject of comparison SSB versus RCB.

The following assumptions have been made for a proper comparison of alternative solutions:

- comparison was carried out on the basis of a mass balance;
- information on the weight of the backfill should refer to the same range in the cross-section of the bridges SBB and RCB;
- the environmental impact of the SSB structures made of corrugated steel sheet with zinc coating comes from the Type III Environmental Declaration No. 127/2020, issued by ITB, based on data inventoried (year 2019) provided by ViaCon Sp z o.o. and the Ecoinvent v.3.6 database;
- environmental impacts related to the use of a paint coating on a steel sheet structure with a zinc coating have been determined on the basis of data inventoried (year 2019)
- environmental characteristics of concrete, non-alloy steel rebars and backfill come from the Ecoinvent v.3.8 database

Using an environmental calculator, the authors of this paper conducted a comparison of the bridge structure located in north-eastern Poland, under the S5 express road near Ostróda. Basic functions of this facility are grade separation and wild life underpass.
In the design phase of this structure, two solutions were prepared, first as SSB structure and alternative

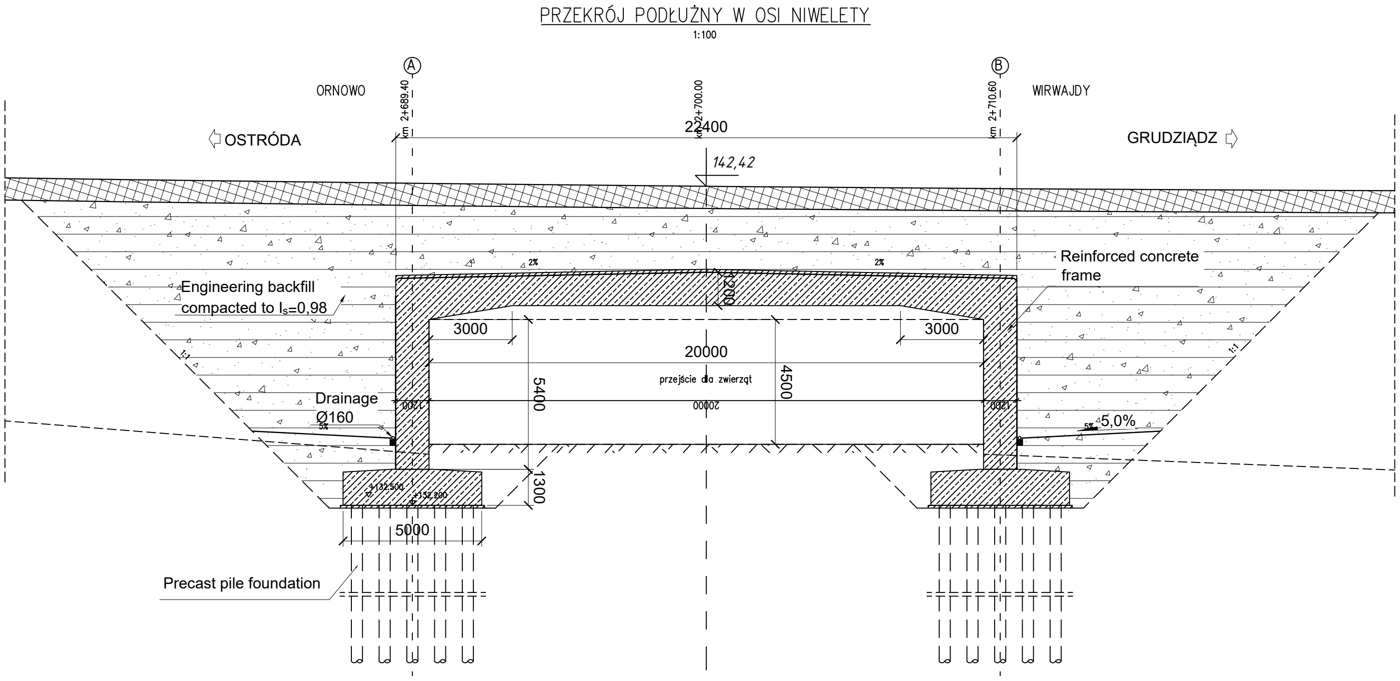


Fig. 2. The reinforced concrete bridge (RCB) as wild life underpass solution

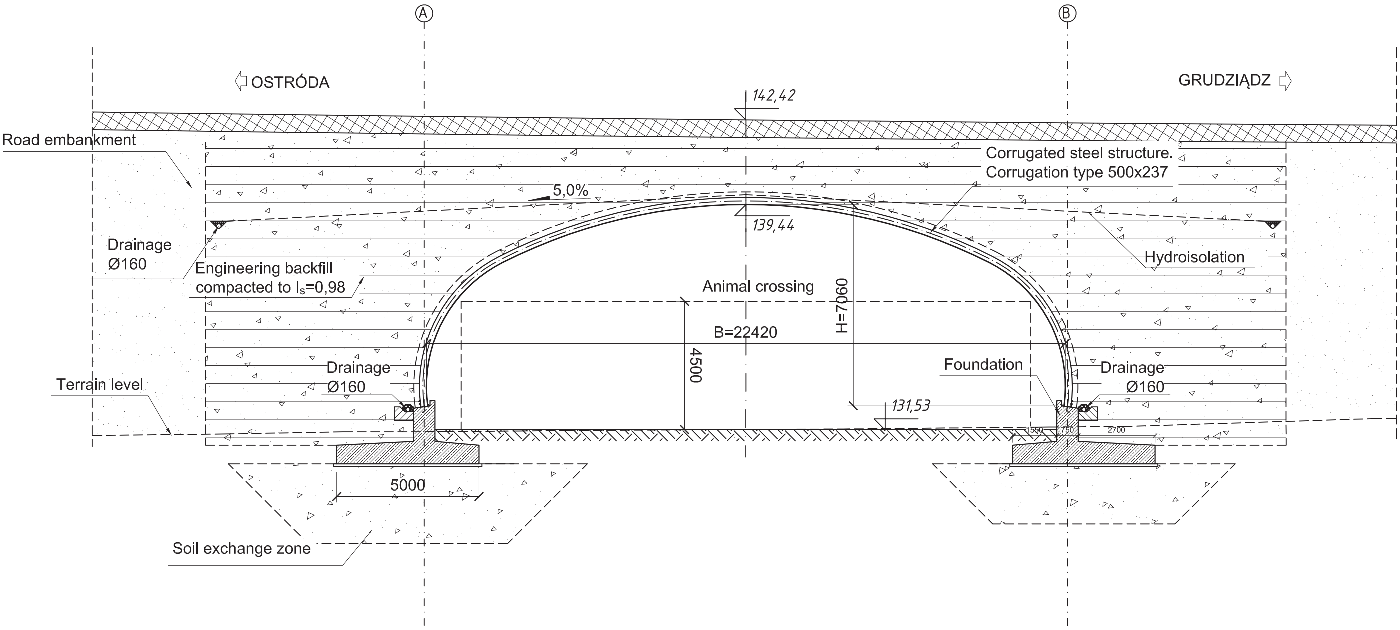
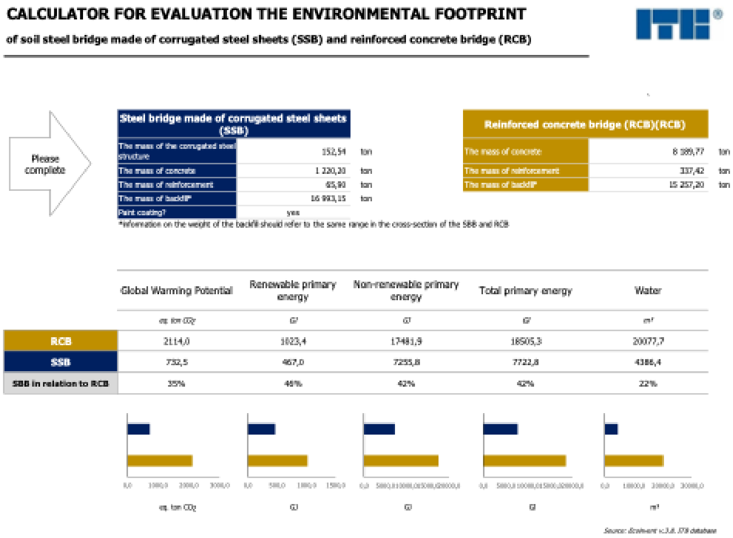


Fig. 3. The soil-steel Bridge (SSB) as wild life underpass solution.



CALCULATOR FOR EVALUATION THE ENVIRONMENTAL FOOTPRINT

of soil steel bridge made of corrugated steel sheets (SSB) and reinforced concrete bridge (RCB)

Please complete

Steel bridge made of corrugated steel sheets (SSB)		
The mass of the corrugated steel structure	152,54	ton
The mass of concrete	1 220,20	ton
The mass of reinforcement	65,90	ton
The mass of backfill*	16 993,15	ton
Paint coating?	yes	

*Information on the weight of the backfill should refer to the same range in the cross-section of the SBB and RCB

Reinforced concrete bridge (RCB)(RCB)		
The mass of concrete	8 189,77	ton
The mass of reinforcement	337,42	ton
The mass of backfill*	15 257,20	ton

	Global Warming Potential	Renewable primary energy	Non-renewable primary energy	Total primary energy	Water
	eq. ton CO2	GJ	GJ	GJ	m³
RCB	2114,0	1023,4	17481,9	18505,3	20077,7
SSB	732,5	467,0	7255,8	7722,8	4386,4
SBB in relation to RCB	35%	46%	42%	42%	22%

Source: Ecoinvent v.3.6. ITB database

Fig. 4. The result of environmental footprint SSB vs RCB

RCB structure. The quantitative data for comparative analysis were taken from the prepared drawing documentation.

The results of this comparison show that all analyzed environmental indicators have lower values for the SSB solution. For instants, the environmental impact value on Global Warming Potential for SSB is only 35% to compare with RCB solution. The water consumption indicator is even lower, for SSB is 22% lower versus RCB solution. Soil-steel bridge solutions, with use of corrugated steel palates, has much lower environmental impact with the LCA range that calculate allow us to analyze and compare.

Conclusions

By using lightweight corrugated steel structures instead of concrete, both energy consumption in manufacturing and installation as well as CO2 emissions can be reduced. A comparative life cycle analysis study of corrugated steel structures and reinforced concrete pipes for an underground stormwater drainage pipe (diameter 1.8 m, length 11.8 m) for the North American market confirms this. This was commissioned by the Canadian Corrugated Steel Pipe Institute (CSPI) and carried out by the Canadian consulting firm Groupe AGĒCO. The study concludes that corrugated steel pipes cause 77 percent less CO2 emissions in their entire life cycle compared to reinforced concrete pipes [3].

Bridges with the span up to 35 m, can be designed in a variety of available on the markets technologies, including buried soil-steel technology as well.

Such solutions are very often compared at the design stage with so-called traditional, i.e. reinforced concrete bridges. This comparative analyzes carried out so far concerned the technology of building the facilities, strength and durability aspects, and above all direct cost comparison.

In this paper, the authors presented a comparison of these two solutions in terms of their impact on the environment, using the LCA analysis and based on data from the EPD certificate and the environmental database Ecoinvent v.3.6.

Bibliography

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[3] Herbert Sikovc (Wuppermann Stahl GmbH) and Dipl.-Ing. (FH) Christian Hammes (ViaCon Hamco). Technical article for the magazine Straße & Autobahn, issue 8, 15 July 2021.