sustainable infrastructure systems

FRP Composite Bridges 2m to 30m Clear Span

FiberCore europe

CERTIFIED SUPPLIER InfraCore

Version 2.2

Contents

When you are ready to talk, contact our structures team to set a meeting, for samples or to discuss your project.

1300 26 10 74
service@sisau.com.au
sisau.com.au

Australian Head Office
26 The Parade West
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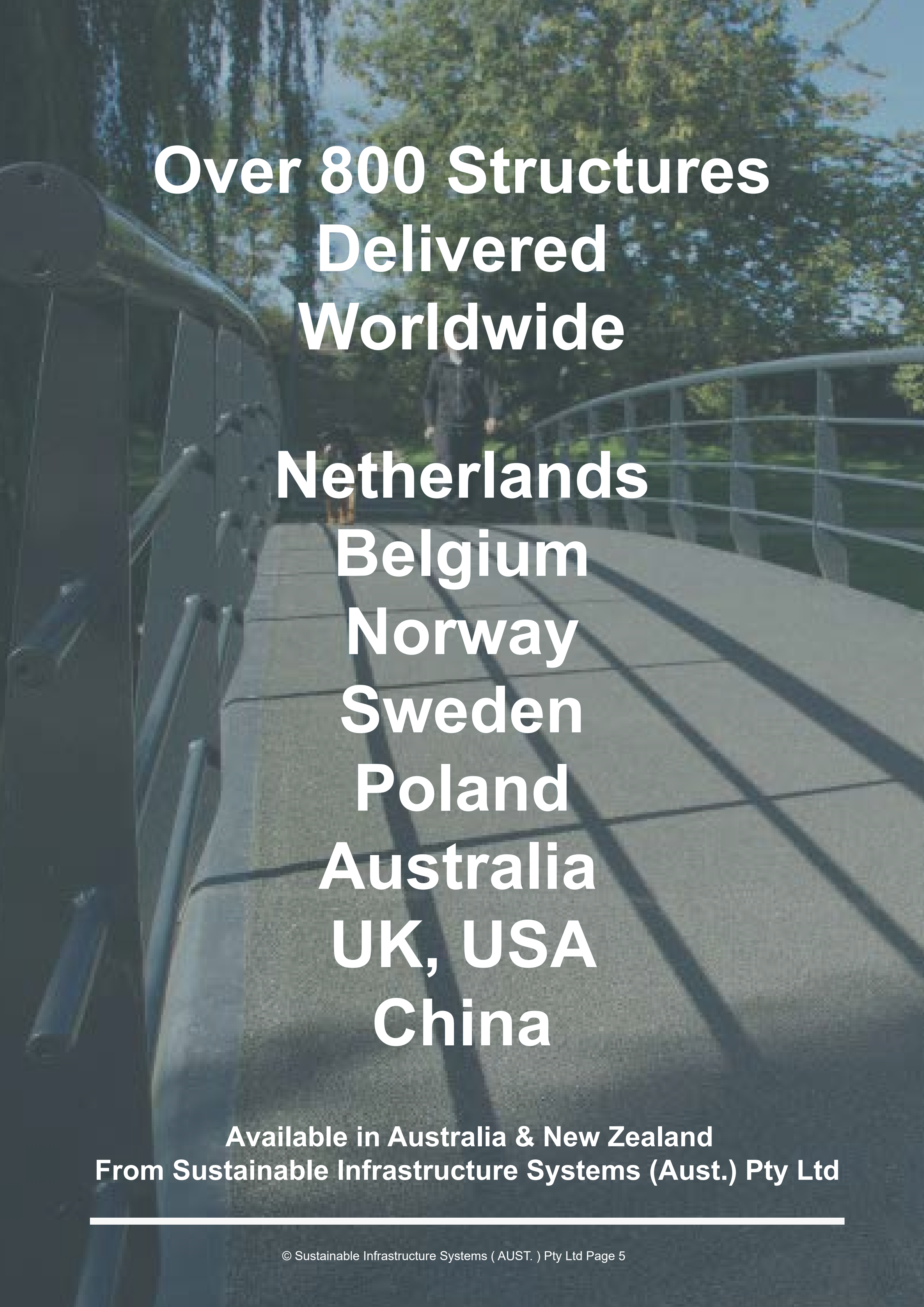

Over 800 Structures
Delivered
Worldwide
Netherlands
Belgium
Norway
Sweden
Poland
Australia
UK, USA
China
Available in Australia & New Zealand
From Sustainable Infrastructure Systems (Aust.) Pty Ltd

Welcome to the future of bridge building.

Until now, lightweight large single span composite bridges have not been available to designers, architects, engineers and stakeholders in Australia & New Zealand.

Sustainable Infrastructure Systems (SIS) is proud to introduce FiberCore Europe's InfraCore® Inside technology

About Sustainable Infrastructure Systems (Aust.) Pty Ltd

SIS is a unique organisation focused on manufacturing and distributing sustainable and recycled products and projects for diversified clients around the world.

From recycled plastic, recycled wood plastic composites (WPC), fiberglass reinforced polymers (FRP) and recycled rubber through to our CoreSpan® co-extruded multi-composites and aluminum WPC hybrid composite and OEM manufacturing, SIS are market leaders in delivering sustainable products to customers in many markets.

SIS specialise in delivering our product range to markets including Civil Infrastructure, Building & Construction, Oil & Gas, Mining, Aviation, Aquaculture, Marine & Ports, Transport & Logistics and Agriculture.

High Tech Manufacturing & Quality Materials

Products designed, manufactured and supplied by SIS embody state of the art technology and are engineered by our teams to deliver enhanced performance and sustainability effective operation for customers worldwide.

All our products are manufactured to the highest industry standards, following strict quality assurance guidelines. With many employees dedicated to production, quality product and technical expertise is ensured at all times.

Excellent long term relationships with our key suppliers of raw materials and components provide confidence in material quality as well as sustainable and efficient manufacturing and supply chain processes. The close relationship with our research and development division ensures that SIS manufacturing teams can react quickly and professionally to customer needs.

SIS has built a reputation based on excellent customer service, high quality manufacturing and on providing the right solution in sustainable product design and manufacturing.

Continuous improvement of equipment design, materials and manufacturing technology ensures SIS maintains its capability of offering clients the latest and most commercially viable sustainable products and projects available. SIS also works with clients to develop specific solutions to meet their unique needs through the application of research and development efforts in a partnering relationship.

We manufacture and supply products from materials that include:

- Recycled Plastic
- Fiberglass Reinforced Polymers
- Recycled Wood Plastic Composite
- Recycled Rubber
- Co-Extruded Aluminium / Wood Plastic Composite

With a global network of manufacturing facilities, along with projects delivered in Africa, the Middle East, Asia, Australia and the Pacific Rim, combined with over 20 years of composite experience, SIS can be trusted to provide easy, efficient and seamless supply to almost any place on earth.

Our Mission

SIS aims to set a responsible standard of sustainable product design and manufacture and project delivery for our diverse client base in both the short and the long term.

We all have a significant impact on the world around us and each of us should play a part in protecting future generations. Designers, engineers and stake holders have a big responsibility to set standards of product and project design that benefits the environment and the people who live in it.

SIS' aspiration is that ultimately, talking about sustainability will become superfluous, because it will be the expected.

About FiberCore Europe

In 1995, Jan Peeters developed Europe's first publicly accessible composite bridge in Harlingen. His engineering firm Composieten Team worked together on the project with the Dutch Department of Waterways.

Although composite is in many respects superior to concrete, wood and steel, the application of this great material in heavily loaded constructions requires extra attention.

Jan Peeters resigned from the Plastic and Rubber Institute at TNO and focused all his attention on developing a revolutionary construction technology with composite.

Despite the long history of composites, these high-tech materials had not been paid much attention. It took almost 10 years before the inventions of Jan Peeters could be applied in infrastructure.

Together with Simon de Jong, Jan Peeters founded FiberCore Europe in 2008.

With their patented technology InfraCore® Inside, FiberCore Europe is now a worldwide success.

More than 700 InfraCore® bridges, bridge decks and lock gates have been delivered in the Netherlands, Belgium, England, France, Italy, Sweden, Norway, China and the USA.

An important moment in the development of the company was the real scale research, which proved that the InfraCore® technology does not show any fatigue or any other structural failure for 100 years.

FiberCore Europe has grown steadily in recent years. Over the years, numerous patent positions were developed worldwide on the technology and the production method. 2015 showed company growth of over 140% and proved to be the real breakthrough, with the realisation of five moving road bridges and eight lock gates for the Wilhelmina Canal in Tilburg. After years of investment, the acceptance of the InfraCore® technology in civil infrastructure has become a reality.

Today, Jan Kroon is general manager of FiberCore Europe. Focus will be on further professionalisation and the ambitious (international) growth of the infrastructure company.

Quality System Certification

The InfraCore® Inside technology was invented, developed and promoted by FiberCore Europe. It took a significant amount of time to come up with a structure that is cost effective to build, efficient in use, and best in bringing the potential of FRP to clients in the world of infrastructure.

FiberCore Europe operates an IS09001 certified quality control system. The systems ensures that products are built as specified and meet high quality standards. It includes everything from the supply of raw materials to verification of individual stages in the fabrication process.

What is Sustainable Infrastructure

Sustainable infrastructure is not just about new infrastructure, it is about rehabilitation, reuse or the optimisation of existing infrastructure, which is consistent with the principles of sustainability and sustainable product development, whether it be from civil infrastructure to mining sectors.

This encompasses infrastructure renewal, long-term economic analysis of infrastructure, energy use and reduced infrastructure costs, the protection of existing infrastructure from environmental degradation, material selection for sustainability, quality, durability and energy conservation, minimising waste and materials, the redesign of infrastructure in light of climate change and the remediation of environmentally damaged areas of our world. Clearly, sustainable infrastructure will lead to improvements to society through better socio-economics. Responsible design needs to balance social, economic and environmental issues.

InfraCore Technology

FiberCore Europe structures are made with our patented technology, InfraCore® Inside.

InfraCore® technology was specially developed for the construction of extremely strong panels made of fiber-reinforced polymer composite.

In order to guarantee this safety, all InfraCore® structures are provided with the InfraCore® Inside quality mark.

No Delamination or Cracking

In the past the weakness of regular composite constructions (sandwiches) was their delamination, a problem caused by the skin coming loose from the core.

Delamination mainly occurs after impact load, followed by fatigue load. In bridges this could be the case after cracking damage followed by passages with a wheel print.

InfraCore® technology is still the only technology that offers a solution for delamination. This solution cleared the way for the use of fiber reinforced polymers in Infrastructure.

Modular Construction

The ability to construct elements off-site can dramatically improve how projects are delivered. Ultimately, this method of construction provides significant benefits when it comes to maximising speed and safety and minimising disruption. The low weight of InfraCore® elements and manufacturing off-site has some significant advantages;

- The disruption to surrounding road or rail infrastructure can be heavily reduced
- Safety risks for the construction of bridge elements are redirected towards the manufacturing plants - being controlled environments there is much less that can go wrong, when it comes to safety.
- Elements also benefit from being manufactured in a factory environment, avoiding the complications that can arise on a construction worksite.
- Production of bridge elements off-site means projects are more predictable when it comes to costs.
- Fewer labour elements necessary for constructing projects on site. This is a significant benefit when it comes to projects in congested or remote areas.
- Foundations required are approximately only one third of that required for concrete and steel constructions.
- The construction speed will minimise building time and road closures. For construction work that is well prepared, a bridge with InfraCore® Inside can be installed within one hour.
- As demand on scarce raw materials is reduced and emissions are very low, the technology is sustainable with regard to the environment.

Maintenance Free & Guaranteed for 50 years

Structures with InfraCore® Inside require no maintenance after installation.

The materials used are not affected by moisture, rot, fungi, temperature, etc.

For this reason, InfraCore® elements are covered by a 50-year guarantee.

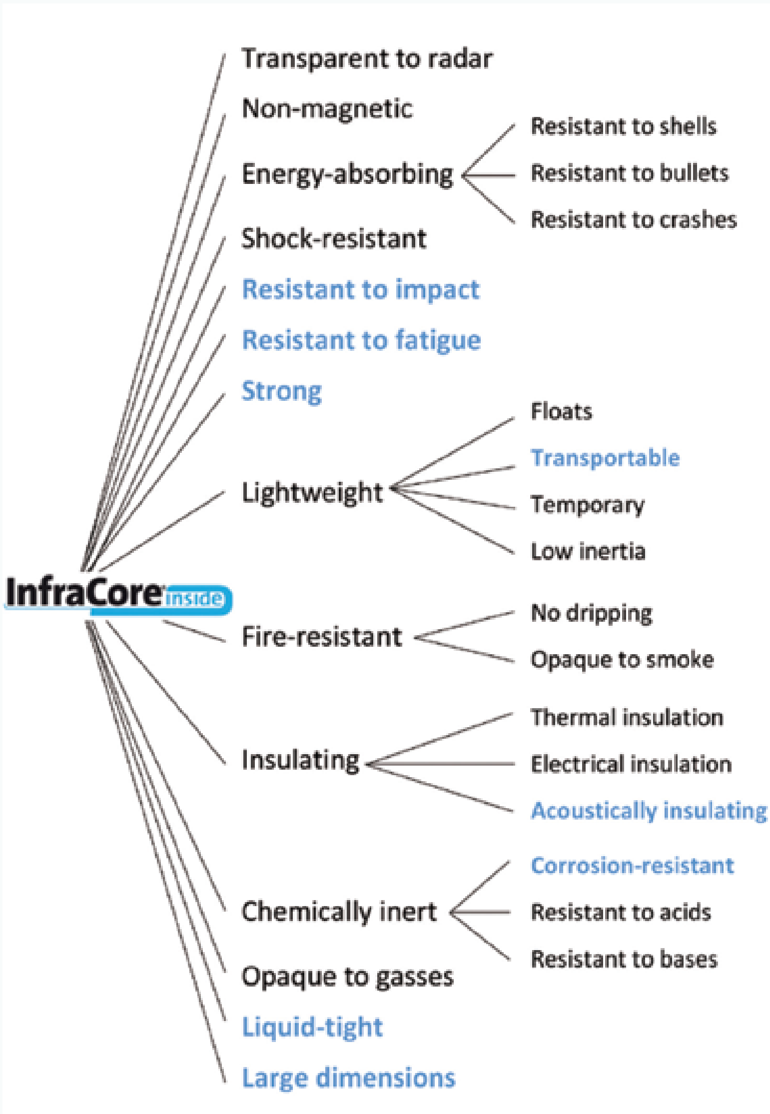
The outer surface of the bridges are finished in a high-quality gel coat or topcoat. As this finish is based on the same polymer as the bridge, they form one consistent unit.

InfraCore® is resistant to almost all forms of vandalism, such as graffiti and fire. Maintenance is limited to the cleaning and repair of the wearing surface. Repair will be required after the normal decrease of the roughness of the sacrificial layer.

FRP Material

Fiber reinforced polymers are a composite material of structural fibers in a matrix of thermoset resin. The resin restrains the fibers against buckling and enables transfer of shear stress between the fibers. Thermoset resin does not get soft at elevated temperatures, unlike thermoplastic material in coffee cups and many household plastics.

The fibers in FRP are typically glass fibers, although also superior, generally more costly, carbon or aramid fibers can be used. Glass fibers have a strength of 2800N/mm^2 (or MPa) thus are stronger than steel (~355N/mm^2). Glass fibers are available as roving or as mat, either with fibers in one direction or combining a number of different directions. The fibers are like the reinforcement in reinforced concrete structures, yet at a much more refined level and entirely dispersed over the structure.



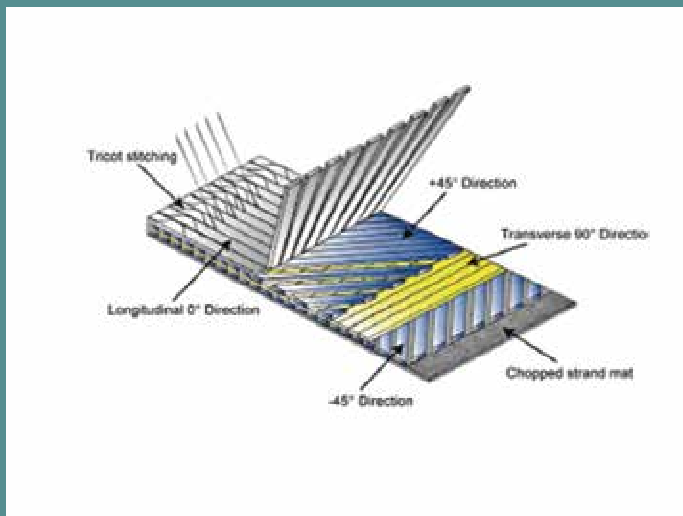
Overview of the Properties of InfraCore® Inside, with those applicable to civil engineering structures highlighted.

InfraCore® - Technology

InfraCore® Inside is FiberCore Europe's proprietary technology to construct strong, lightweight and durable structures in FRP. The technology comprises of the design, the way the fibers are laid out and the method of fabrication.

While some freedom exists to tune the technology for each specific application, the fabrication follows a modular construction. The dimensional constraints are due to handling and transportation, but not the technology itself.

Structures manufactured using InfraCore® Inside technology are fully prefabricated and integral, with no internal bonding or bolting. The strength therefore relies on the fibers, which themselves are stronger than steel.



Rolls of glass fibers and an example of a glass fiber fabric comprising multiple fiber directions.

InfraCore® Inside

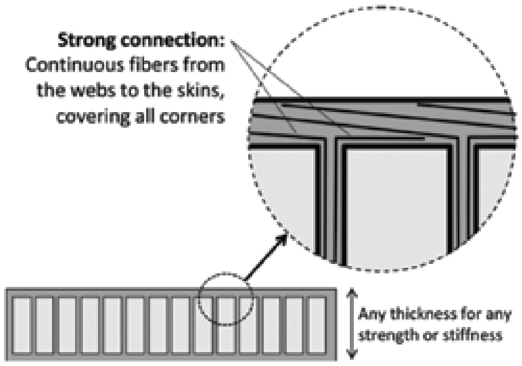
Mechanically behaves like a highly efficient sandwich structure.

In such structures, two skins are spaced in order to create a layer arm.

The space in between is filled with lightweight material that only transfers shear stresses.

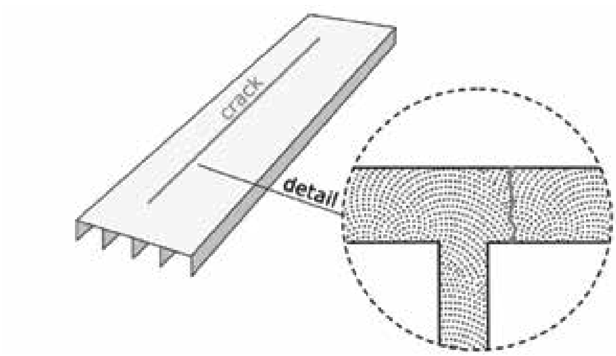
The significance of InfraCore® Inside is that it incorporates a continuous structural connection between the two skins.

This eliminates the brittle failure as a result of debonding between skin and core.

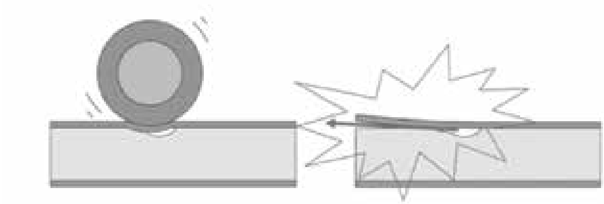


The Principle of InfraCore® Inside :
no skin-core debonding

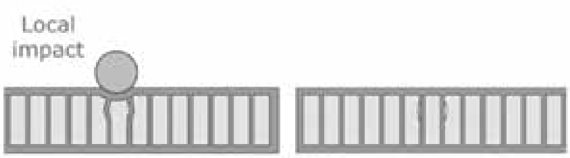
The importance of strength being dominated by fibers means that a resin-dominated fracture path should be avoided, and it is demonstrated below:



In structures with fibers predominately in one direction, cracks eliminate the load distribution, and then propagate until failure. Fibers in cross-direction are essential to avoid this



In conventional sandwich structures, initial damage is propagated by rolling wheels, leading to skin-core debonding and total failure.



In InfraCore® Inside, local damage can not lead to catastrophic failure modes. Moreover, the core-material (foam) is not part of the load-bearing structure, but only acts as a placeholder during construction.

Typical Values

The properties of composite materials depend on the type, orientation and amount of fibers.

Typical values are as follows:

- Strength, span direction: 55N/mm^2 (or MPa)
- Strength, transverse: 150N/mm^2 (or MPa)
- Stiffness, span direction: 3900N/mm2 (or 39GPa)
- Stiffness, transverse: 1100N/mm^2 (or 11GPa)

InfraCore® Inside technology is a modified and improved sandwich, significantly improved to eliminate the debonding between the core and the skins that is normally critical and fatal in sandwich construction. For preliminary design purposes it is usually sufficient to consider InfraCore® Inside as a sandwich typology, and ignore the contribution of the interior foam and webs.

InfraCore® Inside has so far been used to support vehicles of up to 60 tonnes.

The density of infused rigid solid FRP varies with the proportion of resin and fibers, but is normally between 1600 and 1800kg/m^3. The bare core material, which has no structural role and only serves as a lost mould during construction, weighs 35kg/m^3.

Codes & Standards

While the design of FRP structures is not covered by the Eurocodes, the material independent parts of these codes can be used. The use of FRP is well established in naval and aerospace construction and abundant design experience is available. Design guidance that considers the specifiers of FRP in civil engineering applications is available, the most advanced being the Dutch design guideline CUR 96-2017

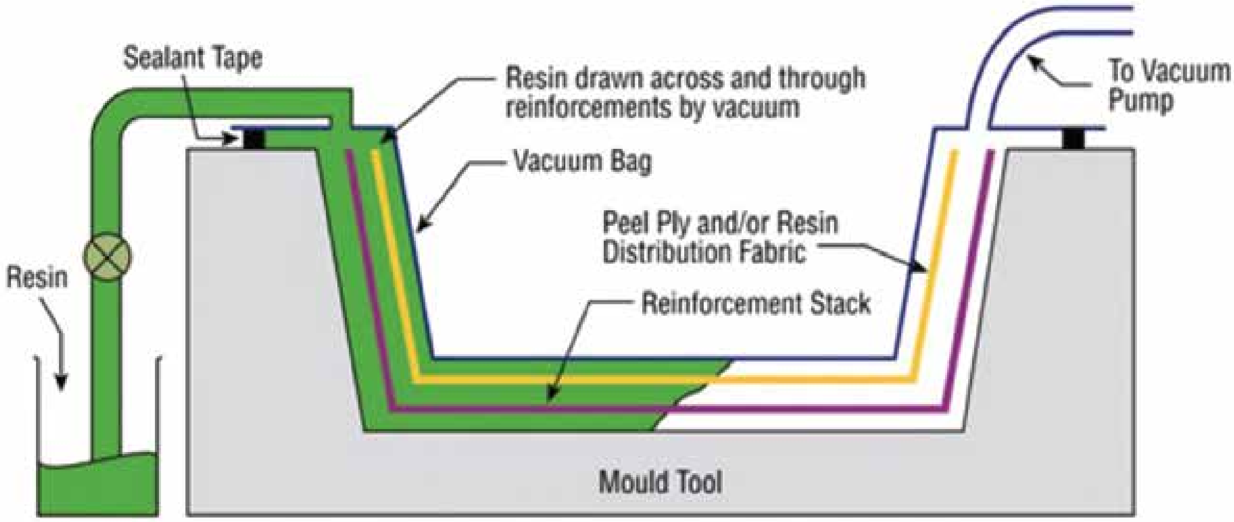
Following the limit state design methodology of Eurocodes, it proposes reduction factors on theoretical material properties, depending on the application, the method of construction and the environment where it is applied. For the design of its InfraCore® Inside structure, FiberCore Europe follows the loadings set out in Eurocodes, and the checking as per the CUR 96-2017 guideline.

SIS engaged FMG Engineering to conduct a full review of the codes and compliance to Australian Standards and Codes.

Fabrication

InfraCore® Inside is constructed with the vacuum infusion technique. This method allows fabricating integral structures in a structurally efficient way, in bespoke geometries.

The process involves transporting resin through a stack of glass fibers and foam blocks. The process takes place inside an airtight bag, with no emissions.



Schematic view of the vacuum infusion technique

Since InfraCore® Inside is a technology with the same principles at its core, it combines the fabrication efficiency of a system-based approach, with the flexibility of a customised fabrication method. The dimensions of the biggest element that can be produced are dictated by logistics, not by the technology itself. Currently the maximum element length that can be manufactured is 56m and the maximum width 8m

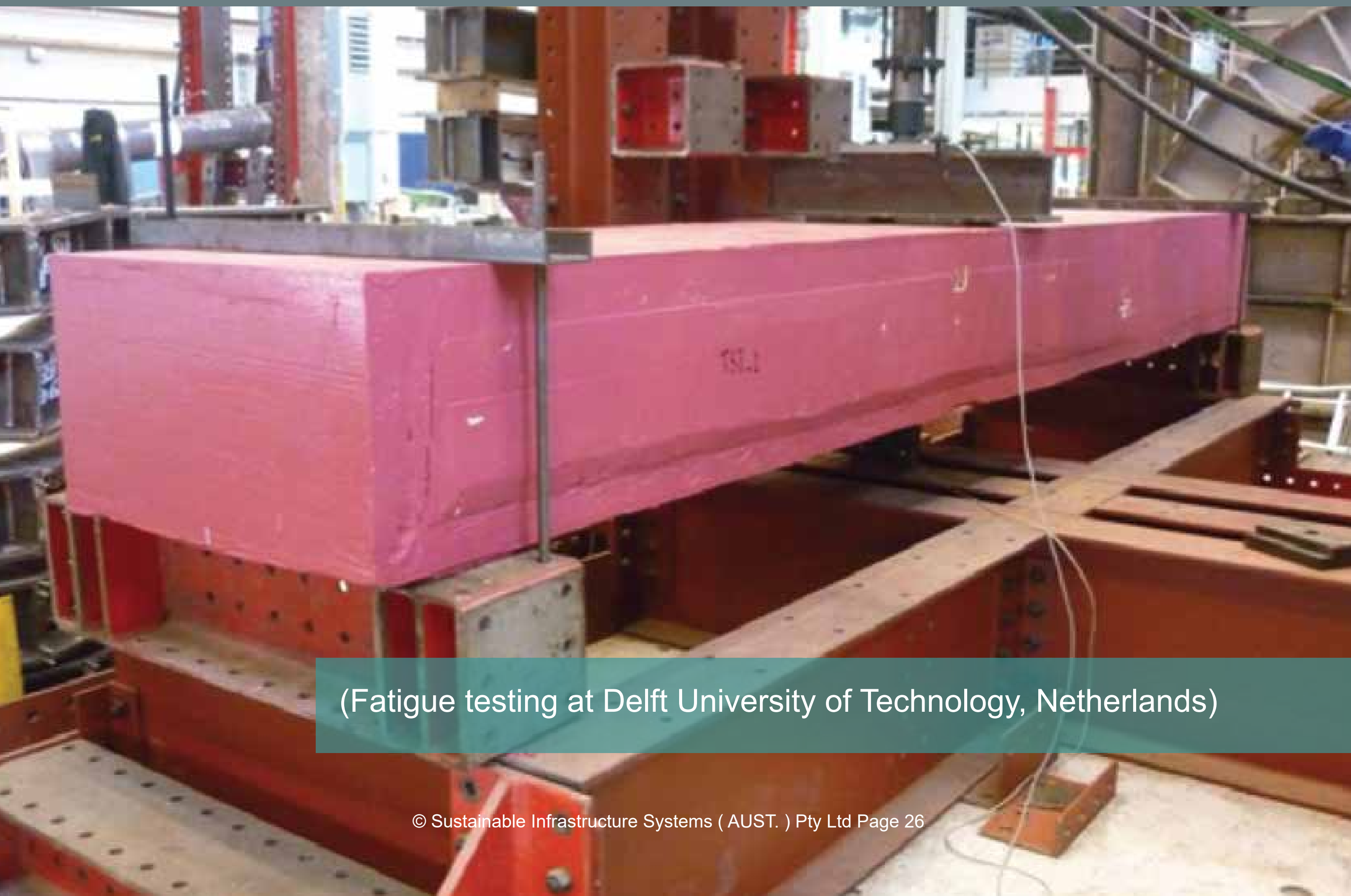
Resistance to Fatigue

When FRP is used in bridge construction, the design is most often governed by stiffness requirements.

In such stiff structures, the levels of strain are so low that the material is well outside the domain where it would be sensitive to fatigue.

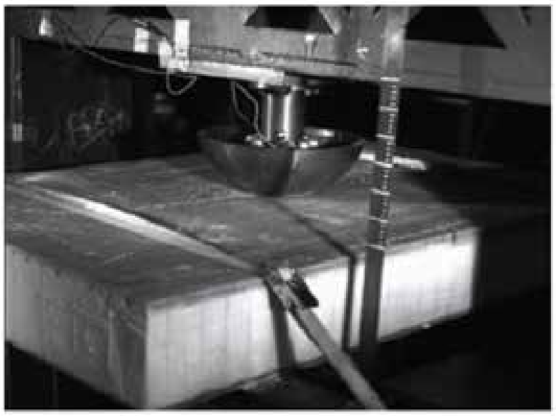
FRP is also used in windmill blades. These endure much higher levels of stress and strain. From this application, a vast amount of information is available on fatigue behavior.

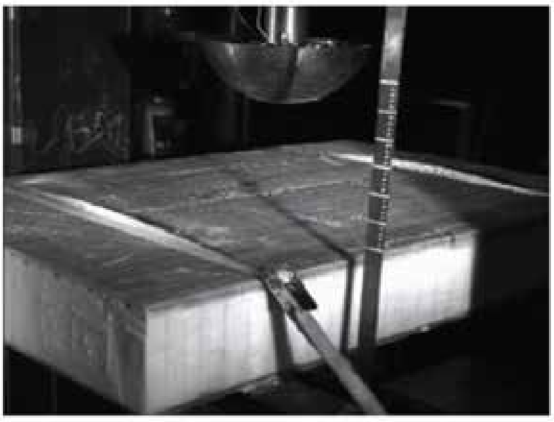
The resistance of InfraCore® Inside against fatigue has been comprehensively tested at Delft University of Technology. In the tests, a sample was subjected to a loading equivalent to a design life of 150 years.

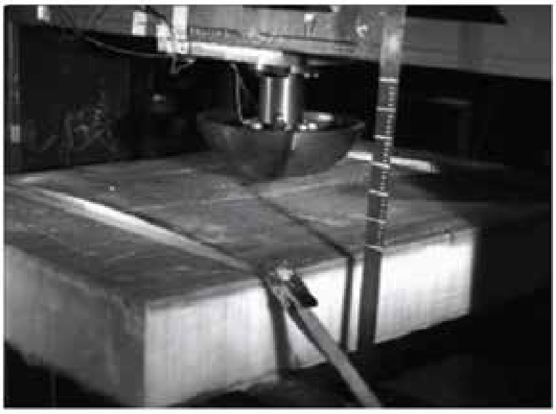


(Fatigue testing at Delft University of Technology, Netherlands)

Resistance to Impact







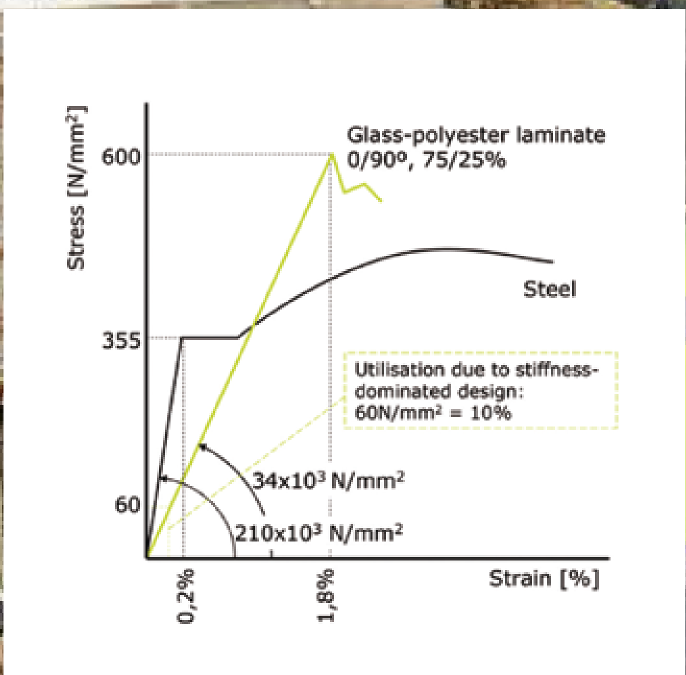
In infrastructure applications, not only is the loading distribution as prescribed by design codes, but also the resistance to impacts as well.

To demonstrate the resilience of InfraCore® Inside against impacts, panels were subjected to a mass in free fall at the laboratories of TNO. The test showed FRP's significant strain-capacity, as the applied mass bounced back.

Images made with high-speed camera show no panel failure but an elastic response instead.

Built in Safety

In isolation glass fibers show a linear elastic behavior until failure. However when constructed together as a multi-directional laminate through the infusion method, failure behaviour is gradual and the fibers fail one by one, rather than all at the same time. Also, fibers in cross direction will be virtually unaffected by failure in the span direction. For this reason, the bespoke fiber layout of infusion is the key to safe FRP structures.



Thermal Behaviour

InfraCore® Inside is normally based on glass fibers and a polyester resin. These materials are subject to thermal movement like most other materials, but the magnitude varies with the orientation and proportion of the fibers.

Typical values for the coefficient of thermal expansion are:

- Span direction: $7x10^{-6}/K$
- Transverse direction: $50x10^{-6}/K$

Since the coefficient of thermal expansion can be tweaked, it can be matched with that of steel ($12x10^{-6}/K$). which enables integrally connected hybrid structure with minimal build-up of thermal stresses. It is worthwhile noting that in case carbon fibers are used, the thermal expansion is near zero.

Fire

In case FRP or InfraCore® Inside are set on fire, the resin will char but flames are self-extinguished as soon as the external heat source is taken away. The structural fibers are resistant to very high temperatures and will withstand fire without any adverse effect.

The material's response to fire can be optimised with additives that release water from within the material. Local damage as a result of fire can be repaired by re-infusion.

Climate

The structural fibers inside FRP are based on silicon (effectively sand) and are fully resistant to both high and low temperatures.

InfraCore® Inside has been exposed to liquid nitrogen (-1960^{C}), and has come out of the test fully functional.

In hot climates, exposure to temperatures over 90^{C} should be avoided.
In areas of long term heat exposure a layer of asphalt can be applied to protect assets long term.

Sustainability

Due to the low dead load, almost zero maintenance, long design life and the ability to recycle and regain the embodied energy after use, FRP structures have very positive sustainability credentials. Comparisons with other materials should be performed on a case-by-case basis, and include all the project characteristics, including the foundations, maintenance and after-use.

Sustainability is a very broad subject and depending on the location and the client's ambition, the following positive contributions could be considered:

- Reduced noise emissions during construction and in-use;
- Fast construction, shorter disruption, less detours being made by ongoing traffic;
- Less and lighter movements by transportation and crane-operations.

Weights

Examples of Structure Weights:

Length [m]	Width [m]	Deck Depth [mm]	Weight [kg]
5.0	1.2	100	508,02
7.5	1.2	100	812.84
10.0	1.2	220	1117.65
12.5	1.2	370	1625.67
15.0	1.2	510	2032.09
5.0	2.2	100	1016.04
7.5	2.2	120	1524.07
10.0	2.2	180	2133.70
12.5	2.2	270	2946.54
15.0	2.2	370	3759.37

Design Criteria for Weights Above:

- Design load: 5kN/m2 + 8ton axle load
- Deflection criteria: L/100
- Load natural frequency >2,3 Hz (TC3 0,5 P/m2);
- Max. weight railing: 50kg/m1

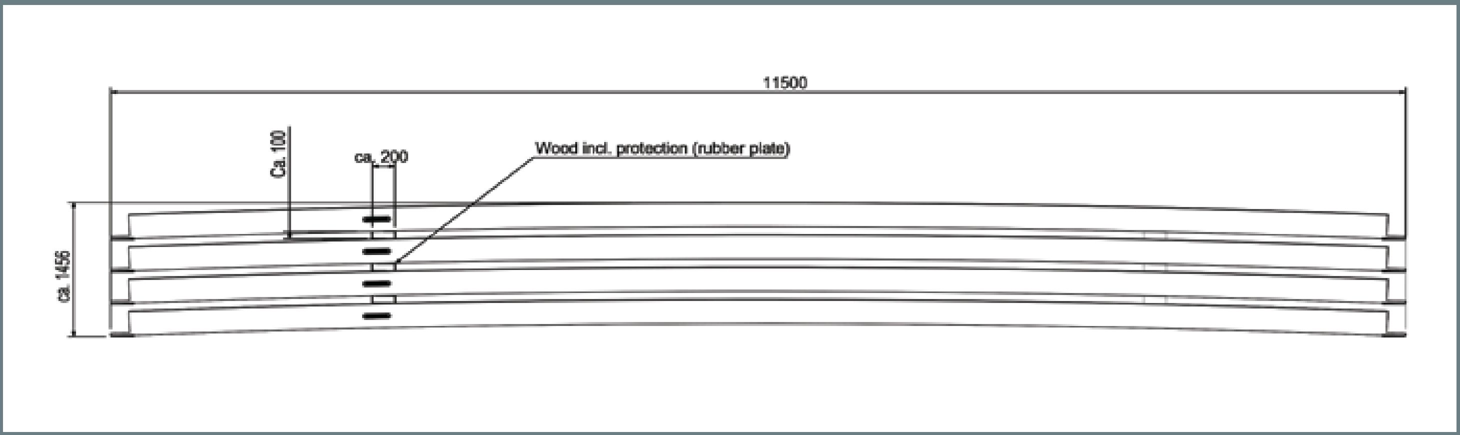
Weights are an indication and includes the mass of the deck including a wear surface.

Transport, Shipping & Lifting

Containerised Freight

Bridge elements from 2m to 30m can be shipped globally by SIS efficiently and cost effectively using our world wide transport partners, either inside containers or top loaded, via road, sea, rail or if required air.

Bridge elements can be stacked to reduce shipping costs

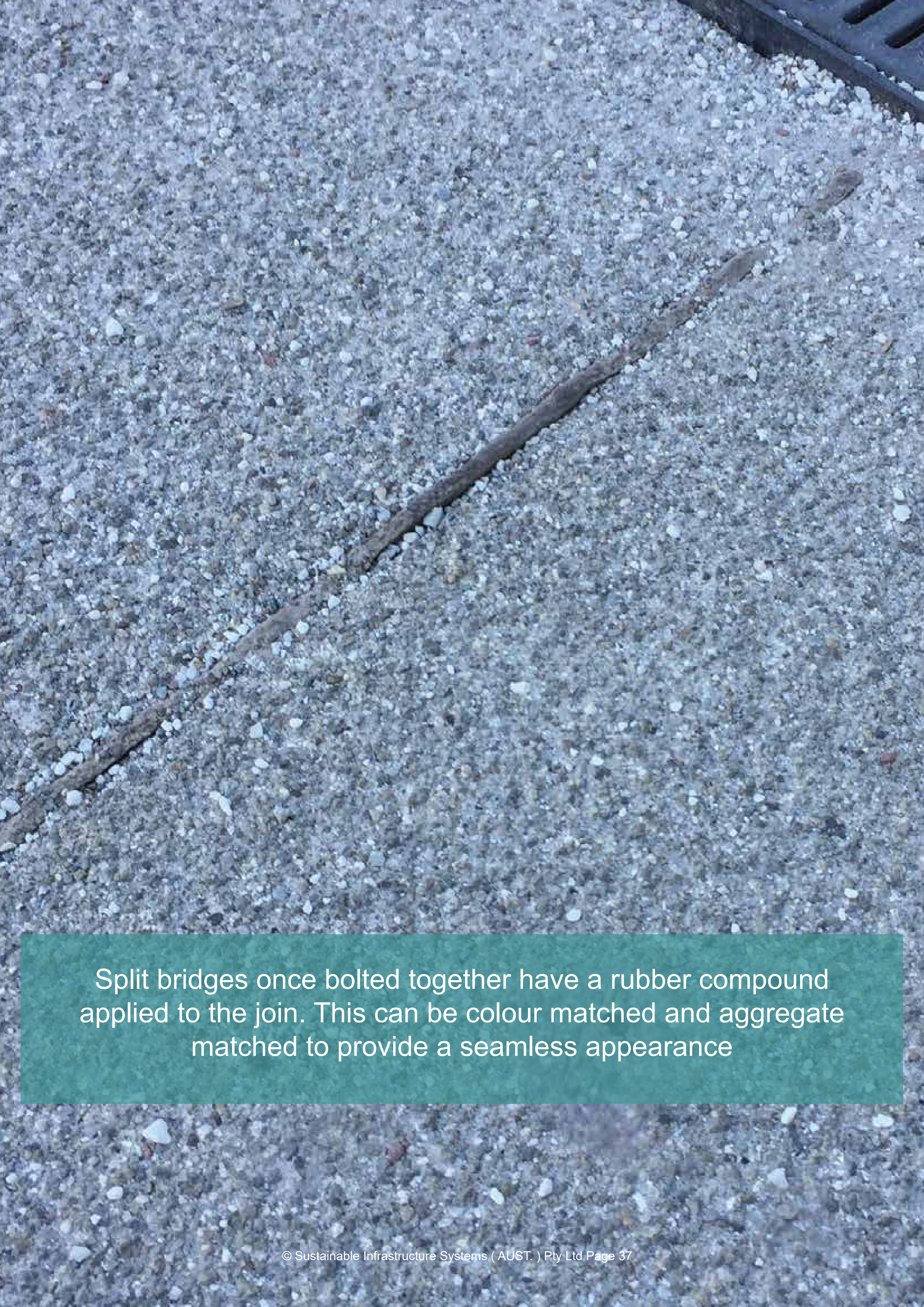


Split Bridges

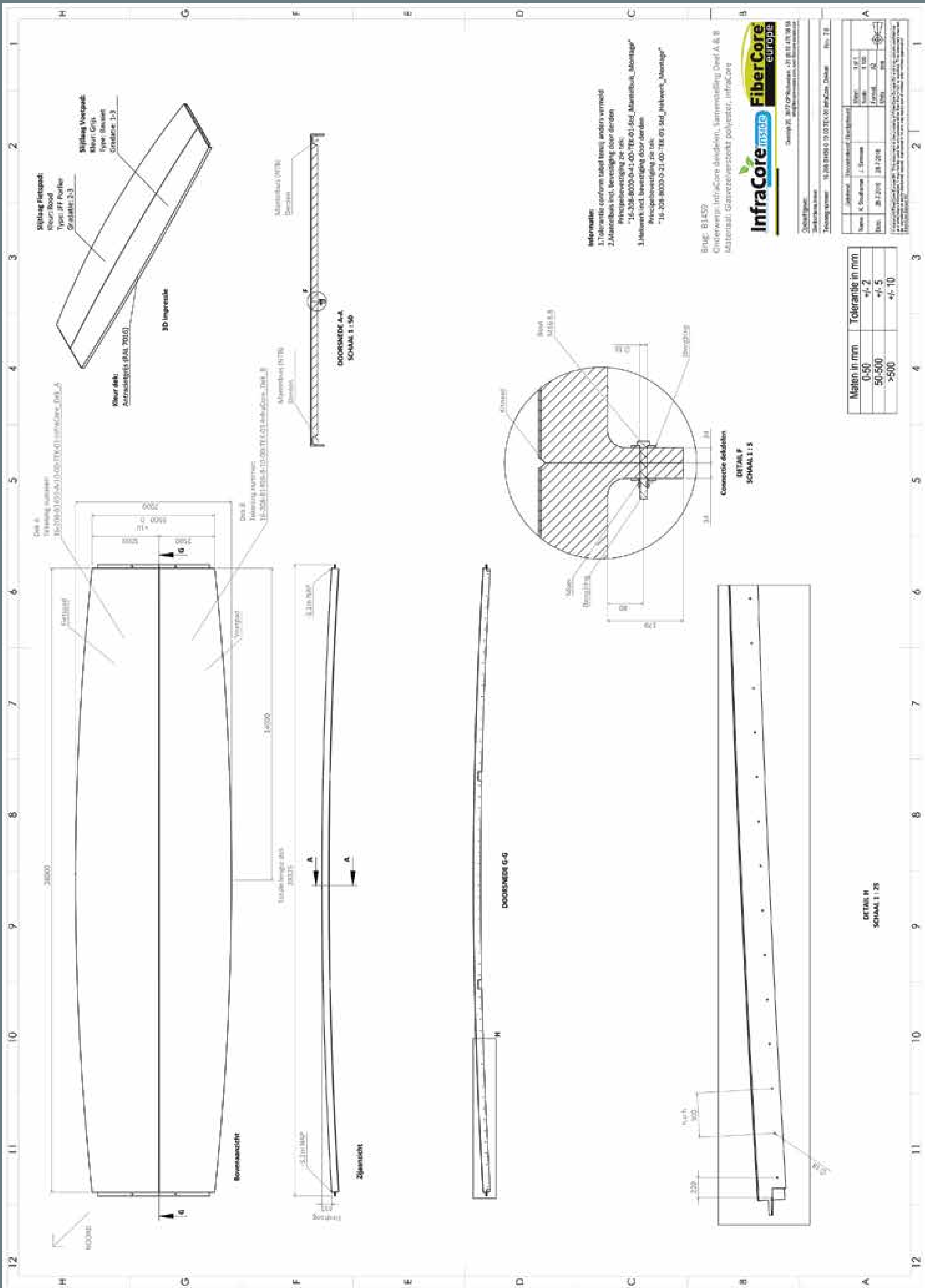
To ensure cost effective shipping and transport, InfraCore® bridge elements wider than 2.4m can be manufactured in parts, allowing for 2, 3 or 4 elements to become 1. This inventive step is ground breaking in it's ability to enable wide structures to be delivered to site using standard transport options and therefore dramatically reducing costs normally associated with moving wide structures.

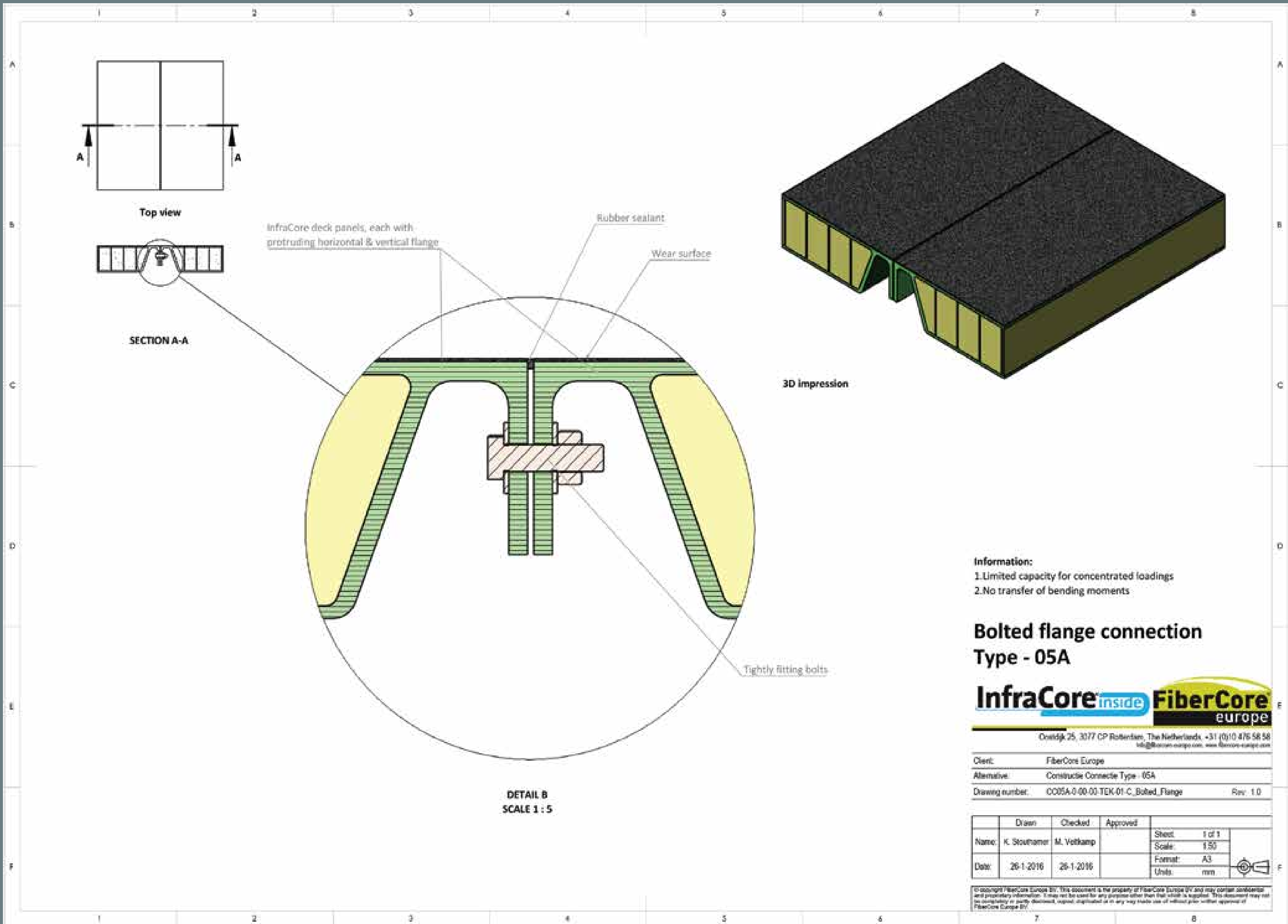
See drawings following on how this is achieved

Photographs below show a bridge delivered to site in 2 sections, bolted together and then installed



Split bridges once bolted together have a rubber compound applied to the join. This can be colour matched and aggregate matched to provide a seamless appearance


InfraCore inside
FiberCore europe
Maten in mm
Tolerantie in mm
0-50
+/- 2
50-500
+/- 5
>500
+/- 10
DOORSNEDE A-A
DOORSNEDE G-G
Bovenaanzicht
Zijaanzicht
3D impressie
DETAIL F
DETAIL H



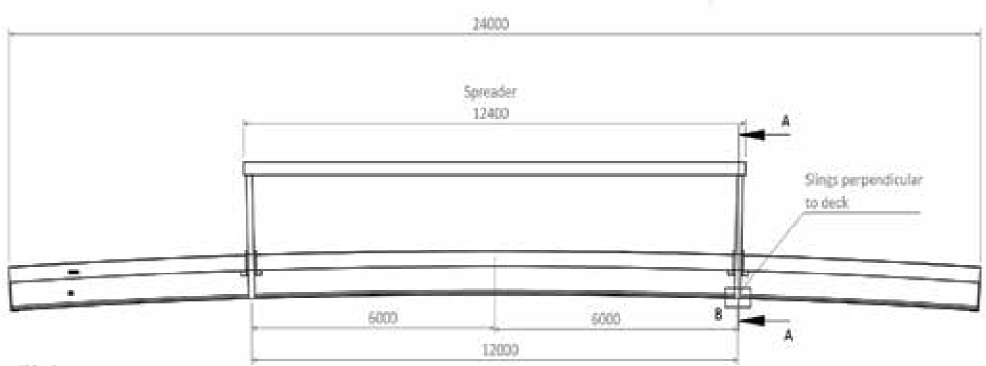
Top view
A
A
SECTION A-A
InfraCore deck panels, each with protruding horizontal & vertical flange
Rubber sealant
Wear surface
Tightly fitting bolts
DETAIL B
SCALE 1 : 5
3D impression
Information:
1.Limited capacity for concentrated loadings
2.No transfer of bending moments
Bolted flange connection
Type - 05A
InfraCore inside
FiberCore europe
Oostdijk 25, 3077 CP Rotterdam, The Netherlands, +31 (0)10 476 58 58
Client: FiberCore Europe
Alternative: Constructie Connectie Type - 05A
Drawing number: CC05A-0-00-00-TEK-01-C_Bolted_Flange
Rev: 1.0
Drawn
Checked
Approved
Name: K. Stouthamer M. Veltkamp
Date: 26-1-2016 26-1-2016
Sheet: 1 of 1
Scale: 1:50
Format: A3
Units: mm

Lifting

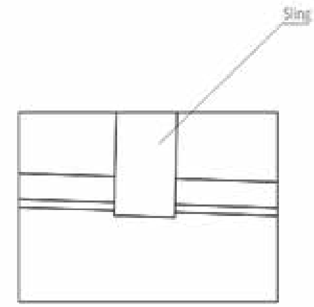
Each FiberCore bridge element is designed and engineered for its own unique application.

All elements ordered come with a lifting / slinging drawing and instructions on how to best lift and install each element.

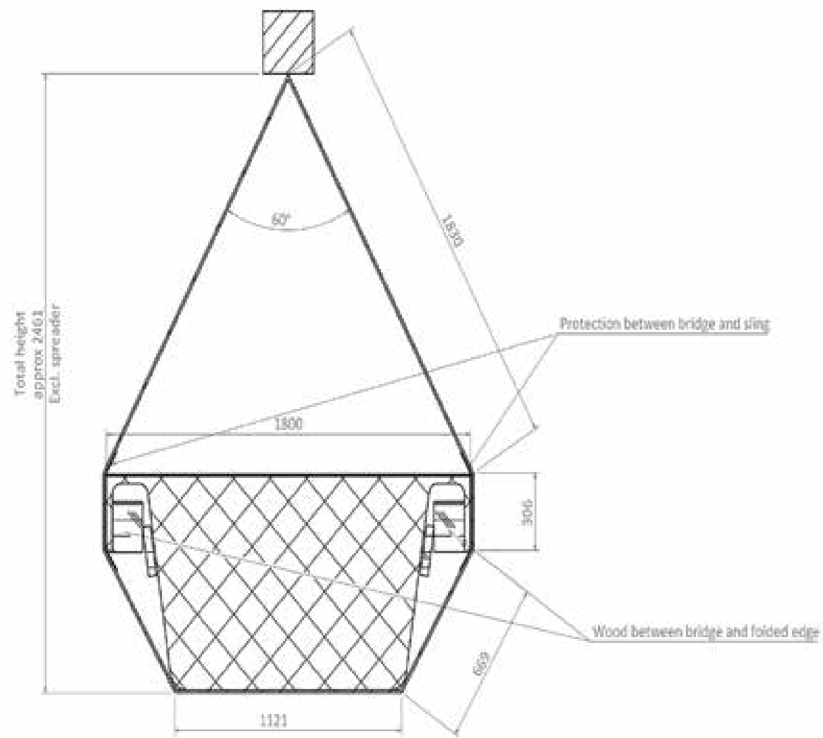
See next page for example.



Side view



DETAIL B
SCALE 1 : 10



SECTION A-A
SCALE 1 : 20

Information:

Weight deck: 8,6 Tonnes including wear surface
Alternatively: use a lifting frame

Distance in mm	Tolerance in mm
0-50	+/- 2
50-500	+/- 5
500-5000	+/- 10
>5000	+/- 20

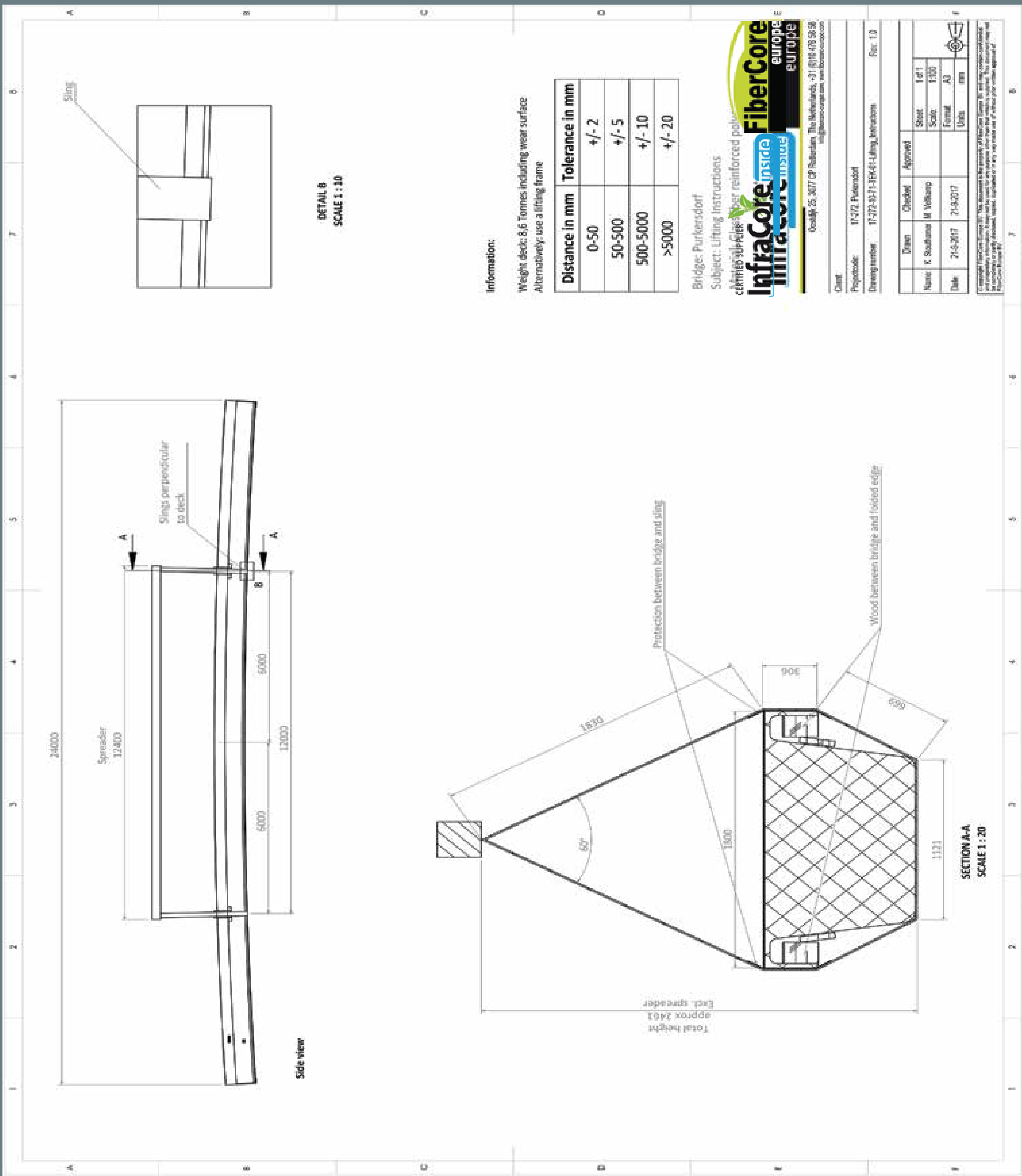
Bridge: Purkersdorf
Subject: Lifting Instructions
Material: Glassfiber reinforced poly...

CERTIFIED SUPPLIER
InfraCore inside
FiberCore europe

Oostdijk 25, 3077 CP Rotterdam, The Netherlands, +31 (0)10 478 58 58

Client:
Projectcode: 17-272, Purkersdorf
Drawing number: 17-272-10-71-TEK-01-Lifting_Instructions Rev: 1.0

	Drawn	Checked	Approved		
Name	K. Stoutjesdijk	M. Veltkamp		Sheet:	1 of 1
				Scale:	1:100
Date	21-9-2017	21-9-2017		Format:	A3
				Units:	mm



Distance in mm	Tolerance in mm
0-50	+/- 2
50-500	+/- 5
500-5000	+/- 10
>5000	+/- 20

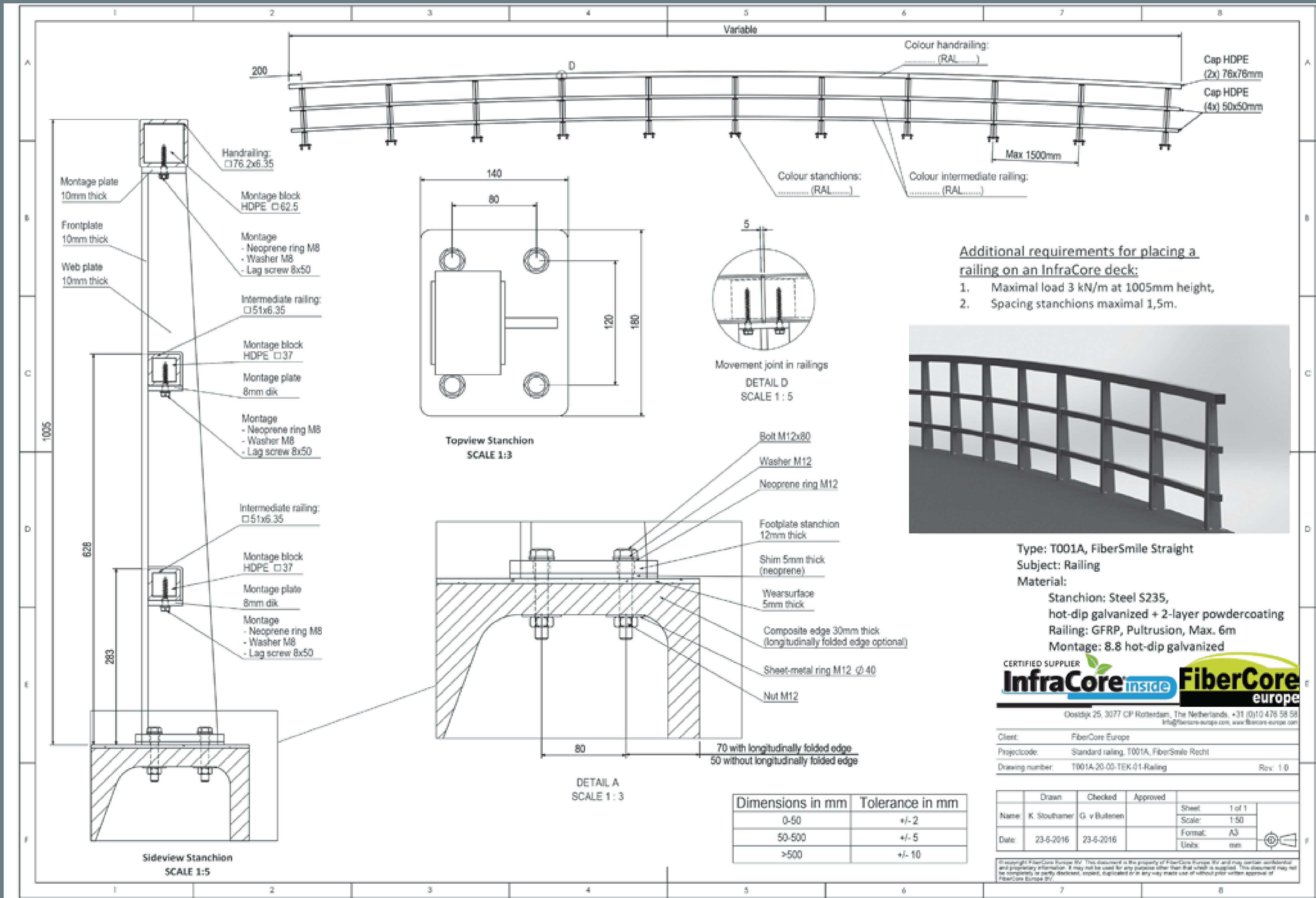
Handrail Systems

FiberCore can create a unique handrail design which is as individual and bespoke as your project.

A full range of standard handrail designs are also available.

Each project has a handrail design drawing specific to its design

See next page for example.



Dimensions in mm	Tolerance in mm
0-50	+/- 2
50-500	+/- 5
>500	+/- 10

#1

Engineering Case Study

Staines Moore Bridge United Kingdom

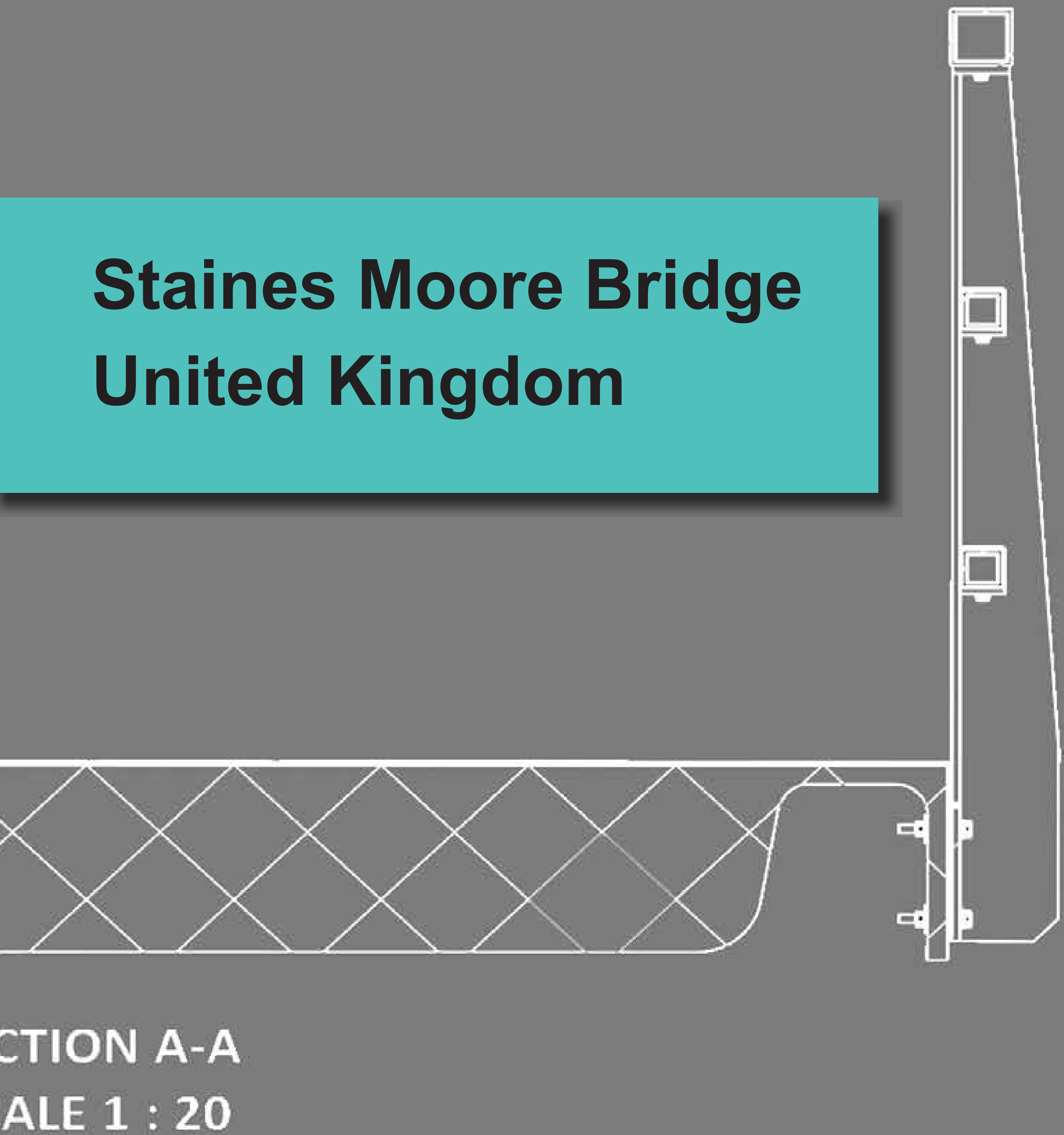


Table of content

Corresponding drawings

- 17-293-SM-010-TKK-1-Deck_R1.0

Rev.	Status	Date	Author	Track changes
1.0	Final	13-12-2017	FZ	Initial version

1. Introduction

This report describes the construction of the new InfraCore Inside pedestrian bridge in Staines, England, designed and built by FiberCore Europe (Rotterdam, The Netherlands) commissioned by ECS Engineering Services.

This bridge has a length of $L_{rd} = 6.1\,m$ and a width of $B_{tot} = 1.50m$.

The InfraCore Inside bridge is an integral structure made from fiber-reinforced polymers (FRP), more specifically glassfibers in combination with a polyester matrix (glassfiber reinforced polyester or GFRP). The glassfibers carry the loads acting on the bridge, the matrix supports the fibers, transfers loads between fibers and gives the bridge its shape.

GFRP has a high specific strength (strength vs specific weight), resulting in relatively lightweight structures (bridges) capable of carrying large loads with high margins of safety.

The bridge has been designed according to Eurocodes, including British national annexes, and CUR-recommendation 96.

FiberCore Europe is responsible for the engineering and manufacturing of the composite bridge.

2. Design principles and geometry of the decks

The InfraCore Inside decks are designed in compliance with the following relevant standards:

- EN 1990+A1+A1/C2:2011, "Eurocode 0: Basis of structural design"
- EN 1991-2+C1:2011, "Eurocode 1: Actions on structures - Part 2: Traffic loads on bridges"
- EN 1991-1-5+C1:2011, "Eurocode 1: Actions on structures - Part 5: General actions - Thermal actions"
- [EUR23984] "Design of Lightweight Foot-Bridges for Human Induced Vibrations"
- [CUR-recommendation 96: 2003]" Fibre reinforced plastics in civil engineering supporting frameworks"

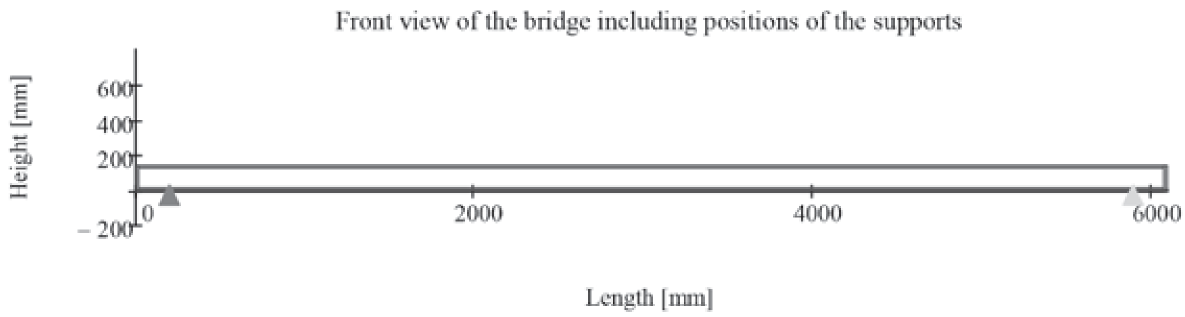
- Technical design life 100yr
- Consequence class CC1
- Traffic class TC3

The main parameters describing the design of the considered deck are given below. For more details on the geometry of the decks, refer to the accompanying drawing.

Total length	$L_{tot} = 6.1 \cdot m$
Length of deck	$L_{rd} = 6.1 \cdot m$
Span	$L_o = 5.7 \cdot m$
Width	$B_{tot} = 1.5\, m$
Effective width (between railings)	$B_{eff} = 1.2\, m$
Construction height	$H_b = 140 \cdot mm$
Width flange	$B_{fh} = 200 \cdot mm$
Total surface area	$A_{bridge} = 9.1\, m^2$
Total mass	$M_{tot} = 1.2 \times 10^3 \cdot kg$
Assumed mass of the railing per meter	$M_{L.rail} = 50\, kg \cdot m^{-1}$

The bridge is assumed to be simply supported on the two abutments beneath the two bulkheads. Both abutments are acting as line supports for the bridge were all webs are supported such that the loads are transferred from the webs through the bulkheads into the abutments.

The bridge will be fixed in longitudinal and transverse direction at one abutment. The bridge will be fixed in transverse direction and will be free to move in longitudinal direction and at the second abutment to accommodate the thermal expansion. The fixation is done with threaded rods trough the bottom of the bridge.



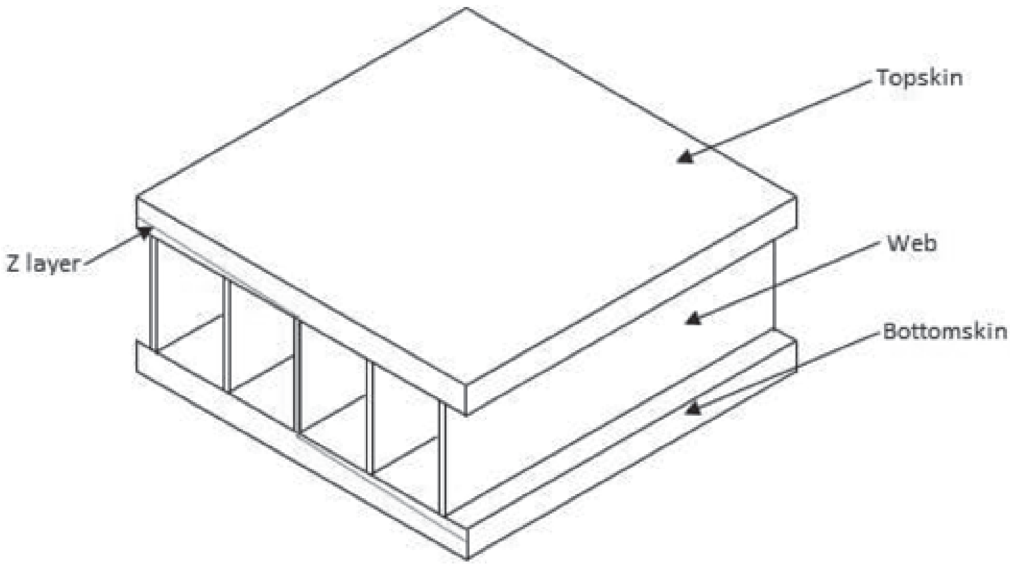
3. Construction principle: InfraCore Inside

The bridge is produced as an InfraCore Inside structure (ICI). An ICI structure can be described as a sandwich structure with two FRP skins at the top and bottom of the bridge, and an FRP-reinforced foam core. The core reinforcement consists of FRP shear webs in longitudinal (flat) direction of the bridge.

Skins and longitudinal shear webs are constructed from the same base materials, in this case non-crimp fabrics, running through the top skin, a shear web and the bottomskin. This ensures a durable, fiber-reinforced connection between skins and shear webs, eliminating the risk of skin-core debonding. Such a layer connecting both skins through the core are called Z-layers, after the shape of each of these layers. To add stiffness or strength, extra material can be added to the skin and/or shear webs.

The stacking sequence of fabrics results in a layered structure (a laminate), each layer called a ply.

All fibers are E-glass fibers, the matrix is a polyester resin.



4 Laminate- & mechanical properties of the cross-section

The applied laminates are anisotropic. The local coördinate systems of each laminate is orientated as follows:

x axis: in-plane, in span direction of the bridge
y axis: in-plane, perpendicular to the span direction of the bridge
z axis: out of plane, perpendicular to the laminate

Multiple different laminates, with each their own properties, are applied in the bridge. The laminate properties are calculated with standard micromechanics models and classical lamination theory as is stated in the CUR96.

The used properties used in the calculations are listed here:

Topskin	$t_{ts} = 12 \cdot mm$	$E_{x.ts} = 32 \cdot GPa$	$E_{y.ts} = 19 \cdot GPa$	
	$\sigma_{x.ts} = 386 \cdot MPa$	$\sigma_{y.ts} = 226 \cdot MPa$	$\tau_{xy.ts} = 98 \cdot MPa$	
Bottomskin	$t_{bs} = 12 \cdot mm$	$E_{x.bs} = 34 \cdot GPa$	$E_{y.bs} = 17 \cdot GPa$	
	$\sigma_{x.bs} = 413 \cdot MPa$	$\sigma_{y.bs} = 199 \cdot MPa$	$\tau_{xy.bs} = 98 \cdot MPa$	
Flange	$t_f = 20 \cdot mm$	$E_{x.f} = 26 \cdot GPa$	$E_{y.f} = 26 \cdot GPa$	$G_{xy.f} = 6 \cdot GPa$
	$\sigma_{x.f} = 306 \cdot MPa$	$\sigma_{y.f} = 306 \cdot MPa$	$\tau_{xy.f} = 98 \cdot MPa$	$\tau_{yz.f} = 39 \cdot MPa$
Edge	$t_e = 13 \cdot mm$	$E_{x.e} = 26 \cdot GPa$	$E_{y.e} = 26 \cdot GPa$	$G_{xy.e} = 6 \cdot GPa$
	$\sigma_{x.e} = 306 \cdot MPa$	$\sigma_{y.e} = 306 \cdot MPa$	$\tau_{xy.e} = 98 \cdot MPa$	
Webs	$t_w = 5 \cdot mm$	$E_{x.w} = 12 \cdot GPa$	$E_{y.w} = 12 \cdot GPa$	$G_{xy.w} = 4 \cdot GPa$
	$\sigma_{x.w} = 143 \cdot MPa$	$\sigma_{y.w} = 143 \cdot MPa$	$\tau_{xy.w} = 64 \cdot MPa$	
Support flange	$t_{sf} = 10 \cdot mm$	$E_{x.sf} = 26 \cdot GPa$	$E_{y.sf} = 26 \cdot GPa$	$G_{xy.sf} = 6 \cdot GPa$
	$\sigma_{x.sf} = 306 \cdot MPa$	$\sigma_{y.sf} = 306 \cdot MPa$	$\tau_{xy.sf} = 98 \cdot MPa$	

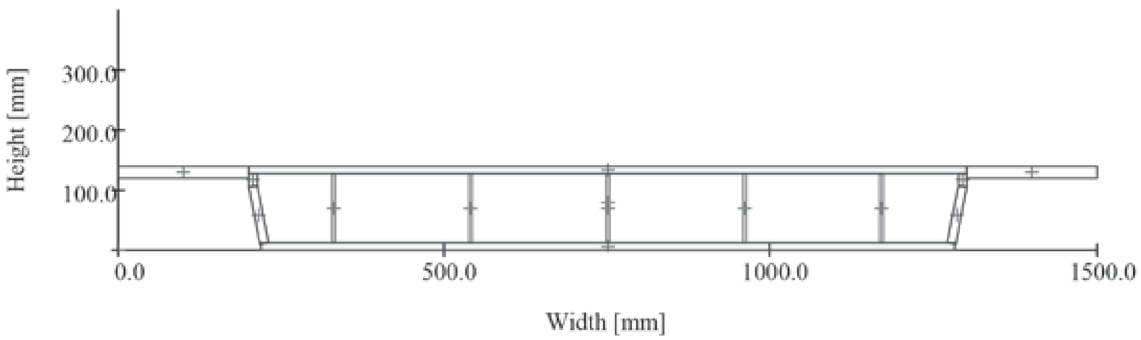
The normal, bending and shear stiffness of the bridge are calculated by the summation of the property of each independent laminate. Only the webs and edges taken into account in the calculation of the shear stiffness.

$$EA_x = 1.2 \times 10^9 \cdot N \qquad EI_{yy} = 4 \cdot MN \cdot m^2 \qquad GA_{xz} = 3.1 \times 10^7 N$$

The thermal behaviour of the bridge is dominated by the skins. The thermal expansioncoëfficiënt of the top and bottomskins can vary a bit from each other due to a small difference in lay-up. The average thermal expansion coëfficiënt of both skins is taken to determine the thermal behaviour of the bridge.

$$\alpha_x = 11.6 \times 10^{-6} \cdot K^{-1} \qquad \alpha_y = 19.5 \times 10^{-6} \cdot K^{-1}$$

Cross-section of the construction



5 Actions, combination of actions & partial factors

5.1 Actions

Permanent loads

The permanent load on the bridge is its self-weight of the structural and non-structural members. The structural member is the InfraCore Inside GFRP bridge deck. The non structural members are the wear surface and railings.

Total self-weight as distributed load $q_m = M_{tot} \cdot g \cdot A_{bridge}^{-1} = 1.3 \cdot kN \cdot m^{-2}$

Live loads

The normative live loads that are taken into account are given below. Live loads, like wind and snow loads, not mentioned are assumed to be not normative and therefore not taken into account in the design. This assumption is based on the combination rules and combination factors listed in EN1990.

Uniform distributed load [EC-1] $q_{fk} = 5 \cdot kN \cdot m^{-2}$

Concentrated load [EC-1]

Load $Q_{fwk} = 10 \cdot kN$

Acting on square surface with sides $B_{fwk} = 0.1 \cdot m$

Horizontal load [EC-1]

Due to uniform distributed load $Q_{flk.q} = 4 \cdot kN$

Dense crowd for dynamic response [EUR23984]

Mass of one person $P_1 = 800\,N$

Density crowd $d_{TC} = 0.5 \cdot P_1 \cdot m^{-2}$

Load on railings [EC-1]

Line load on top of railing $q_{lk} = 1.0 \cdot kN \cdot m^{-1}$

Accidental loads

There are no accidental loads taken into account for this bridge.

5.2 Combination of actions

The combinations of actions on this bridge are based on formula 6.10b EN1990 6.4.3.2 and the tables in EN1990, A 2.2.6 and are listed below. The design of the bridge is dominated by its servicebility (stiffness) when loaded with the live loads. All load combinations are used to check the safety (strength) of the bridge.

LC =

"-"	"LC0"	"LC1"	"LC3"
"Load"	"EG"	"gr1"	"Qfwk"
"q.EG"	1	1	1
"q.fk"	0	1	0
"Q.flk.q"	0	1	0
"Q.fwk"	0	0	1

5.3 Partial factors

The used partial factors are given in the Eurocode and CUR-recommendation 96. The consequence class of this bridge is defined as CC1 ($K_{FI} = 0.9$). The CUR defines different conversionfactors to take into account the effect on the materialproperties of different sources. Which conversionfactors are taken into account are depending on the situation and type of load.

Material factors	Scatter in material properties		$\gamma_{m1} = 1.35$
	Production proces		$\gamma_{m2} = 1.20$
Conversion factors	Temperature (t)		$\gamma_{ct} = 1.10$
	Moisture (v)		$\gamma_{cv} = 1.10$
	Fatigue (f)		$\gamma_{cf} = 1.10$
	Creep (k)		$\gamma_{ck} = 1.24$

Factors for the service limit state (SLS)

Load factor			$\gamma_f = 1.00$
Material factor			$\gamma_{m.SLS} = 1.00$
Conversion factors	Vibrations	Permanent loads (t,v,f)	$\gamma_{cv.p} = 1.33$
		Live loads (t,v)	$\gamma_{cv.l} = 1.21$
	Deformations	Permanent loads (t,v,f,k)	$\gamma_{cd.p} = 1.65$
		Live loads (t,v,f)	$\gamma_{cd.l} = 1.21$

Factors for the ultimate limit state (ULS)

Load factors	Permanent loads		$\gamma_G = 0.89 \cdot 1.35 \cdot K_{FI} = 1.08$
	If favorable		$\gamma_{G.inf} = 0.89 \cdot 1.0 = 0.89$
	Live loads		$\gamma_Q = 1.35 \cdot K_{FI} = 1.22$
Material factors (m1, m2)			$\gamma_{m.ULS} = 1.62$
Conversion factors	Strength	Permanent loads (t,v,k)	$\gamma_{cs.p} = 1.50$
		Live loads (t,v)	$\gamma_{cs.l} = 1.21$

Additional reductionfactor due to the productionproces (ULS)

Topskin	$\gamma_{ts} = 1.18$
Bottomskin	$\gamma_{bs} = 1.12$
Webs	$\gamma_w = 1.47$

Some fibers/layers are locally interrupted in the construction due to the productionproces. These interruptions, which are very locally, are resulting in local weaker spots in the construction. The additional reduction factors are taken into account for the ULS (strength) to compensate the interruption of the fibers. These interruptions have no significant influence on the stiffness of the bridge. Therefore they are not taken into account in the SLS.

6 Thermal behaviour of the bridge

Due to changes in temperature the bridge deck will contract/expand in longitudinal en transverse direction. The temperature componentsare derived from the EN 1991-1-5+C1:2011. This design is more of type 1 than any of the other types.

Design temperature	$T_0 = 10 \cdot °C$
Minimal temperature in the shadow	$T_{min} = -18\ °C$
Maximum temperature in the shadow	$T_{max} = 34\ °C$
Temperature difference between shadow - bridge	$\Delta T_{e.min} = -3 \cdot \Delta °C$
	$\Delta T_{e.max} = 16 \cdot \Delta °C$
Temperature difference component	$\Delta T_{Mheat} = 30 \cdot \Delta °C$
	$\Delta T_{Mcool} = 8 \cdot \Delta °C$
Additional temperature difference for expansion joints	$\Delta T_{dil} = 20 \cdot \Delta °C$
Combination factors	$\omega_N = 0.35$
	$\omega_M = 0.75$
Uniform temperature component bridge	$T_{e.min} = T_{min} + \Delta T_{e.min} = -21 \cdot °C$
	$T_{e.max} = T_{max} + \Delta T_{e.max} = 50 \cdot °C$
	$\Delta T_N = T_{e.max} - T_{e.min} = 71 \cdot \Delta °C$
Maximum temperature change contraction	$\Delta T_{N.con} = T_0 - T_{e.min} = 31 \cdot \Delta °C$
Maximum temperature change expansion	$\Delta T_{N.exp} = T_{e.max} - T_0 = 40 \cdot \Delta °C$

Normative temperature combination for the bridge and expansion joints

$$\Delta T_{exp} = \max\left(\Delta T_{Mheat} + \omega_N \cdot \Delta T_{N.exp}, \omega_M \cdot \Delta T_{Mheat} + \Delta T_{N.exp}\right) = 63 \cdot \Delta °C$$
$$\Delta T_{con} = \max\left(\Delta T_{Mcool} + \omega_N \cdot \Delta T_{N.con}, \omega_M \cdot \Delta T_{Mcool} + \Delta T_{N.con}\right) = 37 \cdot \Delta °C$$
$$\Delta T_{d.e} = \max\left[\Delta T_{Mheat} + \omega_N \cdot \left(\Delta T_{N.exp} + \Delta T_{dil}\right), \omega_M \cdot \Delta T_{Mheat} + \left(\Delta T_{N.exp} + \Delta T_{dil}\right)\right] = 83 \cdot \Delta °C$$
$$\Delta T_{d.c} = \max\left[\Delta T_{Mcool} + \omega_N \cdot \left(\Delta T_{N.con} + \Delta T_{dil}\right), \omega_M \cdot \Delta T_{Mcool} + \left(\Delta T_{N.con} + \Delta T_{dil}\right)\right] = 57 \cdot \Delta °C$$

Maximum expansion/contraction due to the normative temperature components

Bridge	Total expansion joints
$\Delta L_{dek.exp} = \Delta T_{exp} \cdot \alpha_x \cdot L_{rd} = 4.4 \cdot mm$	$\Delta L_{dil.exp} = \Delta T_{d.e} \cdot \alpha_x \cdot L_{rd} = 5.8 \cdot mm$
$\Delta L_{dek.con} = \Delta T_{con} \cdot \alpha_x \cdot L_{rd} = 2.6 \cdot mm$	$\Delta L_{dil.con} = \Delta T_{d.c} \cdot \alpha_x \cdot L_{rd} = 4.0 \cdot mm$
$\Delta B_{dek.exp} = \Delta T_{exp} \cdot \alpha_y \cdot B_{tot} = 1.8 \cdot mm$	$\Delta B_{dil.exp} = \Delta T_{d.e} \cdot \alpha_y \cdot B_{tot} = 2.4 \cdot mm$
$\Delta B_{dek.con} = \Delta T_{con} \cdot \alpha_y \cdot B_{tot} = 1.1 \cdot mm$	$\Delta B_{dil.con} = \Delta T_{d.c} \cdot \alpha_y \cdot B_{tot} = 1.7 \cdot mm$

The fixation of the bridge with one foundation has slotted holes such that the bridge can freely expand/contract. Therefore, there will be no significance thermal stresses in the construction.

7 Check on serviceability, SLS

The following design requirements are applicable to the design in order to ensure that the use of the bridge is comfortable.

- Minimum eigenfrequency of 3.0 Hz when unloaded
- Minimum eigenfrequency of 2.3 Hz when loaded with the dense crowd
- Maximum deflection of $\delta_{all} = \frac{L_o}{100} = 57 \cdot mm$ under live loads
- Maximum gradiant of $\varphi_{max} = 4.0\%$ to ensure easy and good accessibility
- Average gradient of minimal $\varphi_{avg} = 0.5\%$ to ensure good drainage of the bridge

7.1 Eigenfrequency

The bridge is modelled as a simply supported beam. The first eigenfrequency of a simply supported beam is calculated with:

$$f(K, d_{TC}) = \frac{K}{2\pi} \cdot \sqrt{\frac{EI_{yy} \cdot g \cdot \gamma_{m.SLS}^{-1}}{\left(\gamma_{cv.p} \cdot q_m \cdot B_{tot} + \gamma_{cv.l} \cdot d_{TC} \cdot B_{eff}\right) \cdot L_o^4}}$$

Where constant $K_{ss.0} = 9.87$ and dependent on the boundary conditions and which eigenfrequency is evaluated. In previous research it is concluded that the calculated eigenfrequency can increased with 18% due to the fact that the support conditions in reality are not fully simply supported. This 18% is determined with a confidence level of 95%.

First eigenfrequency, unloaded bridge $f_{0.unloaded} = f\left(1.18 \cdot K_{ss.0}, 0\right) = 7.3 \cdot Hz$

First eigenfrequency, loaded bridge $f_{0.loaded} = f\left(1.18 \cdot K_{ss.0}, d_{TC}\right) = 6.6 \cdot Hz$

The eigenfrequencies are high enhough to avoid uncomfortable accelerations.

7.2 Deformations

The deformations due to the live loads are calculated with the beam theory.

Deformation load combination 1, uniform distributed load

$$\delta_{LC1} = \frac{5}{384} \cdot \frac{q_{fk} \cdot B_{eff} \cdot L_o^4}{EI_{yy}} + \frac{1}{8} \cdot \frac{q_{fk} \cdot B_{eff} \cdot L_o^2}{GA_{xz}} = 20 \cdot mm$$

$$\delta_{LC1.k} = \gamma_f \cdot \gamma_{m.SLS} \cdot \gamma_{cd.l} \cdot \delta_{LC1} = 24 \cdot mm$$

Unity checks $uc_{\delta.LC1} = \frac{\delta_{LC1.k}}{\delta_{all}} = 0.42$

7.3 Camber & Gradient

The bridge is produced with a constant radius. The camber maximum and average gradient during production, begin design life (self weight taken into account) and end design life (creep and material degradation taken into account) are:

$Bulge_p = 39 \cdot mm$	$Bulge_i = 32 \cdot mm$	$Bulge_e = 28 \cdot mm$
$\varphi_{max.p} = 2.5 \cdot \%$	$\varphi_{max.i} = 2.1 \cdot \%$	$\varphi_{max.e} = 1.8 \cdot \%$
$\varphi_{avg.p} = 1.3 \cdot \%$	$\varphi_{avg.i} = 1.1 \cdot \%$	$\varphi_{avg.e} = 0.9 \cdot \%$

The maximum and average gradient are satisfying the requirements for the accessibility and drainage of the bridge.

8 Check on safety (ULS)

The laminates of the skins, webs and flanges are checked on their strengths for the most critical load combinations. the fixation of the railings and of the bridge to the foundations are also checked on their strength.

8.1 Strength of the skins

The strength of the skins is checked for load combination 1.

Maximum bending moments

Self weight $M_m = \frac{1}{8} \cdot q_m \cdot B_{tot} \cdot L_o^2 = 8 \cdot kN \cdot m$

Uniform distributed load $M_q = \frac{1}{8} \cdot q_{fk} \cdot B_{tot} \cdot L_o^2 = 30 \cdot kN \cdot m$

Per load combination $M_{LC1} = \gamma_{m.UGT} \cdot \left(\gamma_G \cdot \gamma_{cs.p} \cdot M_m + \gamma_Q \cdot \gamma_{cs.l} \cdot M_q\right) = 93 \cdot kN \cdot m$

Stress in the skins

Distance of topskin to neutralline $z_{ts} = 61 \cdot mm$

Distance of bottomskin to neutralline $z_{bs} = -79 \cdot mm$

Second moment of inertia of the skins $I_h = 1.1 \times 10^8 \cdot mm^4$

Stress in topskin $\sigma_{ts.x.M} = \frac{\gamma_{ts} \cdot M_{LC1} \cdot z_{ts}}{I_h} = 61 \cdot MPa$

Stress in bottomskin $\sigma_{bs.x.M} = \frac{\gamma_{bs} \cdot M_{LC1} \cdot z_{bs}}{I_h} = -76 \cdot MPa$

Allowable stress in the skins

Topskin $\sigma_{x.ts} = 386 \cdot MPa$

Bottomskin $\sigma_{x.bs} = 413 \cdot MPa$

Unity checks $uc_{ts.\sigma} = \frac{\left|\sigma_{ts.x.M}\right|}{\sigma_{x.ts}} = 0.16$ $uc_{bs.\sigma} = \frac{\left|\sigma_{bs.x.M}\right|}{\sigma_{x.bs}} = 0.18$

8.2 Strength of the webs

The stength of the webs is checked on shear for load combination 1 and 3 and on compression for load combination 3.

All the webs are considered to be the thin web of a I-beam with thick flanges. The shear stress is calculated with $\tau = \frac{V}{A}$ ■

where A is the cross-sectional area of the web. The height of the webs are taken as the distance between the two centroids of the top and bottomskins. the center-to-center distance of the webs is $c\_c_w = 210 \cdot mm$

Maximum shearforce one one web

Self weight $V_m = \frac{1}{2} q_m \cdot c\_c_w \cdot L_o = 0.8 \cdot kN$

Uniform distributed load $V_q = \frac{1}{2} q_{fk} \cdot c\_c_w \cdot L_o = 3.0 \cdot kN$

Concentrated load $V_{fwk} = Q_{fwk} = 10.0 \cdot kN$

Per load combination

$V_{LC1} = \gamma_w \cdot \gamma_{m.UGT} \cdot \left(\gamma_G \cdot \gamma_{cs.p} \cdot V_m + \gamma_Q \cdot \gamma_{cs.l} \cdot V_q\right) = 14 \cdot kN$

$V_{LC3} = \gamma_w \cdot \gamma_{m.UGT} \cdot \left(\gamma_G \cdot \gamma_{cs.p} \cdot V_m + \gamma_Q \cdot \gamma_{cs.l} \cdot V_{fwk}\right) = 38 \cdot kN$

Shearstress in web

Cross-section area of one web $A_w = t_w \cdot \left(H_b - \frac{t_{ts} + t_{bs}}{2} \right) = 644 \cdot mm^2$

Shear stress $\tau_{w.xy.V} = \max\left(V_{LC1}, V_{LC3}\right) \cdot A_w^{-1} = 59 \cdot MPa$

Allowable shear stress $\tau_{xy.w} = 64 \cdot MPa$

Unity check $uc_{w.\tau} = \frac{\tau_{w.xy.V}}{\tau_{xy.w}} = 0.93$

The maximum compression stress in one web occurs when the concentrated load is placed directly above the web and is calculted with $\sigma = \frac{P}{A}$.

The maximum compresion force on one web (load and material factors included):

$$P_{LC3} = \gamma_{m.ULS} \cdot \left(\gamma_{cs.p} \cdot \gamma_G \cdot q_m \cdot c\_c_w \cdot B_{fwk} + \gamma_{cs.l} \cdot \gamma_Q \cdot Q_{fwk}\right) = 24 \cdot kN$$

The maximum compression stress in one web: $\sigma_{w.max} = \frac{P_{LC3}}{B_{fwk} \cdot t_w} = 47 \cdot MPa$

Design strength of the web $\sigma_{y.w} = 143 \cdot MPa$

Unity check $uc_{w.\sigma} = \frac{\sigma_{w.max}}{\sigma_{y.w}} = 0.33$

8.3 Strength of the fixation of the railing

It is assumed that the railings are fixed to the flange with 2 pairs of bolts. The strength of the bolts is checked on the situation that the railing is loaded with the line load on the top rail.

Heigth of the railing		$H_{rail} = 1.2m$
Spacing stanchion		$s_{stan} = 1.5m$
Diameter bolt, metric		$d_{b.l} = 12 \cdot mm$
class of the bolt		$klasse_{b.l} = 8.8$
c-c distance bolts	x direction	$c\_c_{x.b} = 120 \cdot mm$
	y direction	$c\_c_{y.b} = 80 \cdot mm$
Edge distance bolt - baseplate	x direction	$e_{x.base} = 30 \cdot mm$
	y direction	$e_{y.base} = 30 \cdot mm$
Edge distance bolt - edge laminate		$e_{y.b} = 50 \cdot mm$

Load on one bolt

Tensile $$F_{t.b} = \frac{\gamma_{Q1} \cdot q_{lk} \cdot s_{stan} \cdot H_{rail}}{2 \cdot \left(\frac{e_{y.base}^2}{e_{y.base} + c\_c_{y.b}} + e_{y.base} + c\_c_{y.b} \right)} = 9 \cdot kN$$

Shear $$F_{v.b} = \frac{1}{4}\left(\gamma_{Q1} \cdot q_{lk} \cdot s_{stan}\right) = 0.5 \cdot kN$$

Allowable load on one bolt

Tensile $F_{t.b.alw} = 49 \cdot kN$

Shear $F_{v.b.alw} = 27 \cdot kN$

Unity check $uc_{b.l} = \left(\frac{F_{t.b}}{F_{t.b.alw}} \quad \frac{F_{v.b}}{F_{v.b.alw}} \quad \frac{F_{v.b}}{F_{v.b.alw}} + \frac{F_{t.b}}{1.4F_{t.b.alw}} \right) = (0.19 \quad 0.02 \quad 0.15)$

8.4 Strength of the flanges

The strength of the flanges is checked around the connections of the stanchions.

Diameter hole $d_{g.l} = 14 \cdot mm$

Diameter washer $d_{r.l} = 40 \cdot mm$

Laminate around the holes for the bolts

Allowable stress in y direction $\sigma_{y.f.alw} = \frac{\sigma_{y.f}}{\gamma_{m.ULS} \cdot \gamma_{cs.l}} = 156 \cdot MPa$

Allowable shearstress in xy plane $\tau_{xy.f.alw} = \frac{\tau_{xy.f}}{\gamma_{m.ULS} \cdot \gamma_{cs.l}} = 50 \cdot MPa$

Allowable shearstress in yz plane $\tau_{yz.f.alw} = \frac{\tau_{yz.f}}{\gamma_{m.ULS} \cdot \gamma_{cs.l}} = 20 \cdot MPa$

Compressive stresses

Stress concentration factor $K_c = \left(\frac{d_{g.l}}{d_{b.l}} \right)^2 = 1.36$

Compressive stress $\sigma_{f.b.y.c} = \frac{F_{v.b} \cdot K_c}{d_{g.l} \cdot t_f} = 2.2 \cdot MPa$

Unity check $uc_{f.b.\sigma yc} = \frac{\sigma_{f.b.y.c}}{\sigma_{y.f.alw}} = 0.01$

Tensile stresses

The tensile stresses around the holes are calculated according to the theory published in "Peterson's stress concentration factors" author Walter D. Pilkey and Deborah F. Pilkey, 2008. The graph used to determine the stress concentration factor is republished in the figure below

Ratio diameter hole - c_c distance holes $r_{g.b.l} = \frac{d_{g.l}}{c\_c_{x.b}} = 0.12$

Stress concentration factor $K_t = 8$

Tensile stress $\sigma_{f.b.y.t} = \frac{K_t \cdot F_{v.b}}{\left(c\_c_{x.b} - d_{g.l}\right) \cdot t_f} = 1.7 \cdot MPa$

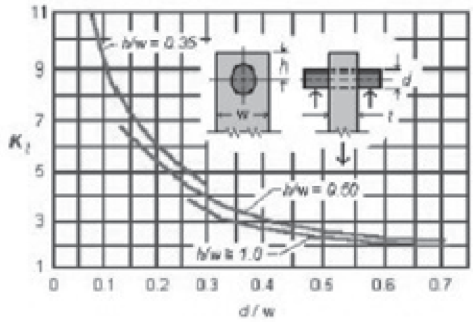
Unity check $uc_{f.b.\sigma yt} = \frac{\sigma_{f.b.y.t}}{\sigma_{y.f.alw}} = 0.01$

Shear stress

Shear stress due to shear out $\tau_{f.b.xy.s} = \dfrac{F_{v.b}}{2 \cdot e_{y.b} \cdot t_f} = 0.2 \cdot MPa$

Shear stress due to pull-through $\tau_{f.b.yz.p} = \dfrac{F_{t.b}}{\pi \cdot d_{r.l} \cdot t_f} = 3.6 \cdot MPa$

Unity check $uc_{f.b.\tau yz} = \left(\dfrac{\tau_{f.b.xy.s}}{\tau_{xy.f.alw}} \quad \dfrac{\tau_{f.b.yz.p}}{\tau_{yz.f.alw}} \right) = (0.00 \quad 0.18)$



8.5 Strength of the fixation of the bridge

The bridge is fixed to the two abutments with threaded rods. These rods are fitted through the holes in the support flanges which are attached to the bottomside of the bridge. In one of the flanges, the holes are slotted such that the thermal expansion or contraction of the bridge doesn't lead to thermal stresses. One function of these rods is to transfer the horizontal force to the abutments.

The threaded rods

Total number of rods $n_d = 4$

Number of load bearing rods in x direction $n_{d.x} = 2$

Number of load bearing rods in y direction $n_{d.y} = 4$

Diameter rods, metric $d_d = 24 \cdot mm$

Diameter washer $d_{d.r} = 72mm$

Material class $klasse_d = 8.8$

Diameter hole $d_{g.d} = 32 \cdot mm$

Edge laminate - hole distance $e_{x.d} = 100 \cdot mm$

Load per rod

Shear in x direction $F_{v.x.LC1} = \dfrac{\gamma_Q \cdot Q_{flk.q}}{n_{d.x}} = 2 \cdot kN$

Shear in y direction $F_{v.y.LC1} = \dfrac{\gamma_Q \cdot Q_{flk.q}}{n_{d.y}} = 1 \cdot kN$

Allowable shear force on one rod $F_{v.d.alw} = 112 \cdot kN$

Unity check $uc_d = \left(\dfrac{F_{v.x.LC1}}{F_{v.d.alw}} \quad \dfrac{F_{v.y.LC1}}{F_{v.d.alw}} \right) = (0.02 \quad 0.01)$

8.6 Strength of the support flanges

The laminate around the holes for the rods is checked on strenght.

Allowable stress in x direction $\sigma_{x.sf.alw} = \dfrac{\sigma_{x.sf}}{\gamma_{m.ULS} \cdot \gamma_{cs.l}} = 156 \cdot MPa$

Allowable stress in y direction $\sigma_{y.sf.alw} = \dfrac{\sigma_{y.sf}}{\gamma_{m.ULS} \cdot \gamma_{cs.l}} = 156 \cdot MPa$

Allowable shear stress in xy direction $\tau_{xy.sf.alw} = \dfrac{\tau_{xy.sf}}{\gamma_{m.ULS} \cdot \gamma_{cs.l}} = 50 \cdot MPa$

Compressive stress

Stress concentration factor $K_c = \left(\dfrac{d_{g.d}}{d_d}\right)^2 = 1.78$

Compressive stress in x direction $\sigma_{sf.x.c} = \dfrac{F_{v.x.LC1} \cdot K_c}{d_{g.d} \cdot t_{sf}} = 12 \cdot MPa$

Compressive stress in y direction $\sigma_{sf.y.c} = \dfrac{F_{v.y.LC1} \cdot K_c}{d_{g.d} \cdot t_{sf}} = 6 \cdot MPa$

Unity check $uc_{sf.\sigma c} = \left(\dfrac{\sigma_{sf.x.c}}{\sigma_{x.sf.alw}} \quad \dfrac{\sigma_{sf.y.c}}{\sigma_{y.sf.alw}}\right) = (0.08 \quad 0.04)$

Tensile stress

The loaded width is limited due to the limited edge laminate - hole distance.

Loaded width $B_{eff.d} = d_{g.d} + 2e_{x.d} = 232 \cdot mm$

Ratio hole diameter - loaded width $r_{g.b.d} = \dfrac{d_{g.d}}{B_{eff.d}} = 0.14$

Stress concentration factor $K_t = 7$

Tensile stress in x direction $\sigma_{sf.x.t} = \dfrac{K_t \cdot F_{v.x.LC1}}{(B_{eff.d} - d_{g.d}) \cdot t_{sf}} = 8 \cdot MPa$

Tensile stress in y direction $\sigma_{sf.y.t} = \dfrac{K_t \cdot F_{v.y.LC1}}{(B_{eff.d} - d_{g.d}) \cdot t_{sf}} = 4 \cdot MPa$

Unity check $uc_{sf.\sigma t} = \left(\dfrac{\sigma_{sf.x.t}}{\sigma_{x.sf.alw}} \quad \dfrac{\sigma_{sf.y.t}}{\sigma_{y.sf.alw}}\right) = (0.05 \quad 0.02)$

Shear stress

Shear stress due to shear out $\tau_{sf.xy.s} = \dfrac{\max(F_{v.x.LC1}, F_{v.y.LC1})}{2 \cdot e_{x.d} \cdot t_{sf}} = 1 \cdot MPa$

Unity check $uc_{sf.\tau} = \dfrac{\tau_{sf.xy.s}}{\tau_{xy.sf.alw}} = 0.02$

Check on buoyancy

The buoyancy will be determined by calculating the buoyancy force using Archimede's principle.

The volume of water displaced by the bridge $V_{tot} = 1.00 \cdot m^3$

Density of fresh water $\rho_{fresh.water} = 1000 \frac{kg}{m^3}$

Buoyancy force $F_b = V_{tot} \cdot \rho_{fresh.water} \cdot g = 9.76 \cdot kN$

Weight of the bridge $W_b = M_{tot} \cdot g = 12.07 \cdot kN$

The bridge is heavier than an equal volume of water and therefore will not float.

9 Actions on the abutments

The actions on the abutments due to the permanent and live loads on the bridge are:

In vertical direction per abutment over the full width of the bridge

Permanent loads	$F_{v.p} = \gamma_G \cdot 0.5M_{tot} \cdot g = 7 \cdot kN$
Live loads	$F_{v.l} = \frac{1}{2} \cdot \gamma_Q \cdot q_{fk} \cdot B_{eff} \cdot L_o = 21 \cdot kN$
Total	$F_{v.abutment} = F_{v.p} + F_{v.l} = 27 \cdot kN$

In longitudinal direction at the abutments

$$F_{h.x.abutment.1} = \gamma_Q \cdot Q_{flk.q} = 4 \cdot kN$$

$$F_{h.x.abutment.2} = 0 \cdot kN$$

In lateral direction per abutment

$$F_{h.y.abutment} = \frac{1}{2} \cdot \gamma_Q \cdot Q_{flk.q} = 2 \cdot kN$$

10 Conclusion

SLS results

First eigenfrequency	Unloaded	$f_{0.unloaded} = 7.3 \cdot Hz$	≥ 3.0 Hz
	Loaded	$f_{0.loaded} = 6.6 \cdot Hz$	≥ 2.3 Hz
Deformations	LC1	$uc_{\delta.LC1} = 0.42$	≤ 1.00
Maximum gradient		$\varphi_{max.i} = 2.1 \cdot \%$	$\leq \varphi_{max} = 4.0 \cdot \%$
Average gradient		$\varphi_{avg.e} = 0.9 \cdot \%$	$\geq \varphi_{avg} = 0.5 \cdot \%$

ULS results

Topskin	Moment	$uc_{ts.\sigma} = 0.16$	≤ 1.00
Bottomskin	Moment	$uc_{bs.\sigma} = 0.18$	≤ 1.00
Webs	Shear	$uc_{w.\tau} = 0.93$	≤ 1.00
	Compression	$uc_{w.\sigma} = 0.33$	≤ 1.00
Bolts of the railing		$uc_{b.l} = \begin{pmatrix} 0.19 & 0.02 & 0.15 \end{pmatrix}$	≤ 1.00
Flange	Compression around holes	$uc_{f.b.\sigma yc} = 0.01$	≤ 1.00
	Tension around holes	$uc_{f.b.\sigma yt} = 0.01$	≤ 1.00
	Shear around holes	$uc_{f.b.\tau yz} = \begin{pmatrix} 0.00 & 0.18 \end{pmatrix}$	≤ 1.00
Threaded Rods		$uc_{d} = \begin{pmatrix} 0.02 & 0.01 \end{pmatrix}$	≤ 1.00
Support flange	Compression around holes	$uc_{sf.\sigma c} = \begin{pmatrix} 0.08 & 0.04 \end{pmatrix}$	≤ 1.00
	Tension around holes	$uc_{sf.\sigma t} = \begin{pmatrix} 0.05 & 0.02 \end{pmatrix}$	≤ 1.00
	Shear around holes	$uc_{sf.\tau} = 0.02$	≤ 1.00

The bridge is checked on bouyance and is heavy enough to counter the uplift force due to bouyancy.

Total thermal expansion/contraction of the bridge

Length direction	Expansion	$\Delta L_{dek.exp} = 4.4 \cdot mm$
	Contraction	$\Delta L_{dek.con} = 2.6 \cdot mm$
Width direction	Expansion	$\Delta B_{dek.exp} = 1.8 \cdot mm$
	Contraction	$\Delta B_{dek.con} = 1.1 \cdot mm$

Total thermal expansion/contraction for the dilatations

Length direction	Expansion	$\Delta L_{dil.exp} = 5.8 \cdot mm$
	Contraction	$\Delta L_{dil.con} = 4.0 \cdot mm$
Width direction	Expansion	$\Delta B_{dil.exp} = 2.4 \cdot mm$
	Contraction	$\Delta B_{dil.con} = 1.7 \cdot mm$

Engineering Case Study

Ordnance Bridge United Kingdom

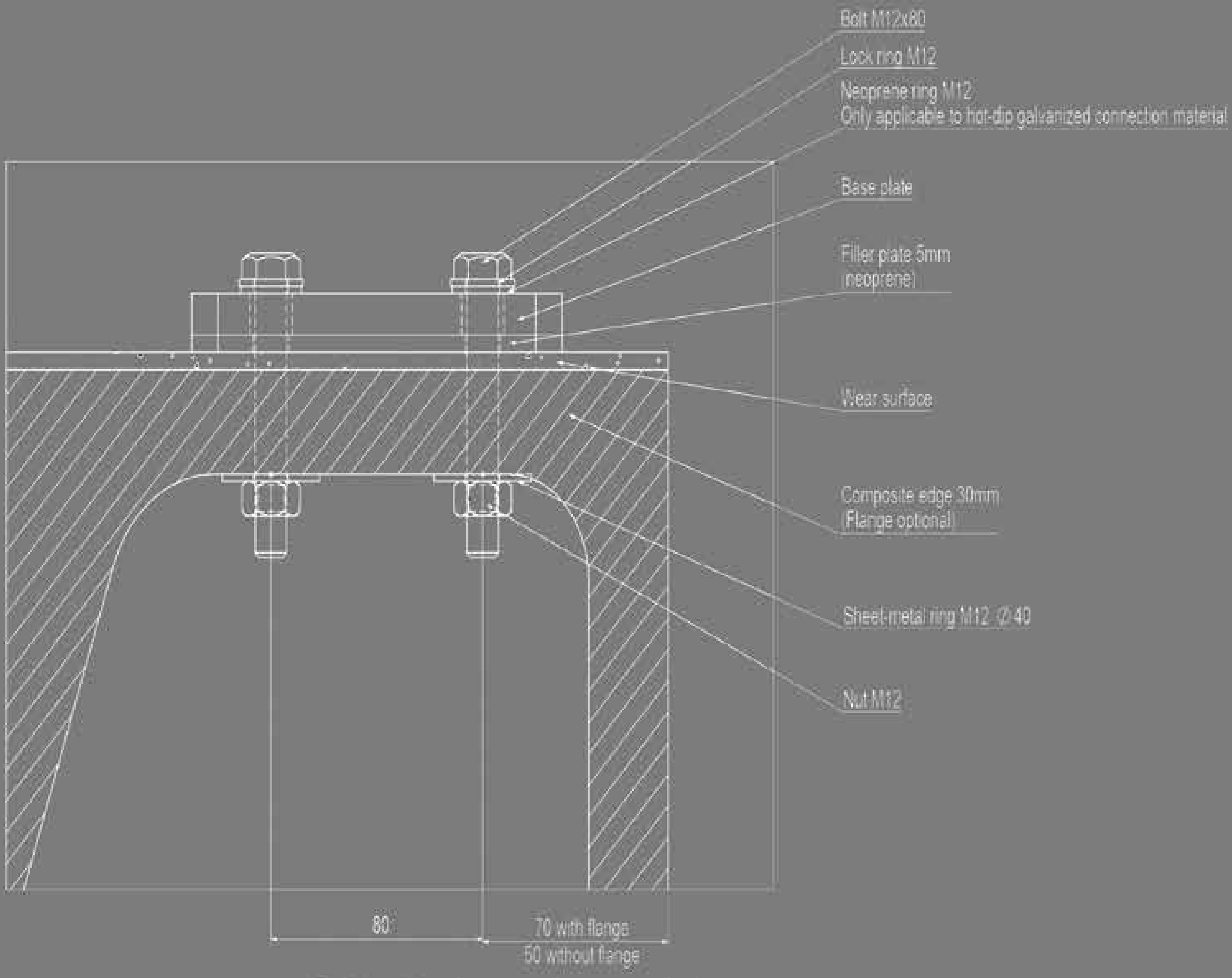


Table of content

Corresponding drawings
- 17-294-OR-010-TKK-1-Deck_R1.0

Rev.	**Status**	**Date**	**Author**	**Track changes**
1.0	Final	10-1-2018	FZ	Initial version

1. Introduction

This report describes the construction of the new InfraCore Inside pedestrian bridge The Ordnance bridge near the river Lee in England, designed and built by FiberCore Europe (Rotterdam, The Netherlands) commissioned by ECS Engineering Services.

This bridge has a length of $L_{rd} = 9.00\text{m}$ and a width of $B_{tot} = 1.50\text{m}$.

The InfraCore Inside bridge is an integral structure made from fiber-reinforced polymers (FRP), more specifically glassfibers in combination with a polyester matrix (glassfiber reinforced polyester or GFRP). The glassfibers carry the loads acting on the bridge, the matrix supports the fibers, transfers loads between fibers and gives the bridge its shape.

GFRP has a high specific strength (strength vs specific weight), resulting in relatively lightweight structures (bridges) capable of carrying large loads with high margins of safety.

The bridge has been designed according to Eurocodes, including British national annexes, and CUR-recommendation 96.

FiberCore Europe is responsible for the engineering and manufacturing of the composite bridge.

2. Design principles and geometry of the decks

The InfraCore Inside decks are designed in compliance with the following relevant standards:

- EN 1990+A1+A1/C2:2011, "Eurocode 0: Basis of structural design"
- EN 1991-2+C1:2011, "Eurocode 1: Actions on structures - Part 2: Traffic loads on bridges"
- EN 1991-1-5+C1:2011, "Eurocode 1: Actions on structures - Part 5: General actions - Thermal actions "
- [EUR23984] "Design of Lightweight Foot-Bridges for Human Induced Vibrations"
- [CUR-recommendation 96: 2003]" Fibre reinforced plastics in civil engineering supporting frameworks"

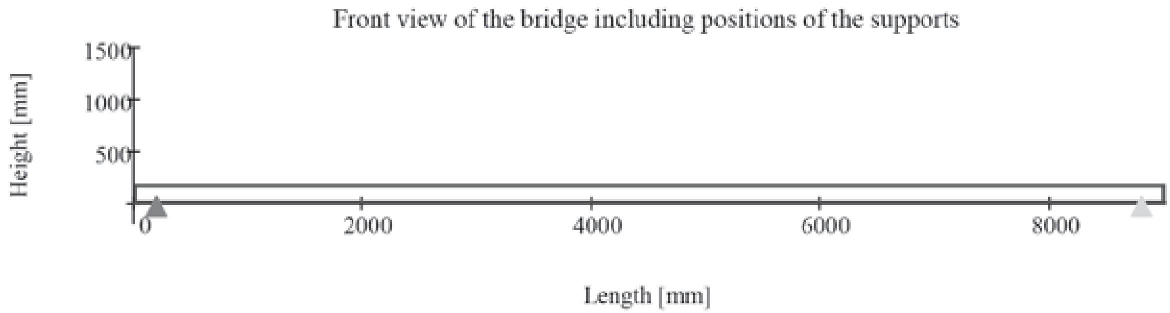
- Technical design life 100yr
- Consequence class CC1
- Traffic class TC3

The main parameters describing the design of the considered deck are given below. For more details on the geometry of the decks, refer to the accompanying drawing.

Total length	$L_{tot} = 9 \cdot m$
Length of deck	$L_{rd} = 9 \cdot m$
Span	$L_o = 8.6 \cdot m$
Width	$B_{tot} = 1.5\ m$
Effective width (between railings)	$B_{eff} = 1.2\ m$
Construction height	$H_b = 170 \cdot mm$
Width flange	$B_{fh} = 200 \cdot mm$
Total surface area	$A_{bridge} = 13.5\ m^2$
Total mass	$M_{tot} = 1.9 \times 10^3 \cdot kg$
Assumed mass of the railing per meter	$M_{L.rail} = 50\ kg \cdot m^{-1}$

The bridge is assumed to be simply supported on the two abutments beneath the two bulkheads. Both abutments are acting as line supports for the bridge were all webs are supported such that the loads are transferred from the webs through the bulkheads into the abutments.

The bridge will be fixed in longitudinal and transverse direction at one abutment. The bridge will be fixed in transverse direction and will be free to move in longitudinal direction and at the second abutment to accommodate the thermal expansion. The fixation is done with threaded rods trough the bottom of the bridge.



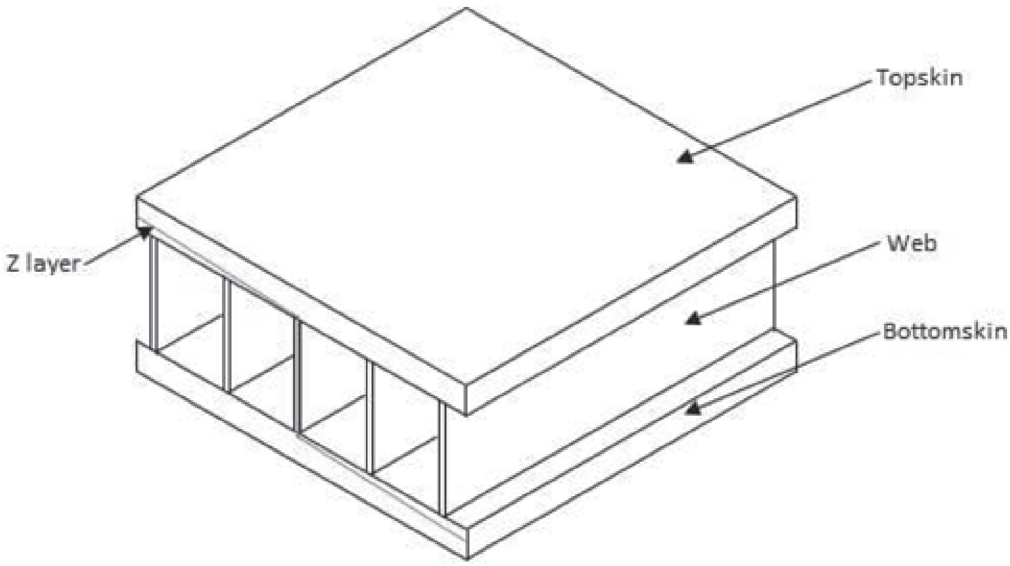
3. Construction principle: InfraCore Inside

The bridge is produced as an InfraCore Inside structure (ICI). An ICI structure can be described as a sandwich structure with two FRP skins at the top and bottom of the bridge, and an FRP-reinforced foam core. The core reinforcement consists of FRP shear webs in longitudinal (flat) direction of the bridge.

Skins and longitudinal shear webs are constructed from the same base materials, in this case non-crimp fabrics, running through the top skin, a shear web and the bottom skin. This ensures a durable, fiber-reinforced connection between skins and shear webs, eliminating the risk of skin-core debonding. Such a layer connecting both skins through the core are called Z-layers, after the shape of each of these layers. To add stiffness or strength, extra material can be added to the skin and/or shear webs.

The stacking sequence of fabrics results in a layered structure (a laminate), each layer called a ply.

All fibers are E-glass fibers, the matrix is a polyester resin.



4 Laminate- & mechanical properties of the cross-section

The applied laminates are anisotropic. The local coördinate systems of each laminate is orientated as follows:

x axis: in-plane, in span direction of the bridge
y axis: in-plane, perpendicular to the span direction of the bridge
z axis: out of plane, perpendicular to the laminate

Multiple different laminates, with each their own properties, are applied in the bridge. The laminate properties are calculated with standard micromechanics models and classical lamination theory as is stated in the CUR96.

The used properties used in the calculations are listed here:

Topskin	$t_{ts} = 12 \cdot mm$	$E_{x.ts} = 32 \cdot GPa$	$E_{y.ts} = 19 \cdot GPa$	
	$\sigma_{x.ts} = 386 \cdot MPa$	$\sigma_{y.ts} = 226 \cdot MPa$	$\tau_{xy.ts} = 98 \cdot MPa$	
Bottomskin	$t_{bs} = 12 \cdot mm$	$E_{x.bs} = 34 \cdot GPa$	$E_{y.bs} = 17 \cdot GPa$	
	$\sigma_{x.bs} = 413 \cdot MPa$	$\sigma_{y.bs} = 199 \cdot MPa$	$\tau_{xy.bs} = 98 \cdot MPa$	
Flange	$t_f = 20 \cdot mm$	$E_{x.f} = 26 \cdot GPa$	$E_{y.f} = 26 \cdot GPa$	$G_{xy.f} = 6 \cdot GPa$
	$\sigma_{x.f} = 306 \cdot MPa$	$\sigma_{y.f} = 306 \cdot MPa$	$\tau_{xy.f} = 98 \cdot MPa$	$\tau_{yz.f} = 39 \cdot MPa$
Edge	$t_e = 13 \cdot mm$	$E_{x.e} = 26 \cdot GPa$	$E_{y.e} = 26 \cdot GPa$	$G_{xy.e} = 6 \cdot GPa$
	$\sigma_{x.e} = 306 \cdot MPa$	$\sigma_{y.e} = 306 \cdot MPa$	$\tau_{xy.e} = 98 \cdot MPa$	
Webs	$t_w = 5 \cdot mm$	$E_{x.w} = 12 \cdot GPa$	$E_{y.w} = 12 \cdot GPa$	$G_{xy.w} = 4 \cdot GPa$
	$\sigma_{x.w} = 143 \cdot MPa$	$\sigma_{y.w} = 143 \cdot MPa$	$\tau_{xy.w} = 64 \cdot MPa$	
Support flange	$t_{sf} = 10 \cdot mm$	$E_{x.sf} = 26 \cdot GPa$	$E_{y.sf} = 26 \cdot GPa$	$G_{xy.sf} = 6 \cdot GPa$
	$\sigma_{x.sf} = 306 \cdot MPa$	$\sigma_{y.sf} = 306 \cdot MPa$	$\tau_{xy.sf} = 98 \cdot MPa$	

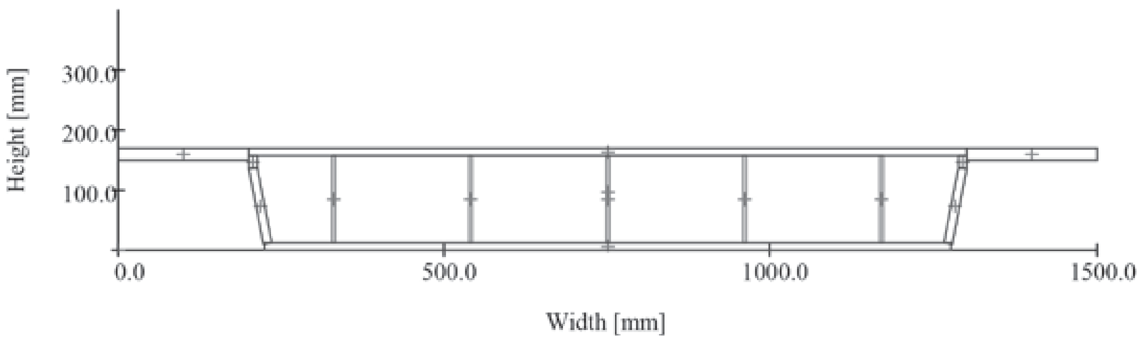
The normal, bending and shear stiffness of the bridge are calculated by the summation of the property of each independent laminate. Only the webs and edges taken into account in the calculation of the shear stiffness.

$$EA_x = 1.2 \times 10^9 \cdot N \qquad EI_{yy} = 7 \cdot MN \cdot m^2 \qquad GA_{xz} = 3.8 \times 10^7 N$$

The thermal behaviour of the bridge is dominated by the skins. The thermal expansioncoëfficiënt of the top and bottomskins can vary a bit from each other due to a small difference in lay-up. The average thermal expansion coëfficiënt of both skins is taken to determine the thermal behaviour of the bridge.

$$\alpha_x = 11.6 \times 10^{-6} \cdot K^{-1} \qquad \alpha_y = 19.5 \times 10^{-6} \cdot K^{-1}$$

Cross-section of the construction



5 Actions, combination of actions & partial factors

5.1 Actions

Permanent loads

The permanent load on the bridge is its self-weight of the structural and non-structural members. The structural member is the InfraCore Inside GFRP bridge deck. The non structural members are the wear surface and railings.

Total self-weight as distributed load $q_m = M_{tot} \cdot g \cdot A_{bridge}^{-1} = 1.3 \cdot kN \cdot m^{-2}$

Live loads

The normative live loads that are taken into account are given below. Live loads, like wind and snow loads, not mentioned are assumed to be not normative and therefore not taken into account in the design. This assumption is based on the combination rules and combination factors listed in EN1990.

Uniform distributed load [EC-1] $q_{fk} = 5 \cdot kN \cdot m^{-2}$

Concentrated load [EC-1]

Load $Q_{fwk} = 10 \cdot kN$

Acting on square surface with sides $B_{fwk} = 0.1 \cdot m$

Horizontal load [EC-1]

Due to uniform distributed load $Q_{flk.q} = 5 \cdot kN$

Dense crowd for dynamic response [EUR23984]

Mass of one person $P_1 = 800\,N$

Density crowd $d_{TC} = 0.5 \cdot P_1 \cdot m^{-2}$

Load on railings [EC-1]

Line load on top of railing $q_{lk} = 1.0 \cdot kN \cdot m^{-1}$

Accidental loads

There are no accidental loads taken into account for this bridge.

5.2 Combination of actions

The combinations of actions on this bridge are based on formula 6.10b EN1990 6.4.3.2 and the tables in EN1990, A2.2.6 and are listed below. The design of the bridge is dominated by its servicebility (stiffness) when loaded with the live loads. All load combinations are used to check the safety (strength) of the bridge.

LC =

"-"	"LC0"	"LC1"	"LC3"
"Load"	"EG"	"gr1"	"Qfwk"
"q.EG"	1	1	1
"q.fk"	0	1	0
"Q.flk.q"	0	1	0
"Q.fwk"	0	0	1

5.3 Partial factors

The used partial factors are given in the Eurocode and CUR-recommendation 96. The consequence class of this bridge is defined as CC1 ($K_{FI} = 0.9$). The CUR defines different conversionfactors to take into account the effect on the materialproperties of different sources. Which conversionfactors are taken into account are depending on the situation and type of load.

Material factors	Scatter in material properties		$\gamma_{m1} = 1.35$
	Production proces		$\gamma_{m2} = 1.20$
Conversion factors	Temperature (t)		$\gamma_{ct} = 1.10$
	Moisture (v)		$\gamma_{cv} = 1.10$
	Fatigue (f)		$\gamma_{cf} = 1.10$
	Creep (k)		$\gamma_{ck} = 1.24$

Factors for the service limit state (SLS)

Load factor			$\gamma_f = 1.00$
Material factor			$\gamma_{m.SLS} = 1.00$
Conversion factors	Vibrations	Permanent loads (t,v,f)	$\gamma_{cv.p} = 1.33$
		Live loads (t,v)	$\gamma_{cv.l} = 1.21$
	Deformations	Permanent loads (t,v,f,k)	$\gamma_{cd.p} = 1.65$
		Live loads (t,v,f)	$\gamma_{cd.l} = 1.21$

Factors for the ultimate limit state (ULS)

Load factors	Permanent loads		$\gamma_G = 0.89 \cdot 1.35 \cdot K_{FI} = 1.08$
	If favorable		$\gamma_{G.inf} = 0.89 \cdot 1.0 = 0.89$
	Live loads		$\gamma_Q = 1.35 \cdot K_{FI} = 1.22$
Material factors (m1, m2)			$\gamma_{m.ULS} = 1.62$
Conversion factors	Strength	Permanent loads (t,v,k)	$\gamma_{cs.p} = 1.50$
		Live loads (t,v)	$\gamma_{cs.l} = 1.21$

Additional reductionfactor due to the productionproces (ULS)

Topskin	$\gamma_{ts} = 1.18$
Bottomskin	$\gamma_{bs} = 1.12$
Webs	$\gamma_w = 1.47$

Some fibers/layers are locally interrupted in the construction due to the productionproces. These interruptions, which are very locally, are resulting in local weaker spots in the construction. The additional reduction factors are taken into account for the ULS (strength) to compensate the interruption of the fibers. These interruptions have no significant influence on the stiffness of the bridge. Therefore they are not taken into account in the SLS.

6 Thermal behaviour of the bridge

Due to changes in temperature the bridge deck will contract/expand in longitudinal en transverse direction. The temperature componentsare derived from the EN 1991-1-5+C1:2011. This design is more of type 1 than any of the other types.

Design temperature	$T_0 = 10 \cdot °C$
Minimal temperature in the shadow	$T_{min} = -18 \ °C$
Maximum temperature in the shadow	$T_{max} = 34 \ °C$
Temperature difference between shadow - bridge	$\Delta T_{e.min} = -3 \cdot \Delta °C$
	$\Delta T_{e.max} = 16 \cdot \Delta °C$
Temperature difference component	$\Delta T_{Mheat} = 30 \cdot \Delta °C$
	$\Delta T_{Mcool} = 8 \cdot \Delta °C$
Additional temperature difference for expansion joints	$\Delta T_{dil} = 20 \cdot \Delta °C$
Combination factors	$\omega_N = 0.35$
	$\omega_M = 0.75$
Uniform temperature component bridge	$T_{e.min} = T_{min} + \Delta T_{e.min} = -21 \cdot °C$
	$T_{e.max} = T_{max} + \Delta T_{e.max} = 50 \cdot °C$
	$\Delta T_N = T_{e.max} - T_{e.min} = 71 \cdot \Delta °C$
Maximum temperature change contraction	$\Delta T_{N.con} = T_0 - T_{e.min} = 31 \cdot \Delta °C$
Maximum temperature change expansion	$\Delta T_{N.exp} = T_{e.max} - T_0 = 40 \cdot \Delta °C$

Normative temperature combination for the bridge and expansion joints

$$\Delta T_{exp} = \max\left(\Delta T_{Mheat} + \omega_N \cdot \Delta T_{N.exp}, \omega_M \cdot \Delta T_{Mheat} + \Delta T_{N.exp}\right) = 63 \cdot \Delta °C$$
$$\Delta T_{con} = \max\left(\Delta T_{Mcool} + \omega_N \cdot \Delta T_{N.con}, \omega_M \cdot \Delta T_{Mcool} + \Delta T_{N.con}\right) = 37 \cdot \Delta °C$$
$$\Delta T_{d.e} = \max\left[\Delta T_{Mheat} + \omega_N \cdot \left(\Delta T_{N.exp} + \Delta T_{dil}\right), \omega_M \cdot \Delta T_{Mheat} + \left(\Delta T_{N.exp} + \Delta T_{dil}\right)\right] = 83 \cdot \Delta °C$$
$$\Delta T_{d.c} = \max\left[\Delta T_{Mcool} + \omega_N \cdot \left(\Delta T_{N.con} + \Delta T_{dil}\right), \omega_M \cdot \Delta T_{Mcool} + \left(\Delta T_{N.con} + \Delta T_{dil}\right)\right] = 57 \cdot \Delta °C$$

Maximum expansion/contraction due to the normative temperature components

Bridge	Total expansion joints
$\Delta L_{dek.exp} = \Delta T_{exp} \cdot \alpha_x \cdot L_{rd} = 6.5 \cdot mm$	$\Delta L_{dil.exp} = \Delta T_{d.e} \cdot \alpha_x \cdot L_{rd} = 8.6 \cdot mm$
$\Delta L_{dek.con} = \Delta T_{con} \cdot \alpha_x \cdot L_{rd} = 3.9 \cdot mm$	$\Delta L_{dil.con} = \Delta T_{d.c} \cdot \alpha_x \cdot L_{rd} = 5.9 \cdot mm$
$\Delta B_{dek.exp} = \Delta T_{exp} \cdot \alpha_y \cdot B_{tot} = 1.8 \cdot mm$	$\Delta B_{dil.exp} = \Delta T_{d.e} \cdot \alpha_y \cdot B_{tot} = 2.4 \cdot mm$
$\Delta B_{dek.con} = \Delta T_{con} \cdot \alpha_y \cdot B_{tot} = 1.1 \cdot mm$	$\Delta B_{dil.con} = \Delta T_{d.c} \cdot \alpha_y \cdot B_{tot} = 1.7 \cdot mm$

The fixation of the bridge with one foundation has slotted holes such that the bridge can freely expand/contract. Therefore, there will be no significance thermal stresses in the construction.

7 Check on serviceability, SLS

The following design requirements are applicable to the design in order to ensure that the use of the bridge is comfortable.

- Minimum eigenfrequency of 3.5 Hz when unloaded
- Minimum eigenfrequency of 2.3 Hz when loaded with the dense crowd
- Maximum deflection of $\delta_{all} = \frac{L_o}{100} = 86 \cdot mm$ under live loads
- Maximum gradiant of $\varphi_{max} = 4.0\%$ to ensure easy and good accessibility
- Average gradient of minimal $\varphi_{avg} = 0.5\%$ to ensure good drainage of the bridge

7.1 Eigenfrequency

The bridge is modelled as a simply supported beam. The first eigenfrequency of a simply supported beam is calculated with:

$$f(K, d_{TC}) = \frac{K}{2\pi} \cdot \sqrt{\frac{EI_{yy} \cdot g \cdot \gamma_{m.SLS}^{-1}}{(\gamma_{cv.p} \cdot q_m \cdot B_{tot} + \gamma_{cv.l} \cdot d_{TC} \cdot B_{eff}) \cdot L_o^4}}$$

Where constant $K_{ss.0} = 9.87$ and dependent on the boundary conditions and which eigenfrequency is evaluated. In previous research it is concluded that the calculated eigenfrequency can increased with 18% due to the fact that the support conditions in reality are not fully simply supported. This 18% is determined with a confidence level of 95%.

First eigenfrequency, unloaded bridge $\quad f_{0.unloaded} = f(1.18 \cdot K_{ss.0}, 0) = 3.9 \cdot Hz$

First eigenfrequency, loaded bridge $\quad f_{0.loaded} = f(1.18 \cdot K_{ss.0}, d_{TC}) = 3.6 \cdot Hz$

The eigenfrequencies are high enhough to avoid uncomfortable accelerations.

7.2 Deformations

The deformations due to the live loads are calculated with the beam theory.

Deformation load combination 1, uniform distributed load

$$\delta_{LC1} = \frac{5}{384} \cdot \frac{q_{fk} \cdot B_{eff} \cdot L_o^4}{EI_{yy}} + \frac{1}{8} \cdot \frac{q_{fk} \cdot B_{eff} \cdot L_o^2}{GA_{xz}} = 65 \cdot mm$$

$$\delta_{LC1.k} = \gamma_f \cdot \gamma_{m.SLS} \cdot \gamma_{cd.l} \cdot \delta_{LC1} = 79 \cdot mm$$

Unity checks $\quad uc_{\delta.LC1} = \frac{\delta_{LC1.k}}{\delta_{all}} = 0.92$

7.3 Camber & Gradient

The bridge is produced with a constant radius. The camber maximum and average gradient during production, begin design life (self weight taken into account) and end design life (creep and material degradation taken into account) are:

$Bulge_p = 84 \cdot mm$	$Bulge_i = 62 \cdot mm$	$Bulge_e = 48 \cdot mm$
$\varphi_{max.p} = 3.8 \cdot \%$	$\varphi_{max.i} = 2.8 \cdot \%$	$\varphi_{max.e} = 2.1 \cdot \%$
$\varphi_{avg.p} = 1.9 \cdot \%$	$\varphi_{avg.i} = 1.4 \cdot \%$	$\varphi_{avg.e} = 1.1 \cdot \%$

The maximum and average gradient are satisfying the requirements for the accessibility and drainage of the bridge.

8 Check on safety (ULS)

The laminates of the skins, webs and flanges are checked on their strengths for the most critical load combinations. the fixation of the railings and of the bridge to the foundations are also checked on their strength.

8.1 Strength of the skins

The strength of the skins is checked for load combination 1.

Maximum bending moments

Selfweight $M_m = \frac{1}{8} \cdot q_m \cdot B_{tot} \cdot L_o^2 = 19 \cdot kN \cdot m$

Uniform distributed load $M_q = \frac{1}{8} \cdot q_{fk} \cdot B_{tot} \cdot L_o^2 = 69 \cdot kN \cdot m$

Per load combination $M_{LC1} = \gamma_{m.UGT} \cdot \left(\gamma_G \cdot \gamma_{cs.p} \cdot M_m + \gamma_Q \cdot \gamma_{cs.l} \cdot M_q\right) = 214 \cdot kN \cdot m$

Stress in the skins

Distance of topskin to neutralline $z_{ts} = 73 \cdot mm$

Distance of bottomskin to neutralline $z_{bs} = -97 \cdot mm$

Second moment of inertia of the skins $I_h = 1.7 \times 10^8 \cdot mm^4$

Stress in topskin $\sigma_{ts.x.M} = \frac{\gamma_{ts} \cdot M_{LC1} \cdot z_{ts}}{I_h} = 111 \cdot MPa$

Stress in bottomskin $\sigma_{bs.x.M} = \frac{\gamma_{bs} \cdot M_{LC1} \cdot z_{bs}}{I_h} = -140 \cdot MPa$

Allowable stress in the skins

Topskin $\sigma_{x.ts} = 386 \cdot MPa$

Bottomskin $\sigma_{x.bs} = 413 \cdot MPa$

Unity checks $uc_{ts.\sigma} = \frac{\left|\sigma_{ts.x.M}\right|}{\sigma_{x.ts}} = 0.29$ $uc_{bs.\sigma} = \frac{\left|\sigma_{bs.x.M}\right|}{\sigma_{x.bs}} = 0.34$

8.2 Strength of the webs

The stength of the webs is checked on shear for load combination 1 and 3 and on compression for load combination 3.

All the webs are considered to be the thin web of a I-beam with thick flanges. The shear stress is calculated with $\tau = \frac{V}{A}$ where A is the cross-sectional area of the web. The height of the webs are taken as the distance between the two centroids of the top and bottomskins. the center-to-center distance of the webs is $c\_c_w = 210 \cdot mm$

Maximum shearforce one one web

Selfweight $V_m = \frac{1}{2} q_m \cdot c\_c_w \cdot L_o = 1.2 \cdot kN$

Uniform distributed load $V_q = \frac{1}{2} q_{fk} \cdot c\_c_w \cdot L_o = 4.5 \cdot kN$

Concentrated load $V_{fwk} = Q_{fwk} = 10.0 \cdot kN$

Per load combination

$V_{LC1} = \gamma_w \cdot \gamma_{m.UGT} \cdot \left(\gamma_G \cdot \gamma_{cs.p} \cdot V_m + \gamma_Q \cdot \gamma_{cs.l} \cdot V_q\right) = 21 \cdot kN$

$V_{LC3} = \gamma_w \cdot \gamma_{m.UGT} \cdot \left(\gamma_G \cdot \gamma_{cs.p} \cdot V_m + \gamma_Q \cdot \gamma_{cs.l} \cdot V_{fwk}\right) = 40 \cdot kN$

Shearstress in web

Cross-section area of one web $A_w = t_w \cdot \left(H_b - \frac{t_{ts} + t_{bs}}{2} \right) = 796 \cdot mm^2$

Shear stress $\tau_{w.xy.V} = \max(V_{LC1}, V_{LC3}) \cdot A_w^{-1} = 50 \cdot MPa$

Allowable shear stress $\tau_{xy.w} = 64 \cdot MPa$

Unity check $uc_{w.\tau} = \frac{\tau_{w.xy.V}}{\tau_{xy.w}} = 0.78$

The maximum compression stress in one web occurs when the concentrated load is placed directly above the web and is calculted with $\sigma = \frac{P}{A}$.

The maximum compresion force on one web (load and material factors included):

$$P_{LC3} = \gamma_{m.ULS} \cdot (\gamma_{cs.p} \cdot \gamma_G \cdot q_m \cdot c\_c_w \cdot B_{fwk} + \gamma_{cs.l} \cdot \gamma_Q \cdot Q_{fwk}) = 24 \cdot kN$$

The maximum compression stress in one web: $\sigma_{w.max} = \frac{P_{LC3}}{B_{fwk} \cdot t_w} = 47 \cdot MPa$

Design strength of the web $\sigma_{y.w} = 143 \cdot MPa$

Unity check $uc_{w.\sigma} = \frac{\sigma_{w.max}}{\sigma_{y.w}} = 0.33$

8.3 Strength of the fixation of the railing

It is assumed that the railings are fixed to the flange with 2 pairs of bolts. The strength of the bolts is checked on the situation that the railing is loaded with the line load on the top rail.

Heigth of the railing		$H_{rail} = 1.2m$
Spacing stanchion		$s_{stan} = 1.5m$
Diameter bolt, metric		$d_{b.l} = 12 \cdot mm$
class of the bolt		$klasse_{b.l} = 8.8$
c-c distance bolts	x direction	$c\_c_{x.b} = 120 \cdot mm$
	y direction	$c\_c_{y.b} = 80 \cdot mm$
Edge distance bolt - baseplate	x direction	$e_{x.base} = 30 \cdot mm$
	y direction	$e_{y.base} = 30 \cdot mm$
Edge distance bolt - edge laminate		$e_{y.b} = 50 \cdot mm$

Load on one bolt

Tensile
$$F_{t.b} = \frac{\gamma_{Q1} \cdot q_{lk} \cdot s_{stan} \cdot H_{rail}}{2 \cdot \left(\frac{e_{y.base}^2}{e_{y.base} + c\_c_{y.b}} + e_{y.base} + c\_c_{y.b} \right)} = 9 \cdot kN$$

Shear
$$F_{v.b} = \frac{1}{4}(\gamma_{Q1} \cdot q_{lk} \cdot s_{stan}) = 0.5 \cdot kN$$

Allowable load on one bolt

Tensile $F_{t.b.alw} = 49 \cdot kN$

Shear $F_{v.b.alw} = 27 \cdot kN$

Unity check $uc_{b.l} = \left(\frac{F_{t.b}}{F_{t.b.alw}} \quad \frac{F_{v.b}}{F_{v.b.alw}} \quad \frac{F_{v.b}}{F_{v.b.alw}} + \frac{F_{t.b}}{1.4F_{t.b.alw}} \right) = (0.19 \quad 0.02 \quad 0.15)$

8.4 Strength of the flanges

The strength of the flanges is checked around the connections of the standhions.

Diameter hole $d_{g.l} = 14 \cdot mm$

Diameter washer $d_{r.l} = 40 \cdot mm$

Laminate around the holes for the bolts

Allowable stress in y direction $\sigma_{y.f.alw} = \frac{\sigma_{y.f}}{\gamma_{m.ULS} \cdot \gamma_{cs.l}} = 156 \cdot MPa$

Allowable shearstress in xy plane $\tau_{xy.f.alw} = \frac{\tau_{xy.f}}{\gamma_{m.ULS} \cdot \gamma_{cs.l}} = 50 \cdot MPa$

Allowable shearstress in yz plane $\tau_{yz.f.alw} = \frac{\tau_{yz.f}}{\gamma_{m.ULS} \cdot \gamma_{cs.l}} = 20 \cdot MPa$

Compressive stresses

Stress concentration factor $K_c = \left(\frac{d_{g.l}}{d_{b.l}} \right)^2 = 1.36$

Compressive stress $\sigma_{f.b.y.c} = \frac{F_{v.b} \cdot K_c}{d_{g.l} \cdot t_f} = 2.2 \cdot MPa$

Unity check $uc_{f.b.\sigma yc} = \frac{\sigma_{f.b.y.c}}{\sigma_{y.f.alw}} = 0.01$

Tensile stresses

The tensile stresses around the holes are calculated according to the theory published in "Peterson's stress concentration factors" author Walter D. Pilkey and Deborah F. Pilkey, 2008. The graph used to determine the stress concentration factor is republished in the figure below

Ratio diameter hole - c_c distance holes $r_{g.b.l} = \frac{d_{g.l}}{c\_c_{x.b}} = 0.12$

Stress concentration factor $K_t = 8$

Tensile stress $\sigma_{f.b.y.t} = \frac{K_t \cdot F_{v.b}}{(c\_c_{x.b} - d_{g.l}) \cdot t_f} = 1.7 \cdot MPa$

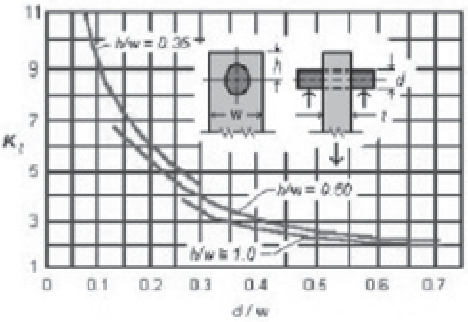
Unity check $uc_{f.b.\sigma yt} = \frac{\sigma_{f.b.y.t}}{\sigma_{y.f.alw}} = 0.01$

Shear stress

Shear stress due to shear out $\tau_{f.b.xy.s} = \frac{F_{v.b}}{2 \cdot e_{y.b} \cdot t_f} = 0.2 \cdot MPa$

Shear stress due to pull-through $\tau_{f.b.yz.p} = \frac{F_{t.b}}{\pi \cdot d_{r.1} \cdot t_f} = 3.6 \cdot MPa$

Unity check $uc_{f.b.\tau yz} = \left(\frac{\tau_{f.b.xy.s}}{\tau_{xy.f.alw}} \quad \frac{\tau_{f.b.yz.p}}{\tau_{yz.f.alw}} \right) = (0.00 \quad 0.18)$



8.5 Strength of the fixation of the bridge

The bridge is fixed to the two abutments with threaded rods. These rods are fitted through the holes in the support flanges which are attached to the bottomside of the bridge. In one of the flanges, the holes are slotted such that the thermal expansion or contraction of the bridge doesn't lead to thermal stresses. One function of these rods is to transfer the horizontal force to the abutments.

The threaded rods

Total number of rods $n_d = 4$

Number of load bearing rods in x direction $n_{d.x} = 2$

Number of load bearing rods in y direction $n_{d.y} = 4$

Diameter rods, metric $d_d = 24 \cdot mm$

Diameter washer $d_{d.r} = 72mm$

Material class $klasse_d = 8.8$

Diameter hole $d_{g.d} = 32 \cdot mm$

Edge laminate - hole distance $e_{x.d} = 100 \cdot mm$

Load per rod

Shear in x direction $F_{v.x.LC1} = \frac{\gamma_Q \cdot Q_{flk.q}}{n_{d.x}} = 3 \cdot kN$

Shear in y direction $F_{v.y.LC1} = \frac{\gamma_Q \cdot Q_{flk.q}}{n_{d.y}} = 2 \cdot kN$

Allowable shear force on one rod $F_{v.d.alw} = 112 \cdot kN$

Unity check $uc_d = \left(\frac{F_{v.x.LC1}}{F_{v.d.alw}} \quad \frac{F_{v.y.LC1}}{F_{v.d.alw}} \right) = (0.03 \quad 0.01)$

8.6 Strength of the support flanges

The laminate around the holes forth e rods is checked on strenght.

Allowable stress in x direction $\sigma_{x.sf.alw} = \frac{\sigma_{x.sf}}{\gamma_{m.ULS} \cdot \gamma_{cs.l}} = 156 \cdot MPa$

Allowable stress in y direction $\sigma_{y.sf.alw} = \frac{\sigma_{y.sf}}{\gamma_{m.ULS} \cdot \gamma_{cs.l}} = 156 \cdot MPa$

Allowable shear stress in xy direction $\tau_{xy.sf.alw} = \frac{\tau_{xy.sf}}{\gamma_{m.ULS} \cdot \gamma_{cs.l}} = 50 \cdot MPa$

Compressive stress

Stress concentration factor $K_c = \left(\frac{d_{g.d}}{d_d}\right)^2 = 1.78$

Compressive stress in x direction $\sigma_{sf.x.c} = \frac{F_{v.x.LC1} \cdot K_c}{d_{g.d} \cdot t_{sf}} = 18 \cdot MPa$

Compressive stress in y direction $\sigma_{sf.y.c} = \frac{F_{v.y.LC1} \cdot K_c}{d_{g.d} \cdot t_{sf}} = 9 \cdot MPa$

Unity check $uc_{sf.\sigma c} = \left(\frac{\sigma_{sf.x.c}}{\sigma_{x.sf.alw}} \quad \frac{\sigma_{sf.y.c}}{\sigma_{y.sf.alw}}\right) = (0.12 \quad 0.06)$

Tensile stress

The loaded width is limited due to the limited edge laminate - hole distance.

Loaded width $B_{eff.d} = d_{g.d} + 2 \cdot e_{x.d} = 232 \cdot mm$

Ratio hole diameter - loaded width $r_{g.b.d} = \frac{d_{g.d}}{B_{eff.d}} = 0.14$

Stress concentration factor $K_t = 6.5$

Tensile stress in x direction $\sigma_{sf.x.t} = \frac{K_t \cdot F_{v.x.LC1}}{(B_{eff.d} - d_{g.d}) \cdot t_{sf}} = 11 \cdot MPa$

Tensile stress in y direction $\sigma_{sf.y.t} = \frac{K_t \cdot F_{v.y.LC1}}{(B_{eff.d} - d_{g.d}) \cdot t_{sf}} = 5 \cdot MPa$

Unity check $uc_{sf.\sigma t} = \left(\frac{\sigma_{sf.x.t}}{\sigma_{x.sf.alw}} \quad \frac{\sigma_{sf.y.t}}{\sigma_{y.sf.alw}}\right) = (0.07 \quad 0.03)$

Shear stress

Shear stress due to shear out $\tau_{sf.xy.s} = \frac{\max(F_{v.x.LC1}, F_{v.y.LC1})}{2 \cdot e_{x.d} \cdot t_{sf}} = 2 \cdot MPa$

Unity check $uc_{sf.\tau} = \frac{\tau_{sf.xy.s}}{\tau_{xy.sf.alw}} = 0.03$

Check on buoyancy

The buoyancy will be determined by calculating the buoyancy force using Archimede's principle.

The volume of water displaced by the bridge $V_{tot} = 1.77 \cdot m^3$

Density of fresh water $\rho_{fresh.water} = 1000 \frac{kg}{m^3}$

Buoyancy force $F_b = V_{tot} \cdot \rho_{fresh.water} \cdot g = 17.31 \cdot kN$

Weight of the bridge $W_b = M_{tot} \cdot g = 18.15 \cdot kN$

Uplift force $F_{uplift} = F_b - W_b = -0.84 \cdot kN$

The weight of the bridge equal to an equal volume of water and therefore the flange and the rods do not have to be checked.

9 Actions on the abutments

The actions on the abutments due to the permanent and live loads on the bridge are:

In vertical direction per abutment over the full width of the bridge

Permanent loads	$F_{v.p} = \gamma_G \cdot 0.5M_{tot} \cdot g = 10 \cdot kN$
Live loads	$F_{v.l} = \frac{1}{2} \cdot \gamma_Q \cdot q_{flk} \cdot B_{eff} \cdot L_o = 31 \cdot kN$
Total	$F_{v.abutment} = F_{v.p} + F_{v.l} = 41 \cdot kN$
Uplift due to buoyancy	$F_{up.abutment} = \frac{F_{uplift}}{2} = -0 \cdot kN$

In longitudinal direction at the abutments

$$F_{h.x.abutment.1} = \gamma_Q \cdot Q_{flk.q} = 7 \cdot kN$$
$$F_{h.x.abutment.2} = 0 \cdot kN$$

In lateral direction per abutment

$$F_{h.y.abutment} = \frac{1}{2} \cdot \gamma_Q \cdot Q_{flk.q} = 3 \cdot kN$$

10 Conclusion

SLS results

First eigenfrequency	Unloaded	$f_{0.unloaded} = 3.9 \cdot Hz$	≥ 3.5 Hz
	Loaded	$f_{0.loaded} = 3.6 \cdot Hz$	≥ 2.3 Hz
Deformations	LC1	$uc_{\delta.LC1} = 0.92$	≤ 1.00
Maximum gradient		$\varphi_{max.i} = 2.8 \cdot \%$	$\leq \varphi_{max} = 4.0 \cdot \%$
Average gradient		$\varphi_{avg.e} = 1.1 \cdot \%$	$\geq \varphi_{avg} = 0.5 \cdot \%$

ULS results

Topskin	Moment	$uc_{ts.\sigma} = 0.29$	≤ 1.00
Bottomskin	Moment	$uc_{bs.\sigma} = 0.34$	≤ 1.00
Webs	Shear	$uc_{w.\tau} = 0.78$	≤ 1.00
	Compression	$uc_{w.\sigma} = 0.33$	≤ 1.00
Bolts of the railing		$uc_{b.l} = (0.19 \quad 0.02 \quad 0.15)$	≤ 1.00
Flange	Compression around holes	$uc_{f.b.\sigma yc} = 0.01$	≤ 1.00
	Tension around holes	$uc_{f.b.\sigma yt} = 0.01$	≤ 1.00
	Shear around holes	$uc_{f.b.\tau yz} = (0.00 \quad 0.18)$	≤ 1.00
Threaded Rods		$uc_{d} = (0.03 \quad 0.01)$	≤ 1.00
Support flange	Compression around holes	$uc_{sf.\sigma c} = (0.12 \quad 0.06)$	≤ 1.00
	Tension around holes	$uc_{sf.\sigma t} = (0.07 \quad 0.03)$	≤ 1.00
	Shear around holes	$uc_{sf.\tau} = 0.03$	≤ 1.00

The bridge is checked on buoyancy and is heavy enough to counter the uplift force due to bouyancy.

Total thermal expansion/contraction of the bridge

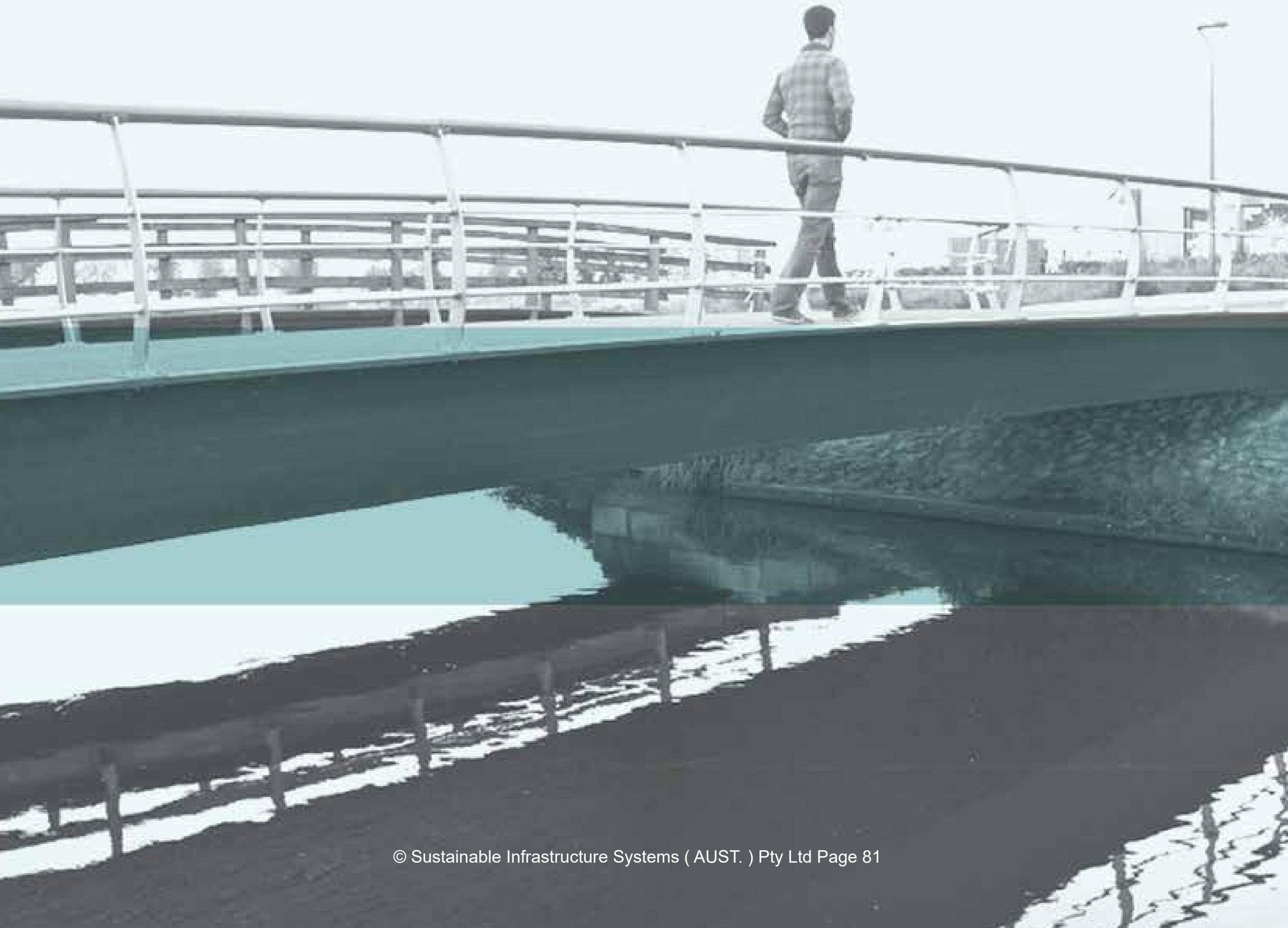
Length direction	Expansion	$\Delta L_{dek.exp} = 6.5 \cdot mm$
	Contraction	$\Delta L_{dek.con} = 3.9 \cdot mm$
Width direction	Expansion	$\Delta B_{dek.exp} = 1.8 \cdot mm$
	Contraction	$\Delta B_{dek.con} = 1.1 \cdot mm$

Total thermal expansion/contraction for the dilatations

Length direction	Expansion	$\Delta L_{dil.exp} = 8.6 \cdot mm$
	Contraction	$\Delta L_{dil.con} = 5.9 \cdot mm$
Width direction	Expansion	$\Delta B_{dil.exp} = 2.4 \cdot mm$
	Contraction	$\Delta B_{dil.con} = 1.7 \cdot mm$

Project Gallery

Cycleway Bridges



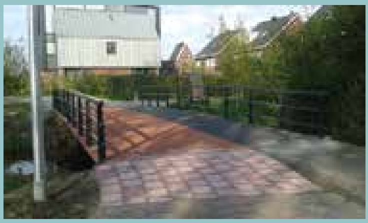
Project Number: 07-001

Location: Dronten, Netherlands
Length: 24m
Width: 5m
Span: 21.5m
Category: 5kN + Service Vehicle
Production Year: 2007

Project Number: 11-007

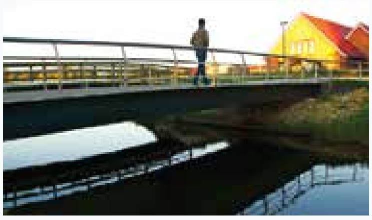
Location: Nagelervaart Netherlands
Length: Both 20m
Width: Bridge 1: 1.5m Bridge 2: 2.25m
Span: Both 20m
Category: 5kN + Service Vehicle
Production Year: 2011

Project Number: 12-061



Location: Aalsmeer, Aletta Jacobs
Netherlands
Length: 11.1m
Width: 4.5m
Span: 11.1m
Category: 5kN + Service Vehicle
Production Year: 2012

Project Number: 11-006

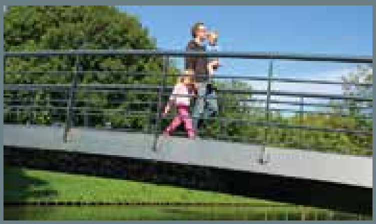


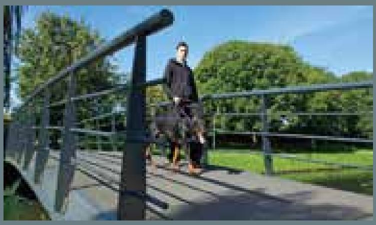
Location: Borne, Netherlands
Length: both 15m
Width: both 4m
Span: both 15m
Category: 5kN + Service Vehicle
Production Year: 2011

Project Number: 11-018

Location: Amersfoort, Netherlands
Length: Both 17.74m
Width: Both 5m
Span: Both 17.74m
Category: 5kN + Service Vehicle
Production Year: 2011

Project Number: 10-026





Location: Potgieterstraat
Rotterdam, Netherlands
Length: 18m
Width: 2.25m
Span: 18m
Category: 5kN/m2
Production Year: 2010

Project number: 11-020

Location: Kamerinkse Wetering, Netherlands
Length: Bridge 1: 13.8m Bridge 2: 14.9m
Width: Both 1.5m
Span: Bridge 1: 13.8m Bridge 2: 14.9m
Category: 5kN/m2
Production Year: 2011

Project Number: 11-019

Location: Sommelsdijk, Netherlands
Length: 31m & 29m
Width: 1.2m & 4m
Span: In Three Parts
Category: 5kN + Service Vehicle
Production Year: 2012

Project Number: 14-109

Location: Gouwebos, Netherlands
Length: 39.1m
Width: 4x 2.45m 1x 4m
Span: 5 Parts
Category: 5kN/m2
Production Year: 2014

Project Number: 13-067

Location: Den Oever, Netherlands
Length: 8.5m
Width: 2.1m
Span: 8.5m
Category: 5kN/m2
Production Year: 2013

Project Number: 14-147

Location: Dongen, Netherlands
Length: 14.5m
Width: 2m
Span: 14.5m
Category: 5kN + Service Vehicle
Production Year: 2014

Project Number: 14-139

Location: Hillegersberg, Netherlands
Length: 18.3m
Width: 6.6m
Span: 18.3m
Category: VK35
Production Year: 2014

Project Number: 15-166

Exercitiesingel placed a bicycle footbridge with InfraCore® Inside. The bridge has a size of 20 meters by 1.9 meters. Yet the bridge is only 250mm thick by clamping it on its abutments and therefore the bridge has a sleek appearance. In addition, there is special aspect to this bridge that the abstract designed handrail is made entirely of fiber-reinforced polymers.

The bicycle pedestrian bridge serves as a transition to the path towards the nearby cemetery, Kralingen-Crooswijk.

Location: Exercitiesingel, Netherlands
Length: 20m
Width: 1.9m
Span: 20m
Category: 5kN/m2
Production Year: 2015

Project Number: 15-167

A bicycle bridge with InfraCore® Inside was installed on 4 November for the municipality of Amersfoort.

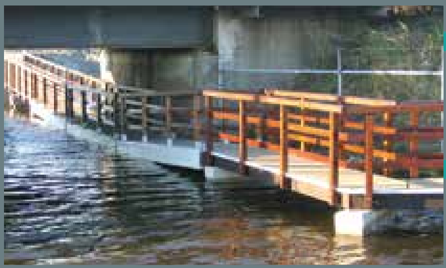
The bridge is 20m long and 4m wide. The bicycle bridge is part of the Laak zone Phase B project and contributes to the expansion of the recreational possibilities and amenities of and along the Laak. FiberCore already provided a bridge for the Laakzone project: a traffic bridge near Bunschoten.

Location Amersfoort, Netherlands
Length: 20m
Width: 4m
Span: 20m
Category: 5kN + Service Vehicle
Production Year: 2015

Project Number: 13-071

Location, Beverwaard, Netherlands
Length: variety of lengths
Width: variety of widths
Span: variety of spans
Category: 33 bridges delivered
Production Year: 2013

Project Number: 11-035



This floating bridge was built with a different technique than Inside, the solution for the limited space under the bridge; Cyclists now have sufficient height.

Location: Uitgeest, Netherlands
Length: 5m
Width: 1.3m
Span: 5m
Category: 5 ton
Production Year: 2004

Project Number: 13-092

Location : Rhenen, Netherlands
Length: 24m
Width: 2m
Span: 24m
Category: Ecoduct
Production Year: 2014

Project Number: 14-146

Location: Malmo, Netherlands
Length: 4.5m
Width: 3.05m
Span: 4.5m
Category: 5kN/m2
Production Year: 2014

Project Number: 10-005

This bicycle footbridge consists of three 12 meter bridge sections.

The contract work of this project was carried out by Haasnoot Bruggen.

Location: Hoveniersberg Roosendaal, Netherlands
Length: 36m
Width: 5m
Span: 3x 12m
Category: 5kN + Service Vehicle
Production Year: 2010

Project Number: 09-010

This bicycle bridge, consisting of two parts. Both parts were injected simultaneously, in 2010 this was a world record resin injection.

Location: Spoorlaan, Den Haag, Netherlands
Length: 26.5m
Width: 10m
Span: 2x 13.25m
Category: 5kN/m2
Production Year: 2009

Project Number: 09-014

Both bridges are very smart even though they have relatively large spans.

The railings for this project are made by contractor, Haasnoot Bruggen.

Location: Purmerend, Netherlands
Length: Both 16m
Width: Bridge 1: 2.5m Bridge 2: 3.75m
Span: Both 16m
Category: 5kN/m2
Production Year: 2009

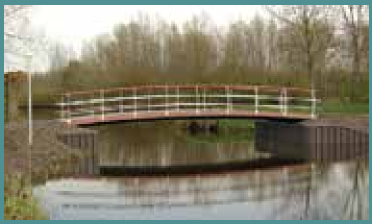
Project Number: 09-015

In collaboration with DSM, FiberCore Europe delivered a bridge to the Chinese province of Nanjing in 2009.

Before it was placed, it was exhibited at the World Expo in Shanghai.

Location: Shanghai, China
Length: 11.5m
Width: 2m
Span: 11.5m
Category: 5kN + Service Vehicle
Production Year: 2009

Project Number: 07-002



Location: Krimpenerwaard, Netherlands
Length: 10m
Width: 2.75m
Span: 10m
Category: 5kN + Service Vehicle
Production Year: 2007

Project Number: 13-088

Location: Kunstwerk, Netherlands
Length: 21.5m
Width: 3.35m
Span: 21.5m
Category: 5kN + Service Vehicle
Production Year: 2013

Project Number: 11-022

Location: Deventer, Netherlands
Length: All 3; 22m
Width: All 3; 2.5m
Span: All 3; 22m
Category: 5kN/m2
Production Year: 2012

Project Number: 13-101

Location: Gouderak, Netherlands
Length: 8.5m
Width: 3m
Span: 8.5m
Category: 5kN + Service Vehicle
Production Year: 2013

Project Number: 13-072

This beautiful bicycle bridge connects two uneven banks with each other, the south bank is higher than the north bank.

Thanks to the double bar, cycling comfort is guaranteed and an aesthetic effect is also created.

Location: Lely Maassluis, Netherlands
Length: 10.2m
Width: 3.5m
Span: 10.2m
Category: 5kN + Service Vehicle
Production Year: 2013

Project Number: 12-049

Location: Rozenburg, Netherlands
Length: 26m
Width: 1.5m
Span: 26m
Category: 5kN/m2
Production Year: 2012

Project Number: 12-060

This project was realised in cooperation with Met Janson Bridging.

Location: De Dors Zaanstad, Netherlands
Length: 9.8m
Width: 2.5m
Span: 9.8m
Category: VK30
Production Year: 2012

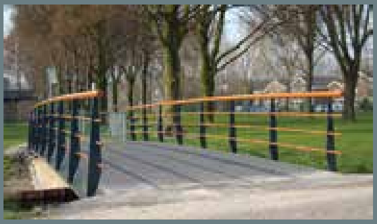
Project Number: 08-021

Location: Hoogvliet, Netherlands
Length: 14m
Width: 2.75m
Span: 14m
Category: 5kN + Service Vehicle
Production Year: 2008/2009

Project Number: 15-184

Location: Alkmaar, Netherlands
Length: 12.5m
Width: 1.52m
Span: 12.5m
Category: 5kN/m2
Production Year: 2015

Project Number: 08-001



Location: IJsselmonde, Netherlands
Length: 9.8m
Width: 2.75m
Span: 9.8m
Category: 5kN + Service Vehicle
Production Year: 2009

Project Number: 11-030 & 14-118

Location: Twickel, Netherlands
Length: Both 11.24m
Width: Both 1.6m
Span: Both 11.24m
Category: 5kN/m2
Production Year: 2014

Project Number: 15-177

Location: Grote & Terwoldse Wetering Heerde, Netherlands
Length: Grote Wetering = 32m
Terwoldse Wetering 12m
Width: Both 2.6m
Span: Grote Wetering = 32m
Terwoldse Wetering 12m
Category: 5kN/m2
Production Year: 2015

Project Number: 10-035

In Belgium, a new InfraCore® Inside bridge was commissioned on 8 November 2010, perhaps at one of the most special places in Flanders; the Fish Market in the historic city of Ghent.

The synthetic bridge forms an important part of the walking route through the old center of Ghent.

This bridge is unique in several respects; on the one hand, it is the first InfraCore® Inside bridge in Belgium, on the other it is also the first InfraCore® Inside bridge that is installed in a completely 17th-century environment. The modern, subdued design of the bridge forms a harmonious unity with the historical environment.

Location: Vismijn Gent, Belgium
Length: 17.5m
Width: 2.5m
Span: 14.5m
Category: 5kN/m2
Production Year: 2010

Project Number: 13-099

Location: Mosselbrug Hellevoetsluis, Netherlands
Length: 13.1m
Width: 1.9m
Span: 13.1m
Category: 5kN + Service Vehicle
Production Year: 2013

Project number: 11-030

Location: De Zuidert, Netherlands
Length: 3 Bridges10.5m 2 Bridges12.5m
Width: All 3.1m
Span: 3 Bridges 10.5m 2 Bridges 12.5m
Category: 5kN/m2
Production Year: 2011

Project Number: 12-062

InfraCore® Inside by FiberCore Europe has landed in Italy, in the Venice-region.The 17.5m long bridge is installed in the Comune S. Stino di Livenza, a country town northeast of Venice.

The bridge will be used by pedestrian and bicycle traffic. It is probably the first all-FRP bridge in Italy.

The project has been a joint operation between FiberCore Europe and Janson Bridging Italia. The client has chosen for InfraCore® Inside because of its short lead time and low-maintenance features.

The bridge being lightweight strongly facilitated transportation and installation.InfraCore® Inside bridges have already been installed in The Netherlands, Belgium, the United Kingdom, China and the United States.

Location: Livenza, Italy
Length: 17.5m
Width: 2.5m
Span: 17.5m
Category: 5kN + Service Vehicle
Production Year: 2013

Project Number: 14-111

Location: Zwanenkade, Netherlands
Length: 11.21m
Width: 3.81m
Span: 11.21m
Category: 5kN + Service Vehicle
Production Year: 2014

Project Number: 16-209

Location: Neerwoldeiland
Eelderwolde, Netherlands
Length: 15m
Width: 2.5m
Span: 15m
Category: 5kN/m2
Production Year: 2016

Project Number: 11-026

Location: Schalwijkerstraat
Haarlem, Netherlands
Length: 13.2m & 15m
Width: 9.5m & 7.4m
Span: 13.2m & 15m
Category: 5kN + Occasional
Vehicle
Production Year: 2012

Project Number: 15-177

Location: Grote & Terwoldse
Wetering Heerde, Netherlands
Length: Grote Wetering = 32m
Terwoldse Wetering 12m
Width: Both 2,6m
Span: Grote Wetering = 32m
Terwoldse Wetering 12m
Category: 5kN/m2
Production Year: 2015

Project number: 15-149

The two bridges have been placed near the N216 for the province of Zuid-Holland, between Schoonhoven and Groot-Ammer.

Both bridges have the same dimensions, and are made with the InfraCore® Inside technology.

Location: Schoonhoven, Netherlands
Length: Both 9m
Width: Both 3.5m
Span: 9m
Category: 5kN + Service Vehicle
Production Year: 2014

Project Number: 13-074

Location: Zaanstad, Netherlands
Length: 35.16m
Width: 4.16m
Span: In 3 Parts, 1x 15.2m 1x 5m & 1x 14.96m
Category: 5kN + Service Vehicle
Production Year: 2013

Project Number: 1997

First FiberCore bridge in history

This was the first bridge in the history of FCE. After realising this bridge, it was proven that with the InfraCore® technique in fact a robust bridge could be built.

The shape and section has changed over the years, the technique inside stayed the same. (see page 10.)

Location: Harlingen, Netherlands
Length: 15m
Width: 2.5m
Span: 15m
Category: 5kN/m2
Production Year: 1997

Project Number: 12-061

Location: Aalsmeer, Netherlands
Length: 14.9m
Width: 4.5m
Span: 14.9m
Category: 5kN + Service Vehicle
Production Year: 2012

Project Number: 12-056

Location, Hoogstraten, Belgium
Length: 10m
Width: 2.25m
Span: 10m
Category: 5kN/m2
Production Year: 2012

Project Number: 11-024

Location: Krampenloop, Netherlands
Length: 14m
Width: 3.2m
Span: 14m
Category: 5kN + Service Vehicle
Production Year: 2011

Project Number: 12-040

Location: Bordeaux, France
Length: 36.05m
Width: 2m
Span: In 2 Parts; 1x 21.1m
1x14.95m
Category: 5kN/m2
Production Year: 2012

Golf Bridges

Project Number: 15-148

Two bridges have been placed near the N216 for the province of Zuid-Holland, between Schoonhoven & Groot-Ammer.

Both bridges have the same dimensions, and are made with the InfraCore®Inside technology.

Location: Dubai Desert Golf Club
Length: 10m
Width: 2.5m
Span: 10m
Category: 5kN + Service Vehicle
Production Year: 2015

Project Number: 11-008

Flanders Nippon Golf & Business Club in Hasselt / BE An impressive golf course in Belgian Limburg. The course created by Baron Rolin winds its fairways through a plain next to the Demer and between challenging ponds. Obstacles go up beautifully in this protected landscape and make the players a technically very correct game.

In the design of the plantations special attention was paid to a harmonious color choice during all seasons. Native trees, shrubs and plants form a home for the local fauna.

The course has also been developed in such a way that it is an interesting challenge for both the experienced and the less experienced golfer.

The Flanders Nippon Golf & Business Club was one of the first courses where a maintenance free InfraCore® Golf Bridge for light traffic was installed.

Location: Flanders Nippon Golf, Belgium
Length: 6m
Width: 3m
Span: 6m
Category: 5kN/m2
Production Year: 2011

Project Number: 11-032

Golf course Delfland in Schipluiden / NL
Delfland is considered by many as the nicest Pay & Play golf course in South Holland! Not for nothing the slogan is: Golf is fun & for everyone! Play inexpensively when and how often you want on our 36 holes course!

Golfbaan Delfland is located on the border of Delft and Schipluiden and is easily accessible on the A4 from both The Hague and Rotterdam in 10 to 15 minutes. In the more than 17 years of existence, the job has grown into one of the most popular and pleasant jobs in South Holland.

For young and old; beginners and advanced players and always accessible to players from other courses. Delfland golf course was the first golf course to opt for maintenance-free InfraCore® wave bridges. Meanwhile, there are already three beautiful bridges in the orbit. The first one since 2011.

Location: Golf Course Delfland, Netherlands
Length: 7.5m
Width: 1.5m
Span: 7.5m
Category: 5kN + Service Vehicle
Production Year: 2011

Project Number: 12-062

Wood Range Golf Club at Simi Valley / USA
Wood Ranch Golf Club is an original design by Ted Robinson. The beautiful course is located in the rolling hills of Venture County, less than an hour northwest of Los Angeles.

After examining the many options available, it became clear that the InfraCore® Wave Bridges offered us the best solution on all fronts; In addition to the sleek design and durability of this product, this company offered a very edge-oriented approach throughout the process, “said David Coote, Wood Estate Golf Club inspector. “In view of the trend of the golf industry with regard to choosing environmentally friendly products, InfraCore® came first.”

Location: Wood Ranch Golf Club,USA
Length: -
Width: -
Span: -
Category: -
Production Year: -

Project Number: 11-032

The Dutch in Lingewaal / NL.
This special Inland Links Golf course at International Championship level and designed by the famous Scottish golfer and top designer Colin Montgomerie.

The course has been constructed according to the highest European standards and is therefore the leader in terms of quality, durability and playability in the Netherlands.

Challenging for golf professionals, but also playable for the average golfer.

This 18-hole golf course is integrated in the rural area of Spijk (municipality Lingewaal). The Dutch decided to start with three ultra-slim InfraCore® Wave Bridges. The Dutch annually organizes the prestigious KLM Open, which was won in 2016 by Joost Luiten.

Location: Lingewaal, Netherlands
Length: 9.6m
Width: 1.9m
Span: 9.6m
Category: 5kN + Service Vehicle
Production Year: 2011

Project Number: 15-163

Location: Orlando, USA
Length: 8.9m
Width: 2m
Span: 8.9m
Category: 5kN + Service Vehicle
Production Year: 2015

Albert Palmer's Bay Hill Club and Lodge in Orlando / USA

This is one of the best places in the world to stay. It was only in 1960 that the barren soil was turned into a landscape that would become known 50 years later as one of the most beautiful golf courses in the world.

Bay Hill organizes every year the Arnold Palmer Invitational presented by MasterCard. The most important golfers in the world play at this prestigious PGA tournament. "It gave me peace of mind when I heard that these bridges do not need maintenance for decades. This allows me to focus on more important issues such as course management and presentation" said Matt Beaver, superintendent at Bay Hill.

"We chose InfraCore® Golf Bridges because of the long life and sustainability of these bridges," said Roy Saunders, Bay Hill Vice President.

Port Bridges

Project Number: 14-134

The bridges are built according to a totally new bridge concept: The lattice bridge made of glass fiber instead of steel.

The bridges are in the Rotterdam port area. Matthijs Tromp tells in the interview about the many advantages of a FiberCore port bridge such as larger spans, the long, low maintenance life, the strength with respect to the weight and the specific wishes of the client.

Watch the video here explaining why we opted for the lightweight port bridges of FiberCore Europe.

Location: Hartelkanaal, Netherlands
Length: 19.4m
Width: 1.5m
Span: 19.4m
Category: 5kN/m2
Production Year: 2015

Project Number: 15-183

Location, Pistool & Madroelhaven, Netherlands
Length: 31.4m
Width: 1.5m
Span: 31.4m
Category: 5kN/m2
Production Year: 2015

Project Number: 16-210

Location: Calandkanaal Oost, Netherlands
Length: 31.4m
Width: 1.5m
Span: 31.4m
Category: 5kN/m2
Production Year: 2016

Project Number: 16-220

Location Spyderbridges
Length: 31.4m & 29m
Width: 1.5m
Span: 31.4m & 29m
Category: 5kN/m2
Production Year: 2016

Road Bridges

Project Number: 14-142

The wooden bridge deck was replaced Monday 12 January with a fiber reinforced polymer bridge deck, in which the InfraCore® Inside technology was applied.

The Friese Bridge, gateway to the city center of Alkmaar, is a bridge for all traffic. With the new deck, the bridge is ready for the coming decades.

Location: Friesebrug, Netherlands
Length: 16.4m
Width: 7m
Span: 16.4m
Category: Eurocodes
Production Year: 2014

Project Number: 12-052

In the end of 2012, FiberCore Europe placed, in close cooperation with construction company Haukes, a small traffic bridge in Paramaribo, Suriname.

Location: Paramaribo, Suriname, Netherlands
Length: 9.5m
Width: 3.5m
Span: 9.5m
Category: VK30 Bicycle, Pedestrian & Car Traffic
Production Year: 2012

Project Number: 11-001

This sustainable road bridge with InfraCore® Inside for the heaviest traffic class lies in a provincial road. The bridge even made it to the NOS journal. Here you can view the broadcast.

Location: Maarssenseweg, Netherlands
Length: 6.8m
Width: 9m
Span: 6.8m
Category: VK60
Production Year: 2011

Project Number: 15-159

Location: Brunschoten, Netherlands
Length: 6.8m
Width: 5.8m
Span: 6.8m
Category: Eurocodes
Production Year: 2015

Project number: 15-152

A road bridge with InfraCore®Inside was placed near London Wednesday 22 April.

The 13 meter long bridge (4 meters wide) has been transported to England via Vlaardingen over the water. The main contractor for the project is ECS Engineering Services.

Location: Mapledurham, England
Length: 13m
Width: 4,4m
Span: 13m
Category: Eurocodes
Production year: 2015

Project Number: 09-016

A project of 7 identical traffic bridges that each connect the public roads to a company surrounded by water.

This project is realized in close cooperation with Haasnoot Bruggen, who also delivered the railings

Location: Albrandswaard, Netherlands
Length: 10.5m
Width: 4.5m
Span: 10.5m
Category: VK30 Bicycle, Pedestrian & Car Traffic
Production Year: 2009/2010

Project Number: 14-119

On Friday afternoon, July 10 the bridge deck for the Crusade Bridge was transported to Utrecht.

The 15m long bridge section, fully produced with InfraCore® Inside, was transported from Rotterdam by boat, and then transported through the city center to its final destination.

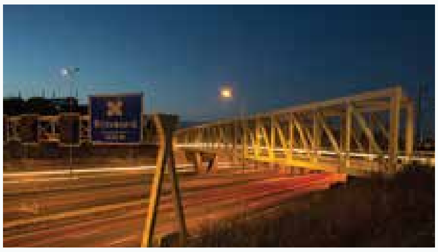
Location: Kruisvaartbrug, Netherlands
Length: 13.4m
Width: 11.8m
Span: 13.4m
Category: Eurocodes
Production Year: 2014

Project Number: 11-012

Three traffic bridges and 2 cycle bridges, all with specially designed railings (by Ooms Construction).

Location: Wognum, Netherlands
Length: 10 a 11 meter
Width: Between 1.5 & 5.4m
Span: Between 10 & 11m
Category: van 5kN/m2 up to 45 Tons of Traffic
Production Year: 2011

Project Number: 11-014



This 142-meter-long traffic viaduct over the A27 is equipped with an InfraCore® Inside bridge deck of fiber-reinforced plastic.

The deck is constructed out of seven parts and has already been linked to the steel structure at the construction site. The assembled construction was then placed in its entirety over the A27 motorway.

The enormous weight savings were guiding in the choice for a composite deck, in hybrid with the steel construction. The much longer lifespan and maintenance free character of the deck also played a role.

The viaduct was built on behalf of ProRail, Heijmans was the main contractor.

Location: Lunetten, Netherlands
Length: 140m
Width: 6.2m
Span: 6.2
Category: 60 Tons of Traffic
Production Year: 2011/2012

How can we help?

1300 26 10 74
service@sisau.com.au
sisau.com.au

Australian Head Office
26 The Parade West
Kent Town SA 5067

1300 26 10 74
service@sisau.com.au
sisau.com.au