# Why use Composites?

Benefits of using composites on rail infrastructure projects

Environmental Friendly

ilecsys RAIL

“The difficulty lies not so much in developing new ideas, as in escaping the old ones”

John Maynard Keynes

# Why use Composites?

Profiles made of composite - Glassfibre-reinforced plastics (GRP) - today provide an alternative to conventional structural materials such as concrete, steel, aluminium and wood.

Used for structural purposes, composite has the advantage of combining a number of properties not usually found together in a single material.

In particular it combines high strength and low weight, while at the same time it is non-corrosive and has thermal and electrical insulation properties. It can also be machined like wood using diamond tool equipment.

Using composites rather than conventional materials such as steel usually provides major weight savings. This is partly die to the specific properties and low weight of the individual components, and partly because it is possible to manufacture composites for very particular purposes. For example, a composite component can be specified and designed for a particular type of load. It is also offers a number of advantages over conventional materials, such as resistance to chemicals and thermal and electrical insulation properties.

## Composite Benefits

- **Reduced Build Times**
- **Reduced Maintenance**
- **Environmentally Friendly**
- **Whole Life Costs (WLC)**
- **Reduced Vehicle Movements**
- **Thermally Insulated**
- **No Earth Bonding**

# Composite Applications

Left: Backfillable FRP gabion basket
Right: GRP alternative to concrete base
*Both options remove the requirement for expensive concrete works*

## GRP TIS Base


## GRP Platforms and Walkways

Bowes Park walkway

Bristol downbank Loc staging

Reading POS refuge platform

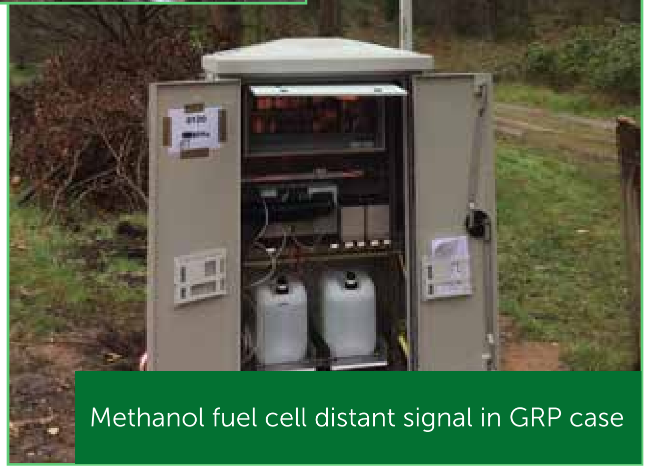
# Composite Applications

## GRP Steps & Staircases

Bowes Park Staircase


## GRP Apparatus Case


Dawlish GRP apparatus case



Methanol fuel cell distant signal in GRP case

# Composite Applications

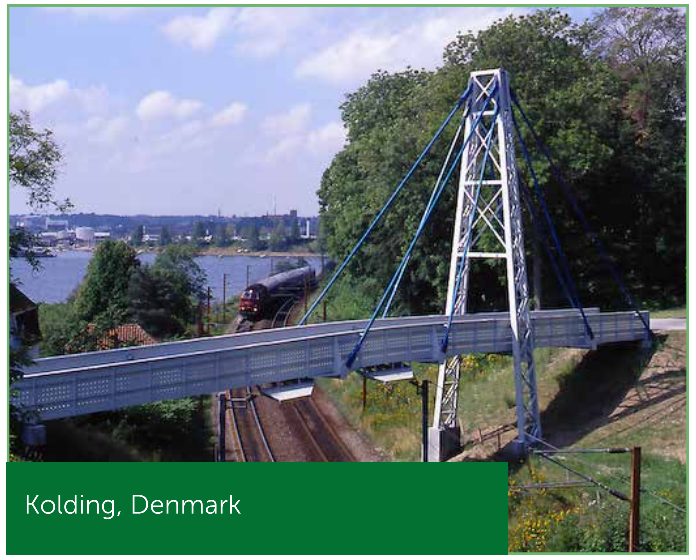
## Disconnection Boxes

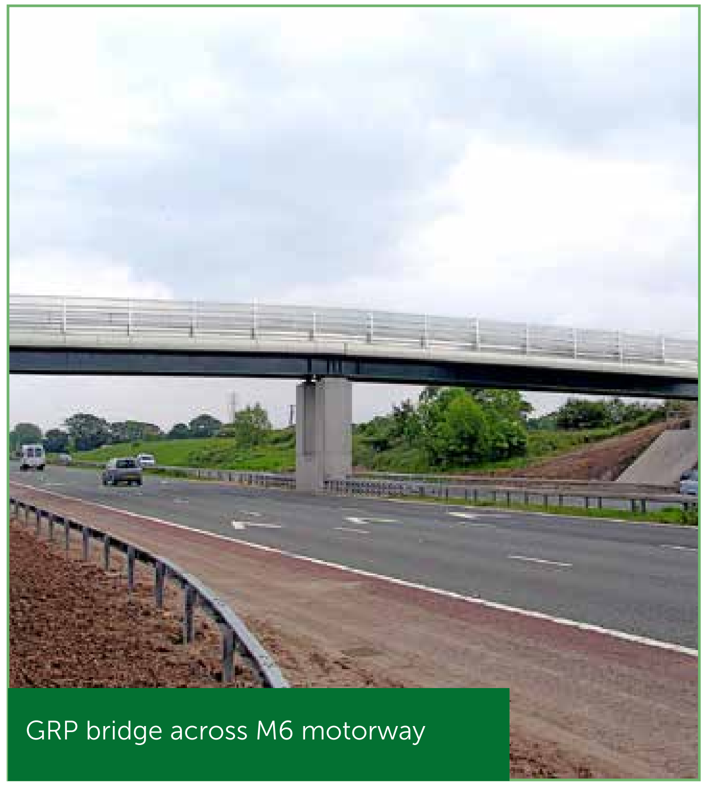

## Signalling Power Supplies


GRP enclosures - perfect for public access sites

# Composite Applications

## Larger GRP Structures


Kolding, Denmark


GRP bridge across M6 motorway


Greenland's first GFRP composite bridge


Thornaby station footbridge



# CASE STUDIES

# Case Studies

## Reading POS Refuge Platforms

### Remit
Install 7 POS (Point of Safety) GRP refuge platforms

### Constraints
Short delivery time, close proximity to track, sloping ground, limited possession availability

### Solution
- Site appraisal and walkover
- Use iLECSYS Rails Network Rail approved GRP staging
- Design and submit completed forms 1/2/3
- All platforms transported to night possession access within 4 weeks, for delivery to POS refuge sites
- GRP refuges and micro piles delivered to locations during Saturday night possession using only hand trolleys
- Locations CAT scanned and 1200mm inspection pits completed
- Piling works undertaken using the micro pile and platforms erected during "site warden working" day shifts
- 7 Platforms installed in 6 day shifts

### Conclusion
Client was very pleased with fast turnaround time and the option of site warden working reduced costs, was safer and helped to make use of normally unproductive midweek shifts

**KEY POINTS**
- **No RRV movements**
- **Hand delivered to site**
- **7 Platforms installed in 6 working day shifts**
- **Installed using only hand portable tools**
- **40+ Year life expectancy**

## StrucSol Rapid Root

### Concept
The Strucsol RapidRoot anchor was developed following years of frustration regarding foundation solutions for nominal structural loads where the remote location or the limited access made traditional piling rigs cost prohibitive or logistically difficult. With traditional piling techniques capacity is improved by either increasing the pile diameter and the weight of the hammer or by increasing the auger diameter and the backfill material specification. Using small installation equipment typically means a reduction in capacity, however with the Strucsol RapidRoot anchor multiple small diameter raked piles are driven by a 20kg or 30kg self powered driving hammer. These small diameter piles are connected at ground level by a load transfer plate, which in turn carries the structural loads. As the structural load increases, the number of piles attached to the load transfer plate increases with arrays of between four and sixteen piles achievable. Piles are available in diameters of between 42mm and 68mm and multiple length arrangements can be achieved with piles extended in length by mechanical connections and 1.5m long extension tubes. Piles can be arranged in any configuration and are driven to lockout or set.

Typical installation equipment would normally consist of:
- 1 x 20kG Petrol drive hammer
- 1 x Scanner for cable detection
- Spade for excavation
- Spirit level
- Tape measure
- Cordless impact driver

StrucSol FOUNDATION SOLUTIONS

**Applications**
The StrucSol rootpile can be scaled to work cost effectively on projects as diverse as signage support and bridges.
The method of extending the pile means that piles can be continuously driven until set is achieved. The use of a crimped extension, means it is possible to use shorter sections of pile, which is beneficial for manual handling and transporting the piles and equipment to site. Once the pile is installed, levels and alignment can be adjusted via a load transfer plate levelling head.

# Case Studies

## Manchester Viaduct

### Remit
Build a bespoke GRP (Glass Reinforced Polyester) hand portable access staircase to replace a highly corroded steel one.

### Constraints
- Only access via scaffolding
- No heavy plant access
- 4 week turnaround from design to install

### Solution
Create a similar designed product to the existing structure using GRP. The material is much lighter than steel and due to its modularity can be designed to be hand portable.

### Conclusion
The project was successfully installed on time and the project team were very happy with the product. In this circumstance the use of GRP was the only viable option. This was due to the access and possession challenges. The new GRP staircase was installed during day working shifts with no disruption to train services.

**KEY POINTS**
- **No RRV movements**
- **Hand delivered to site**
- **Short turnaround from design to install**
- **40+ Year life expectancy**
- **Installed during day working shifts**

## Bristol Loc Platforms

### Remit
Supply a number of platforms for use in the Bristol area. A range of different size platforms that can be used as Loc stagings

### Constraints
Platforms needed to be made so as they are able to be delivered by hand. Limited possessions meant that the installs had to take place during the day. Due to the landscape a range of up and down bank stagings were needed.

### Solution
- A range of stagings were designed and delivered on schedule in-keeping with the projects required timescale
- Pre-site inspections and surveys were carried out to establish timescales and requirements for each location
- Stagings were delivered 'flat packed' so as they could be hand delivered to site

### Conclusion
The Client was very pleased with the staging solutions. The ability to hand deliver the platforms to site and assemble them in situ is estimated to have resulted in approximately 48 Road Rail Vehicle (RRV) movements being removed from the scheme. The client was also pleased with the amount of day working that was achieved. Teams were able to deliver and install in a far greater time.

**KEY POINTS**
- **Est. 48 RRV Movements Removed**
- **Single, double, triple and seven stage platforms designed and delivered**
- **Installed in normally unproductive day shifts**

# Reigate GRP Loc Case

**Remit**
To provide a new Class II signalling power supply to provide compliant 650V to existing signalling locations

**Constraints**
To provide a non-conductive enclosure for switchgear and 3kVA signalling transformers in a public access area.

**Solution**
Install a new generation of composite signalling and FSP apparatus case (PA05/06490)

**Conclusion**
The GRP apparatus case proved to be a successful and viable solution to safely locating the 650V signalling power supply equipment into public access area. The case required no earthing and bonding, offers a high insulation resistance value and a reduced maintenance regime.

KEY POINTS

- **No RRV movements**
- **Hand delivered to site**
- **Removed touch potential issues**
- **40+ Year life expectancy**
- **No earthing and bonding**

# Newton Abbott Annexe FSPs

**Remit**
To deliver a new 650V IT signalling power supply to over 350 signalling cases on the Western Tranche project.

**Constraints**

- Short possessions
- Challenging environmental conditions
- Restricted Access

**Solution**
To design and manufacture a non-metallic IP rated low maintenance Class II FSP capable of mounting onto an existing structure. This was achieved using the iLECSYS Annexe FSP and some innovative installation and commissioning techniques.

**Conclusion**
"The Annexe FSP has solved numerous issues including reducing cost, de-risking the project, reducing isolation and possession times along with reducing the overall length of the project. The Annexe FSP can be installed safely, quickly and very easily as a two man job without the need for any civils works. The total time spent trackside including, surveying, correlation of 650V, preparation, installation and commissioning of 650V/110V cables was 4 hours"
*Michael Ewart, Operations Director*
*The Giffen Group*

KEY POINTS

- **Every annexe install accounted for a saving equivalent to the installation of a concrete base and a RRV movement**
- **By removing a large amount of civils works this resulted in a saving of £2.8 Million on a £8 Million project**

# SUPPORTING DOCUMENTS

## GRP Bridge Across M6 Motorway

**Rapid construction and reduced disruption for road users were important considerations in the decision of the UK Highways Agency to span the M6 motorway in Lancashire with a new lightweight bridge made of GRP composite.**

"The innovative bridge, which is 52 metres long and built using Fiberline's FBD 600 bridge deck profiles, is two-thirds the weight of the one it replaces, but is stronger and offers cost savings through reduced maintenance in the future," says Phil Davies, Highways Agency project manager.

"This is the first time the Highways Agency has used GRP for road bridge construction on the motorway network, but we have been using it for several years to strengthen existing bridges, and we have also built two footbridges with GRP decks," says Phil Davies.

The motorway bridge replaces a 40-year-old life-expired bridge and is designed to carry vehicles up to 40 tonnes. The Highways Agency points out that the new bridge has a superior strength/weight ratio to steel or concrete and is non-corrosive to water and salt.

Reduced maintenance costs

"Although GRP is 5% more expensive than a conventional build, significant savings have been achieved through quicker construction, crane costs, installation costs and labour costs. The difference will also be more than offset by future savings in maintenance," says Phil Davies.

"The project will demonstrate the benefits of GRP to a wide range of clients, consultants and contractors. Feedback has already been received from the contractor Balfour Beatty and the designers AmeyMouchel and Mouchelparkmann, and it is clear that the use of GRP for bridge building is a success".

"The Highways Agency wishes to promote wider use of GRP and stimulate further development of the technology, thereby paving the way for improved cost effectiveness. Wider experience of the materials is needed by the construction industry. And, as with all construction, workmanship is a key issue".

"It is a global market and there is potential to export the technology or even develop modular bridge systems, which can be transported to different parts of the world for infrastructure projects or disaster relief," says Phil Davies.

# RENEWABLE VALUE

**What to do with fibregalss waste? The industry has been searching for a valid answer to this question for many years. The answer has now been found.**

Fibreglass is widely acknowledged as a material that has major advantages over more conventional rivals, such as wood, steel and aluminium. It is less energy intensive in development and is used extensively for products which decrease carbon emissions - products such as low energy windows. But what do we do with the fibreglass when its useful life is over?

Fiberline Composites, which manufactures fibreglass and carbon fibre profiles, is pleased to report that it now has the answer. Fiberline has signed a contract with two companies: Zajons in Germany, which specialises in converting waste to alternative fuels for industry - and Holcim (Germany), subsidary of the world leading cement manufacturer from Switzerland. Under the contact, surplus fiberglass from Fiberline's production in Denmark will be shipped south for use as a key constituent of cement.

The contract is a good example of a true win-win situation as everyone benefits; Fiberline gains a waste solution it has been seeking for many years, and Holcim can utilise both the energy as well as the minerals in the fibreglass for cement production, thereby saving on fossil fuel and raw materials.

## The next step - a collection scheme

Fiberline's sustainability manager Benedikte JØrgensen sees major perspectives in the contract: "In the short term this contract marks an important breakthrough for our company, but the next step will naturally be to look at a formalised collection scheme that also meets customer and user needs by ensuring that their fibreglass waste - such as life-expired low energy windows - will not simply pile up but be recycled".

## Fiberline nearing 'zero landfill, zero energy' goal.

For Fiberline, recycling of production waste is yet another step on the way to realising the company's goal of 'zero landfill, zero energy'. A winner of the Danish Energy Prize in 2009, Fiberline curently obtains around 50% of the electricity it needs for manufacturing from it's own wind turbine.

### How fibreglass is recycled

The production of cement is dependant on large quantities of sand. Sand is also the main constituent of glass, and thus also of fibreglass. Fibreglass additionally contains polyester which can be used as an energy source in cement production, thereby replacing the use of fossil fuels.

The recycling process

1. Fiberline sends the fibreglass waste to Zajons in Germany
2. Zajons consolidates the fibreglass in a giant crusher and adjusts the calorific value by adding other types of recycling materials
3. The waste is sent to the cement manufacturer
4. Holcim feeds the waste to the huge kilns that produces the finished cement

Recycling 1000 tonnes of Fiberline profiles in cement manufacture saves up to 450 tonnes of coal, 200 tonnes of chalk, 200 tonnes of sand and 150 tonnes of aluminium oxide (Source: Holcim, 2010). The recycling process produces no dust, ash or other residues.

Source: Press release from Fiberline Composites, Middlefart, 14 September 2010




# Fiberline Waste Management

## CompoCycle

Fibre reinforced polymers (composites) have a documented long life span of more than 50 years without any perceptible loss of the functional properties. This means that more and more applications gain access – during the last few years particularly to the construction industry. This has resulted in a development of further applications and recycling solutions for superannuated GRP profiles.

Since 2010 Fiberline has been affiliated to the European recycling scheme CompoCycle, a co-operation between Zajons Logistik and Holcim AG Geocycle, who handle all forms of fibre reinforced plastics (FRP).

**Saving potential:**

When recycling one thousand tonnes of Fiberline profiles in cement manufacture you save:

- 450 tonnes of coal
- 200 tonnes of chalk
- 200 tonnes of sand
- 150 tonnes of aluminium oxide

No dust, ash or other by-products are formed in the process.

Ref.: Holcim AG, 2010

**The concept of CompoCycle:**
When producing on the production lines at Fiberline, all residual waste is collected on pallets or in containers and carried to Zajons Logistik in Germany for further processing.

**The 3 stages of the concept:**

A grinding mill at the plant reduces the composite to granulate

The calorific value of the granulate is adjusted by blending with other recycled materials in a patented process

The finished product is used as a substitute fuel and raw material at cement plants

Composite Recycling

FIBERLINE COMPOSITES
www.fiberline.com


# Fiberline Carbon footprint

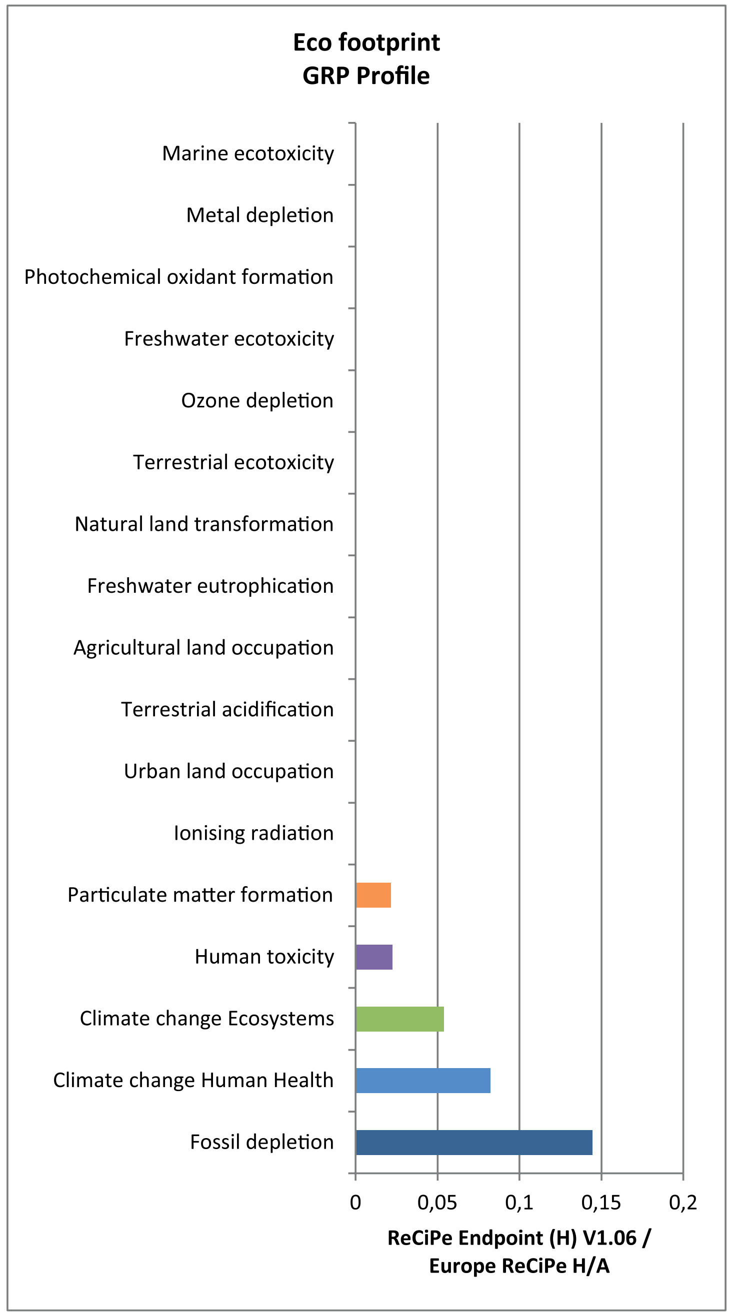
## Standard window profiles

**Assessment of the environmental impact of the production of Fiberline standard window profiles (cradle-to-gate assessment).**

The Carbon footprint has been assessed by using IPCC 2007 GWP 100a method which assess the global warming potential of the process in terms of emissions of greenhouse gases expressed as kg of $CO^2$ equivalent.

**The Carbon footprint of 1 kg standard window profile is 3.0 kg $CO^2$ eq.**

The Eco footprint has been assessed by using ReCiPe v1.05 method, assessing all environmental impacts across categories that relate to human health, natural resources, and eco-system quality.




FIBERLINE COMPOSITES
www.fiberline.com

# Green Trough

## Polymer Cable Troughing Systems

Made from a rugged polymer and designed to carry cabling anywhere; horizontally, vertically, at an angle, around an obstruction, along a wall, as a walkway, or even in an elevated position. With weight savings of up to 85% compared to the concrete alternatives, Green Troughing substantially reduces transport and on-site handling costs and offers installers a truly customisable solution.

### Advantages

Railway operators will welcome the long list of advantages that polymer cable troughing offers. The units are quick to install, easy-to-handle, light enough for a HSE compliant, one-man lift, easy-to-cut with hand tools (without smoke or dust) and have built-in anti-vandal and anti-theft features with lockable lids to help deter cable theft.

### Easy To Connect

Connecting Green Trough units is easy and any troughing combination is possible. With a male and female connector moulded into t he end of each base unit, no joint grouting is required. Pan and tilting flexibility in the joints also means a bending angle of 2° to 5° can be achieved (enabling the route to form a natural minimum radius of 13 to 15 metres).

This function makes laying on uneven surfaces much easier and they can be effectively installed into various ground types, including ballast, soil (or a combination) and as a free-standing cable troughing route. The polymer troughing system can also interface with existing concrete units.

### A commitment to sustainability

It is important that we understand how we can contribute more to society than just an end product, and that we must manage the potentially damaging consequences of the construction process. Society as a whole has become more aware of the importance of sustainability and because of this the construction industry is changing.
Whilst delivering site operation to a high standard it is still critical, we are also committed to working with our clients, employees and suppliers to ensure we are operating in the most sustainable way possible, which goes way beyond just our construction sites.
This includes how we treat and support our employees and suppliers, our health and safety culture, our environmental management, reducing our waste and our carbon emissions, the potential impact on the local communities we work within and much, much more.

For more information on polymer cable troughing systems contact iLECSYS Rail on 01442 828387 or email us at enquiry@ilecsysrail.co.uk

**Green Trough Systems are friendly to the environment.**

- Manufactured from a 100% recycled polymer. Recycling the past for a better future.
- Lighter than concrete, they help reduce transport and on-site handling costs.
- Made from a flame-retardant polymer with self-extinguishing characteristics
- No need for special lifting tools or equipment.

MADE FROM 100% RECYCLED POLYMER
GREEN TROUGH
SUPPLIED BY TTS

# A Composite Bridge is Favoured by Quantifying Ecological Impact

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## Abstract

Carrying traffic loads is not the only objective of bridge designers nowadays. Other demands include constructing a bridge in a sustainable way, which reduces pollution and other harm to the environment. In The Netherlands, the government responds to such demands by promoting technologies and materials that decrease the environmental impact of construction projects.

An assessment of that impact is, however, quite complex for bridge projects. The existing analytical methods, such as life-cycle analysis (LCA), require an extensive data input. Moreover, their results are more reliable for relatively simple products of short life cycles, for example, door or window frames, than for complex construction projects. In construction projects, the life cycles cannot be determined with the same precision and the materials are usually chosen in the very early stage of design. As a result, the data required by the LCA are often incomplete or even disputable. Therefore, there is a demand for ecological analysis methods that enable quick scanning of several material options, require less-extensive data input and are hardly, or not, vulnerable to arbitrariness.

**Keywords:** FRP structures; eco-analysis, material choice; sustainable material; sustainable bridge; energy input; exergy; emissions; pollution data.

## Introduction

This paper answers the above-mentioned demand by presenting a method for ecological material selection for a bridge. It shows a way to quantify the environmental impacts of possible material choices in comparable terms and to assess those choices with respect to their impact. The method was first developed and applied for the quay footbridges in the Noordland inner harbour, province of Zeeland, The Netherlands. Five material options were considered: structural steel, stainless steel, composites (fibre-reinforced polymers, FRPs), aluminium and reinforced concrete. The analysis allowed evaluating these options in terms of three crucial ecological indicators: energy consumption, pollution to air and pollution to water.

The ecological analysis was performed along with the costs and service-life assessment. The computed performances of all the material options considered resulted in an advice to construct a bridge of pultruded FRP profiles (*Fig. 1*). The customer followed that advice. It was the first bridge constructed using this technology in The Netherlands. The bridge was assembled and brought into service in 2001. It has been performing remarkably well since then, validating the computed ecological and other indicators. Its good performance suggests the possible construction of more similar footbridges in that area in future. This paper presents a comparison of those indicators for the material options considered, and discusses these and some selected problems of the ecological analyses.

The applied ecological analysis has been presented on various occasions since the bridge construction.[1–3] Yet, it still evokes much interest because of the importance of environmental engineering in relation to, for example, climatic processes. This paper aims to respond to that interest, giving more details of both the applied ecological analysis and the constructed FRP bridge.

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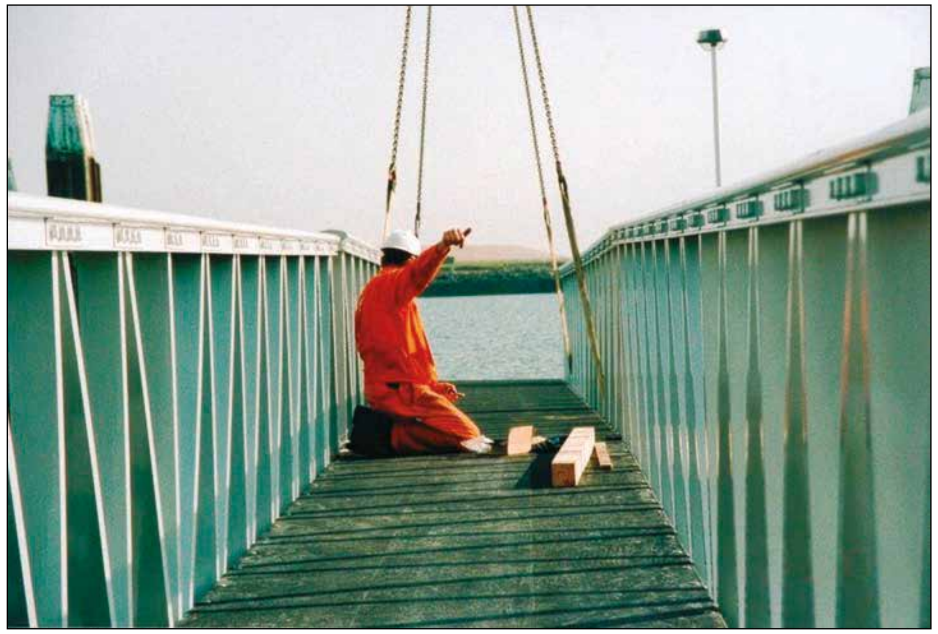

*Fig. 1: Installation of the Noordland inner harbour footbridge*

## Project Objectives and Scope

The Dutch province of Zeeland is a costal area in the south-western delta of the rivers Rhine, Meuse and Scheldt. High exposure to sea water, wind loads and chloride corrosion form part of the usual design specifications. At the end of 1999, the Regional



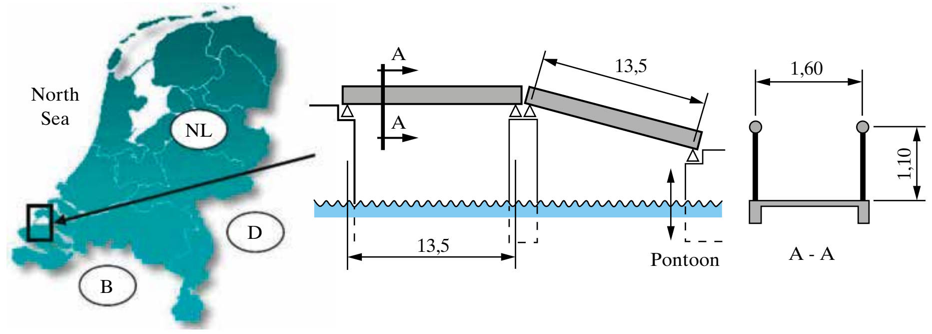


*Fig. 2: Bridge location and dimensions (Units: m)*

Authority for Public Works and Water Management ordered an investigation on construction materials for a footbridge in the Noordland inner harbour that forms part of the Eastern Scheldt Storm Surge Barrier complex. The bridge provides a double span access to a mooring pontoon (*Fig. 2*). The new bridge was to replace the old steel bridge that was largely deteriorated by corrosion after only 35 years of service. This was not surprising, considering the extreme conditions at that location.

The service load of the bridge is 400 kN/$m^2$. Other loads are wind, snow, glitter ice, and so on. There is no navigation under the bridge. The support level to pontoon varies because of the tides. The allowable span deflection is limited to 1/250. The customer was interested in comparing the performances of the first four bridge materials from the following list:

– structural steel (with coating);
– stainless steel;
– synthetic material (composite);
– aluminium;
– concrete.

The fifth material was investigated later for the sake of completeness. The weight of a concrete bridge made it unfit for a pontoon support. Timber was also not an interesting option because of its maintenance requirements, combustibility and short service life at this particular location. Nonetheless, it certainly can be considered—also with respect to the environment—in other bridge projects. In this paper, timber is not included, because the considerations that determine its environmental performances are of a different nature. An important criterion is, for example, sustainable forest management.[4] It is difficult to quantify such criteria in a manner that allows for a comparison with other materials.

The performances of each option had to be quantified in terms of the following four criteria: construction costs, maintenance costs, service life and environmental impact. Aesthetics was not a prior concern at this desolate location. Maintenance and service life appeared to show a strong correlation. It was, therefore, agreed to impose a uniform service life of 50 years on all material options. This period reflects the current design views in The Netherlands. In this way, the number of assessment criteria was reduced to three, which simplified the analysis.

Construction and maintenance costs are quite common criteria in engineering; therefore, only the final results are presented. To quantify the environmental impact, however, an investigation method had to be set up first. As already discussed, the existing methods like the LCA[5] were not very helpful. The footbridge appeared to be too complex and too vaguely determined at this stage. Making detailed bridge designs and life-cycle inventories for all material options was, obviously, not the intention. Therefore, a simplified, but workable, two-way evaluation was chosen:

– energy consumption analysis—taking also account of the energy "stored" in materials and products (the so-called "exergy" method[6]);
– analysis of loads (pollutions) to water and air as a result of material winning, processing, fabrication of the final product and its maintenance.

In current views, the first approach can be seen as a measure of not only energy consumption as such (i.e. decrease of global energy resources) but also the processes resulting from fossil fuel combustion, like the greenhouse effect, rise in ocean level, global climatic changes, and so on. The second approach (loads to air and water apart) produced global pollution data of the bridge options under consideration. Loads to soil appeared to be insignificant, but they can be analysed in the same way, whenever relevant.

## Conceptual Designs

As the materials in question represented in fact five groups of materials, the material grades had to be chosen. In accordance with the existing practice, the following grades were selected:

– structural steel: S235J0 or S355J0, according to the European norm EN 10025. An arc-sprayed aluminium coating was considered as an alternative to the conventional paint system.
– stainless steel: X2CrNi18-11 or X2CrNiMo18-14-3 according to the European norms (AISI 304L or 316L according to the US standards).
– composite: fibreglass-reinforced polyester resin (FGRP) in pultruded sections.
– aluminium: AlMgSi1,0 F31 according to the DIN 1748 code (or 6061 and 6063 alloys according to the ASTM B221).
– concrete: B35 according to the European norm EN 1992-1, 150 kg of reinforcement per 1 $m^3$; 100 kg of other steel accessories (e.g. handrails) per 1 $m^3$.

The next step was to complete five rough conceptual bridge designs, one in each optional material. It soon became clear that each option required a different form, system, manufacturing approach, and so on. In structural steel and concrete, for example, conventional girders with separate handrails were an evident choice, whereas in the other, more expensive materials the handrails were integrated in truss or truss-like girders. Major differences appeared also in section shapes, deck systems, and so on. In *Fig. 3*, one span of the bridge in each of the five materials is shown. The structural analysis was very brief in all cases. Nevertheless, it is fair to say that the bridge spans shown in *Fig. 3* are representative for the considered materials, and comparable with each other in terms of strength and durability.

The material mass estimations are based on a brief analysis and data from similar projects. These masses form the data for estimating both total costs and environmental impact. Remarkably large mass differences are seen between the material options. This requires a few comments. The mass of structural steel span would have been lower (2200–2500 kg) if truss girders

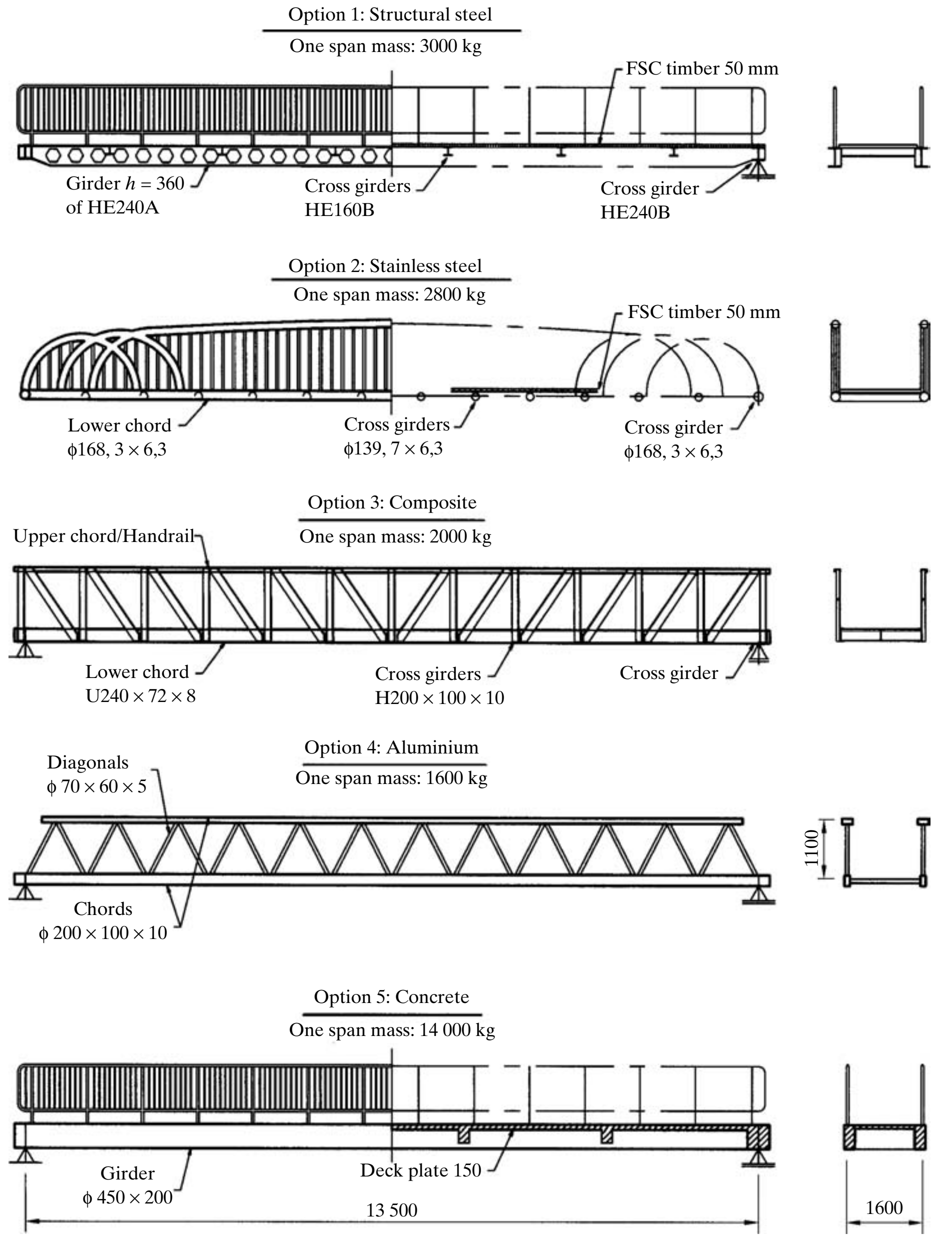


*Fig. 3: Bridge span in five material options (length units: mm)*

integrated with handrails were chosen instead of beams. This has deliberately not been done to justify neglecting the impact of steel coating. In any case, however, the composite and aluminium bridges appear to be the lightest. The concrete bridge is 5–10 times heavier than the other bridges. The dead weight was of minor importance here, as long as it did not cause pontoon overloading. A smaller weight is, however, desirable in large bridges. It allows for higher traffic loads, lighter foundations, pillars, transport and assembly equipment.

## Global Assessment

The bridge conceptual designs were employed to collect more data for the evaluation—not only the total material masses. The drawings in the form of outlines prompted specific questions and enabled collection of relevant data on the market. The desired data covered, in general, the following subjects:

- quantities and unit prices of the materials involved;
- available manufacturing technologies, their costs, conditions, quality assurances and risks;
- transport and assembly requirements, like access, time, heavy equipment, specific provisions;
- inspection and maintenance frequencies during the service life;
- environmental impact of all processes involved.

The accuracy of these data was not always high because of the preliminary nature of bridge design. In some cases, rough estimations had to be made. The concerned specialists agreed, nonetheless, that a sufficient, well balanced base was provided to evaluate the bridge options. The concise results of this evaluation are shown in *Table 1*. The general conclusions are as follows:

- In terms of construction costs, the structural steel and the concrete bridges are favourable. The stainless steel bridge is too expensive; the composite and aluminium bridges score in the middle.
- In terms of maintenance costs, the scores are opposite. The stainless steel bridge is the cheapest, followed by the concrete bridge. The structural steel bridge (conventionally painted) is the most expensive. The scores of the composite and aluminium bridges lie in between.
- Adding construction and maintenance costs (whether or not capitalized) puts the concrete bridge in the first place and the structural steel bridge in the second. The composite bridge takes a good third place, closely followed by aluminium. The stainless steel bridge is evidently the most expensive.
- Analysis of the energy consumption makes the composite bridge a winner. Every other option results in energy consumption that is more than two times as high. Energy consumption is seen as an important indicator of the contribution to the global warming effect.
- The composite bridge is also the best in terms of the resulting water and air pollution levels. The structural steel bridge is the second, concrete bridge is the third and aluminium bridge is the fourth.

The customer was advised as follows: if construction cost was the primary concern, the choice of a structural steel bridge was the best. But if a little extra cost was acceptable in the interest of the environment, the composite bridge of pultruded profiles was the best choice. An additional argument in support of the composite bridge was the innovative character of such a project. It was to be the first composite bridge of pultruded profiles in The Netherlands. The customer was indeed in a position, and willing, to choose the second, pro-environmental option. The composite bridge was constructed in October 2001. It has been closely monitored since then, confirming the results of the analysis.



| Bridge material | Criterion | | | |
|---|---|---|---|---|
| | **Construction costs (EUR)** | **Maintenance costs (EUR)** | **Environment: Energy consumption (MJ)** | **Environment: Critical volume of polluted air and water** |
| Structural steel | Painted: 40 000<br>Aluminium coated: 50 000 | Painted: 30 000<br>Aluminium coated: 6 000 | "Exergy" method: 294 000 | Water: 697,4 $m^3$<br>Air: 7,09 × $10^6$ $m^3$ |
| Stainless steel | Steel AISI 316L: 110 000<br>Steel AISI 304L: 96 000 | Steel AISI 316L: 6000<br>AISI 304L more, life cycle shorter | "Exergy" method: 329 600 | Not investigated but certainly more pollution than for structural steel |
| Composite | Pultruded sections of FGRP: 70 000 | Rough estimation: 17 000 | "Exergy" method: 120 000 | Water: 85,8 $m^3$<br>Air: 7,92 × $10^6$ $m^3$ |
| Aluminium | Quality AlMgSi1 acc. to DIN 1748: 77 000 | Rough estimation: 19 000 | "Exergy" method: 268 700 | Water: 565,3 $m^3$<br>Air: 41,10 × $10^6$ $m^3$ |
| Concrete | Reinforced concrete B35, handrails etc: 30 000 | Rough estimation: 10 000 | "Exergy" method: 277 200 | Water: 341,9 $m^3$<br>Air: 31,04 × $10^6$ $m^3$ |

*Table 1: Performances of the five material options for the bridge*

## Eco-Analysis in Terms of Energy Consumption

Ecological performances of a particular material option cannot be expressed in a single indicator, although it is advisable to keep the number of indicators small. Energy consumption, therefore, does not reveal everything about the ecological performances, but it is an important indicator in this field. It requires no argument today that energy consumption is a global environmental issue in both direct and indirect senses. In the first sense, it decreases the global energy resources which are—for the biggest part—not renewable. In the second sense, it harms the environment in many ways, including its contribution to the emission of $CO_2$, other "greenhouse gases" and the resulting climatic changes. However, if the latter is seen as the main or only issue of eco-analysis (which is not the author's view), a direct analysis of greenhouse gas emission,[7] will be more appropriate.

The required data is that of the energy use for the processing and manufacturing—from obtaining the raw materials to the final product—of one mass unit of the product in question (in MJ/kg). These data vary because the same materials and products can be obtained using different technologies. As eco-analyses are quite new, there is still much arbitrariness in defining the data. Therefore, it is always advisable to check which processes are covered by the received data. During this study, for example, the following energy consumption rates for structural steel products were found in various sources:

- Source 1 (The Netherlands):[6] 46 MJ/kg;
- Source 2 (The Netherlands):[8] 31 MJ/kg;
- Source 3 (The Netherlands):[9] 18 MJ/kg;
- Source 4 (USA):[10] 6 MJ/kg.

Such differences may be surprising to engineers who are used to approved specifications, standard codes and reliable and well tested data. However, the databases held by various institutes appear to be usable. When high figures, for example, for structural steel are quoted, they usually include energy input for rolling, surface treatment, transport, welding, fabrication, delivery and assembly of the structure. Low figures comprise smaller numbers of those processes. Data on other materials are collected in a similar way so that every database is usually consistent. It is, therefore, recommended to use data from the same source throughout the entire analysis. The lack of standards should temporarily be accepted. In the interest of the environment, one should rather critically apply the existing data than wait until they become better.

The so-called "exergy" method was used to quantify the energy use for the five bridge options. In this method, the total energy consumption is a sum of energy value decreases for the materials in the processes involved. The analysis was limited to basic materials; wooden bridge decks in both structural and stainless steel bridges, stainless steel connectors in aluminium and FRP bridges and so on were ignored. The energy consumption rates per material unit were collected from the first[6] database except for composites (second[8] data base). Although both companies were involved in the official "Eco-indicator" project,[11] no uniform energy database for all materials was available at that time. The review resulted in some adjustments to the data for the purpose of this analysis (*Table 2*). According to recent views, the data for composites might still require a minor increase. These data should, however, not be confused with the much higher energy rates for plastics. Polyester resin usually makes up less than 50% in volume (about 30% in weight) of pultruded profiles. The rest is fibreglass.

In the following example, energy consumption is estimated for a structural steel bridge:

Total mass of two spans: 6000 kg. Assumed: 80% of the primary and 20% of the secondary (recycled) material. Energy consumption on delivery:

$$Ex_0 = 6000 \times [0,8 \times (46-7) + 0,2 \times (36-7)] = 222\,000 \text{ MJ} \quad (1)$$

The energy used during maintenance (2 × blast cleaning and painting) was approximated by subtracting the figure for unpainted structure (31 MJ/kg) obtained from another database.[9] To take account of the time delay (about 20 and 35 years), a factor of 0,75 was introduced:

$$Ex_1 = 6000 \times 2 \times 0,75 \times (46-7-31) = 72\,000 \text{ MJ} \quad (2)$$

This gives the total energy consumption:

$$Ex = Ex_0 + Ex_1 = 222\,000 + 72\,000 = 294\,000 \text{ MJ} \quad (3)$$

The energy consumptions for the other material options were estimated in a similar manner. This gave the energy impact graph for all the five bridge options (*Fig. 4*).

| Material | Condition | Energy consumption value (MJ/kg) | Remaining "stored" energy (MJ/kg) |
|---|---|---|---|
| Structural steel (e.g. S235J0) | Primary<br>Secondary | 46<br>36 | 7<br>7 |
| Stainless steel (e.g. AISI 316L) | Primary<br>Secondary | 69<br>54 | 11<br>11 |
| Composites (FGRP) | Primary<br>Secondary | 33<br>— | 9<br>— |
| Aluminium (e.g. AlMgSi1) | Primary<br>Secondary | 137<br>45 | 33<br>33 |
| Reinforced concrete (B35, handrails) | Primary<br>Secondary | 11<br>— | 2<br>— |

*Table 2: Energy consumption data for the five material options for the bridge*

These results are not as "hard" as, for example, those from structural analyses. One may wonder why the delay factor of 0,75 is used for the maintenance of the structural steel bridge—and if so, then why it is not applied to deck replacements in other bridge options. In this case, the engineers felt that spare decks of "unusual" materials (composite, aluminium) should be secured, that is, delivered together with the bridges. This assumption is, however, arbitrary. Another simplification is that the energy for dismantling after the service life has been neglected. Including it would probably point to the concrete bridge as the most energy-consuming option. Concrete demolition and utilization requires much energy. As mentioned, there are also differences in energy rating between various institutions and countries, especially in regard to composites. German data,[12] often result in higher energy rates and American data[10] in lower energy rates. However, it is undisputable that the composite bridge had the lowest energy consumption.

## Loads to the Environment

Energy analyses do not indicate how "clean" or "dirty" the considered options are, that is, they provide no comparison in terms of environmental pollution. The problem with such a comparison is that each material option gives a spectrum of qualitatively different pollutions, which cannot simply be added up. The solution is found by taking account of the so-called "legal thresholds" of the particular pollutants. This was, to the author's best knowledge, the first time that this approach was used in an infrastructure project. The applied method is derived from the so-called critical load method,[10] and is based on the following two data records:

- $B_{m,i}$ (kg/m$^3$), emitted masses of the pollutants $i$ due to production and processing of 1 m$^3$ of the material $m$. Such emissions are usually recorded as loads to air, water and (exceptionally) soil.
- $B_{0,i}$ (kg/m$^3$), legal thresholds of the pollutants $i$ in 1 m$^3$ of air, water and (exceptionally) soil.

When these two data records are known along with the total mass $G_m$ and density $\gamma_m$ of the material $m$, the total critical volume of polluted air $V^a_m$ or water $V^w_m$ (m$^3$) can be computed as follows:

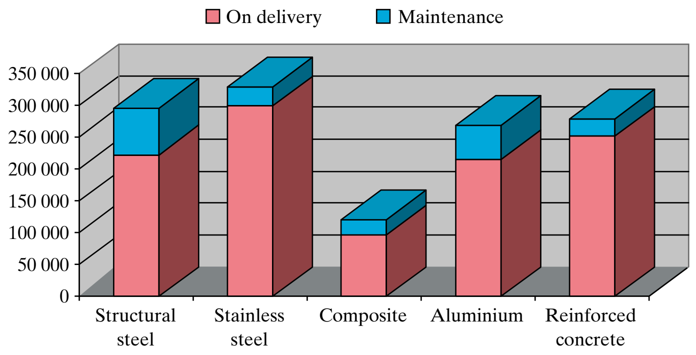


*Fig. 4: Energy impact of the bridge for the five material options*

$$V_m = \frac{G_m}{\gamma_m} \times \sum_i \frac{B_{m,i}}{B_{0,i}} \qquad (4)$$

*Tables 3 and 4* present the emissions $B_{m,i}$ and their legal thresholds $B_{0,i}$ for the four final material options: structural steel, composite, aluminium and concrete. The stainless steel option was not given up at that stage. The data for structural steel and aluminium bridges were collected from Refs. [10, 13]. The emission data for polyester resin were provided by the world market leader in this branch, and combined with the data for glass to give the aggregated emissions for FRP. The data for reinforced concrete (including steel accessories like handrails) were obtained by combining the records for concrete and steel.

Apart from the global results (see *Table 1*), it is interesting to compare the pollutions to water and air qualitatively. For example, for the composite bridge, Eq. (4) and the data in *Tables 3 and 4* give the following critical volumes of polluted air, $V^a_{cp}$ and water $V^w_{cp}$:

$$V^a_{cp} = \frac{G_{cp}}{\gamma_{cp}} \times \sum_i \frac{B_{cp,i}}{B_{0,i}} = \frac{4000}{1700} \times \left( \frac{1{,}03 \times 10^3}{9{,}0 \times 10^{-3}} + \cdots + \frac{1{,}2 \times 10^{-1}}{8{,}0 \times 10^{-7}} \right) = 2{,}35 \times 3{,}37 \times 10^6 = 7{,}92 \times 10^6 \text{ m}^3 \qquad (5)$$

$$V^w_{cp} = \frac{G_{cp}}{\gamma_{cp}} \times \sum_i \frac{B_{cp,i}}{B_{0,i}} = \frac{4000}{1700} \times \left( \frac{2{,}0 \times 10^{-6}}{5{,}0 \times 10^{-5}} + \cdots + \frac{3{,}0 \times 10^{-2}}{1{,}0 \times 10^{-3}} \right) = 2{,}35 \times 36{,}5 = 85{,}8 \text{ m}^3 \qquad (6)$$

The components of these sums, multiplied by the ratio $G_{cp}/\gamma_{cp}$, are represented in diagrams (left) in *Fig. 5*, along with the results for the other material options. The total critical volumes of polluted air and water are compared in pie charts (right) in *Fig. 5*. Also, the composite bridge appears to be more favourable than the other considered options.

The analysis in this paper was deliberately kept simple. The bridge options were approached as single-material cases. Although there usually exists a single dominant material in all bridge projects, it may be advisable to consider other component materials as well. Examples are concrete



| Polluter | Structural steel $B_{st,i}$ | Composite $B_{cp,i}$ | Aluminium $B_{al,i}$ | Concrete $B_{cr,i}$ | Threshold $B_{0,i}$ |
|---|---|---|---|---|---|
| $CO_2$ | $2{,}56 \times 10^{+3}$ | $1{,}03 \times 10^{+3}$ | $2{,}1 \times 10^{+4}$ | $4{,}95 \times 10^{+2}$ | $9 \times 10^{-3}$ |
| CO | $9{,}58 \times 10^{+1}$ | 1,32 | $5{,}15 \times 10^{+1}$ | 3,48 | $4 \times 10^{-5}$ |
| $CH_4$ | 5,95 | 1,21 | $5{,}39 \times 10^{+1}$ | $9{,}89 \times 10^{-1}$ | $6{,}7 \times 10^{-3}$ |
| $N_2O$ | $3{,}7 \times 10^{-2}$ | $4{,}8 \times 10^{-3}$ | $2{,}94 \times 10^{-1}$ | $1{,}51 \times 10^{-2}$ | $1 \times 10^{-7}$ |
| PM Fe/Al-oxi.* | $2{,}2 \times 10^{-1}$ | $1{,}05 \times 10^{-1}$ | 1,65 | $6 \times 10^{-2}$ | $1 \times 10^{-7}$ |
| PM Si/Ca-oxi.* | $4{,}2 \times 10^{-2}$ | $5{,}05 \times 10^{-1}$ | $2{,}7 \times 10^{-1}$ | $4{,}7 \times 10^{-1}$ | $3 \times 10^{-7}$ |
| $SO_2$ | 3,28 | $2{,}51 \times 10^{-3}$ | $1{,}27 \times 10^{+1}$ | $2{,}8 \times 10^{-1}$ | $1{,}2 \times 10^{-6}$ |
| $NO_x$ | 3,08 | 2,83 | $2{,}45 \times 10^{+1}$ | 1,27 | $1 \times 10^{-5}$ |
| Styrene | — | $1{,}2 \times 10^{-1}$ | — | — | $8 \times 10^{-7}$ |

*PM = particulate matter (dust), here predominately Fe/Al or Si/Ca oxides.

*Table 3: Emissions to air for structural steel, composite, aluminium and reinforced concrete*

| Polluter | Structural steel $B_{st,i}$ | Composite $B_{cp,i}$ | Aluminium $B_{al,i}$ | Concrete $B_{cr,i}$ | Threshold $B_{0,i}$ |
|---|---|---|---|---|---|
| Aluminium | $3{,}33 \times 10^{-6}$ | $2 \times 10^{-6}$ | $3{,}09 \times 10^{-5}$ | $1{,}65 \times 10^{-7}$ | $5 \times 10^{-5}$ |
| Ammonia | $4{,}58 \times 10^{-3}$ | $1{,}1 \times 10^{-3}$ | $4{,}23 \times 10^{-2}$ | $2{,}38 \times 10^{-4}$ | $2{,}2 \times 10^{-3}$ |
| Cadmium | $4{,}57 \times 10^{-5}$ | $2{,}1 \times 10^{-6}$ | $4{,}28 \times 10^{-4}$ | $2{,}18 \times 10^{-6}$ | $3{,}5 \times 10^{-6}$ |
| Copper | $1{,}96 \times 10^{-8}$ | $7{,}9 \times 10^{-4}$ | $1{,}82 \times 10^{-7}$ | $0{,}99 \times 10^{-9}$ | $2 \times 10^{-4}$ |
| Cyanide | $3{,}08 \times 10^{-4}$ | $7{,}4 \times 10^{-5}$ | $2{,}85 \times 10^{-3}$ | $1{,}6 \times 10^{-5}$ | $1 \times 10^{-4}$ |
| Fluoride | $1{,}03 \times 10^{-1}$ | $2 \times 10^{-4}$ | $6{,}49 \times 10^{-3}$ | $3{,}51 \times 10^{-3}$ | $1{,}5 \times 10^{-3}$ |
| Manganese | $6{,}07 \times 10^{-6}$ | $3{,}6 \times 10^{-6}$ | $5{,}64 \times 10^{-5}$ | $3{,}03 \times 10^{-7}$ | $5 \times 10^{-5}$ |
| Mercury | $1{,}57 \times 10^{-4}$ | $7 \times 10^{-7}$ | $1{,}45 \times 10^{-3}$ | $7{,}53 \times 10^{-6}$ | $5 \times 10^{-6}$ |
| Zinc | 3,97 | $1{,}4 \times 10^{-3}$ | $5{,}44 \times 10^{-2}$ | $1{,}35 \times 10^{-1}$ | $5 \times 10^{-3}$ |
| Cobalt | — | $3 \times 10^{-2}$ | — | — | $1 \times 10^{-3}$ |

*Table 4: Emissions to water for structural steel, composite, aluminium and reinforced concrete*

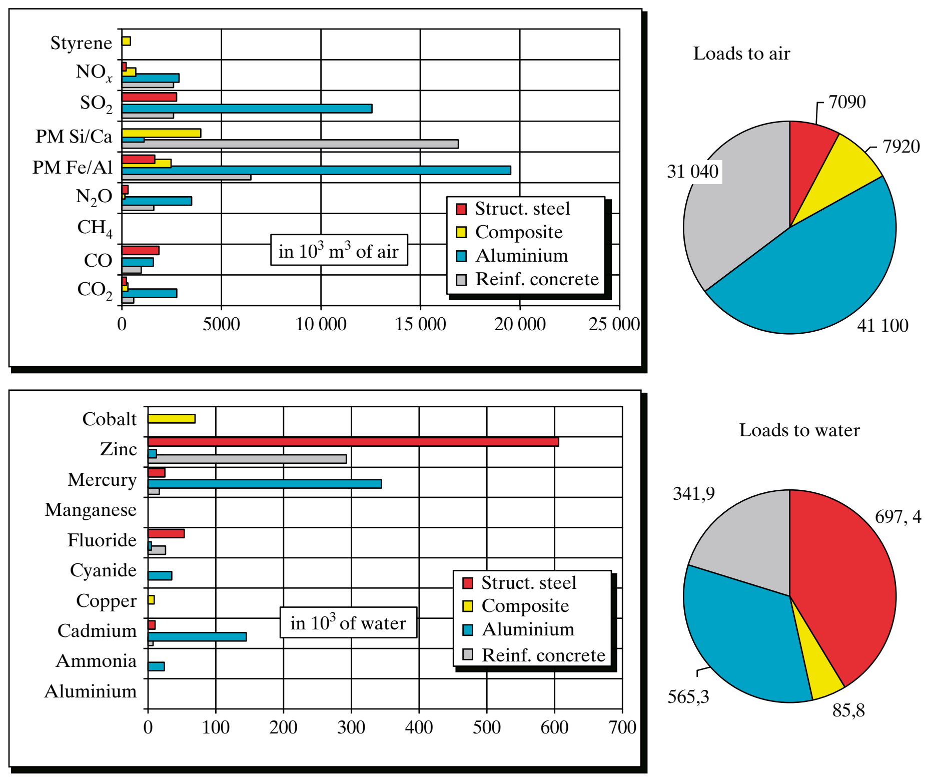


*Fig. 5: Polluted air and water as a result of bridge construction with four material options*

and steel in cable-stayed bridges or steel and composite in steel bridges with composite decks. The discussed method can be applied in such cases too. Equation (4) then takes the following form:

$$V_{complex} = \sum_j \left( \frac{G_j}{\gamma_j} \times \sum_i \frac{B_{j,i}}{B_{0,i}} \right) \qquad (7)$$

where $V_{complex}$ is the critical volume of air or water polluted up to the respective legal threshold (m$^3$); $G_j$ is the total mass of material $j$ in the considered complex material bridge option (kg); $\gamma_j$ is the specific mass of material $j$ (kg/m$^3$); $B_{j,i}$ is the mass of pollutant $i$ emitted by production + processing of 1 m$^3$ of material $j$ (kg/m$^3$); $B_{0,i}$ is the respective legal threshold of pollutant $i$ in air or water (kg/m$^3$).

This may look complex here, but once we have the databases $\boldsymbol{B_{j,i}}$ and $\boldsymbol{B_{0,i}}$ in a PC, this sum presents no problem. In fact, it can easily be generated in a simple spread sheet, along with proper graphs.

## Conclusion and Future Outlook

The considered case proves that synthetic composites (FRPs) constitute a very interesting material option for bridges in terms of environmental impact. A composite bridge project

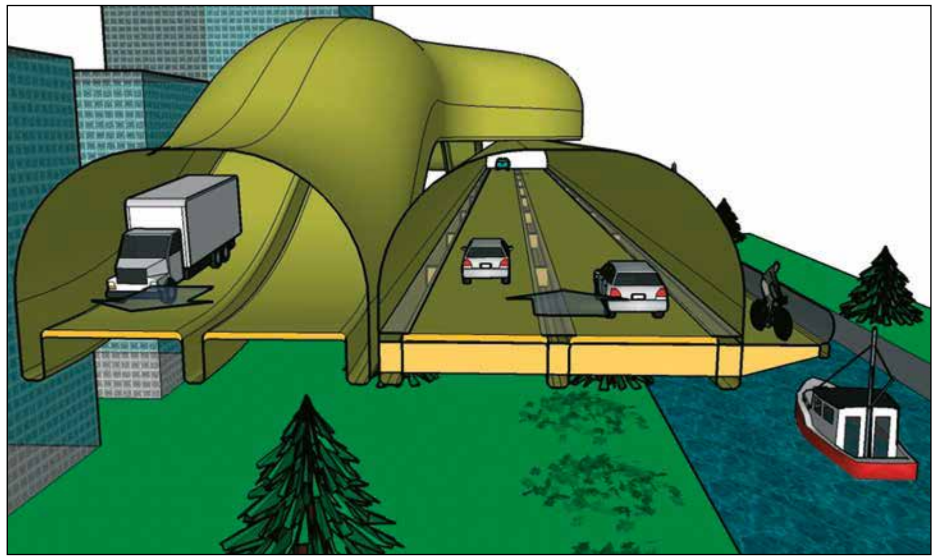

*Fig. 6: Closed 'traffic ducts' concept*

requires less than half of the energy input that is required for an equivalent project constructed using steel, stainless steel, aluminium or concrete. In terms of loads to air, the composite bridge is the second "cleanest" option after the steel bridge. In terms of loads to water, the composite bridge is the undisputable winner. This makes composites an advantageous material for bridges, despite the slightly higher construction costs.

The main reasons for the good performance of FRP are:

- good mechanical properties, particularly the tensile strength, resulting in small quantities required;
- very good chemical stability, resulting in low maintenance and long service life;
- well-controlled processes, resulting in small error margins and low environment impact.

The presented case should be seen as an indication, but not necessarily as evidence, for other bridge projects. Individual requirements and local conditions often play a decisive role in material selection. In the considered Noordland Bridge, for example, high corrosion resistance was particularly valued because of the surrounding environment (sea water). For road bridges, the relatively low elasticity modulus of composites may limit their applications or require other forms and structural systems, for example, "ribbon bridge",[14] membrane deck,[15] high truss girders or closed traffic ducts.[16] The latter also (*Fig. 6*) offer other advantages for the environment. Yet, as the significance of environmental performances steadily grows, the synthetic composites will likely gain a stronger position in the construction market in the future.

It is also predictable that the methods of environmental analyses will develop fast and that their results will enjoy a growing significance. It is important to develop objective, soundly based and well balanced tools enabling us to comparatively assess the environmental impacts on engineering choices. Only such tools can replace emotions, manipulations and free lobbying, which very often control these choices at present. Such tools should be rooted in official regulations, rather than in individual judgements. This is the main reason why the presented assessment method makes use of "legal thresholds". Even if those thresholds are not perfect yet, they must be endorsed. The idea behind it is the same as for referring to the existing databases: it is better to use them and complain about their shortcomings than wait until they improve.

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"Learning and innovation go hand in hand. The arrogance of success is to think that what you did yesterday will be sufficient for tomorrow"

William Pollard








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