FRP Composite Bridges
2m to 30m Clear Span
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When you are ready to talk, contact our structures team to set a meeting, for samples or to discuss your project.
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
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.
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 stakeholders 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.
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.
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 ISO9001 certified quality control system. The system 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.
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.
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.
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.
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/mm² (or MPa) thus are stronger than steel (~355N/mm²). 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.
The Principle of InfraCore® Inside: no skin-core debonding

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.

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/mm² (or MPa)
- Strength, transverse: 150N/mm² (or MPa)
- Stiffness, span direction: 3900N/mm² (or 39GPa)
- Stiffness, transverse: 1100N/mm² (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/m³. The bare core material, which has no structural role and only serves as a lost mould during construction, weighs 35kg/m³.
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.
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.

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.
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.
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.
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.
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: $7 \times 10^{-6}/K$
- Transverse direction: $50 \times 10^{-6}/K$

Since the coefficient of thermal expansion can be tweaked, it can be matched with that of steel ($12 \times 10^{-6}/K$), 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.
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.
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.
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:

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<th>Deck Depth [mm]</th>
<th>Weight [kg]</th>
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<tr>
<td>15.0</td>
<td>2.2</td>
<td>370</td>
<td>3759.37</td>
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</table>

### 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
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
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.
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.
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.
Staines Moore Bridge
United Kingdom
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**Corresponding drawings**
- 17-293-SM-010-TKK-1-Deck_R1.0

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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 $L_{rd} = 6.1 \text{ m}$ 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:

- [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.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<td>Total length</td>
<td>6.1 m</td>
</tr>
<tr>
<td>Length of deck</td>
<td>6.1 m</td>
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<tr>
<td>Span</td>
<td>5.7 m</td>
</tr>
<tr>
<td>Width</td>
<td>1.5 m</td>
</tr>
<tr>
<td>Effective width (between railings)</td>
<td>1.2 m</td>
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<tr>
<td>Construction height</td>
<td>140 mm</td>
</tr>
<tr>
<td>Width flange</td>
<td>200 mm</td>
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<tr>
<td>Total surface area</td>
<td>9.1 m²</td>
</tr>
<tr>
<td>Total mass</td>
<td>$1.2 \times 10^3$ kg</td>
</tr>
<tr>
<td>Assumed mass of the railing per meter</td>
<td>$50$ kg m$^{-1}$</td>
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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. 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 throughout the bottom of the bridge.

![Diagram of the bridge including positions of the supports](image-url)
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 topskin, 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 coordinate 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 CUSR06.

The used properties used in the calculations are listed here:

| Component | \( t_s \) (mm) | \( E_{x,ts} \) (GPa) | \( E_{y,ts} \) (GPa) | \( 
\sigma_{x,ts} \) (MPa) | \( 
\sigma_{y,ts} \) (MPa) | \( \tau_{xy,ts} \) (MPa) | \( \sigma_{x,bs} \) (MPa) | \( 
\sigma_{y,bs} \) (MPa) | \( \tau_{xy,bs} \) (MPa) |
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</tr>
</thead>
<tbody>
<tr>
<td>Topskin</td>
<td>12</td>
<td>32</td>
<td>19</td>
<td>386</td>
<td>226</td>
<td>98</td>
<td>413</td>
<td>199</td>
<td>98</td>
</tr>
<tr>
<td>Bottomskin</td>
<td>12</td>
<td>34</td>
<td>17</td>
<td>34</td>
<td>199</td>
<td>98</td>
<td>34</td>
<td>199</td>
<td>98</td>
</tr>
<tr>
<td>Flange</td>
<td>20</td>
<td>26</td>
<td>26</td>
<td>306</td>
<td>306</td>
<td>98</td>
<td>413</td>
<td>199</td>
<td>98</td>
</tr>
<tr>
<td>Edge</td>
<td>13</td>
<td>26</td>
<td>26</td>
<td>306</td>
<td>306</td>
<td>98</td>
<td>306</td>
<td>306</td>
<td>98</td>
</tr>
<tr>
<td>Webs</td>
<td>5</td>
<td>12</td>
<td>12</td>
<td>143</td>
<td>143</td>
<td>64</td>
<td>143</td>
<td>143</td>
<td>64</td>
</tr>
<tr>
<td>Support flange</td>
<td>10</td>
<td>26</td>
<td>26</td>
<td>306</td>
<td>306</td>
<td>98</td>
<td>306</td>
<td>306</td>
<td>98</td>
</tr>
</tbody>
</table>

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.

\[
E_{A} = 1.2 \times 10^9 \text{ N} \\
E_{I_{yy}} = 4 \cdot \text{MN} \cdot \text{m}^2 \\
G_{A_{xz}} = 3.1 \times 10^7 \text{ N}
\]

The thermal behaviour of the bridge is dominated by the skins. The thermal expansion coefficient of the top and bottom skins can vary a bit from another due to a small difference in lay-up. The average thermal expansion coefficient of both skins is taken to determine the thermal behaviour of the bridge.

\[
\alpha_x = 11.6 \times 10^{-6} \cdot \text{K}^{-1} \\
\alpha_y = 19.5 \times 10^{-6} \cdot \text{K}^{-1}
\]

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.

\[
q_m = M_{tot} \cdot R \cdot A_{bridge}^{-1} = 1.3 \cdot \text{kN} \cdot \text{m}^{-2}
\]

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]

\[q_{fk} = 5 \cdot \text{kN} \cdot \text{m}^{-2}\]

Concentrated load [EC-1]

Load
Acting on square surface with sides

\[Q_{fwk} = 10 \cdot \text{kN}\]
\[B_{fwk} = 0.1 \cdot \text{m}\]

Horizontal load [EC-1]
Due to uniform distributed load

\[Q_{flk,q} = 4 \cdot \text{kN}\]

Dense crowd for dynamic response [EUR23934]
Mass of one person

\[P_1 = 800 \text{N}\]
\[d_{TC} = 0.5 \cdot P_1 \cdot \text{m}^{-2}\]

Load on railings [EC-1]
Line load on top of railing

\[q_{lk} = 1.0 \cdot \text{kN} \cdot \text{m}^{-1}\]

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 serviceability (stiffness) when loaded with the live loads. All load combinations are used to check the safety (strength) of the bridge.

<table>
<thead>
<tr>
<th>LC</th>
<th>&quot;(q)&quot;</th>
<th>&quot;(q_{EG})&quot;</th>
<th>&quot;(q_{flk})&quot;</th>
<th>&quot;(Q_{fwk})&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Load&quot;</td>
<td>&quot;LC0&quot;</td>
<td>&quot;LC1&quot;</td>
<td>&quot;LC2&quot;</td>
<td></td>
</tr>
<tr>
<td>&quot;q,EG&quot;</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>&quot;q,flk&quot;</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>&quot;Q,fwk&quot;</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>&quot;Q,fwk&quot;</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>
5.3 Partial factors

The used partial factors are given in the Eurocode and CIR recommendation 96. The consequence class of this bridge is defined as CC1 ($K_{F1} = 0.9$). The CIR defines different conversion factors to take into account the effect on the material properties of different sources. Which conversion factors are taken into account are depending on the situation and type of load.

<table>
<thead>
<tr>
<th>Material factors</th>
<th>Scatter in material properties</th>
<th>$\gamma_{m1} = 1.35$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Production process</td>
<td>$\gamma_{m2} = 1.20$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Conversion factors</th>
<th>Temperature (T)</th>
<th>$\gamma_{ct} = 1.10$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Moisture (v)</td>
<td>$\gamma_{cv} = 1.10$</td>
</tr>
<tr>
<td></td>
<td>Fatigue (f)</td>
<td>$\gamma_{cf} = 1.10$</td>
</tr>
<tr>
<td></td>
<td>Creep (c)</td>
<td>$\gamma_{ck} = 1.24$</td>
</tr>
</tbody>
</table>

Factors for the service limit state (SLS)

Load factor

<table>
<thead>
<tr>
<th>Material factor</th>
<th>Vibration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conversion factors</td>
<td>Permanent loads ($t_{v,p}$)</td>
</tr>
<tr>
<td></td>
<td>Live loads ($t_{v,l}$)</td>
</tr>
<tr>
<td>Deformations</td>
<td>Permanent loads ($t_{v,d,p}$)</td>
</tr>
<tr>
<td></td>
<td>Live loads ($t_{v,d,l}$)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$\gamma_{L} = 1.00$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma_{m,SLS} = 1.00$</td>
</tr>
<tr>
<td>$\gamma_{cv,p} = 1.33$</td>
</tr>
<tr>
<td>$\gamma_{cv,l} = 1.21$</td>
</tr>
<tr>
<td>$\gamma_{cd,p} = 1.65$</td>
</tr>
<tr>
<td>$\gamma_{cd,l} = 1.21$</td>
</tr>
</tbody>
</table>

Factors for the ultimate limit state (ULS)

Load factors

<table>
<thead>
<tr>
<th>Permanent loads</th>
</tr>
</thead>
<tbody>
<tr>
<td>If favorable</td>
</tr>
<tr>
<td>Live loads</td>
</tr>
</tbody>
</table>

Material factors ($m_1$, $m_2$)

<table>
<thead>
<tr>
<th>Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permanent loads ($t_{v,k}$)</td>
</tr>
<tr>
<td>Live loads ($t_{v,l}$)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$\gamma_{G} = 0.89 \cdot 1.35 \cdot K_{F1} = 1.08$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma_{G,inf} = 0.89 \cdot 1.0 = 0.89$</td>
</tr>
<tr>
<td>$\gamma_{Q} = 1.35 \cdot K_{F1} = 1.22$</td>
</tr>
<tr>
<td>$\gamma_{m,ULS} = 1.62$</td>
</tr>
<tr>
<td>$\gamma_{cs,p} = 1.50$</td>
</tr>
<tr>
<td>$\gamma_{cs,l} = 1.21$</td>
</tr>
</tbody>
</table>

Additional reduction factor due to the production process (ULS)

<table>
<thead>
<tr>
<th>Topskin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottomskin</td>
</tr>
<tr>
<td>Webs</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$\gamma_{ts} = 1.18$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma_{bs} = 1.12$</td>
</tr>
<tr>
<td>$\gamma_{W} = 1.47$</td>
</tr>
</tbody>
</table>

Some fibers/layers are locally interrupted in the construction due to the production process. 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 and transverse direction. The temperature components are derived from the EN 1991-1-5+C1:2011. This design is more of type 1 than any of the other types.

Design temperature

\[ T_0 = 10 \degree \text{C} \]

Minimal temperature in the shadow

\[ T_{\text{min}} = -18 \degree \text{C} \]

Maximum temperature in the shadow

\[ T_{\text{max}} = 34 \degree \text{C} \]

Temperature difference between shadow - bridge

\[ \Delta T_{\text{e.min}} = -3 \cdot \Delta T \]

\[ \Delta T_{\text{e.max}} = 16 \cdot \Delta T \]

Temperature difference component

\[ \Delta T_{\text{Mheat}} = 30 \cdot \Delta T \]

\[ \Delta T_{\text{Mcool}} = 8 \cdot \Delta T \]

Additional temperature difference for expansion joints

\[ \Delta T_{\text{dil}} = 20 \cdot \Delta T \]

Combination factors

\[ \omega_N = 0.35 \]

\[ \omega_M = 0.75 \]

Uniform temperature component bridge

\[ T_{\text{e.min}} = T_{\text{min}} + \Delta T_{\text{e.min}} = -21 \degree \text{C} \]

\[ T_{\text{e.max}} = T_{\text{max}} + \Delta T_{\text{e.max}} = 50 \degree \text{C} \]

\[ \Delta T_N = T_{\text{e.max}} - T_{\text{e.min}} = 71 \degree \text{C} \]

Maximum temperature change contraction

\[ \Delta T_{N,\text{con}} = T_0 - T_{\text{e.min}} = 31 \degree \text{C} \]

Maximum temperature change expansion

\[ \Delta T_{N,\text{exp}} = T_{\text{e.max}} - T_0 = 40 \degree \text{C} \]

Normative temperature combination for the bridge and expansion joints

\[ \Delta T_{\text{exp}} = \max \left( \Delta T_{\text{Mheat}} + \omega_N \cdot \Delta T_{\text{N,exp}} + \omega_M \cdot \Delta T_{\text{Mcool}} + \Delta T_{\text{N,exp}} \right) = 63 \degree \text{C} \]

\[ \Delta T_{\text{con}} = \max \left( \Delta T_{\text{Mheat}} + \omega_N \cdot \Delta T_{\text{N,con}} + \omega_M \cdot \Delta T_{\text{Mcool}} + \Delta T_{\text{N,con}} \right) = 37 \degree \text{C} \]

\[ \Delta T_{\text{d,c}} = \max \left( \Delta T_{\text{Mheat}} + \omega_N \cdot \left( \Delta T_{\text{N,exp}} + \Delta T_{\text{dil}} \right) + \omega_M \cdot \Delta T_{\text{Mcool}} + \left( \Delta T_{\text{N,con}} + \Delta T_{\text{dil}} \right) \right) = 83 \degree \text{C} \]

\[ \Delta T_{\text{d,c}} = \max \left( \Delta T_{\text{Mcool}} + \omega_N \cdot \left( \Delta T_{\text{N,con}} + \Delta T_{\text{dil}} \right) + \omega_M \cdot \Delta T_{\text{Mcool}} + \left( \Delta T_{\text{N,con}} + \Delta T_{\text{dil}} \right) \right) = 57 \degree \text{C} \]

Maximum expansion/contraction due to the normative temperature components

Bridge

\[ \Delta L_{\text{dil.exp}} = \Delta T_{\text{exp}} \cdot \alpha_x \cdot L_{\text{rd}} = 4.4 \text{ mm} \]

\[ \Delta L_{\text{dil.con}} = \Delta T_{\text{con}} \cdot \alpha_x \cdot L_{\text{rd}} = 2.6 \text{ mm} \]

\[ \Delta B_{\text{dil.exp}} = \Delta T_{\text{exp}} \cdot \alpha_y \cdot B_{\text{tot}} = 1.8 \text{ mm} \]

\[ \Delta B_{\text{dil.con}} = \Delta T_{\text{con}} \cdot \alpha_y \cdot B_{\text{tot}} = 1.1 \text{ mm} \]

Total expansion joints

\[ \Delta L_{\text{dil.exp}} = \Delta T_{\text{dil.exp}} \cdot \alpha_x \cdot L_{\text{rd}} = 5.8 \text{ mm} \]

\[ \Delta L_{\text{dil.con}} = \Delta T_{\text{dil.con}} \cdot \alpha_x \cdot L_{\text{rd}} = 4.0 \text{ mm} \]

\[ \Delta B_{\text{dil.exp}} = \Delta T_{\text{dil.exp}} \cdot \alpha_y \cdot B_{\text{tot}} = 2.4 \text{ mm} \]

\[ \Delta B_{\text{dil.con}} = \Delta T_{\text{dil.con}} \cdot \alpha_y \cdot B_{\text{tot}} = 1.7 \text{ mm} \]

The fixation of the bridge with one foundation has slotted holes such that the bridge can freely expand/contract. Therefore, there will be no significant 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 $\delta_{all} = \frac{L_0}{100} = 57 \cdot \text{mm}$ under live loads
- Maximum gradient of $\varphi_{\text{max}} = 4.0\%$ to ensure easy and good accessibility
- Average gradient of minimal $\varphi_{\text{avg}} = 0.5\%$ 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:

$$f(K, d_{TC}) = \frac{K}{2\pi} \cdot \sqrt[4]{\frac{E_{yy} \cdot \gamma_{m, SLS}^{-1}}{\left(\gamma_{cv, p} \cdot q_m \cdot B_{tot} + \gamma_{cv, l} \cdot d_{TC} \cdot B_{eff}\right) \cdot L_0^4}}$$

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
$$f_{0, \text{unloaded}} = f(1.18 \cdot K_{SS,0} \cdot 0) = 7.3 \cdot \text{Hz}$$

First eigenfrequency, loaded bridge
$$f_{0, \text{loaded}} = f(1.18 \cdot K_{SS,0} \cdot d_{TC}) = 6.6 \cdot \text{Hz}$$

The eigenfrequencies are high enough 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

$$\delta_{L1C1} = \frac{5}{384} \cdot \frac{q_{lk} \cdot B_{eff} \cdot L_0^4}{E_{yy}} + \frac{1}{8} \cdot \frac{q_{lk} \cdot B_{eff} \cdot L_0^2}{G_{Axz}} = 20 \cdot \text{mm}$$

$$\delta_{L1C1, k} = \gamma_{f} \cdot \gamma_{m, SLS} \cdot \gamma_{cd, 1} \cdot \delta_{L1C1} = 24 \cdot \text{mm}$$

Unity check
$$u_{c, L1C1} = \frac{\delta_{L1C1, k}}{\delta_{all}} = 0.42$$

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:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_{p}$</td>
<td>39 mm</td>
</tr>
<tr>
<td>$B_{l}$</td>
<td>32 mm</td>
</tr>
<tr>
<td>$B_{e}$</td>
<td>28 mm</td>
</tr>
<tr>
<td>$\varphi_{\text{max}, p}$</td>
<td>2.5 %</td>
</tr>
<tr>
<td>$\varphi_{\text{max}, l}$</td>
<td>2.1 %</td>
</tr>
<tr>
<td>$\varphi_{\text{max}, e}$</td>
<td>1.8 %</td>
</tr>
<tr>
<td>$\varphi_{\text{avg}, p}$</td>
<td>1.3 %</td>
</tr>
<tr>
<td>$\varphi_{\text{avg}, l}$</td>
<td>1.1 %</td>
</tr>
<tr>
<td>$\varphi_{\text{avg}, e}$</td>
<td>0.9 %</td>
</tr>
</tbody>
</table>

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 L.

Maximum bending moments
Selfweight
\[ M_m = \frac{1}{8} q_m \cdot B_{tot} \cdot L_o^2 = 8 \cdot kN \cdot m \]
Uniform distributed load
\[ M_q = \frac{1}{8} q_{Fk} \cdot B_{tot} \cdot L_o^2 = 30 \cdot kN \cdot m \]

Per load combination
\[ M_{LC1} = \gamma_m \cdot \gamma_{UGT} \cdot \left( \gamma_G \cdot \gamma_{CS, p} \cdot M_m + \gamma_Q \cdot \gamma_{CS, 1} \cdot M_q \right) = 93 \cdot kN \cdot m \]

Stress in the skins
Distance of topskin to neutral line
\[ z_{ts} = 61 \cdot mm \]
Distance of bottomskin to neutral line
\[ z_{bs} = -79 \cdot mm \]
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
\[ u_{ts,\sigma} = \frac{\sigma_{ts,x,M}}{\sigma_{x,ts}} = 0.16 \]
\[ u_{bs,\sigma} = \frac{\sigma_{bs,x,M}}{\sigma_{x,bs}} = 0.18 \]

8.2 Strength of the webs
The strength 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 \( c_{cw} = 210 \cdot mm \)

Maximum shearforce one on one web
Selfweight
\[ V_m = \frac{1}{2} q_m \cdot c_{cw} \cdot L_o = 0.8 \cdot kN \]
Uniform distributed load
\[ V_q = \frac{1}{2} q_{Fk} \cdot c_{cw} \cdot L_o = 3.0 \cdot kN \]
Concentrated load
\[ V_{fwk} = Q_{fwk} = 10.0 \cdot kN \]

Per load combination
\[ V_{LC1} = \gamma_w \cdot \gamma_m \cdot \gamma_{UGT} \cdot \left( \gamma_G \cdot \gamma_{CS, p} \cdot V_m + \gamma_Q \cdot \gamma_{CS, 1} \cdot V_q \right) = 14 \cdot kN \]
\[ V_{LC3} = \gamma_w \cdot \gamma_m \cdot \gamma_{UGT} \cdot \left( \gamma_G \cdot \gamma_{CS, p} \cdot V_m + \gamma_Q \cdot \gamma_{CS, 1} \cdot V_{fwk} \right) = 38 \cdot kN \]
Shear stress in web

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

Shear stress
\[ \tau_{w,y,y} = \max \left( V_{l,c1}, V_{l,c3} \right) \cdot A_w^{-1} = 59 \cdot \text{MPa} \]

Allowable shear stress
\[ \tau_{y,y,w} = 64 \cdot \text{MPa} \]

Unity check
\[ u_{c,w,\tau} = \frac{\tau_{w,y,y}}{\tau_{y,y,w}} = 0.93 \]

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

The maximum compression force on one web (load and material factors included):
\[ P_{l,c3} = \gamma_{m,ULS} \cdot \left( \gamma_{cs,p} \cdot c_{c,\gamma} \cdot q_{m} \cdot c_{c,w} \cdot B_{f,wk} + \gamma_{cs,1} \cdot q_{f,wk} \right) = 24 \cdot \text{kN} \]

The maximum compression stress in one web:
\[ \sigma_{w,\text{max}} = \frac{P_{l,c3}}{B_{f,wk} \cdot t_w} = 47 \cdot \text{MPa} \]

Design strength of the web
\[ \sigma_{y,w} = 143 \cdot \text{MPa} \]

Unity check
\[ u_{c,w,\sigma} = \frac{\sigma_{w,\text{max}}}{\sigma_{y,w}} = 0.33 \]

8.3 Strength of the fixation of the railing

It is assumed that the railings are fix 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.

Heigh of the railing
\[ H_{rail} = 1.2 \text{m} \]

Spacing stanchion
\[ s_{stan} = 1.5 \text{m} \]

Diameter bolt, metric
\[ d_{b,1} = 12 \cdot \text{mm} \]

Class of the bolt
\[ k_{b,1} = 8.8 \]

c-c distance bolts
- x direction
  \[ c_{c,x,b} = 120 \cdot \text{mm} \]
- y direction
  \[ c_{c,y,b} = 80 \cdot \text{mm} \]

Edge distance bolt - base plate
- x direction
  \[ e_{x,base} = 30 \cdot \text{mm} \]
- y direction
  \[ e_{y,base} = 30 \cdot \text{mm} \]

Edge distance bolt - edge laminate
\[ e_{y,b} = 50 \cdot \text{mm} \]

Load on one bolt

Tensile
\[ F_{t,b} = \frac{V_{Q_1} \cdot q_{l,k} \cdot s_{stan} \cdot H_{rail}}{2 \cdot \frac{e_{y,base}}{e_{y,base} + c_{c,y,b}}} = 9 \cdot \text{kN} \]

Shear
\[ F_{v,b} = \frac{1}{4} \left( V_{Q_1} \cdot q_{l,k} \cdot s_{stan} \right) = 0.5 \cdot \text{kN} \]
Allowable load on one bolt

Tensile
\[ F_{\text{t.b.alw}} = 49 \cdot \text{kN} \]
Shear
\[ F_{\text{v.b.alw}} = 27 \cdot \text{kN} \]

Unity check
\[ u_{c.b,l} = \left( \frac{F_{\text{t.b}}}{F_{\text{t.b.alw}}} \frac{F_{\text{v.b}}}{F_{\text{v.b.alw}}} \frac{F_{\text{v.b}}}{F_{\text{v.b.alw}} + \frac{F_{\text{t.b}}}{1.4F_{\text{t.b.alw}}}} \right) = \begin{pmatrix} 0.19 \\ 0.02 \\ 0.15 \end{pmatrix} \]

8.4 Strength of the flanges

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

Diameter hole
\[ d_{g,l} = 14 \cdot \text{mm} \]
Diameter washer
\[ d_{r,l} = 40 \cdot \text{mm} \]

Laminate around the holes for the bolts

Allowable stress in any direction
\[ \sigma_{y.f.alw} = \frac{\sigma_{y.f}}{\gamma_{m,ULS} \cdot \gamma_{c.s,l}} = 156 \cdot \text{MPa} \]

Allowable shear stress in xy plane
\[ \tau_{xy.f.alw} = \frac{\tau_{xy.f}}{\gamma_{m,ULS} \cdot \gamma_{c.s,l}} = 50 \cdot \text{MPa} \]

Allowable shear stress in yz plane
\[ \tau_{yz.f.alw} = \frac{\tau_{yz.f}}{\gamma_{m,ULS} \cdot \gamma_{c.s,l}} = 20 \cdot \text{MPa} \]

Compressive stresses

Stress concentration factor
\[ K_C = \left( \frac{d_{g,l}}{d_{b,l}} \right)^2 = 1.36 \]

Compressive stress
\[ \sigma_{f.b.y.c} = \frac{F_{\text{v.b}}}{{d_{g,l}} \cdot t_f} = 2.2 \cdot \text{MPa} \]

Unity check
\[ u_{c.f.b,y.c} = \frac{\sigma_{f.b.y.c}}{\sigma_{y.f.alw}} = 0.01 \]

Tensile stresses

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

Ratio diameter hole \( \cdot c_c \) distance holes
\[ r_{g.b,l} = \frac{d_{g,l}}{c_{c_x,b}} = 0.12 \]

Stress concentration factor
\[ K_C = 8 \]

Tensile stress
\[ \sigma_{f.b.y.t} = \frac{K_C \cdot F_{\text{v.b}}}{(c_{c_x,b} - d_{g,l}) \cdot t_f} = 1.7 \cdot \text{MPa} \]

Unity check
\[ u_{c.f.b,y.t} = \frac{\sigma_{f.b.y.t}}{\sigma_{y.f.alw}} = 0.01 \]
Shear stress

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

Shear stress due to pull-through
\[ \tau_{f,b,yz,p} = \frac{F_{L,b}}{\pi \cdot d_{r,1} \cdot t_f} = 3.6 \cdot \text{MPa} \]

Unity check
\[ u_{c,f,b,yz} = \left( \frac{\tau_{f,b,xy,s}}{\tau_{xy,f,alw}} \frac{\tau_{f,b,yz,p}}{\tau_{yz,f,alw}} \right) = \left( 0.00 \quad 0.18 \right) \]

\[ k_f \]

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 bottom side 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
- Number of load bearing rods in x direction
- Number of load bearing rods in y direction
- Diameter rods, metric
- Diameter washer
- Material class
- Diameter hole
- Edge laminate - hole distance

Load per rod
- Shear in x direction
\[ F_{v,x,LC1} = \frac{\gamma Q \cdot Q_{lk,q}}{n_{d,x}} = 2 \cdot \text{kN} \]
- Shear in y direction
\[ F_{v,y,LC1} = \frac{\gamma Q \cdot Q_{lk,q}}{n_{d,y}} = 1 \cdot \text{kN} \]

Allowable shear force on one rod
\[ F_{v,d,alw} = 112 \cdot \text{kN} \]

Unity check
\[ u_{c,q} = \left( \frac{F_{v,x,LC1}}{F_{v,d,alw}} \frac{F_{v,y,LC1}}{F_{v,d,alw}} \right) = \left( 0.02 \quad 0.01 \right) \]
8.6 Strength of the support flanges
The laminate around the holes for the rods is checked on strength.

Allowable stress in x direction
\[ \sigma_{x,sf,alw} = \frac{\sigma_{x,si}}{\gamma_{m,ULS} \cdot \gamma_{cs,1}} = 156 \text{ MPa} \]

Allowable stress in y direction
\[ \sigma_{y,sf,alw} = \frac{\sigma_{y,si}}{\gamma_{m,ULS} \cdot \gamma_{cs,1}} = 156 \text{ MPa} \]

Allowable shear stress in xy direction
\[ \tau_{xy,sf,alw} = \frac{\tau_{xy,si}}{\gamma_{m,ULS} \cdot \gamma_{cs,1}} = 50 \text{ MPa} \]

Compressive stress

Stress concentration factor
\[ K_c = \left( \frac{d_g}{d_d} \right)^2 = 1.78 \]

Compressive stress in x direction
\[ \sigma_{sf,x,c} = \frac{F_{v,x,LC1} \cdot K_c}{d_g \cdot t_{sf}} = 12 \text{ MPa} \]

Compressive stress in y direction
\[ \sigma_{sf,y,c} = \frac{F_{v,y,LC1} \cdot K_c}{d_g \cdot t_{sf}} = 6 \text{ MPa} \]

Unity check
\[ \frac{\sigma_{sf,x,c}}{\sigma_{x,sf,alw}} \quad \frac{\sigma_{sf,y,c}}{\sigma_{y,sf,alw}} = (0.08 \quad 0.04) \]

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

Loaded width
\[ b_{eff,d} = d_g + 2e_{x,d} = 232 \text{ mm} \]

Ratio hole diameter - loaded width
\[ \frac{r_{g,b,d}}{b_{eff,d}} = \frac{d_g}{b_{eff,d}} = 0.14 \]

Stress concentration factor
\[ K_t = 7 \]

Tensile stress in x direction
\[ \sigma_{sf,x,t} = \frac{K_t \cdot F_{v,x,LC1}}{(b_{eff,d} - d_g) \cdot t_{sf}} = 8 \text{ MPa} \]

Tensile stress in y direction
\[ \sigma_{sf,y,t} = \frac{K_t \cdot F_{v,y,LC1}}{(b_{eff,d} - d_g) \cdot t_{sf}} = 4 \text{ MPa} \]

Unity check
\[ \frac{\sigma_{sf,x,t}}{\sigma_{x,sf,alw}} \quad \frac{\sigma_{sf,y,t}}{\sigma_{y,sf,alw}} = (0.05 \quad 0.02) \]

Shear stress

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

Unity check
\[ \frac{\tau_{sf,xy,s}}{\tau_{xy,sf,alw}} = 0.02 \]
**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 \( V_{\text{tot}} = 1.00 \cdot \text{m}^3 \)

Density of fresh water \( \rho_{\text{fresh\,water}} = 1000 \frac{\text{kg}}{\text{m}^3} \)

Buoyancy force \( F_b = V_{\text{tot}} \cdot \rho_{\text{fresh\,water}} \cdot g = 9.76 \cdot \text{kN} \)

Weight of the bridge \( W_b = M_{\text{tot}} \cdot g = 12.07 \cdot \text{kN} \)

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

\[ F_{V,P} = \gamma_G \cdot 0.5M_{tot} \cdot g = 7 \cdot \text{kN} \]

Live loads

\[ F_{V,L} = \frac{1}{2} \cdot \gamma_Q \cdot q_{lk} \cdot B_{eff} \cdot L_o = 21 \cdot \text{kN} \]

Total

\[ F_{V,\text{abutment}} = F_{V,P} + F_{V,L} = 27 \cdot \text{kN} \]

In longitudinal direction at the abutments

\[ F_{h,x,\text{abutment,1}} = \gamma_Q \cdot q_{lk,q} = 4 \cdot \text{kN} \]

\[ F_{h,x,\text{abutment,2}} = 0 \cdot \text{kN} \]

In lateral direction per abutment

\[ F_{h,y,\text{abutment}} = \frac{1}{2} \cdot \gamma_Q \cdot q_{lk,q} = 2 \cdot \text{kN} \]
10 Conclusion

**SLS results**

<table>
<thead>
<tr>
<th>First eigenfrequency</th>
<th>Unloaded</th>
<th>$f_{0,\text{unloaded}} = 7.3 \cdot \text{Hz}$</th>
<th>$\geq 3.0 \text{ Hz}$</th>
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<tr>
<td></td>
<td>Loaded</td>
<td>$f_{0,\text{loaded}} = 6.6 \cdot \text{Hz}$</td>
<td>$\geq 2.3 \text{ Hz}$</td>
</tr>
<tr>
<td>Deformations</td>
<td>LC1</td>
<td>$u_{c_{\Delta,\text{LC1}}} = 0.42$</td>
<td>$\leq 1.00$</td>
</tr>
<tr>
<td>Maximum gradient</td>
<td>$\phi_{\text{max,i}} = 2.1 \cdot %$</td>
<td>$\leq \phi_{\text{max}} = 4.0 \cdot %$</td>
<td></td>
</tr>
<tr>
<td>Average gradient</td>
<td>$\phi_{\text{avg,e}} = 0.9 \cdot %$</td>
<td>$\geq \phi_{\text{avg}} = 0.5 \cdot %$</td>
<td></td>
</tr>
</tbody>
</table>

**ULS results**

- **Topskin**
  - Moment
    - $u_{c_{\text{ts,}\sigma}} = 0.16$ | $\leq 1.00$
- **Bottomskin**
  - Moment
    - $u_{c_{\text{bs,}\sigma}} = 0.18$ | $\leq 1.00$
- **Webs**
  - Shear
    - $u_{c_{w,\tau}} = 0.93$ | $\leq 1.00$
  - Compression
    - $u_{c_{w,\sigma}} = 0.33$ | $\leq 1.00$

- **Bolts of the railing**
  - $u_{c_{b,\lambda}} = (0.19 \ 0.02 \ 0.15)$ | $\leq 1.00$

- **Flange**
  - Compression around holes
    - $u_{c_{f,\beta,\sigma c}} = 0.01$ | $\leq 1.00$
  - Tension around holes
    - $u_{c_{f,\beta,\sigma t}} = 0.01$ | $\leq 1.00$
  - Shear around holes
    - $u_{c_{f,\beta,\tau}} = (0.00 \ 0.18)$ | $\leq 1.00$

- **Threaded Rods**
  - $u_{c_{d}} = (0.02 \ 0.01)$ | $\leq 1.00$

- **Support flange**
  - Compression around holes
    - $u_{c_{s,\beta,\sigma c}} = (0.08 \ 0.04)$ | $\leq 1.00$
  - Tension around holes
    - $u_{c_{s,\beta,\sigma t}} = (0.05 \ 0.02)$ | $\leq 1.00$
  - Shear around holes
    - $u_{c_{s,}\tau} = 0.02$ | $\leq 1.00$

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

**Total thermal expansion/contraction of the bridge**

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

**Total thermal expansion/contraction for the dilatations**

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

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Engineering Case Study

Ordnance Bridge
United Kingdom
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Corresponding drawings
- 17-294-OR-010/TKK-1-Deck_R1.0

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<th>Status</th>
<th>Date</th>
<th>Author</th>
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<td>Final</td>
<td>10-1-2013</td>
<td>FZ</td>
<td>Initial version</td>
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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 $L_{rd} = 9.00m$ 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:

- [EUR23984] "Design of Lightweight Foot-Bridges for Human Induced Vibrations"
- [CIR-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 deck, refer to the accompanying drawing:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total length</td>
<td>L_{tot} = 9 m</td>
</tr>
<tr>
<td>Length of deck</td>
<td>L_{rd} = 9 m</td>
</tr>
<tr>
<td>Span</td>
<td>L_{o} = 8.6 m</td>
</tr>
<tr>
<td>Width</td>
<td>B_{tot} = 1.5 m</td>
</tr>
<tr>
<td>Effective width (between railings)</td>
<td>B_{eff} = 1.2 m</td>
</tr>
<tr>
<td>Construction height</td>
<td>H_{d} = 170 mm</td>
</tr>
<tr>
<td>Width flange</td>
<td>B_{fl} = 200 mm</td>
</tr>
<tr>
<td>Total surface area</td>
<td>A_{bridge} = 13.5 m²</td>
</tr>
<tr>
<td>Total mass</td>
<td>M_{tot} = 1.9 \times 10^3 kg</td>
</tr>
<tr>
<td>Assumed mass of the railing per meter</td>
<td>M_{L,rail} = 50 kg m⁻¹</td>
</tr>
</tbody>
</table>

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 where 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 through the bottom of the bridge.

![Front view of the bridge including positions of the supports](image-url)
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 coordinate 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 CUI96.

The used properties used in the calculations are listed here:

| Laminate     | \( t \) | \( E_x \) | \( E_y \) | \( 
\sigma_{x,\text{ts}} \) | \( 
\sigma_{y,\text{ts}} \) | \( \tau_{xy,\text{ts}} \) | \( 
\sigma_{x,\text{bs}} \) | \( \sigma_{y,\text{bs}} \) | \( \tau_{xy,bs} \) | \( G_{xy} \) |
<table>
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</tr>
</thead>
<tbody>
<tr>
<td>Topskin</td>
<td>12 mm</td>
<td>32 GPa</td>
<td>19 GPa</td>
<td>386 MPa</td>
<td>226 MPa</td>
<td>98 MPa</td>
<td>413 MPa</td>
<td>199 MPa</td>
<td>98 MPa</td>
<td>6 GPa</td>
</tr>
<tr>
<td>Bottomskin</td>
<td>12 mm</td>
<td>34 GPa</td>
<td>17 GPa</td>
<td>12 MPa</td>
<td>12 MPa</td>
<td>39 MPa</td>
<td>12 MPa</td>
<td>12 MPa</td>
<td>39 MPa</td>
<td>6 GPa</td>
</tr>
<tr>
<td>Flange</td>
<td>20 mm</td>
<td>26 GPa</td>
<td>26 GPa</td>
<td>306 MPa</td>
<td>306 MPa</td>
<td>98 MPa</td>
<td>413 MPa</td>
<td>413 MPa</td>
<td>98 MPa</td>
<td>4 GPa</td>
</tr>
<tr>
<td>Edge</td>
<td>13 mm</td>
<td>26 GPa</td>
<td>26 GPa</td>
<td>413 MPa</td>
<td>413 MPa</td>
<td>64 MPa</td>
<td>413 MPa</td>
<td>413 MPa</td>
<td>64 MPa</td>
<td>4 GPa</td>
</tr>
<tr>
<td>Webs</td>
<td>5 mm</td>
<td>12 GPa</td>
<td>12 GPa</td>
<td>306 MPa</td>
<td>306 MPa</td>
<td>98 MPa</td>
<td>306 MPa</td>
<td>306 MPa</td>
<td>98 MPa</td>
<td>6 GPa</td>
</tr>
<tr>
<td>Support flange</td>
<td>10 mm</td>
<td>26 GPa</td>
<td>26 GPa</td>
<td>306 MPa</td>
<td>306 MPa</td>
<td>98 MPa</td>
<td>306 MPa</td>
<td>306 MPa</td>
<td>98 MPa</td>
<td>6 GPa</td>
</tr>
</tbody>
</table>

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.

\[
\begin{align*}
EA_x &= 1.2 \times 10^9 \text{ N} \\
EI_{yy} &= 7 \cdot \text{MN} \cdot \text{m}^2 \\
GA_{zz} &= 3.8 \times 10^7 \text{ N}
\end{align*}
\]

The thermal behaviour of the bridge is dominated by the skins. The thermal expansion coefficient of the top and bottom skins can vary a bit from another due to a small difference in lay-up. The average thermal expansion coefficient of both skins is taken to determine the thermal behaviour of the bridge.

\[
\begin{align*}
\alpha_x &= 11.6 \times 10^{-6} \text{ K}^{-1} \\
\alpha_y &= 19.5 \times 10^{-6} \text{ K}^{-1}
\end{align*}
\]

Cross-section of the construction

![Cross-section of the construction](image)

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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

\[ q_m = M_{tot} \cdot R \cdot A_{bridge}^{-1} = 1.3 \cdot \text{kN} \cdot \text{m}^{-2} \]

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]
- Concentrated load [EC-1]
  - Load
  - Acting on square surface with sides
- Horizontal load [EC-1]
  - Due to uniform distributed load
- Dense crowd for dynamic response [EUR23934]
  - Mass of one person
  - Density crowd
- Load on railings [EC-1]
  - Line load on top of railing

\[ q_{flk} = 5 \cdot \text{kN} \cdot \text{m}^{-2} \]

\[ Q_{fwk} = 10 \cdot \text{kN} \]

\[ b_{fwk} = 0.1 \cdot \text{m} \]

\[ Q_{flk,q} = 5 \cdot \text{kN} \]

\[ P_1 = 800 \text{N} \]

\[ d_{TC} = 0.5 \cdot P_1 \cdot \text{m}^{-2} \]

\[ q_{lk} = 1.0 \cdot \text{kN} \cdot \text{m}^{-1} \]

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 serviceability (stiffness) when loaded with the live loads. All load combinations are used to check the safety (strength) of the bridge.

<table>
<thead>
<tr>
<th>LC</th>
<th>&quot;L寇&quot;</th>
<th>&quot;L0&quot;</th>
<th>&quot;L1&quot;</th>
<th>&quot;L2&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Load&quot;</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>&quot;q,EG&quot;</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>&quot;q,flk&quot;</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>&quot;Q,flk,q&quot;</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>&quot;Q,fwk&quot;</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
### 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 \( (K_{P1} = 0.9) \). The CUR defines different conversion factors to take into account the effect on the material properties of different sources. Which conversion factors are taken into account are depending on the situation and type of load.

#### Material factors
- Scatter in material properties
- Production process
  
\[ \gamma_{m1} = 1.35 \]
\[ \gamma_{m2} = 1.20 \]

#### Conversion factors
- Temperature (\( ^{\circ} \))
- Moisture (\( v \))
- Fatigue (\( f \))
- Creep (\( k \))
  
\[ \gamma_{ct} = 1.10 \]
\[ \gamma_{cv} = 1.10 \]
\[ \gamma_{cf} = 1.10 \]
\[ \gamma_{ck} = 1.24 \]

#### Factors for the service limit state (SLS)

<table>
<thead>
<tr>
<th>Load factor</th>
<th>Material factor</th>
<th>Conversion factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permanent loads (( t,v,f ))</td>
<td>Vibrations</td>
<td>( \gamma_{t} = 1.00 )</td>
</tr>
<tr>
<td>Live loads (( t,v ))</td>
<td></td>
<td>( \gamma_{t,L} = 1.21 )</td>
</tr>
<tr>
<td>Permanent loads (( t,v,k ))</td>
<td>Deformations</td>
<td>( \gamma_{d,p} = 1.65 )</td>
</tr>
<tr>
<td>Live loads (( t,v,f ))</td>
<td></td>
<td>( \gamma_{d,l} = 1.21 )</td>
</tr>
</tbody>
</table>

#### Factors for the ultimate limit state (ULS)

<table>
<thead>
<tr>
<th>Load factors</th>
<th>Material factors (( m1, m2 ))</th>
<th>Conversion factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permanent loads</td>
<td></td>
<td>( \gamma_{G} = 0.89 \cdot 1.35 \cdot K_{P1} = 1.08 )</td>
</tr>
<tr>
<td>If favorable</td>
<td></td>
<td>( \gamma_{G,inf} = 0.89 \cdot 1.0 = 0.89 )</td>
</tr>
<tr>
<td>Live loads</td>
<td></td>
<td>( \gamma_{Q} = 1.35 \cdot K_{P1} = 1.22 )</td>
</tr>
<tr>
<td></td>
<td>( \gamma_{m,ULS} = 1.62 )</td>
<td>( \gamma_{c,s,p} = 1.50 )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( \gamma_{c,s,l} = 1.21 )</td>
</tr>
</tbody>
</table>

#### Additional reduction factor due to the production process (ULS)

- Tension (\( t_s \))
- Bottomskin (\( t_b \))
- Webs (\( w \))
  
\[ \gamma_{ts} = 1.18 \]
\[ \gamma_{tb} = 1.12 \]
\[ \gamma_{w} = 1.47 \]

Some fibers/layers are locally interrupted in the construction due to the production process. 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 and transverse direction. The temperature components are derived from the EN 1991-1-5+C1:2011. This design is more of type 1 than any of the other types.

Design temperature

\[ T_0 = 10 \, ^\circ C \]

Minimal temperature in the shadow

\[ T_{\text{min}} = -18 \, ^\circ C \]

Maximum temperature in the shadow

\[ T_{\text{max}} = 34 \, ^\circ C \]

Temperature difference between shadow - bridge

\[ \Delta T_{e,\text{min}} = -3 \cdot \Delta^\circ C \]
\[ \Delta T_{e,\text{max}} = 16 \cdot \Delta^\circ C \]

Temperature difference component

\[ \Delta T_{\text{Mheat}} = 30 \cdot \Delta^\circ C \]
\[ \Delta T_{\text{Mcool}} = 8 \cdot \Delta^\circ C \]

Additional temperature difference for expansion joints

\[ \Delta T_{\text{dil}} = 20 \cdot \Delta^\circ C \]

Combination factors

\[ \omega_N = 0.35 \]
\[ \omega_M = 0.75 \]

Uniform temperature component bridge

\[ T_{e,\text{min}} = T_{\text{min}} + \Delta T_{e,\text{min}} = -21 \cdot \Delta^\circ C \]
\[ T_{e,\text{max}} = T_{\text{max}} + \Delta T_{e,\text{max}} = 50 \cdot \Delta^\circ C \]
\[ \Delta T_{\text{N,con}} = T_0 - T_{e,\text{min}} = 31 \cdot \Delta^\circ C \]

Maximum temperature change contraction

\[ \Delta T_{\text{N,exp}} = T_{e,\text{max}} - T_0 = 40 \cdot \Delta^\circ C \]

Normative temperature combination for the bridge and expansion joints

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

Maximum expansion/contraction due to the normative temperature components

Bridge

\[ \Delta L_{\text{dek,exp}} = \Delta T_{\text{exp}} \cdot \alpha_x \cdot L_{rd} = 6.5 \, \text{mm} \]
\[ \Delta L_{\text{dek,con}} = \Delta T_{\text{con}} \cdot \alpha_x \cdot L_{rd} = 3.9 \, \text{mm} \]
\[ \Delta B_{\text{dek,exp}} = \Delta T_{\text{exp}} \cdot \alpha_y \cdot B_{\text{tot}} = 1.8 \, \text{mm} \]
\[ \Delta B_{\text{dek,con}} = \Delta T_{\text{con}} \cdot \alpha_y \cdot B_{\text{tot}} = 1.1 \, \text{mm} \]

Total expansion joints

\[ \Delta L_{\text{dil,exp}} = \Delta T_{\text{d,e}} \cdot \alpha_x \cdot L_{rd} = 8.6 \, \text{mm} \]
\[ \Delta L_{\text{dil,con}} = \Delta T_{\text{d,c}} \cdot \alpha_x \cdot L_{rd} = 5.9 \, \text{mm} \]
\[ \Delta B_{\text{dil,exp}} = \Delta T_{\text{d,e}} \cdot \alpha_y \cdot B_{\text{tot}} = 2.4 \, \text{mm} \]
\[ \Delta B_{\text{dil,con}} = \Delta T_{\text{d,c}} \cdot \alpha_y \cdot B_{\text{tot}} = 1.7 \, \text{mm} \]

The fixation of the bridge with one foundation has slotted holes such that the bridge can freely expand/contract. Therefore, there will be no significant 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 $\delta_{all} = \frac{L_0}{100} = 86 \cdot \text{mm under live loads}$
- Maximum gradient 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:

$$f(K, d_{TC}) = \frac{K}{2\pi} \cdot \sqrt{\frac{E_I}{\gamma_{m, SLS}} \cdot \left[ \gamma_{c_{v,p}} \cdot \gamma_{m} \cdot B_{tot} + \gamma_{c_{v,l}} \cdot d_{TC} \cdot B_{eff} \right]} \cdot L_0^4$$

Where constant $K_{SS,0} = 9.87$ and dependent on the boundary conditions, and the eigenfrequency is evaluated. In previous research it is concluded that the calculated eigenfrequency can increase 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
$\quad f_{0, \text{unloaded}} = f(1.18 \cdot K_{SS,0}, 0) = 3.9 \cdot \text{Hz}$

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

The eigenfrequencies are high enough to avoid uncomfortable accelerations.

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

Deformation load combination 1, uniformly distributed load

$$\delta_{LC1} = \frac{5}{384} \cdot \frac{q_{lc} \cdot B_{eff} \cdot L_0^4}{E_I} + \frac{1}{8} \cdot \frac{q_{lc} \cdot B_{eff} \cdot L_0^2}{G A_x z} = 65 \cdot \text{mm}$$

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

Unity check
$$u_{c\delta, LC1} = \frac{\delta_{LC1,l}}{\delta_{all}} = 0.92$$

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:

<table>
<thead>
<tr>
<th>Bulge $p$</th>
<th>Bulge $i$</th>
<th>Bulge $e$</th>
</tr>
</thead>
<tbody>
<tr>
<td>84 · mm</td>
<td>62 · mm</td>
<td>48 · mm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$\varphi_{max}$</th>
<th>$\varphi_{max}$</th>
<th>$\varphi_{max}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.8 · %</td>
<td>2.8 · %</td>
<td>2.1 · %</td>
</tr>
</tbody>
</table>

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
  \[ M_{m} = \frac{1}{8} \cdot q_{m} \cdot B_{tot} \cdot L_{o}^2 = 19 \cdot \text{kN} \cdot \text{m} \]
- Uniform distributed load
  \[ M_{q} = \frac{1}{8} \cdot q_{f_k} \cdot B_{tot} \cdot L_{o}^2 = 69 \cdot \text{kN} \cdot \text{m} \]

Per load combination

\[ M_{LC1} = \gamma_{m} \cdot UGT \cdot \left( \gamma_{G} \cdot \gamma_{CS,P} \cdot M_{m} + \gamma_{Q} \cdot \gamma_{CS,L} \cdot M_{q} \right) = 214 \cdot \text{kN} \cdot \text{m} \]

Stress in the skins

- Distance of topskin to neutral line: \( z_{TS} = 73 \cdot \text{mm} \)
- Distance of bottomskin to neutral line: \( z_{BS} = -97 \cdot \text{mm} \)
- Second moment of inertia of the skins: \( I_{h} = 1.7 \times 10^8 \cdot \text{mm}^4 \)
- Stress in topskin:
  \[ \sigma_{ts,x,M} = \frac{\gamma_{TS} \cdot M_{LC1} \cdot z_{TS}}{I_{h}} = 111 \cdot \text{MPa} \]
- Stress in bottomskin:
  \[ \sigma_{bs,x,M} = \frac{\gamma_{BS} \cdot M_{LC1} \cdot z_{BS}}{I_{h}} = -140 \cdot \text{MPa} \]

Allowable stress in the skins

- Topskin: \( \sigma_{x,TS} = 386 \cdot \text{MPa} \)
- Bottomskin: \( \sigma_{x,BS} = 413 \cdot \text{MPa} \)

Unity checks

- \( u_{cs,\sigma} = \frac{\sigma_{ts,x,M}}{\sigma_{x,ts}} = 0.29 \)
- \( u_{bs,\sigma} = \frac{\sigma_{bs,x,M}}{\sigma_{x,bs}} = 0.34 \)

8.2 Strength of the webs

The strength 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 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 \( c \cdot c_{w} = 210 \cdot \text{mm} \)

Maximum shear force one one web

- Selfweight
  \[ V_{m} = \frac{1}{2} q_{m} \cdot c \cdot c_{w} \cdot L_{o} = 1.2 \cdot \text{kN} \]
- Uniform distributed load
  \[ V_{q} = \frac{1}{2} q_{f_k} \cdot c \cdot c_{w} \cdot L_{o} = 4.5 \cdot \text{kN} \]
- Concentrated load
  \[ V_{fwk} = Q_{fwk} = 10.0 \cdot \text{kN} \]

Per load combination

- \( V_{LC1} = \gamma_{W} \cdot \gamma_{m} \cdot UGT \cdot \left( \gamma_{G} \cdot \gamma_{CS,P} \cdot V_{m} + \gamma_{Q} \cdot \gamma_{CS,L} \cdot V_{q} \right) = 21 \cdot \text{kN} \)
- \( V_{LC3} = \gamma_{W} \cdot \gamma_{m} \cdot UGT \cdot \left( \gamma_{G} \cdot \gamma_{CS,P} \cdot V_{m} + \gamma_{Q} \cdot \gamma_{CS,L} \cdot V_{fwk} \right) = 40 \cdot \text{kN} \)
Shear stress in web

Cross-section area of one web

\[ A_w = t_w \left( H_b - \frac{t_{ls} + t_{bs}}{2} \right) = 796 \cdot \text{mm}^2 \]

Shear stress

\[ \tau_{w,xy,V} = \max(V_{LC1}, V_{LC3}) \cdot A_w^{-1} = 50 \cdot \text{MPa} \]

Allowable shear stress

\[ \tau_{xy,w} = 64 \cdot \text{MPa} \]

Unity check

\[ u_{c,w} = \frac{\tau_{w,xy,V}}{\tau_{xy,w}} = 0.78 \]

The maximum compression stress in one web occurs when the concentrated load is placed directly above the web and is calculated with \( \sigma = \frac{p}{A} \).

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

\[ P_{LC3} = \gamma_m \cdot ULS \cdot \left( \gamma_{cs,p} \cdot \gamma_G \cdot q_m \cdot c_{c,w} \cdot B_{fwk} + \gamma_{cs,1} \cdot \gamma_Q \cdot q_{fwk} \right) = 24 \cdot \text{kN} \]

The maximum compression stress in one web:

\[ \sigma_{w,max} = \frac{P_{LC3}}{B_{fwk} \cdot t_w} = 47 \cdot \text{MPa} \]

Design strength of the web

\[ \sigma_{y,w} = 143 \cdot \text{MPa} \]

Unity check

\[ u_{c,w,\sigma} = \frac{\sigma_{w,max}}{\sigma_{y,w}} = 0.33 \]

### 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.

- **Height of the railing**: \( H_{rail} = 1.2 \text{m} \)
- **Spacing s anchon**: \( s_{stan} = 1.5 \text{m} \)
- **Diameter bolt, metric**: \( d_{bol} = 12 \cdot \text{mm} \)
- **Class of the bolt**: \( klasse_bol = 8.8 \)
- **C-c distance bolts**: \( x \) direction \( c_{c_x,b} = 120 \cdot \text{mm} \)
  - \( y \) direction \( c_{c_y,b} = 80 \cdot \text{mm} \)
- **Edge distance bolt - baseplate**: \( x \) direction \( e_{x,base} = 30 \cdot \text{mm} \)
  - \( y \) direction \( e_{y,base} = 30 \cdot \text{mm} \)
- **Edge distance bolt - edge laminate**: \( e_y = 50 \cdot \text{mm} \)

**Load on one bolt**

**Tensile**

\[ P_{t,b} = \frac{\gamma_{Q1} \cdot q_{lk} \cdot s_{stan} \cdot H_{rail}}{2 \cdot \left( e_{y,base}^2 + e_{y,base} \cdot c_{c_y,b} + c_{c_y,b}^2 \right)} = 9 \cdot \text{kN} \]

**Shear**

\[ P_{v,b} = \frac{1}{4} \left( \gamma_{Q1} \cdot q_{lk} \cdot s_{stan} \right) = 0.5 \cdot \text{kN} \]
Allowable load on one bolt

Tensile \[ F_{t.b.alw} = 49 \cdot kN \]
Shear \[ F_{v.b.alw} = 27 \cdot kN \]

Unity check \[ u_{c.b,l} = \left( \frac{F_{t.b}}{F_{t.b.alw}} \frac{F_{v.b}}{F_{v.b.alw}} \frac{F_{v.b}}{1.4 F_{t.b.alw}} \right) = (0.19 \quad 0.02 \quad 0.15) \]

8.4 Strength of the flanges

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

Diameter hole \[ d_{g,l} = 14 \cdot \text{mm} \]
Diameter washer \[ d_{r,l} = 40 \cdot \text{mm} \]

Laminate around the holes for the bolts

 Allowable stress in tiny direction \[ \sigma_{y.f.alw} = \frac{\sigma_{y.f}}{\gamma_{m.ULS} \cdot \gamma_{cs,l}} = 156 \cdot \text{MPa} \]
 Allowable shearstress in xy plane \[ \tau_{xy.f.alw} = \frac{\tau_{xy.f}}{\gamma_{m.ULS} \cdot \gamma_{cs,l}} = 50 \cdot \text{MPa} \]
 Allowable shearstress in yz plane \[ \tau_{yz.f.alw} = \frac{\tau_{yz.f}}{\gamma_{m.ULS} \cdot \gamma_{cs,l}} = 20 \cdot \text{MPa} \]

Compressive stresses

Stress concentration factor \[ K_C = \left( \frac{d_{g,l}}{d_{h,l}} \right)^2 = 1.36 \]
Compressive stress \[ \sigma_{f.b,y.c} = \frac{F_{v.b} \cdot K_C}{d_{g,l} \cdot tf} = 2.2 \cdot \text{MPa} \]

Unity check \[ u_{c.b,\sigma_{yc}} = \frac{\sigma_{f.b,y.c}}{\sigma_{y.f.alw}} = 0.01 \]

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 \[ \sigma_{f.b.y.t} = \frac{K_t \cdot F_{v.b}}{(c_c.x.b - d_{g,l}) \cdot tf} = 1.7 \cdot \text{MPa} \]

Unity check \[ u_{c.b,\sigma_{yt}} = \frac{\sigma_{f.b.y.t}}{\sigma_{y.f.alw}} = 0.01 \]
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 bottom side 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

<table>
<thead>
<tr>
<th>Total number of rods</th>
<th>n_d = 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of load bearing rods in x direction</td>
<td>n_d,x = 2</td>
</tr>
<tr>
<td>Number of load bearing rods in y direction</td>
<td>n_d,y = 4</td>
</tr>
<tr>
<td>Diameter rods, metric</td>
<td>d_d = 24·mm</td>
</tr>
<tr>
<td>Diameter washer</td>
<td>d_d,r = 72·mm</td>
</tr>
<tr>
<td>Material class</td>
<td>Klasse_d = 8.8</td>
</tr>
<tr>
<td>Diameter hole</td>
<td>d_g,d = 32·mm</td>
</tr>
<tr>
<td>Edge laminate - hole distance</td>
<td>e_d,x = 100·mm</td>
</tr>
</tbody>
</table>

Load per rod

\[ F_{v,x,LC1} = \frac{\gamma Q \cdot Q_h k_{Q_h}}{n_{d,x}} = 3 \cdot \text{kN} \]

\[ F_{v,y,LC1} = \frac{\gamma Q \cdot Q_h k_{Q_h}}{n_{d,y}} = 2 \cdot \text{kN} \]

Allowable shear force on one rod

\[ F_{v,d,alw} = 112 \cdot \text{kN} \]

Unity check

\[ u_{c_d} = \left( \frac{F_{v,x,LC1}}{F_{v,d,alw}} \frac{F_{v,y,LC1}}{F_{v,d,alw}} \right) = (0.03 \ 0.01) \]
8.6 Strength of the support flanges

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

Allowable stress in x direction
\[ \sigma_{x,sf,alw} = \frac{\sigma_{x,sf}}{\gamma_{m,ULS} \cdot \gamma_{cs,l}} = 156 \text{ MPa} \]

Allowable stress in y direction
\[ \sigma_{y,sf,alw} = \frac{\sigma_{y,sf}}{\gamma_{m,ULS} \cdot \gamma_{cs,l}} = 156 \text{ MPa} \]

Allowable shear stress in xy direction
\[ \tau_{xy,sf,alw} = \frac{\tau_{xy,sf}}{\gamma_{m,ULS} \cdot \gamma_{cs,l}} = 50 \text{ MPa} \]

Compressive stress

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

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

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

Unity check
\[ u_{csf,\sigma} = \left( \frac{\sigma_{sf,x,c}}{\sigma_{x,sf,alw}} \frac{\sigma_{sf,y,c}}{\sigma_{y,sf,alw}} \right) = (0.12 \ 0.06) \]

Tensile stress

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

Loaded width
\[ B_{eff,d} = d_{g,d} + 2 \cdot e_{x,d} = 232 \text{ mm} \]

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
\[ \sigma_{sf,x,t} = \frac{K_t \cdot F_{v,x,LC1}}{(B_{eff,d} - d_{g,d}) \cdot t_{sf}} = 11 \text{ MPa} \]

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

Unity check
\[ u_{csf,\sigma} = \left( \frac{\sigma_{sf,x,t}}{\sigma_{x,sf,alw}} \frac{\sigma_{sf,y,t}}{\sigma_{y,sf,alw}} \right) = (0.07 \ 0.03) \]

Shear stress

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

Unity check
\[ u_{csf,\tau} = \frac{\tau_{sf,xy,s}}{\tau_{xy,sf,alw}} = 0.03 \]
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 \( V_{\text{tot}} = 1.77 \cdot m^3 \)

Density of fresh water \( \rho_{\text{fresh\ water}} = 1000 \frac{\text{kg}}{m^3} \)

Buoyancy force \( F_b = V_{\text{tot}} \cdot \rho_{\text{fresh\ water}} \cdot g = 17.31 \cdot kN \)

Weight of the bridge \( W_b = M_{\text{tot}} \cdot g = 18.15 \cdot kN \)

Uplift force \( F_{\text{uplift}} = F_b - W_b = -0.84 \cdot kN \)

The weight of the bridge equals 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

\[ F_{v,l} = \frac{1}{2} \cdot \gamma_Q \cdot q_{k} \cdot B_{eff} \cdot L_0 = 31 \cdot kN \]

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

\[ F_{h.x.abutment.1} = \gamma_Q \cdot q_{hk,q} = 7 \cdot kN \]

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

In lateral direction per abutment

\[ F_{h.y.abutment} = \frac{1}{2} \cdot \gamma_Q \cdot q_{hk,q} = 3 \cdot kN \]
## 10 Conclusion

### SLS results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>First eigenfrequency Unloaded</td>
<td>$f_{0,\text{unloaded}} = 3.9 \cdot \text{Hz}$</td>
</tr>
<tr>
<td></td>
<td>Loaded</td>
</tr>
<tr>
<td>Deformations</td>
<td>LC1</td>
</tr>
<tr>
<td>Maximum gradient</td>
<td>$\varphi_{\text{max}} = 2.8 \cdot %$</td>
</tr>
<tr>
<td>Average gradient</td>
<td>$\varphi_{\text{avg}} = 1.1 \cdot %$</td>
</tr>
</tbody>
</table>

### ULS results

<table>
<thead>
<tr>
<th>Component</th>
<th>Moment</th>
<th>Shear</th>
<th>Compression</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topskin</td>
<td>$u_{\text{cts},\sigma} = 0.29$</td>
<td>$u_{\text{w},\tau} = 0.78$</td>
<td>$u_{\text{w},\sigma} = 0.33$</td>
</tr>
<tr>
<td>Bottomskin</td>
<td>$u_{\text{bs},\sigma} = 0.34$</td>
<td>$u_{\text{w},\tau} = 0.78$</td>
<td>$u_{\text{w},\sigma} = 0.33$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sub-component</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bolts of the railing</td>
<td>$u_{b,\text{l}} = (0.19 \ 0.02 \ 0.15)$</td>
</tr>
<tr>
<td>Flange</td>
<td>$u_{\text{f},\text{b},\sigma c} = 0.01$</td>
</tr>
<tr>
<td>Threaded Rocks</td>
<td>$u_{d} = (0.03 \ 0.01)$</td>
</tr>
</tbody>
</table>

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

### Total thermal expansion/contraction of the bridge

<table>
<thead>
<tr>
<th>Direction</th>
<th>Expansion</th>
<th>Contraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>$\Delta L_{\text{deq},\text{exp}} = 6.5 \cdot \text{mm}$</td>
<td>$\Delta L_{\text{deq},\text{con}} = 3.9 \cdot \text{mm}$</td>
</tr>
<tr>
<td>Width</td>
<td>$\Delta B_{\text{deq},\text{exp}} = 1.8 \cdot \text{mm}$</td>
<td>$\Delta B_{\text{deq},\text{con}} = 1.1 \cdot \text{mm}$</td>
</tr>
</tbody>
</table>

### Total thermal expansion/contraction for the dilatations

<table>
<thead>
<tr>
<th>Direction</th>
<th>Expansion</th>
<th>Contraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>$\Delta L_{\text{dil},\text{exp}} = 8.6 \cdot \text{mm}$</td>
<td>$\Delta L_{\text{dil},\text{con}} = 5.9 \cdot \text{mm}$</td>
</tr>
<tr>
<td>Width</td>
<td>$\Delta B_{\text{dil},\text{exp}} = 2.4 \cdot \text{mm}$</td>
<td>$\Delta B_{\text{dil},\text{con}} = 1.7 \cdot \text{mm}$</td>
</tr>
</tbody>
</table>
Project Gallery

Cycleway Bridges .............................................. 78
Golf Bridges ...................................................... 104
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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: 4 x 2.45m 1 x 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

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

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.

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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
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

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
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

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
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

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

---

<table>
<thead>
<tr>
<th>Project Number: 13-099</th>
</tr>
</thead>
</table>

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

**Project number: 11-030**

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

**Project Number: 12-062**

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

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

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
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.)

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 Ventura 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: -
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.

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

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
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
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

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
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.
How can we help?

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