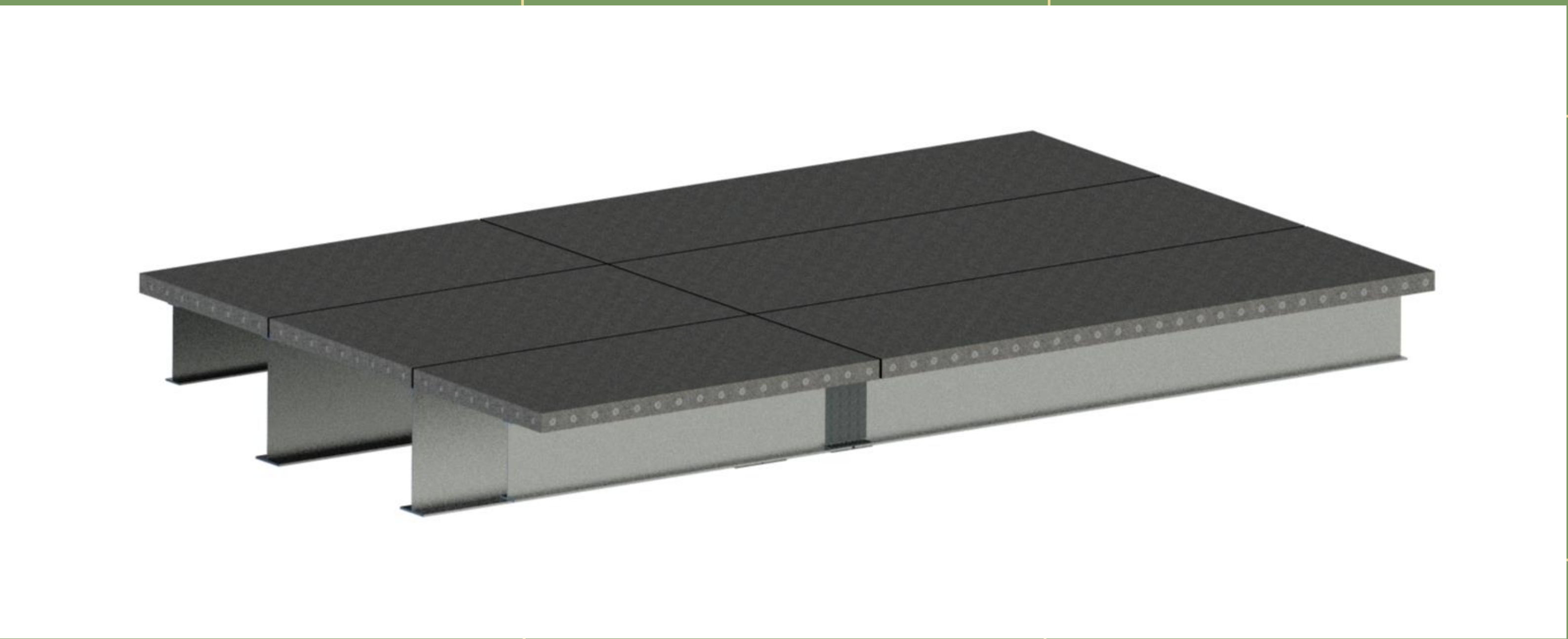
A Modular and Sustainable Steel Superstructure for a Highway Overpass



Jinse Schoorl

A Modular and Sustainable Steel Superstructure for a Highway Overpass

Thesis report

by

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to obtain the degree of Master of Science
at the Delft University of Technology
to be defended publicly on May 27, 2024

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Preface

Before you lies the master thesis ”A Modular and Sustainable Steel Superstructure for a Highway Overpass”. It is the final contribution to the master Structural Engineering, which is part of the Civil Engineering master, at the Delft University of Technology in Delft, the Netherlands. This thesis is the product of dedicated work on research and writing from May 2023 until May 2024.

As I became more familiar with civil engineering, I realised the field is constantly in development. Therefore, I wanted to investigate an actual topic on which I could apply the knowledge learned during my studies. Where at first the scope of the research appeared to me broad, I found out that gaining knowledge allows you to narrow down the scope during the research process. I was also able to use and apply the different skills developed during my study period in my master thesis, ranging from Multi-Criteria Assessments to structural calculations and from literature study to environmental impact calculations. In conclusion, I have learned valuable lessons during the research and writing of this thesis and gained understanding on multiple, relevant topics in engineering.

I would like to thank my daily supervisors, Dr. Trayana Tankova and Ir. Job van Heusden, for the valuable support and feedback. Their experience and suggestions allowed me to improve my work and helped me to include aspects I may not have thought about myself. I would also like to thank the members of my thesis committee: Prof. dr. Milan Veljkovic, Dr. Florentia Kavoura and Dr. Sandra Barbosa Nunes, and Dr. Mauro Poliotti, who was involved in the committee until April. Their advice has helped me to develop new insights and stay on course during my research. I would like to thank all the colleagues at Sweco for their help with my research and the interesting conversations.

Lastly, I want to thank my family and friends for their support during the research and writing of my thesis. To the reader, I hope that you enjoy this thesis and find inspiration for your own projects.

Jinse Schoorl

IJmuiden, May 18, 2024

Abstract

Due to the transition towards a circular economy, sustainable design strategies are growing in importance. An example of such a strategy is IFD: Industrial, Flexible and Demountable design. This design strategy has been developed recently and focuses on modular designs that can be changed in shape and whose components can be demounted and reused. Given the increasing interest in IFD, this thesis aims to investigate how the principles of IFD can be applied in the design of a sustainable superstructure for an overpass. The goal is to assess which structural system is best for use in a sustainable IFD overpass and to determine how the overpass can be converted into a modular overpass by focusing on connections and module dimensions. To demonstrate the potential of the IFD design, the sustainability benefits of the overpass are evaluated.

Through a review of literature on IFD and similar design strategies, guidelines were formulated that are relevant for overpasses. Based on the guidelines, designs for three structural systems were developed using a preliminary design approach. These designs were assessed on their environmental impact and compliance with IFD principles. The environmental impact was quantified using Life-Cycle Assessment data, which was converted into an Environmental Cost Indicator. The compliance with IFD principles was assessed by performing a Multi-Criteria Assessment. Then, a literature study on the connections was performed to investigate the different options. The focus was on the demountability and reusability of the connections. Regarding the most important connection, the shear connection between the deck and girders of the structure, a finite-element model was made to evaluate the effects of different shear connectors on the structural behaviour. To be able to use the connectors in the model, an elastic limit was imposed to ensure demountability and reusability; small adjustments were made on the reported behaviour of the connectors using a parametric study. For the other connections, their feasibility was proved by development of possible design solutions. The sustainability benefits of the final design were evaluated using the Environmental Cost Indicator.

The study showed that, of the three possible designs, the Composite alternative results in the lowest environmental impact. Regarding the MCA on the IFD principles, the Orthotropic alternative performs slightly better than the Composite alternative. The conclusion was that, in terms of the overall behaviour, the Composite alternative is the best. For the shear connection, the number of relevant shear connectors was reduced to four by considering the tolerances for assembly and the protrusion of connectors from the main elements of the structure. From the four remaining connectors, the Embedded Coupler Device connection without injected resin was found to be the most favourable, due to it requiring the lowest number of connectors in the serviceability limit state. For the steel girder connection, a shear-loaded bolted connection was proposed; shear keys were found to be a good solution for the deck connection. Moreover, module dimensions were determined based on sustainability considerations and IFD principles, leading to the final design.

The proposed design shows that IFD principles can successfully be applied to come to a design for an overpass. The use of a small selection of modular elements and demountable connections creates a flexible design, which complies with all the IFD principles. By application of a structural system with a low environmental impact, sustainability of the design is also accounted for. The IFD design is competitive in situations where the overpass is extended or when it is disassembled and reassembled, since for these scenarios it ends up with the lowest overall environmental impact. This leads to the recommendation to use IFD design in situations where flexibility and reusability are advantageous.

Contents

List of Figures

List of Tables

List of Abbreviations

ADPE	Abiotic depletion potential for non-fossil resources
ADPF	Abiotic depletion potential for fossil resources
AP	Acidification potential
BB	Blind Bolt
CLST	Cross-Laminated Secondary Timber
CSP	Coiled Spring Pin
DENB	Double-Embedded Nut Bolt
DfD/A	Design for Disassembly and Adaptability
DHS	Demountable Headed Stud
EC	Eurocode
ECD	Embedded Coupler Device
ECI	Environmental Cost Indicator
EIB	Economisch Instituut voor de Bouw
EP	Eutrophication potential
EPD	Environmental Product Declaration
FAETP	Eco-toxicity potential, freshwater
FLM	Fatigue Load Model
FLS	Fatigue Limit State
FRP	Fibre-Reinforced Polymer
GWP	Global Warming Potential
HSFGB	High-Strength Friction Grip Bolt
HTP	Human toxicity potential
HWO	Handboek Wegontwerp
IFD	Industrial, Flexible and Demountable
iSRR	Injected Steel-Reinforced Resin
LBDSC	Locking-Bolt Demountable Shear Connector
LCA	Life-Cycle Assessment
LM1	Load Model 1
LNSC	Locking-Nut Shear Connector
MCA	Multi-Criteria Analysis
MKI	Milieukostenindicator
NMD	Nationale Milieudatabase
ODP	Depletion potential of the stratospheric ozone layer
POCP	Formation potential of tropospheric ozone
ROA	Richtlijn Ontwerp Autosnelwegen
ROK	Richtlijn Ontwerp Kunstwerken
SENB	Single-Embedded Nut Bolt
SLS	Serviceability Limit State
ULS	Ultimate Limit State
WDSC	Welded Demountable Shear Connector

I

Research Framework

1
Introduction

1.1. Relevance

The Netherlands is heading towards a circular economy. In 2016, the Dutch government announced a national programme to fulfil the transition towards a circular economy by 2050 [1]. Every part of society is involved in this process, which includes the construction industry. In comparison with the government the goals of the construction industry are even more ambitious, as Rijkswaterstaat aims to develop a circular practice by 2030 [2]. The need for this is clear: the Dutch construction industry is responsible for an estimated 50% of the material usage and approximately 35% of the CO2-emissions [1].

The ambition is not only theoretical: circular design has been put into practice already. There are several examples of this, one of which is the SBIR-invitation issued by Rijkswaterstaat. The SBIR-invitation is a challenge proposed to the market to come with innovative circular solutions [3].

The SBIR-invitation shows that there are multiple ways to come to a circular practice. One of the methods is IFD: Industrial, Flexible and Demountable design. Like many circular design approaches, IFD is increasing in importance due to the ambitions regarding a circular economy. This is illustrated by the ambition of the province of Noord-Holland to design all their bridges according to IFD principles [4]. Though IFD design is seen more often, as IFD has become relevant only recently, the field is very much in development. As a result, the scope is often broad, leading to a collection of guidelines that serve many applications, including non-civil applications. For civil structures, two NTAs have been developed in the Netherlands that list guidelines and points of attention for IFD design, yet, as they focus specifically on movable bridges and fixed concrete overpasses, they may not be as relevant for other types of bridges and overpasses. Hence, considering that a vast amount of guidelines or methods exist that are in some form related to IFD, it is important to review these and focus on the guidelines and methods that are relevant specifically for overpasses and bridges. That IFD is a recent development, is also seen in the limited number of examples that exist. Most structures are designed as temporary bridges and not specifically IFD structures. Moreover, they are not always applicable for use in highways, where a significant number of bridges and overpasses is located. An exception is the Circular viaduct, a pilot project initiated by Rijkswaterstaat. This project provides valuable insights in the possibilities and challenges of an IFD design.

Apart from the circular economy, there is another aspect that requires attention. This is the expected growth of projects within the scope of Replacement & Renovation (Vervanging & Renovatie in Dutch). In the coming years, there will be an increasing number of structures that require renovation or replacement, due to them reaching the end of their design life. The extent of this Replacement & Renovation task has been quantified in a prognosis by Rijkswaterstaat: the costs to fulfil this task are expected to be four times higher for the period 2041-2050 compared to the period 2023-2030, visualised in Figure 1.1 [5]. The extent of the Replacement & Renovation task means that there is high demand for new, circular structures. This is where a design approach like IFD has potential. This potential comes not only in the form of the development of flexible and demountable structures, but also by modularity in the design. The high degree of modularity in the design allows for an efficient design process and can potentially reduce engineering costs and installation time.

As one of the three aspects of IFD demountability needs to be incorporated into a design. This requires connections that can easily be demounted. Whilst for steel structures this is common practice - bolted connections are commonly used in various structures - for other materials and most notably concrete, this is less straightforward. In case of the discussed steel-concrete composite structure the connection between the steel and concrete is of particular interest. Traditionally, this connection was created with non-demountable welded studs, yet in recent years various designs have been developed for demountable shear connectors, often utilising bolts. The focus of the existing research is mainly on the individual behaviour of the shear connectors, which is evaluated by performing tests. What is not yet clear is how these connectors

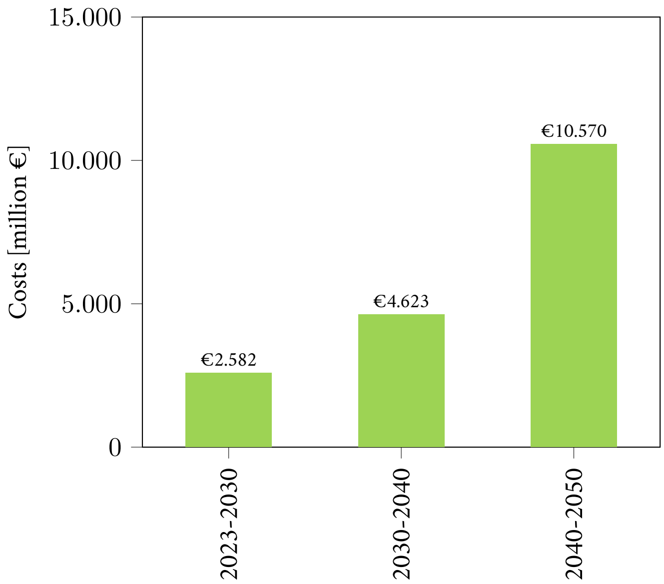


Figure 1.1: Cost prognosis Replacement & Renovation task [adapted from [5]]

behave in an IFD structure. To develop this understanding, it is important to consider the tested behaviour of these connectors in the context of an IFD structure.

1.2. Research formulation

1.2.1. Objectives

The aim of this research is to develop a design for an overpass that contributes to circularity and a more sustainable practice in infrastructure. The central theme is circularity, which comes forward in the design by following the strategy of IFD and the development of a modular structure. Following the application of the IFD design strategy, the first objective is to investigate what the IFD principles are and how they can be applied to optimise an overpass. The second objective is to translate the optimised preliminary design into modules and investigate and develop the connections. The third goal is to assess the benefits of the IFD design in comparison with conventional structures, where the emphasis is on benefits regarding sustainability.

1.2.2. Research questions

The main research question of this thesis has been defined as:

"How can a sustainable overpass be designed with the application of IFD principles?"

To support the main research question the following sub-questions are formulated:

- How can an overpass be optimised complying with IFD principles and using a preliminary design approach?
- What are the best dimensions for the modules and how can these be connected?
- What are the sustainability benefits of the IFD design in comparison with conventional solutions?

1.2.3. Research methodology

The research methodology is described for each of the four phases that can be distinguished in the research. The methodology is explained and graphically shown in Figure 1.2.

The first phase within this research focused on the definition of the requirements for the overpass and an investigation concerning the options for its design. For the requirements, the central theme was the design approach of IFD. Besides literature on IFD principles, publications on similar design approaches were consulted to come to a selection of guidelines and principles that focus on overpasses and bridges. The state-of-the-art regarding demountable structures was also studied. The investigation of the design options looked into the suitability of different materials for the use within an IFD structure. The aspects to consider were derived from the formulated IFD guidelines and principles. Based on the materials

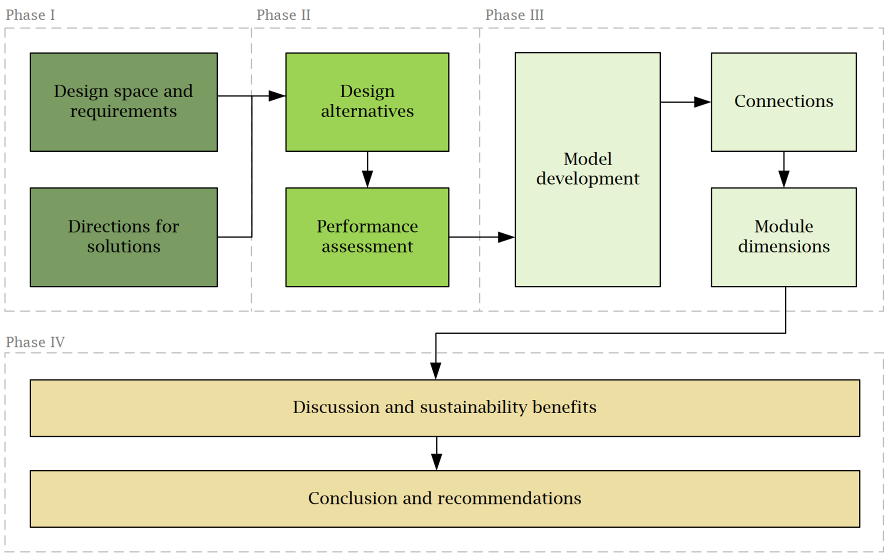


Figure 1.2: Research methodology

that are best applicable, the available structural systems were investigated. From this investigation three alternatives were chosen to explore further.

The objective of the second phase was to determine which of the three alternatives is best suitable as a sustainable IFD overpass. Dimensions were determined for the alternatives with hand calculations and using iterations, with the aim of approaching the optimal dimensions in terms of sustainability. The alternatives were then evaluated on their performance on two aspects: sustainability and IFD principles. Sustainability was assessed by calculating the so-called Environmental Cost Indicator (ECI), which monetises the environmental impact. The environmental impact data was retrieved from existing databases and through published Environmental Product Declarations (EPD). Based on the dimensions of the designs and the environmental impact data for the used materials, the ECI could be calculated to show the environmental impact of the full designs. IFD principles were assessed using a Multi-Criteria Assessment (MCA). The MCA is composed of a number of categories that have been derived from the literature review on IFD principles. The alternatives were scored on these categories quantitatively where possible, or otherwise qualitatively. After a normalisation of the scores, a final score was determined for each of the designs, which illustrates to what extent they comply with IFD principles. This phase concluded with a decision on which of the alternatives is most suitable as a sustainable IFD overpass.

The third phase concerned the details of the design. Through a state-of-the-art study on the relevant connections it was investigated which of the options are the most suitable in the context of an IFD overpass. The main focus was on the shear connectors between the concrete deck and the steel girders. An explanation of the choice for prestressing reinforcement to form the longitudinal joint between the concrete deck plates, which was already included in the design alternatives, was also provided. To determine which of these connectors is best, a finite-element model was created using SCIA Engineer to simulate the behaviour of the structure with the connectors. To be able to build this model, it was necessary to translate test results of shear connectors into input for the model. This was done by determining what behaviour is expected from the connectors and with the help of a parametric study that had been performed on a selection of the shear connectors. Then, based on the verification that was governing for the structure, the most suitable connector was determined. The other connections were designed and verified to prove the validity of the assumptions regarding the connections in the model. The concrete deck connection was verified by combining hand calculations with the finite-element model and with reference to the Circular viaduct; for the steel girder connection a design was made using the finite-element based IDEA StatiCa software. With all connections known, it was possible to determine dimensions for the modules that form the structure. The dimensions were determined based on the sustainability dimensions, translated into the slenderness of the elements and their costs. The conclusion of this phase was the full design.

For the fourth phase it was discussed what the implications of the design are, regarding the preliminary design and the connections. It was also assessed what the sustainability benefits of the IFD design are, in comparison with conventional solutions. Firstly, designs were formulated with similar dimensions for the different solutions. Then, three scenarios were distinguished that highlight a benefit of IFD. Lastly, for each of the scenarios the environmental impact of the different solutions was calculated by using the ECI. The final part of this phase concerned the concluding remarks. Recommendations for further research and future use were also provided.

1.2.4. Delimitations

Due to the limited time available, some delimitations are formulated that indicate which aspects are considered and which are not part of the research.

- The design is made for the main structural components of the superstructure, which is the structure that is placed on the supporting structures. Accordingly, the substructure and non-structural elements, e.g. guardrails or edge panels, are not designed. One of the reasons for this delimitation is that the environmental impact of the superstructure is larger than the impact of the substructure [6]. This means that more improvements can be made regarding the superstructure. Furthermore, there might be possibilities for reuse of existing substructures after removal of their current superstructure, as is shown by a project by Antea [7].
- The design is designed as a simply supported system. As the load-bearing behaviour of the structure will always be similar, optimisation in terms of the structural system and material usage is more straightforward, especially considering the variability in spans that can be connected. It is also favourable for the behaviour of the structural systems that are considered. The use of simply supported systems still allows for the creation of multiple spans. Several simply supported systems can be used to create these spans, with the notion that no changes are needed to the system. Erection of these spans may also be more convenient when using simply supported systems.
- Dynamic effects are not considered.
- Extreme events, e.g. fire or collisions, are not included in the design.
- Environmental influences due to wind and snow are not included in the design.

1.3. Thesis structure

Part I describes the research framework. Part II concerns the study phase, where the design space and requirements are discussed, followed by a literature review and the formulation of design options. Part III is the preliminary design. In this phase the design alternatives are explained and their performance is evaluated. Part IV concerns the detailed design. First, the options regarding the connections are investigated, after which the design is further developed and connections are verified. The dimensions of the modules are also determined. The final part is part V, where the implications of the design are discussed and it is illustrated how the performance of the design is regarding environmental impact. A conclusion and recommendations are also present in this part.

II

Study Phase

2

Design Space and Requirements

Inherent to an IFD overpass is the flexibility in application. Hence, an overpass that can be used in as many situations as possible is preferable. However, as various variables are involved in the design of an overpass, many different configurations are possible and it is inefficient to develop one design that can be used for all these configurations. Accordingly, the design space describes the range of configurations to which the design is applicable. Following this range, requirements have been formulated, which the designs should meet.

2.1. Design space

In the Netherlands, 64% of all existing overpasses is located within a highway [8]. Thus, in order to design an overpass that can be used in the majority of situations, the design adheres to highway requirements. As this is the most demanding application, it is still possible to use the design for other applications.

When investigating the different spans of viaducts within highways, it is found that not all spans are as common as others. A study on existing overpasses shows that the most prevalent are overpasses with a span range of 12-32 m, representing an estimated 75% of the total [9]. As a result, it was decided that the design needs to accommodate spans in a range of 12-32 m.

Apart from the span, the width of the overpass is also variable. The width of the overpass is directly dependent on the road cross-section. As a result, several widths can be expected to occur more frequently than others. With the majority of the overpasses located within highways, the cross-section is defined following highway layouts. It is decided to split the two directions of the road, for this requires a smaller width. In the Netherlands, most highways feature two or three lanes per carriageway, which is illustrated by Figure 2.1. Consequently, a two-lane or three-lane layout should be possible. Additionally, a layout with one lane per carriageway, to be used as parallel lanes for instance, should be possible to increase the potential for use. It is also decided to incorporate a two-lane layout for secondary roads (N-wegen in Dutch). The maximum width considered is a layout with three conventional lanes and a parallel lane, which is slightly larger than a regular four-lane layout. Although various layouts will be possible if the maximum width equals the (3+1)x1-layout, the priority is on the layouts of 2x1, 3x1 and 4x1 for highways and a 2x1 for secondary roads.

2.2. Design requirements

2.2.1. General principles

An overpass is to be designed for consequence class 3 in case it is located either within or over a main road [11]. Since this is the case for a significant number of overpasses within the design space, the overpass is designed according to consequence class 3.

Normally, the design life of highway structures is 100 years. However, to increase the potential of the IFD design, it is designed for a design life of 200 years. This design life is chosen as it is common for the design of circular structures. It has been applied for the example of the Circular viaduct, which is discussed in section 3.2 [12], and it was formulated as the upper limit for the design life in the following SBIR invitation [3].

Relevant material properties are listed in appendix A. These materials include steel, concrete, reinforcement steel and prestressing steel.

With regard to the verification of the design, Load Model 1 from EN 1991-2 is used for ultimate limit state (ULS) and serviceability limit state (SLS). As prescribed by the Dutch ROK (Richtlijn Ontwerp Kunstwegen), fatigue load model 4a

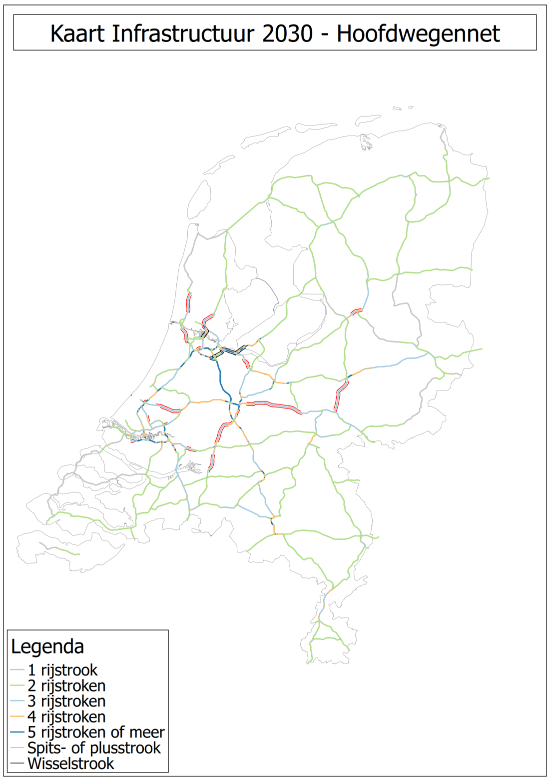


Figure 2.1: Map of the proposed main road network in the Netherlands for 2030 [10]

(FLM4a) is used for steel bridges and overpasses to verify the fatigue limit state (FLS) [13]. Details on the load models and the values used for the loads, load factors and combination factors can be found in appendix A.

2.2.2. Layout

The layouts of concern are 1x1, 2x1 (secondary), 2x1 (main), 3x1, 4x1 and (3+1)x1. Based on the requirements formulated in the Dutch ROA (Richtlijn Ontwerp Autosnelwegen) and HWO (Handboek Wegontwerp) Stroomwegen the width required for these road layouts is determined [14, 15]. This results in the widths for the layouts as shown in Table 2.1. It is evident that layouts that are not explicitly mentioned are possible as well, depending on the design of the overpass. Appendix A can be consulted for insight into the determination of the numbers in Table 2.1.

Table 2.1: Road layout with corresponding width

Layout	Road type	Width [m]
1x1	main	11,20
2x1	secondary	12,95
2x1	main	14,70
3x1	main	18,20
4x1	main	21,70
(3+1)x1	main	22,15

3
Literature Review

This chapter describes existing literature on the topic of research of IFD. First, IFD and similar design approaches are investigated and translated into guidelines. Then, examples of demountable bridges and overpasses are discussed.

3.1. IFD

3.1.1. Principles of IFD

IFD is a Dutch term and stands for *Industrieel, Flexibel en Demontabel*; which translates into the equivalent terms *Industrial, Flexible and Demountable*. IFD is a design strategy that can be used in the design and development of circular and re-usable structures. As explained, the strategy is centred around three principles. Even though each principle addresses a specific aspect of the design, they are related to each other.

Industrial

This principle, in short, can be defined as the use of standardised and prefabricated elements [16]. It also relates to modularity. Use of standardised elements limits the number of different elements and allows for the creation of various configurations. Moreover, the reuse potential of components is increased. Inherent to the use of prefabricated elements, all elements are made off-site and that the on-site construction activities are limited to the assembly of the different components. Advantages of implementation of this principle include monitoring of product quality, good availability of components and a standardised design process [17].

Flexible

Flexible means that a structure is designed such that it is extendable and adaptable. In the context of infrastructure this means a structure can be adapted to the functional requirements, both during the initial design and during the use phase, for instance when the capacity of the road that makes use of the structure has to be increased. Flexibility in a design can prevent replacement of a design when the functional requirements have changed, as the structure can be altered to meet the new functional requirements, thus extending its lifespan.

Demountable

The principle of demountability is a means to facilitate reuse of structural components or structures. Demountability is strongly related to the connections between members. By creating a demountable structure, it is possible to reuse components from a structure in a new structure and to replace components if their quality is insufficient. It also contributes to flexibility in the design.

Potential of IFD

The potential of IFD depends on certain factors. The Economisch Instituut voor de Bouw (EIB) distinguishes four factors that are decisive in the successful application of IFD [18]:

1. *Functional design*: a design that focuses on functionality and is standardised in contrast to iconic.
2. *Normal technical conditions*: the degree in which technical conditions on-site are special, which would require specific solutions. Technical conditions can, for instance, relate to soil conditions.
3. *Different lifespan of components*: for components with a lifespan shorter than other components of a structure, it is beneficial to facilitate independent replacement of these components. The most relevant examples are in movable bridges.
4. *High traffic intensity*: due to the high degree of prefabrication of IFD elements the construction time is reduced in comparison with structures that are constructed in-situ.

The EIB states that factors 1 and 4 are relevant for overpasses and provide opportunities for the use of IFD. Factor 3 is less relevant, as there is less need for intermediate replacement of overpass components. However, in the end-of-life, there could be opportunities for reuse. With regard to factor 2, the conditions are naturally site specific, and therefore it is not evident whether limitations are imposed. Specifically for the superstructure, though, technical conditions are not expected to be very challenging.

The potential for IFD is graphically presented in Figure 3.1, which shows that the large number of overpasses (viaduct) in combination with the relatively high potential for IFD makes that overpasses show potential for the application of IFD.

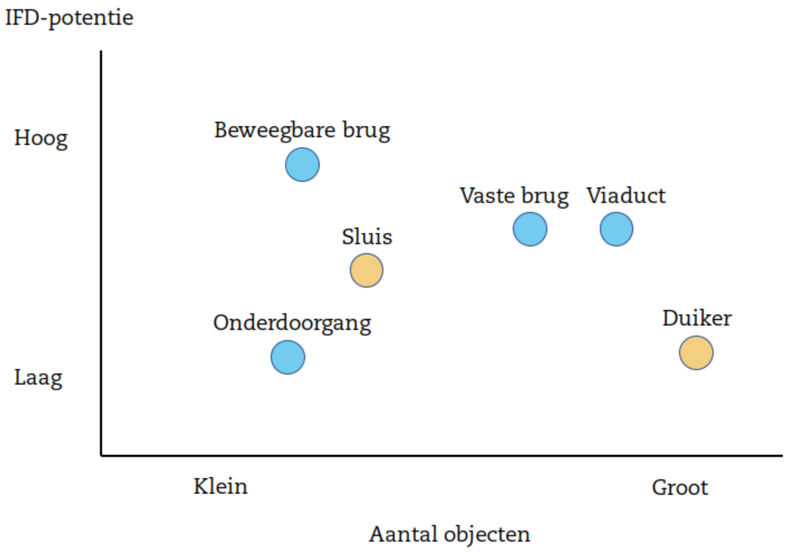


Figure 3.1: Graph with the potential for IFD plotted vs the number of objects [18]

When the principles of IFD have been applied appropriately, several benefits can be created. The following advantages can be achieved, provided that the design is widely applicable [16]:

- Re-usability of materials.
- Prevention of residual waste.
- Reduction of failure costs by controlled manufacturing conditions.
- More efficient and more economic design.
- Reduction in traffic hindrance during execution.
- More flexibility to change the layout of the structure.
- Improved availability of spare parts.

Design life vs. Functional life
Although IFD has numerous advantages, there is a disadvantage in that generally more material is used in comparison with conventional structures. This is the result of the fact that it should be possible for IFD structures to be used in various situations, hereby reducing the potential for optimisation of a specific design. IFD structures have more potential if they are designed with a long design life. Design life in this context means that a structure, from a structural point of view, can be used without significant changes. It is different from functional life. Functional life (or service life) is the period in which the functional requirements align with the function the structure can serve. Well-designed structures generally have a design life equal to the functional life. In practice, though, the functional life of overpasses is often shorter than the design life. The result of this is that the overpass is not used anymore, although it still has sufficient design life. Consequently, by designing for a long design life, the demountable components of an IFD overpass can be reused in a different structure and last for multiple functional lives.

3.1.2. Other design strategies

Guideline for Circular Construction
Circular construction gains importance in the construction industry, given the desire for more sustainability in the sector. To contribute to this goal, Platform CB'23 has published a guideline for Circular Construction in collaboration

with various parties from the construction industry [19]. The guideline lists seven design strategies for circular design. Although all strategies are relevant for sustainable design, only the strategies that relate to IFD are discussed.

Design for quality and maintenance
This strategy focuses on the design of a structure that has a long design life and requires little maintenance. These aspects make that on the long-term less material is used and the environmental impact is reduced. Design for quality and maintenance can be achieved by purposely designing for long design life by using high quality materials and designing details carefully. Maintenance in particular is dependent on the details and the need for maintenance can thus be significantly reduced if details are properly designed.

Design for spatial-functional adaptivity
Spatial-functional adaptivity is explained as the ability to accommodate changes in function or use of space. Possible future changes to the structure should be accounted for by allowing for a change in layout or function. As such, it strongly resembles the aspect of *Flexibility* within IFD.

Design for demountability and re-usability
Design for demountability and re-usability focuses on the development of a design that consists of elements that can be demounted and reused, with the aim to reduce the use of primary materials in the future. The following guidelines can be used to accomplish this goal:

- *Design with demountable connections*: dry connections or connections with additional components (i.e. bolts) are preferred.
- *Ensure accessibility of connections*: make sure connections are accessible to allow for replacement and disassembly. Moreover, design connections in such a manner that they can be reached without damaging the structure.
- *Prevent unnecessary integration*: components with a different lifespan should be separated and the use of components composed of different materials should be limited.
- *Prevent 'lock-up' of connections*: connections of elements with a short lifespan should not be enclosed by members with a longer lifespan.
- *Take into account standardisation and modularisation*

The three mentioned strategies are not standalone. They can complement each other in creating a circular design. As with IFD, the strategies are related and contribute to the same goal.

Design for Disassembly and Adaptability
Similar to IFD, Design for Disassembly and Adaptability (DfD/A) is a design strategy that is used to increase sustainability in a design. The strategy is composed of different aspects that complement each other, equivalent to IFD.

Disassembly is equivalent to the term 'Demountable' featured in IFD. Five general principles can be derived [20]:

- *Ease of access to components and services*: components, in particular components with a short lifespan, should be easily accessible in order to allow for replacement and increase the ease of disassembly.
- *Independence*: the quality to allow components to be removed or upgraded without them affecting the performance of other components. Independence increases the degree of reuse and the adaptability of the structure.
- *Support reuse*: reuse firstly relates to the ability to reuse components of a structure. Components should be designed such that they can be reused easily and without many additional measures to be taken. Where re-usability is not possible, recyclability should be considered. In this instance, the materials are reused. Accordingly, there is a difference between re-using and recycling. Re-using is defined as the use of a component that has not undergone a recycling process, or, alternatively, as the use of a component that has not seen a significant change in its physical composition [21]. Recycling, on the other hand, is defined as components that are processed, often into smaller parts, to create a new component.
- *Simplicity*: simplicity is achieved by limiting the number of different materials and components. This facilitates repair, reduces the likelihood of failure and allows for a more standardised disassembly process.
- *Standardisation*: the use of standardised components relates to dimensions, components, connections and modularity. A high degree of standardisation accommodates simplicity, reuse and adaptability.

The term adaptability can be considered equivalent to the term *Flexibility* from IFD. For adaptability, three general principles have been defined, which aid in the development of adaptable structures [20]:

- *Versatility*: versatility can be described as the ability to accommodate changing functions of a system by only minor changes. The relevance of versatility for civil engineering practices is limited, as the function of an overpass or bridge is not expected to change. Only on a component level some degree of versatility can be beneficial.
- *Convertibility*: convertibility is achieved by making modifications to a system in order to accommodate substantial changes in user needs. Where it is most applicable to overpasses is in the ability to change the structure when the loading increases.
- *Expandability*: expandability relates to the ability to enlarge the capacity or increase the capabilities of a system by making substantial changes. The relevance of expandability is mainly in the increase (or decrease) of the capacity of an overpass.

3.1.3. Design guidelines

The principles of the IFD-terms, their equivalent DfD/A-terms and the circular design strategies are described and can be accounted for in different ways. To come to more specific requirements that can be pursued in the design, more action-based guidelines are formulated. The guidelines should be considered as possibilities to come to a design complying with IFD-principles rather than requirements; if a guideline is not pursued, the goal of the principle can still be met, albeit it to a lesser extent. For each guideline it is specified to which aspect of the design it is relevant: material, structure or connections. These are also the locations in this report where the guidelines are put into use.

Industrial

Inclusion of the aspect 'Industrial' in a design is not separately included in the DfD/A approach. It is considered as a principle for Disassembly, in the form of *Standardisation*. Hence, guidelines for the Industrial-aspect relate to *Standardisation* [22]:

- *Standardisation*
  - Use modular design. *Structure*
  - Use prefabricated components and a system of mass production. *Material*

Flexible

A limited number of guidelines for flexibility (or adaptability) is formulated. The fact that the function of the overpass will in principle not change reduces the need to include different forms of flexibility. Provided that the function will not change, the following guidelines are relevant [20]:

- *Versatility*
  - Use components or connections that can be used at different locations in the structure. *Connections*
- *Convertibility*
  - Accommodate changes in loading. *Structure*
- *Expandability*
  - Include the possibility to change the layout of the structure. *Structure*

Demountable

The guidelines for a demountable (or disassemblable) design are listed for each of the general principles of demountability. Although each guideline is listed once, it should be noted that the guidelines are complementary and contribute to other principles. The following guidelines are considered the most relevant [22, 23]:

- *Ease of access to components and services*
  - Ensure components can be reached without the need to dismantle other parts of the structure. *Structure*
  - Ensure that components with a short lifespan are not enclosed by members with a longer lifespan. *Structure*
- *Independence*
  - Use demountable connections: mechanical rather than chemical connections. *Connections*
  - Separate components with a different lifespan. *Structure*
  - Prioritise parallel (dis)assembly over sequential (dis)assembly. *Structure*
- *Support reuse*
  - Use recyclable materials. *Material*

- Use a minimum number of fasteners or connectors. *Connections*
- Design for durability and longevity. *Material*

• *Simplicity*

- Minimise the number of different types of components. *Structure*
- Use a minimum number of different fasteners or connectors. *Connections*

• *Standardisation*

- Use modular design. *Structure*
- Use prefabricated components and a system of mass production. *Material*

3.1.4. Practical implications

Convertibility

The guideline of *Convertibility* can have different definitions and requires some clarification on the interpretation of these definitions. A change in loading relates to traffic loading. The traffic can change on two aspects: intensity and magnitude.

The impact on the design in case of an increased intensity is mitigated on two levels: functionality and resistance. An increased intensity can result in a loss of functionality of the overpass, in case the capacity of the road on the overpass is insufficient. This problem can be overcome by the addition of a lane. The modular nature of the designs is what makes this possible. Resistance on the other hand is covered by designing for infinite fatigue life. Since a rather high number of load cycles is to be expected, the stresses need to be limited such that an infinite number of cycles can be exerted on an element or detail, thus allowing the structure to withstand an increase in intensity.

Although a small increase has been applied on the loads from the existing traffic load model to include some effects of traffic increase, an uncertainty still exists regarding future changes in load magnitude. Still, as it is not known how the loads on overpasses will develop and whether an increase in traffic loads will mean that the current load model the Eurocode prescribes is not valid anymore, it is decided not to include a change to the load model. Noteworthy is that research has been done into the validity of Eurocode load model 1. Zhou et al. [24] and Paeglitis and Paeglitis [25] both come to the conclusion that LM1 is more conservative than the investigated traffic data, of which the most recent are from 2010 [24, 25]. Although the data used for the validation is not necessarily representative for the situation described in this research, it shows that there is a margin between the actual traffic loads and the load situation LM1 describes.

It can be argued that strengthening is also a method to accommodate changes in loading. It is, however, decided not to include any specific strengthening measures, for the following reasons. Firstly, the use of modular and demountable design enables damaged components to be replaced easily, thus removing the need for measures with the application of strengthening damaged components. Secondly, changes to the nature of loading are a reason for strengthening. It has been argued that changes in intensity can be covered by the design through its modularity. Changes in magnitude, on the other hand, are not directly covered, yet it is uncertain whether these will occur and to what extent. Consequently, it is deemed unfeasible to develop specific strengthening measures for these situations.

Expandability and modularity

The guideline for *Expandability* needs some clarification, as changes to the layout can have multiple interpretations. The most relevant change to the layout would be the width. A variable width allows for the inclusion (or potentially removal) of a lane, hereby increasing the capacity of the overpass. Considering the guideline of *Modularity*, it is evident what the benefit is of including modularity within the width of the overpass. However, it also possible to do this for the length of the overpass. There are number of benefits to design multiple shorter modules instead of a more conventional approach of designing the overpass specifically for each separate length:

- When the overpass is divided into modules, there is more potential to reuse the components. Shorter elements can be used more easily in other structures due to the flexibility in dimensions that exists and without the need for significant adaptations to these elements. Larger elements limit the freedom of application and might even need to be modified to allow for reuse.
- The use of smaller modules means that the dimensions and the weight of the modules are reduced. This is advantageous for two aspects. The first aspect is transportation. Smaller modules are more convenient for transport, since large transports are avoided. The second aspect is the (dis)assembly. Smaller and, in particular, lighter modules are easier to assemble and allow for the use of lighter equipment. This saves on costs and increases the options for use in difficult environments, such as urban areas or locations with weak soils.

- The use of a small set of modules in comparison with specifically designed elements can reduce the time needed for engineering. Automated verification processes can be developed for the modules, resulting in a more efficient and economic design process.
- The availability of the modules is higher than for specific girders, as only a small number of modules exists. This is also beneficial in case of replacement of modules.
- It will be more easy to adapt to changes to the road or other features the overpass crosses, for instance if this road is widened. Although not a frequent requirement for an overpass, it will be possible and without the need for a completely new structure.
- Site conditions for an overpass can differ largely. The benefit of having shorter modules is that more options exist in adapting to these conditions. When, for instance, an overpass connects to a curved road, the dimensions of the overpass can more easily be adapted, resulting in a more efficient transition between the overpass and the connecting road. It is also possible to adjust the position of the abutment to the superstructure, creating more flexibility in the spatial arrangement.

3.2. Demountable bridges and overpasses

To illustrate the possibilities for IFD overpasses, a number of existing structures are investigated. Apart from the Circular viaduct, all examples in this section are originally designed as temporary structures, and they are mostly bridges. Due to the short use, for instance in case of natural disasters, these bridges are not operational for a long time and thus are removed relatively shortly after installation. Consequently, demountability is a desired property. Though not specifically IFD structures, the listed examples show various similarities with the IFD principles and are thus relevant for use as an IFD overpass.

Circular viaduct

Rijkswaterstaat and partners have developed a circular concrete overpass. The overpass consists of concrete modules that fit into each other by means of shear keys. The modules can be combined with prestressing reinforcement to form a strip of the desired span length. Multiple strips can then be combined and prestressed to form the width of the overpass, as illustrated by Figure 3.2. The modules are 2,5 m in length, 1,5 m in width and 1 m in height [26]. This means that spans can be created within intervals of 2,5 m. The overpass is designed for spans between 15 and 25 m. Two different modules are used: one general module and one adapted module at the end of each strip. In-situ concrete is used to fill spaces between the modules.

Figure 3.2: Circular viaduct [27]

Bailey bridge

The Bailey bridge (Figure 3.3) is one of the best known examples of a temporary bridge. The system, invented 80 years ago, makes use of square modules that, when assembled, form a truss-like structure to form the desired span [28]. The module assemblies are placed at either side of the span. An assembly can feature multiple modules in the thickness direction (a maximum of 4) and in the vertical direction (a maximum of 3) [29]. Between the assemblies crossbeams are installed on which the deck can be placed. The deck can be made from different materials. The modules are 3,05 m in width. With these modules spans of up to 67 m can be created for a one-lane width. It is also possible to incorporate more lanes into the design.

Figure 3.3: Bailey bridge [30]

Acrow bridge
The Acrow bridge is an improved version of the Bailey bridge. It follows the same principle: modules of 3,05 m in width can be stacked and connected side-by-side to form the bridge [29]. The difference is that the panels are 50% higher, compared to panels used in Bailey bridges, as can be seen in Figure 3.4. With this change two problems of the Bailey bridge are addressed: excessive sag and unnecessary steel at the neutral axis. The design can span up to 91 m and can carry three highway lanes.

Figure 3.4: Acrow bridge [31]

Mabey-Johnson bridge
The Mabey-Johnson bridge is another design based on the Bailey bridge, shown in Figure 3.5. It uses the same modules as the Bailey bridge, yet the height of the modules increases towards the middle of the span to follow the bending moment line and reduce the self-weight of the structure [29]. The design was also improved by applying increased camber.

Figure 3.5: Variant of Mabey-Johnson bridge, showing differing panel size along span [32]

GFRP truss girder bridge

The GFRP (Glass Fibre-Reinforced Polymer) truss girder bridge is a design for a modular bridge. It has not been constructed, yet tests have been performed on parts of the bridge that show promising results [33]. The bridge is composed of trusses at the two sides of the bridge. Each truss is composed of GFRP tubes that are connected near the crossing points, as shown by Figure 3.6. The joints are prestressed bearing type connections, meaning that bolts are not required. Forces are transferred by ensuring that the contact surface in the connection is permanently under compression. The trusses can be doubled at both sides to create more strength and stiffness. The deck is supported by the trusses and is formed by a GFRP grid floor deck. The distance between two joints in the truss is equal to 1,875 m. The bridge is designed for a limited width of 4,0 m, meaning that the design needs to be altered in order to allow for larger widths. The span the bridge was designed for is 30 m.

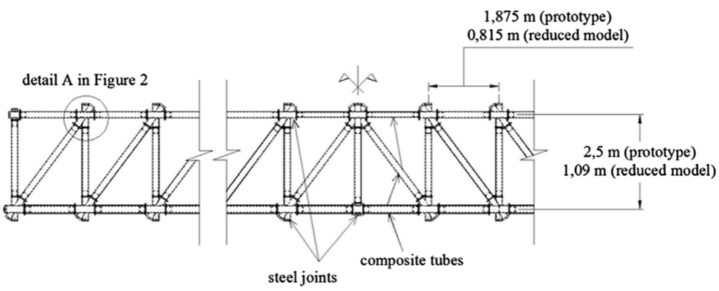


Figure 3.6: Schematic of GFRP truss girder bridge [33]

Modular plate girder bridge

Modular plate girder bridges are composed of steel modules, of which Figure 3.7 shows two. The modules can be combined in width and length direction to form the desired span of the bridge. Different types of the plate girder bridge exist, each with different module sizes [34]. One design features modules of 3,5 m width and varying lengths of 6 m, 9 m, 12 m and 24 m. Another design features modules of 2,5 m width with a length of either 10,5 m or 13,5 m. Both designs allow for the formation of multiple spans, with intervals of 3 m. For the first design the maximum span is 30 m, whilst for the second the span can be as long as 54 m. The modules are connected with various bolted connections. These include splice plate connections to connect the elements in the length direction. Variants exist where the modules are connected with pin connections.

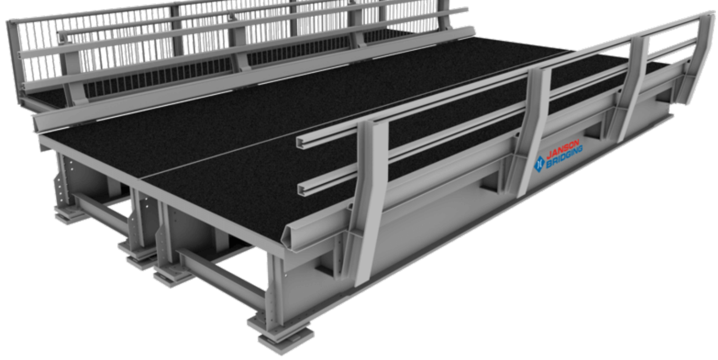


Figure 3.7: Modules of a modular plate girder bridge [34]

Modular girder bridge
Similar to the modular plate girder bridge, the modular girder bridge uses modules, girder elements, which can be combined to form the span [35]. Figure 3.8 shows a section of the girder bridge, which includes prefab concrete panels for the deck. Between the girders, stiffeners can be placed. With this configuration spans of up to 48 m can be constructed. The beam segments are connected using bolted splice connections.

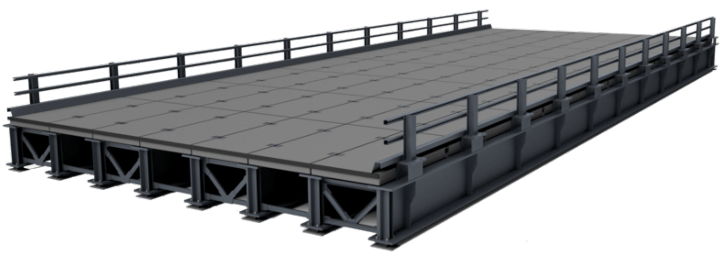


Figure 3.8: Section of a modular girder bridge [35]

3.3. Conclusion

This chapter has focused on existing literature regarding IFD. The principles of IFD were explained along with similar, yet slightly different design strategies. Based on these strategies design guidelines were formulated, divided over the three principles Industrial, Flexible and Demountable and attributed to the three aspects of the design Material, Structure and Connections. Apart from the theory behind IFD, examples of IFD structures and demountable structures were discussed, the majority of which are made from steel.

4
Design Options

The design options are investigated in this chapter. Firstly, different materials are investigated on aspects relevant to IFD, after which the possible structural systems for the materials of choice are examined.

4.1. Material

Each material has different characteristics. In the construction industry, the most common materials are steel, concrete and timber. These materials are therefore considered as options for the design. FRP (Fibre-reinforced polymer) is gaining interest as a construction material and is included as a fourth option. For each of the materials research is done regarding the suitability for use in IFD structures. The focus lies on the IFD guidelines that relate to the material (see section 3.1.3). These are standardisation, recyclability and durability.

4.1.1. Steel

Steel is a metal and as such an isotropic material, which means it has good mechanical properties as strength and stiffness in all directions, making it capable of carrying high loads in multiple directions. Steel also shows ductile behaviour, which is favourable from the point of view of safety.

Current use and standardisation

Steel is widely used in current structures, proving that it is a feasible material. Applications of steel include combinations with concrete, generally for shorter spans, but also on itself for longer spans. As steel is always prefabricated, standardisation is common. Notable examples are I-shaped profiles and hollow sections, though various different shapes are possible.

Recyclability

Steel is known as a well-recyclable material. Theoretically, steel is 100% recyclable. In reality, however, this cannot be achieved, due to factors such as loss because of corrosion and difficulties in retrieving the steel from demolition waste [36]. Nevertheless, the potential is high, which is shown by the fact that currently 85%-90% of the steel is recycled, considering that approximately 10% is even reused [37]. This means that only a small portion is processed as landfill. Furthermore, it is possible for recycled steel to have the same quality as the original steel [38]. This makes that down-cycling can be prevented.

Durability

The durability of steel is good on various aspects. Steel is resistant to chemical components and, as an inorganic material, also to natural influences. The main mechanisms that are of concern and can cause weakening or degradation of steel are corrosion and fatigue [39]. Corrosion weakens the steel, which results in less resistance. Fatigue is the result of varying stresses due to cyclic loading and can cause cracks in steel. Contrary to corrosion, it is related to stresses in the steel and can thus be considered a design feature. Steel is also sensitive to temperature changes, which may cause damage if not properly designed for. Corrosion can be prevented in different ways. One of the most applied options is to paint the steel elements, which can last 15 to 30 years [40]. Paint acts as a physical barrier between the steel and the atmosphere, hereby preventing the corrosion process from occurring. Corrosion under a proper paint layer is minimal, yet at locations where the paint is damaged corrosion will occur more substantially [41]. Hence, by ensuring an intact paint layer by performing repetitive maintenance, a very long design life is possible. Another method is galvanising, which is the process of applying a sacrificing material, zinc for instance, on steel. The applied material will be the material that corrodes and the steel will be protected. A design life up to 100 years is possible with this protection system. The problem with galvanising is that the most efficient galvanising process can only be performed in the factory and is not possible to apply in the field [40].

It can be concluded that design for longevity can be achieved by performing repetitive maintenance to protect the steel form corrosion and by properly designing for fatigue and thermal expansion.

4.1.2. Concrete

Concrete is known to have a good compression strength and requires little maintenance. The natural weaknesses of concrete are its low tensile strength and limited ductility. This is why reinforcement steel is used, as it resists tensile stresses and can incorporate some ductility. Concrete is rather heavy for the strength it provides, compared to other construction materials.

Current use and standardisation

Together with steel, concrete is one of the materials that is used the most for civil structures. In particular for shorter spans, concrete is a cost-effective option, though for longer spans concrete can be viable too. Its widespread use proves that concrete is a feasible option. Concrete can be made in-situ and by prefabrication. Prefabrication is the logical choice, as this allows for standardisation. Currently, this already exists in the form of, for example, box beams.

Recyclability

Due to the composite nature of concrete, recycling is more complex than for metallic materials. This is explained by the irreversibility of the chemical reactions between the concrete components [42]. As a result, the recycling of concrete is limited mostly to re-processing rather than a return to its original state. The main challenges that exist are related to the quality of the recycled aggregate. The quality is lower than of aggregate made from virgin material and due to the variation in quality of demolished concrete products, variation exists in the properties of the recycled aggregate [43]. Nonetheless, recycling of concrete is done, particularly in the form of recycled aggregate. Aggregate from virgin materials is replaced by recycled aggregate in the production of new concrete elements. Currently, research is done on concrete elements, where over 75% of their weight is waste material [44]. At the moment, however, the main destination of end-of-life concrete is down-cycling, for instance for use in road construction, and a small amount is processed as landfill [45]. Naturally, the share of end-of-life concrete used for recycling can increase if the quality of the products increases and the use of them proves to be cost-effective.

It can be concluded that recycling is possible and may become more viable in the future, yet more research on the matter needs to be conducted to allow for the production of added-value material [46].

Durability

With respect to the durability of concrete, the causes of degradation are of the following natures: chemical, physical and biological [39]. Chemical degradation is caused by chemical reactions of the concrete with compounds like chlorides or sulphates. These reactions can have different consequences, such as cracking of the concrete due to expansion or corrosion of reinforcement steel. Biological degradation is caused by by-products of bacteria and can have similar consequences as chemical degradation. Physical degradation occurs due to processes like shrinkage or freeze-thaw cycles.
Degradation can be prevented or strongly reduced by good design of the concrete. This includes optimising the concrete properties by using a specific concrete mix and quality and ensuring a sufficient concrete cover [47]. Additionally, surface treatment or corrosion-resistant reinforcement bars can be used to further protect the concrete structure [48]. Maintenance is important as well and should be done on a regular basis. When properly designed and maintained it is possible to reach service lives well over a 100 years [49].

In short, it is possible to create a durable structure using concrete by using surface treatments and other protective measures.

4.1.3. Timber

Timber is a natural and renewable material. It has a low self-weight, which, in combination with good strength properties, makes it possible to create strong and light structures. It is, however, anisotropic, which should be considered during design. Timber also has a lower stiffness than steel and concrete.

Current use and standardisation

Timber bridges or overpasses are mostly constructed for low-load applications, such as pedestrian bridges. Recently, timber road bridges are gaining more interest, due to the increased importance of sustainability in engineering. Existing examples show that timber is a good alternative to concrete and steel for low-load applications. For structures with heavier loads, the low stiffness makes it challenging to design timber structures. Nonetheless, timber can be a feasible option. For nearly all structures engineered wood products are used. These are standardised products that have improved mechanical properties compared to solid wood elements and can be produced on a large scale. Examples of these products are Cross-Laminated Timber and Glue-Laminated Timber.

Recyclability

Common practice for recycling of timber is the production of particleboard from chipped timber products, which is, in fact, down-cycling [50]. A requirement is that the timber is clean. Incineration is an alternative when this is not the case. Recently, recycling of timber into engineered wood products has gained interest. Rose and Stegemann have performed research into Cross-Laminated Secondary Timber (CLST) [51]. CLST is made partially with secondary timber and partially with primary timber. Separate plies are made from recycled timber, which can be used in combination with plies from primary timber. CLST has the potential to be used in the industry, yet more research needs to be done in order to understand the behaviour and the possibilities.

Durability

As a natural material, timber is prone to biological degradation. Fungi and insects can cause damage, which can reduce the resistance of the timber. The extent to which timber is vulnerable to degradation depends strongly on the moisture content: a high moisture content makes timber more vulnerable [39]. As a significant part of the problems related to durability of timber relates to the presence of moisture in the material, the structure can be designed to either prevent moisture from entering the material or to allow the moisture to easily exit the material. Additionally, the timber can be protected by surface treatment or modifying the timber. Nevertheless, according to companies from the industry, a design life of up to 80 or 100 years might be difficult to achieve [52]. This is also illustrated by the example of the Van Brienenoordbrug. This bridge uses panels of hardwood for the deck. After 40 years, which was above expectations, a quarter of the panels needed to be replaced; the panels under the heavy traffic lanes saw the most damage.

This shows that reaching a design life in the realm of 200 years is difficult for timber. Even if the timber is well protected and behaves better than anticipated, a design life of 200 years appears to be improbable.

4.1.4. FRP

Fibre-reinforced polymers are a composite material, consisting of fibres and a matrix, that form plies. These plies combine into a strong and lightweight laminate. Different types of fibres exist, with carbon and glass fibres being the most common. Bio-based fibres do exist, such as fibres, though their performance needs to be enhanced to allow for extensive use in construction. With regard to the matrix, thermoset and thermoplastic resins are possible. Thermoset resins are the most prevalent, as they have superior performance compared to thermoplastic resins. Thermoset resin types include vinyl esters and epoxies, of which epoxies are used the most due to their good mechanical properties. Thermoplastics have advantages over thermoset resins, but their properties are, at the moment, still inferior to thermosets. FRP materials require low maintenance and have good fatigue resistance. The fibres in the laminates can be orientated in multiple directions, creating numerous possibilities in terms of the mechanical properties of the laminate. Disadvantages of the material are the high environmental impact and the low stiffness.

Current use and standardisation

As a relatively new material, FRP has not been used much in civil engineering structures. The construction of FRP structures has been increasing recently, although the application of full FRP structures is limited to low-load applications. Current uses include strengthening of existing bridges and bridge decks. FRP is used in a standardised form. Manufacturing processes like pultrusion allow for the production of large quantities and, due to the procedure of the production, the creation of various profiles with standardised properties.

Recyclability

With regard to the recyclability of FRP material, it is critical to distinguish between thermosets and thermoplastics. Whereas thermoplastics can easily be remelted and remoulded, the recycling process of thermosets is more complicated [53]. Considering the superiority in terms of mechanical behaviour of thermosets over thermoplastics, the recycling process of the thermosets is the most relevant. At the moment, landfill is the processing form that is used most for thermoset FRP material [54]. Incineration is another option to dispose FRP. It is evident that the methods are not truly forms of recycling. In terms of actual recycling, two approaches can be considered. The first is mechanical recycling. Mechanical recycling is the most mature method of the two and is done by crushing or shredding [53]. The created recyclates can be used in new products, such as concrete or FRP products. The quality of the recyclates is lower than the original material, meaning that this is a form of down-cycling. The other approach is thermal/chemical recycling. This approach focuses on retrieving the fibres by breaking down the matrix with a chemical or thermal reaction. Due to the high costs and often aggressive components used, it is best applicable to high-value and chemically stable fibres, such as carbon fibres. However, as the matrix is decomposed, the material is not fully recycled.

Durability

The main points of concern regarding the durability of FRP are related to environmental influences. UV-radiation can cause the matrix and fibres to degrade, losing their strength, whilst moisture penetrates the matrix and leads to degradation of the fibres [39].

Due to the insusceptibility to corrosion, FRP materials have lasted 50 years without degradation, providing a strong basis for a design life towards 100 years [55]. To ensure the durability of the FRP material on other aspects, protective measures exists, such as the use of UV-stabilisers to reduce influence of UV-radiation and the application of coatings to protect from moisture [56]. A point of attention is the uncertainty in the long-term regarding the durability. Although the durability of FRP has proven to behave well on the short-term, the material has only been in use for a limited time, which is why the durability on the long-term is not yet fully understood.

To conclude, FRP can be used for a durable structure, due to the good durability of the material itself in combination with additional protective measures. The exact design life that can be achieved is uncertain, though.

4.1.5. Material selection

In principle, all materials can be used for the design of an IFD overpass. However, some materials are considered to be more appropriate for the application of the overpass. Furthermore, to reduce the number of possible options, one material is chosen for the main parts of the superstructure as well as for the deck structure.

The main material that will be used is steel. Steel has good mechanical properties and excellent durability, a very high recycling potential and can reach a long design life with proper maintenance. With concrete, it is difficult to connect complete elements in a way that makes them demountable. There are, however, options to connect deck elements. In combination with the good durability that can be achieved, concrete is used as the material for deck structures. Regarding timber, the limited durability is an issue. If the timber cannot last for the required lifespan, which is found to be ambitious for timber, it needs to be replaced. This diminishes the advantage it has on environmental impact and reduces the effectiveness of the IFD design, which is why it is not used for the main structure. The connection between the deck and the main structure is also a point of concern. At the time of study, limited tests have been performed on demountable shear connectors. Demountable shear connectors form an essential part of the final design, as becomes clear later in this report. By considering a concrete deck, it is possible to include more connectors and their behaviour is also better understood, thanks to the greater number of tests performed. As a result, timber is excluded as material for the deck. Due to the fact that FRP has not really been used in highway bridges or overpasses, it is considered not (yet) feasible to design the full overpass with FRP. The low stiffness of FRP is a disadvantage too. As material for deck elements it is also excluded. The connection between the deck elements is expected to be a point of concern, as most connections use adhesion and are not demountable. Though it might be possible to develop demountable connections for FRP panels, this could be considered a different research topic and, therefore, it is out of scope.

In conclusion, the main material for the designs is steel. For designs that do not have a steel deck, concrete is the material of choice.

4.2. Structural systems

Different options exist for an overpass with a span of 12-32 m. Currently, prefabricated concrete structures are mainly used for these spans. Steel structures are also a possibility within this range. Figure 4.1 shows a number of possibilities for short-span bridges/overpasses made from either concrete or composite material. Given the focus on steel as the basis for the superstructure, composite structures are for the short span range the most relevant. Figure 4.2a shows a composite structure. Welded beam bridges and plate girder bridges are the most economic bridges that utilise composite action. The difference between a welded beam and a plate girder is that a welded beam has standardised cross-section, whilst flange sizes and web thicknesses can be optimised for plate girders, as they are built-up from different elements [57]. Trough girder bridges (or half-through bridges) are also a possibility for the longer spans within the span range. Trough girders are bridges where the girders are placed at both sides of the bridge, allowing for girders with a higher height without the need of increasing the structural height of the structure under the deck.

Although Figure 4.1 only mentions steel bridges that include composite action with the concrete deck, it is also possible to construct a sufficiently long bridge without composite action. Bridges without composite action are commonly applied for approximately the same span range as their composite equivalent [58].

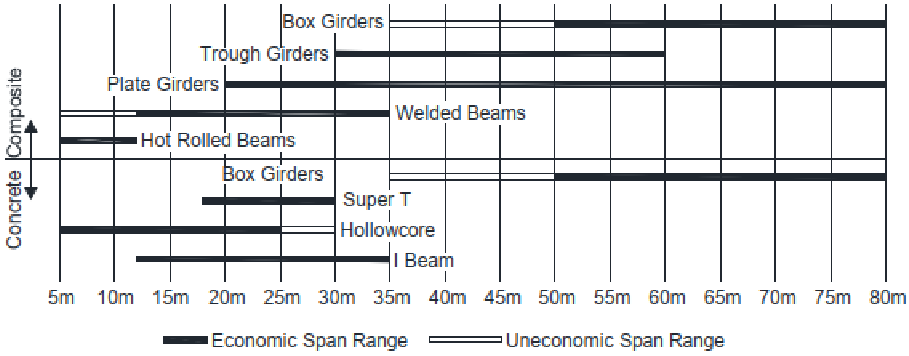
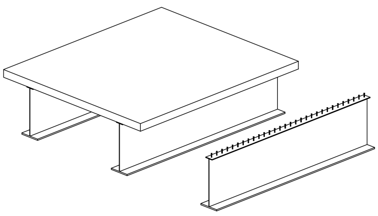


Figure 4.1: Structural systems for short-span bridges/overpasses [57]

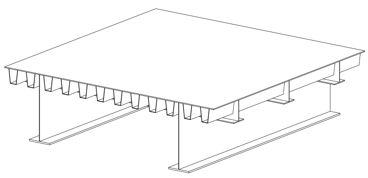
Overpasses made entirely from steel are other possible solutions. A notable example is the orthotropic deck bridge. Bridges with an orthotropic deck are supported by girders, similar to composite bridges. An example is shown in Figure 4.2b. Orthotropic decks are generally lighter than concrete decks, making them economic especially for bridges for longer spans, such as arch bridges [59]. Although the application on a shorter span might be less economic, given the high fabrication costs, the lower weight is an advantage with respect to handling during (de-)construction. Thus, the orthotropic deck structure could be a viable option.

A truss bridge is also a frequently used structural system for bridge structures. Truss bridges can be found in various forms, yet always feature trusses on both sides of the deck it supports. The deck, not necessarily a steel deck, is supported by crossbeams and can be placed both on top of the trusses and at the bottom of the trusses, of which the first option due to height restrictions is less popular. Figure 4.2c shows an example of a truss bridge. Truss bridges are normally applied for slightly longer spans [58]. Nevertheless, as a truss can be constructed with a high degree of repetition, it might be a good solution for modular designs. Existing truss bridges are generally for smaller widths, i.e., one or two lane roads. Larger highway bridges also exist, yet these structures feature elements connecting the trusses at the top. As a result, the trusses themselves need to be rather large in order to create sufficient height of the structure. Several of the discussed demountable structures are truss-like structures. These tend to be smaller than conventional trusses in that the supporting trusses are lower. This is because the upper flanges of the trusses are not connected, allowing the side trusses to be substantially lower. Hence, their application is mainly for small widths. An important aspect regarding the existing demountable structures, such as the bailey bridge, is the fatigue life. Due to the limited period of use the fatigue resistance of these structures is not always high, which should be the case for a structure that is used on a more permanent basis. Considering the often limited fatigue life and small width it is concluded that a design based on a conventional truss has more potential than an existing demountable truss for the application of interest.

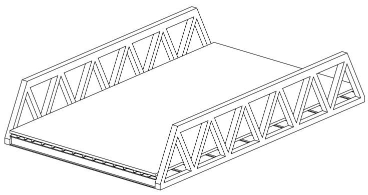
Other structural systems include arch bridges and cable-stayed bridges. These bridges are only economic for larger spans and are therefore excluded.



(a) Composite structure



(b) Orthotropic deck structure



(c) Truss structure

Figure 4.2: Illustrations of structural systems

4.3. Conclusion

The aim of this chapter was to investigate the options that exist with respect to the design, focusing on material and structural system. The materials steel, concrete, timber and FRP were investigated on the IFD-relevant topics of standardisation, recyclability and durability. Steel has been found to be the material with the best characteristics on these aspects and is the main material to be used in the design. Concrete is the secondary material, in particular due to the larger number of options that exist in terms of connections and its good durability. Following steel as the main material, three structural systems are chosen for an assessment on their sustainability: a steel truss structure, a steel-concrete composite structure and a steel girder structure with an orthotropic deck.

III

Preliminary Design

5
Design Alternatives

This chapter describes the design alternatives. First, design requirements and assumptions are explained, along with the general dimensions of the overpass. Then, the designs of the alternatives are described, which have been optimised for a minimal environmental impact.

5.1. Design requirements and assumptions

Design requirements

The design requirements are derived from section 3.1.3. Not all guidelines, however, are considered to be requirements. Some guidelines are assumed to be optional: they are not required for an IFD structure, yet can improve, for instance, the demountability. The guidelines that are seen as requirements are listed below. The other guidelines are used in the assessment of the design alternatives.

- The design should be modular.
- Elements that form (a part of) a module should be made from prefabricated components with standardised dimensions.
- The design needs to accommodate different widths.
- The design needs to accommodate different span lengths.
- The connections between the modules should be demountable.

Design assumptions

The design of the alternatives is a preliminary design, meaning some assumptions and limitations need to be clarified.

- The ULS and FLS are the main focus of the verification. The only SLS checks that are performed are checks on deformations and concrete stresses.
- It is acknowledged that some orthotropic and composite structures feature a change in cross-section along the span, in particular for longer spans. Although this could provide a reduction in impact, this would be the case for all alternatives and the extent of the reduction would be limited. As a result, a change in cross-section is not applied.
- The fact that a design life of 200 years is assumed means that more strict requirements are to be expected regarding durability. For concrete, this can be accounted for by a properly designed cover. Following the approach described in Eurocode 2, the nominal cover c_{nom} is determined as the sum of c_{min} and Δc_{dev}. c_{min} is determined based on a construction class S. Considering the concrete class of C45/55, a plate-like geometry, quality control and a design life of 100 years the class becomes S3. Construction class S3 requires a c_{min} of 40 mm for environmental class XD3 (as the overpass could be exposed to chlorides, which can cause corrosion, and can be considered to be cyclically wet and dry, exposure class XD3 is used). As this method does not include service lives over 100 years, it is decided to increase c_{min} by 5 mm to 45 mm to include the 200 years of design life. For c_{dev}, 5 mm is the conventional value in the Netherlands [60]. An additional 5 mm is applied since the top surface is not well maintainable (due to the asphalt layer) [13], equalling a total Δc_{dev} of 10 mm. c_{nom} then becomes 55 mm. For the sake of symmetry, this value is applied to both the top and bottom of the deck.
- Connections are neither designed nor verified. Since they are yet to be determined at this stage, they are excluded from the designs.

Optimisation
The designs are optimised to minimise the environmental impact. The optimisation of the alternatives has been done through an iterative process. The spatial arrangement, i.e., the spacing of girders, beams, etc., is varied by set intervals. Then, the dimensions of the individual elements are adjusted to satisfy all unity checks. Based on these dimensions the environmental impact is calculated following the approach described in section 6.1.1. The environmental impact is evaluated for each road layout. The sum of these impacts displays the performance across all possible layouts and is used as the value of comparison, as it shows which arrangement is the most efficient for all lane layouts. This process is repeated until the difference between the summed impacts of the best and second best arrangement is below 5%. Accordingly, for the overpass with the largest width the difference is at a maximum around 2%. This is considered to provide sufficient accuracy to build a solid argument on the performance of the alternatives, taking into account the differences that exist in the final environmental impact. Further iteration is not expected to result in a meaningful improvement of the accuracy. The designs shown in this chapter are the result of the optimisation process and are expected to be close-to-optimal solutions.

5.2. General overpass dimensions

The span length and width are the same for all alternatives. As explained in section 2.2.2 the maximum length is 32 m and the maximum width should be 22,15 m. The designs are developed as conventional overpasss to which adaptations are made to create an IFD design.

Since the design needs to follow IFD principles, it is necessary to divide the overpass in modules or segments. The initial assumption is that the modules in the length direction are equal in size and that in the width direction, two different modules are distinguished: a regular module and a guardrail module. The guardrail module is located at the section of the structure where the guardrail is installed. In combination with an inspection path and railing, this section is 1,6 m in width. Since this section is always present in an overpass and consistently has the same dimensions, these modules are designed differently from the regular modules. Apart from the fact that this allows for a more economic design for the guardrail modules - these modules usually receive lower loads - there are also benefits in that modifications required for guardrails or railings are only needed in the guardrail modules and regular modules can be designed more efficiently. It also allows for the inclusion of services for attachment of edge panels, in order to customise the appearance of the overpass.

Figure 5.1 shows how an overpass with a width of 22,15 m is formed (Figure A.4 shows how the width of 22,15 m is determined). The guardrail sections are removed from the layout, since these are directly accounted for by the end modules. What remains is 18,95 m, for which one unique regular module is used. In the example this module has a width of 4 m. Hence, a total of five of these modules is needed, which results in a width of 20 m. This does mean that the width is larger than strictly necessary. For all the layouts considered, the widths without guardrails are listed in Table 5.1. These are the widths that are used to optimise the width of the individual modules. In terms of dimensions of the guardrail sections, the starting point is that the elements are the same as the central sections. Some dimensions, however, can be changed. In appendix B.4 it is shown which dimensions are changed for each of the alternatives. These dimensions are determined following the same design process as for the regular modules.

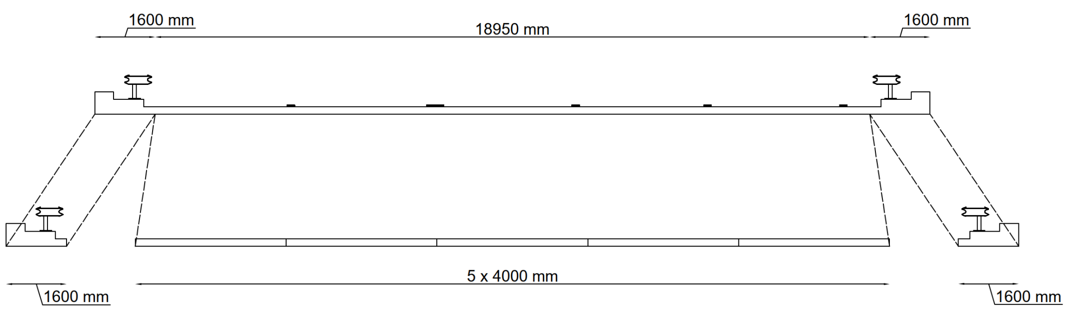


Figure 5.1: Division of road layout into modules

The length of the components is more variable and does not follow set dimensions. However, for the development of the alternatives no module length is required, as the assumption is that the structure is continuous. The module length becomes of importance when optimisation of the chosen alternative takes place.

Table 5.1: Road layout width without guardrails

Layout	Road type	Width [m]
1x1	main	8,00
2x1	secondary	9,75
2x1	main	11,50
3x1	main	15,00
4x1	main	18,50
(3+1)x1	main	18,95

5.3. Truss

The Truss alternative consists of two trusses, one on each side of the structure. Popular trusses are the Pratt Truss and Warren Truss, shown in Figure 5.2. The Warren Truss is chosen over the Pratt Truss, as it uses less material and can easily be elongated following the same pattern. An extension of the Pratt Truss would require the truss to be extended at both ends, compromising execution, or the truss would lose its symmetry, resulting in unfavourable behaviour. As a variation on the Warren Truss vertical members could be added. One reason for this is to reduce the buckling length of the top chord. However, since this has been found not to be an issue, there is no need for vertical members. Secondly, vertical members allow for the inclusion of more crossbeams, which then receive less loads. Still, it has been found that, in terms of an optimal solution, there is very little difference between a design with and without verticals. The layout with only diagonals behaves slightly better and features less elements, which is why it is used.

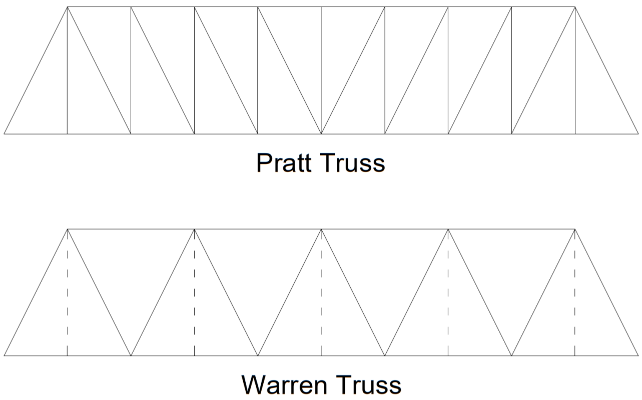


Figure 5.2: Truss models

The design is a semi-through design, which means that the trusses are not connected at the top, creating a U-shaped structure. Compared to a through truss, the semi-through design is usually more economic for shorter spans and allows for more freedom, as there are no height restraints. Between the trusses crossbeams support the deck structure. The deck structure consists of a concrete deck, which is supported by small steel beams referred to as stringers, to limit the span the concrete deck needs to bridge. As the overpass supports one single carriageway, intermediate trusses cannot be included, restricting the design to two exterior trusses.

In order to create an IFD truss overpass, some measures need to be taken:

- All elements should be prefabricated and standardised.
- The trusses need to be divisible into multiple, standardised parts. This could be in the form of individual members, assemblies of members or other solutions.
- All connections between the crossbeams, stringers and deck need to be demountable.
- Crossbeams, stringers and the deck (in both directions) need to be divisible into smaller parts.

Prefabrication is achieved by using prefabricated elements for the concrete deck. Division of the trusses is possible at, for instance, the nodes. To promote division into smaller, standardised parts regularity is present in the design, both in the truss and in terms of spacing between crossbeams, stringers and reinforcement. Although connections are not designed, the connection between the concrete deck elements is considered, as this strongly influences the behaviour of the structure. The connection is made by post-tensioned prestressing reinforcement. An explanation to why prestressing reinforcement is used is provided in section 7.4.

Existing trusses tend to follow the following dimensions:

- Angle of the diagonals 40-60 deg
- Slenderness truss $l/h \approx 10$
- Crossbeams spacing should be aligned with joints in the truss to ensure efficient force transfer.
- Stringer spacing $\approx$ 2 m, based on existing structures.

Figure 5.3 shows the dimensions of the truss. The number of crossbeams is the most influential parameter to the environmental impact. As crossbeams are aligned with nodes in the truss, the crossbeam spacing is dependent on the truss layout. The distance between the truss nodes, and thus the crossbeam spacing, has been varied in such a manner that all nodes are equidistant. The best spacing has been found to be 5,34 m. The height of the truss has been varied according to the slenderness. From a slenderness of 12 to one of 6, the slenderness with the best results is 7. Though this is somewhat lower than is common, it is not too far from existing structures. The angle of the diagonals is in line with the prescribed range. For the truss members square hollow sections are used, as they have the same buckling resistance in both principal directions and are favourable with respect to maintenance. Apart from these dimensions, the spacing between the stringers has been varied as well. This results in the cross-section shown in Figure 5.4. The figure shows the cross-section perpendicular to the span, illustrating the side of the crossbeam, on top of which stringers and the deck are placed. The deck consists of separate elements connected by post-tensioned prestressing reinforcement. Practical reinforcement is also applied. Figure 5.5 shows the cross-section of the deck.

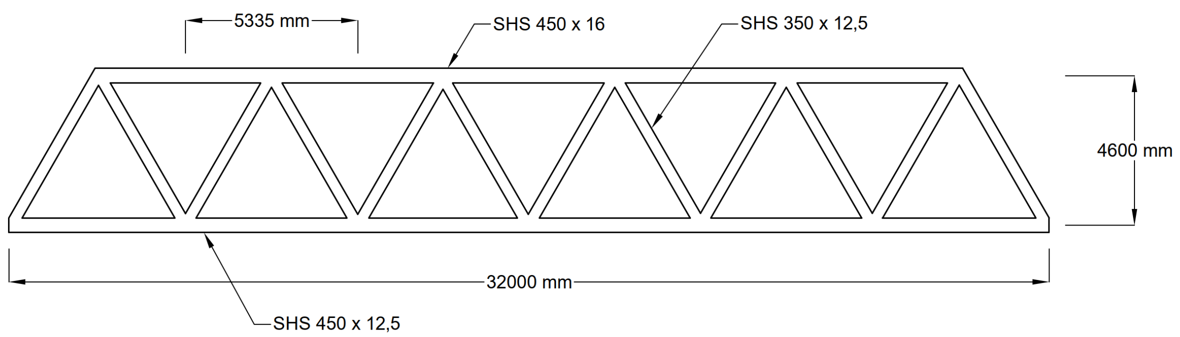


Figure 5.3: Truss layout

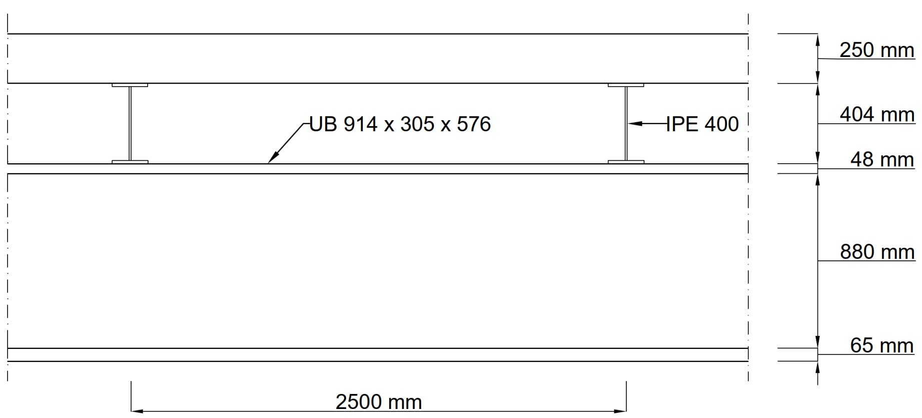


Figure 5.4: Cross-section perpendicular to span

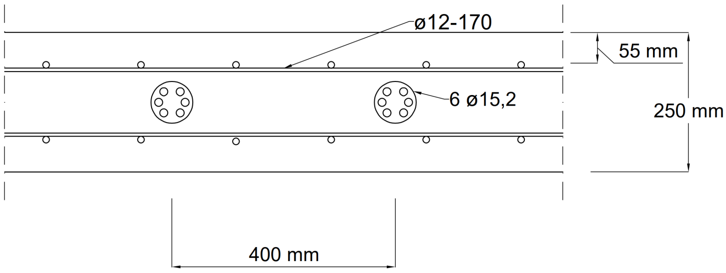


Figure 5.5: Cross-section deck Truss design

5.4. Composite

The Composite design consists of steel girders that support a concrete deck. The concrete deck is connected to the steel girders, in order to create composite action and enhance the performance of the system. A multi-girder system is chosen. An alternative would be a twin-girder system, yet considering the flexibility from the IFD principles, a twin-girder system effectively becomes a multi-girder system when additional lanes would be required, thus making it more efficient to design the full structure using multi-girders. Additionally, multi-girder systems are generally more economic for shorter spans. As the system is simply supported, the bottom flange of the girder will be in tension, removing the need for bracing or crossbeams in the use phase. In the transportation or construction phase a change to the cross-section or the use of bracing might be required to ensure stability of the girders, however, this is not verified during the preliminary design. The design is verified for unpropped construction. Though propped construction might result in smaller girders, unpropped construction is favourable from the point of view of assembly. Since no temporary supports are required, the construction time is decreased and the assembly has less impact on the underlying road. The fact that temporary supports are not needed also increases the potential for reuse.

To ensure the Composite design is following IFD principles, a number of requirements need to be met:

- All elements need to be prefabricated and standardised.
- The connection between the deck and the girders needs to be demountable.
- The girders and the deck (in both directions) need to be divisible into smaller, standardised parts.

Prefabrication is achieved by using prefabricated concrete deck elements. The connections between steel elements are not designed, yet the connection between the concrete deck elements needs to be considered to some extent, as it directly impacts the behaviour of the structure. The connection is made by post-tensioned prestressing reinforcement. The division requirement is met by including regularity in the design, which is done by maintaining one set spacing for the main girders and by placing reinforcement at set intervals.

Existing composite structures generally follow these dimensions:

- Slenderness girder $l/h \approx 12 - 18$
- Spacing girders 2,5-4 m
- Deck thickness 230-250 mm

Figure 5.6 shows a cross-section of the girder and the deck. The girders have a height of 2058 mm, which results in a slenderness of 16, given the design span of 32 m. This slenderness is in line with existing structures. The girders are spaced 4 m apart. This has been found to be the most efficient spacing in terms of environmental impact and corresponds to existing structures. All girders have the same spacing, creating regularity in the layout. Illustrated by Figure 5.7, the deck plate elements have a thickness of 325 mm, are constructed with practical reinforcement and are connected by means of post-tensioned prestressing reinforcement. Generally, the deck has a lower thickness, around 250 mm. The reason the thickness needs to be larger is related to the requirement of no tension in the concrete between the deck elements in ULS, which is required to ensure full interaction between the deck elements, and the omission of shear reinforcement. Due to the strict requirement of no tension in midspan at the interface, a variable thickness of the concrete deck is also not possible.

It is not verified whether all interfaces will remain fully effective under shear loads. If this is not the case, shear keys can be added to allow for shear force transfer. This has not been included in the design, as it will not result in any significant change in material use. The deck is connected to the girder by shear connectors. As specifications of these are yet unknown, the assumption is made that a full degree of composite action is achieved.

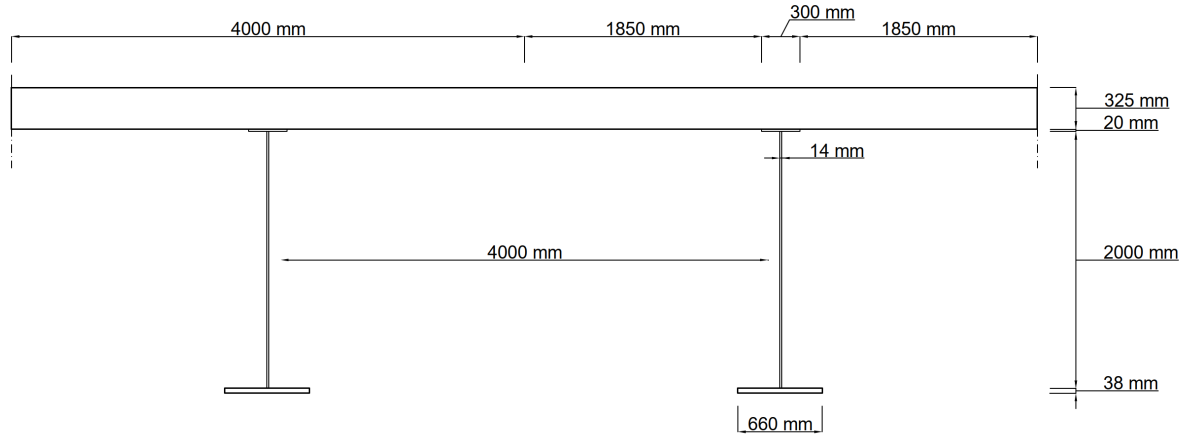


Figure 5.6: Cross-section Composite design

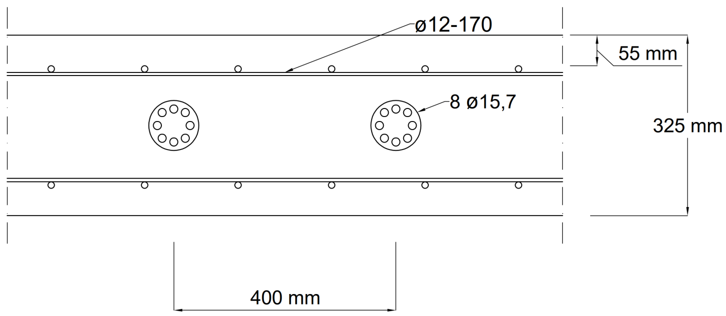


Figure 5.7: Cross-section deck Composite design

5.5. Orthotropic deck

The orthotropic deck alternative is a design consisting of only steel members. It is composed of girders and cross-girders, which in conjunction support the orthotropic deck: a deck plate with trapezoidal stiffeners, running in longitudinal direction. Trapezoidal stiffeners are considered to be favourable over open stiffeners due to the high torsional rigidity and good ability to distribute transverse loads, resulting in more efficient load transfer. In conventional orthotropic deck structures, all connections are welded, though bolted connections are possible. Bolted connections provide possible solutions to create a demountable orthotropic deck, but there are several points of attention regarding these, such as tolerances and finishing.

To make an orthotropic deck overpass IFD, the following needs to be done:

- The structure needs to be divisible into smaller, standardised parts in both directions of the structure.
- Connections between girders, crossbeams and stiffeners need to be demountable, i.e., conventional welded splice connections cannot be used.
- Stiffeners need to be either connected by demountable connections, or they need to be closed at the end of a module to eliminate the need for a connection.

As for the other alternatives, regularity is applied to allow for divisibility. With regard to the connections, no solutions are proposed. The stiffeners are assumed to be continuous, though.

The following dimensions are generally seen in existing structures:

- Slenderness girder $l/h \approx 20$
- Slenderness crossbeam $l/h \approx 20$, lower slenderness is also frequently seen.
- Spacing girders variable, from 2,5 m to well over 10 m.
- Spacing crossbeams 3-5 m

A cross-section of the design is shown in Figure 5.8. The optimal spacing of the main girders has been found to be 5 m, which is within the feasible range, whereas the crossbeam spacing is 4 m, as illustrated by Figure 5.9. The latter is restrained by the ROK [13]. The slenderness of the main girder is 14, which is somewhat lower than usual. This is also the case for the crossbeams, yet this is seen in other structures as well. For the stiffeners the minimum possible dimensions have been used, according to the requirements formulated by the ROK. They have been placed at a fixed distance of each other to ensure regularity. The dimensions are shown in Figure 5.10.

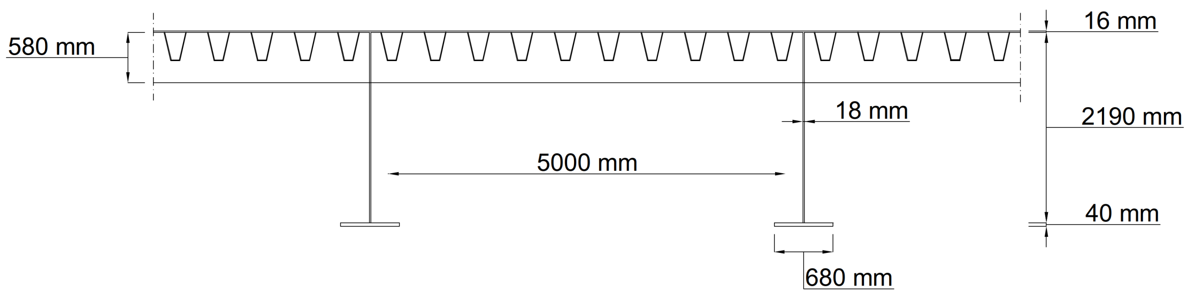


Figure 5.8: Cross-section Orthotropic design

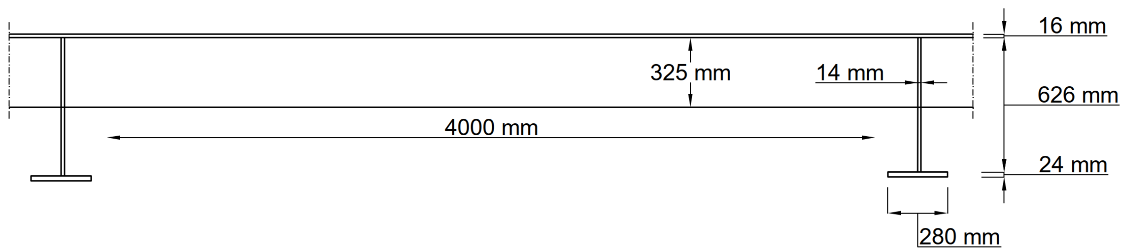


Figure 5.9: Cross-section crossbeam Orthotropic design

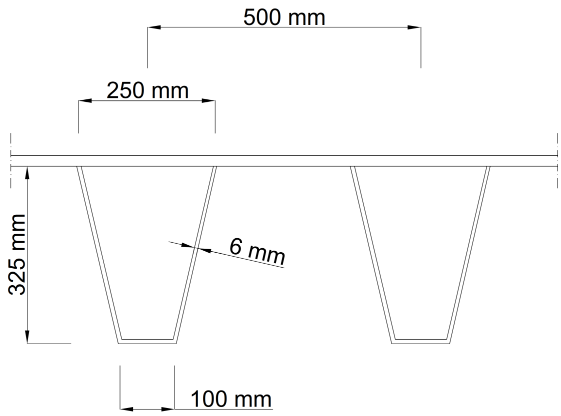


Figure 5.10: Dimensions of stiffeners

5.6. Conclusion

The design of the alternatives has led to dimensions of all the elements, as well as the number of elements that are needed to create an overpass of 32 m long and 23,2 m in width. These values can be used in chapter 6 to assess the performance of the alternatives. As a summary of the alternatives, Table 5.2 lists the most important parameters for the three alternatives. All dimensions belong to the main elements of the structure; the numbers for the guardrail sections may differ slightly. Any changes are documented in appendix B.4.

Table 5.2: Overview of dimensions of the alternatives

	Truss	**Value**	**Unit**	**Composite**	**Value**	**Unit**	**Orthotropic**	**Value**	**Unit**
Main elements	Nr. of trusses	2	-	Nr. of girders	7	-	Nr. of girders	6	-
	Truss height	5050	mm	Girder height	2058	mm	Girder height	2250	mm
	Spacing trusses	23,65	m	Spacing girders	4	m	Spacing girders	5	m
Secondary elements	Nr. of crossbeams	7	-	-	-	-	Nr. of crossbeams	8	-
	Crossbeam height	993	mm	-	-	-	Crossbeam height	580	mm
	Spacing crossbeams	5,335	m	-	-	-	Spacing crossbeams	4	m
	Nr. of stringers	10	-	-	-	-	Nr. of stiffeners	48	-
	Stringer height	404	mm	-	-	-	Stiffener height	325	mm
	Spacing stringers	2,5	m	-	-	-	Spacing stiffeners	0,5	m
Deck	Thickness	250	mm	Thickness	325	mm	Thickness	20	mm
	Prestress (∅15,2)	2100	mm^2/m	Prestress (∅15,7)	3000	mm^2/m	-	-	

6

Performance Assessment of Design Alternatives

This chapter describes the assessment of the performance of the design alternatives on the matters of sustainability and IFD guidelines. The chapter is divided in two parts: the first part describes the framework that is used and the second part illustrates the results that have been determined.

6.1. Assessment framework

The assessment framework consists of sustainability, composed of three dimensions, and a Multi-Criteria Analysis, where the performance with respect to the IFD principles and guidelines is assessed.

6.1.1. Sustainability framework

Sustainability is a term that can be interpreted in many different ways. Though different concepts exist, a common approach is to characterise sustainability through three dimensions: the environmental, economic and social dimensions. ISO 21931 lists different areas of concern for each of these dimensions [61].
The environmental dimension focuses on the impact of a structure on the environment, as well as other environmental aspects. There are different ways in which this dimension can be quantified. The approach that is chosen is to perform a calculation on the environmental impact using Life-Cycle Assessment (LCA) data. It is limited to environmental impact, as this is considered to provide a clear and comprehensive quantification of the environmental dimension.
The economic dimension encompasses various aspects that affect the economy. With regard to civil structures, the most relevant aspect is the economic viability of a structure. Different approaches of determining this are possible, but commonly used is a life-cycle costs analysis. This analysis provides a measure for the total costs of a structure, from the construction phase towards the demolition phase, thus allowing for a comparison in terms of costs.
The social dimension is a very elaborate dimension for which ISO 21931 lists various aspects related to social performance. Some of these correspond to IFD principles, i.e., adaptability and maintainability, whilst others are site-specific, i.e., accessibility, impacts on neighbourhood, and safety and security. As such, these aspects are not explicitly included as a point of assessment. A measure that is included separately is architectural quality. Although the surroundings of the overpass are unknown, the visual quality of the overpass itself can be assessed to some extent.

Environmental dimension

For the assessment of environmental impact, an ECI is determined for each of the alternatives. The ECI, equivalent to the Milieukostenindicator (MKI) used in the Netherlands, is a measure that combines the environmental impact of an object across different environmental impact categories into one indicator by converting the impact into a monetary value. It is an expression of the burden an object places on the environment. Before an ECI can be determined, the environmental impact needs to be known. These data are retrieved from LCAs. LCAs list the impact of an object across different environmental impact categories for all life-cycle stages of the object.

Goal and scope

The goal of the assessment is to determine which of the considered alternatives has the lowest environmental impact. The results are used for a comparison; the relative performance is of more importance than the absolute value of the impact. LCA in particular is a useful tool for comparison between alternatives, which is why it is considered an applicable method to use.

Besides the goal, a functional unit is required. A functional unit is the measure of comparison; if all alternatives have the same functional unit, an equal comparison can be performed. The functional unit for this assessment is an overpass with

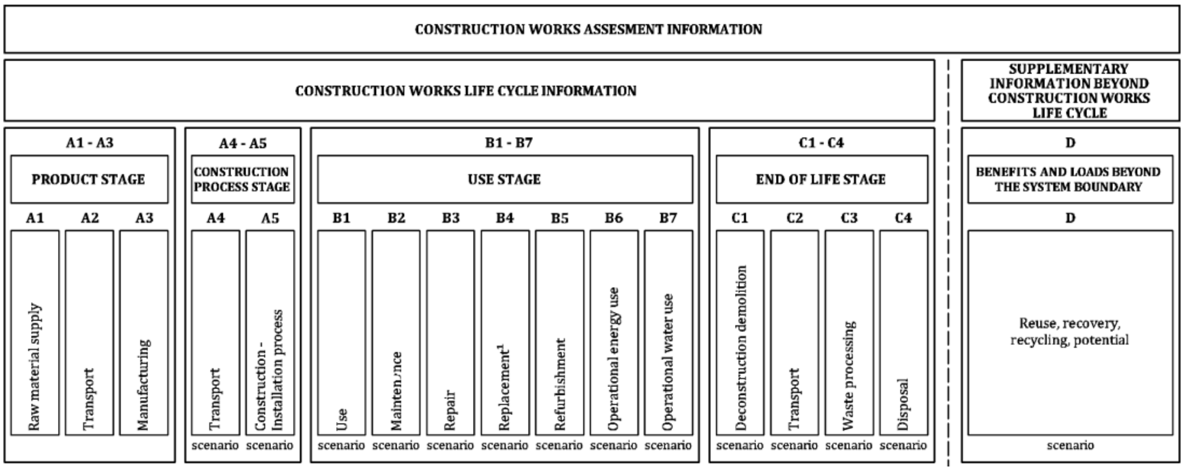


Figure 6.1: LCA-modules [62]

a design life of 200 years. The maximum width is 23,2 m and the span 32 m. It should also be possible for the overpass to be divided into modules. Furthermore, all requirements from section 5.1 must be met.

Life-cycle modules
An LCA can be performed taking into account the full life-cycle of a material by means of four modules. Figure 6.1 shows these modules. Module A includes all processes related to manufacturing and construction, module B relates to the use phase and module C concerns the end-of-life phase. Module D describes benefits and loads beyond the boundaries of the system. These benefits and loads come from reuse or energy extraction from products that leave the system considered in the LCA. Naturally, there is a lot of uncertainty regarding this category, which should be considered when drawing conclusions.

The assessment that is done in this study includes the full life-cycle of the product. In theory, this means all four modules are included. Module B, however, is often unreported or reported as having no impact, for the application of a material is usually unknown in advance. Practically, this means that module B is not included, apart from the impact of products that are used for the application of maintenance. Given that it is assumed the materials are used for their full design life, replacement (module B4) is not accounted for either.

Environmental impact categories
To determine the overall impact of an object, different environmental impact categories need to be included. Currently, EN 15804 prescribes a set of 19 different categories. Most of the data that is found, however, uses a set of 11 categories (following the previous version of EN 15804), which has its use in the Netherlands. Hence, a selection of this set of 11 categories is used for the assessment.
Although some data is reported using the 19 category approach, there is overlap between the two approaches, which is shown by listing the equivalence of certain categories from both approaches. The following categories are considered:

Based on EN 15804, the following impact categories and indicators are considered [62]:

- Climate change (GWP) - *equivalent to Climate change total (GWP-total),*
- Ozone Depletion (ODP)
- Acidification (AP)
- Eutrophication (EP) - *equivalent to the sum of*
  - *Eutrophication aquatic freshwater (EP-freshwater)*
  - *Eutrophication aquatic marine (EP-marine)*
  - *Eutrophication terrestrial (EP-terrestrial)*
- Photochemical ozone formation (POCP)
- Depletion of abiotic resources – minerals and metals (ADPE)
- Depletion of abiotic resources – fossil fuels (ADPF)

- Human toxicity (HTP) - *equivalent to the sum of*
  - *Human toxicity, cancer (HTP-c)*
  - *Human toxicity, non-cancer (HTP-nc)*
- Eco-toxicity, freshwater (FAETP)

**The approach with 11 categories also includes marine and terrestrial eco-toxicity. As in the new approach no reporting is done on these aspects, they are excluded from the analysis to allow for an equal comparison. Besides, the contribution of these categories is limited and thus does not result in a substantial difference.*

Data
The data that is used is, for the most part, retrieved from the Nationale Milieudatabase (NMD), a Dutch database that contains environmental impact data of various elements and objects used in the construction industry. Data from this database are used in order to perform the analysis. The time of collection of the data is 8 April 2024.
In case elements or objects that are not included in the database need to be analysed, so-called EPDs can be consulted. An EPD is a form that is supplied by the producer of a product and that includes an LCA of this specific product and thus data on its environmental impact. As EPDs are verified by independent partners, they are an appropriate source for additional data. The data in recent EPDs is mainly reported using the 19 category approach, where some categories feature different units. Hence, a conversion needs to take place to be able to compare the categories. Table C.4 shows which units are converted and into which unit, by multiplication with a certain conversion factor.

As the different impact categories have different units, normalisation of the values is required. Normalisation is done by means of monetisation: each impact category has an impact expressed in a specific unit. Multiplying the impact by a monetisation factor for this unit allows for conversion to a monetary value of environmental impact. This can be seen as the cost of the impact. The sum of these costs for all impact categories yields the ECI. In Table C.5 the monetisation factors are listed for the respective units of the environmental impact categories.

The data in the NMD is divided into three categories. Categories 1 and 2 are data provided by producers and the industry. These data are quite specific and verified by a third party, which is why they are considered to be accurate. Category 3 data are compiled by the administrators of the NMD. Data from category 3 are generic and not validated by a third party, thus reducing their accuracy. Consequently, a correction is made to compensate for this effect by means of an increase of the reported impact of the object by 30%. It is highlighted which components use category 3 data and receive a correction on their calculated impact.

Further assumptions
Apart from the aspects described in previous sections, some other assumptions are made:

- The assessment is limited to the superstructure, for the contribution of the substructure to the total impact is significantly smaller than the contribution of the superstructure. This is supported by research done by Beco [63] and Stutech/Stufib [64].
- With repetitive maintenance and infinite fatigue life, the elements are assumed to be able to last for the required design life of 200 years.
- Transport is included to cover the relocation of elements in case of reuse of the structure or its components. The impact of the transport is based on the transport of all components of the structure over 200 km, simulating two reuse cycles of 100 km each. The 100 km results from the transport to and from a storage site, assumed to be 50 km. The storage site is needed as the elements, once disassembled, may not directly be of use for another structure.
- All elements that are not specific for a design are excluded. These elements are non-structural elements, such as guardrails, expansion joints, asphalt layers and any other non-protective finishing. The contribution of joints is not included either, as their mass contribution is limited compared to the main structural components.
- The impact of equipment and machinery is not explicitly included.
- For steel maintenance, the main objective is to provide protection against corrosion. Hence, it is assumed that the members will be maintained in order to provide continuous corrosion protection. Although Stephens et al. [40] state that the maintenance interval can be up to 30 years, current practice in the Netherlands is to repaint steel elements approximately every 15 years, which is the interval adopted for application of the corrosion protection [65, 66]. The material that is used is a zinc-rich epoxy primer. Data on this material is provided in an EPD by PPG [67]. For concrete, it is assumed that there is no significant preventive maintenance required. The main activities related to concrete maintenance will be responsive, such as repairing cracks. It is assumed that the impact of the materials used for the maintenance is limited, allowing for the exclusion of the impact.

- Traffic hindrance due to maintenance is not included. As maintenance can be scheduled efficiently and the duration of the maintenance is not expected to be substantially different for each alternative, according to Zhang et al. [68], large differences in impact are not expected.
- All steel grades will be assumed to have the same environmental impact, as most EPDs of steel provide the data independent from the precise type of steel. Although there is a difference between different steel grades, Berggren [69] illustrates that the difference is small and can be neglected.

Economic dimension
The economic dimension can be described by cost calculations. Within this research the focus is strongly on the environmental dimension. A cost analysis is, therefore, only used for the optimisation of module dimensions. For this aspect the focus is on the costs that are involved with the production of elements, both the raw material costs and the manufacturing, as well as the assembly costs, covering transportation to the construction site and on-site assembly. In relation to the environmental dimension, this could be considered as module A from Figure 6.1.

Social dimension
The third dimension that describes sustainability is the social dimension. This dimension encompasses various aspects and can be interpreted in many different ways, depending on the application. With regard to civil engineering, most logical is to consider the value of the structure for society. In part, this depends on the location of the structure and its effect on the environment, and to the function of the structure within a larger system. These aspects, however, are variable given that the design should be usable at different locations. As a result, the most relevant characteristic for the value of the overpass is its aesthetics.

The aesthetics of the overpass are largely determined in the final stages of the design (through elements such as edge beams for instance) or, once more, dependent on the surroundings of the overpass, which are all out of scope. The one aspect that is related directly to the overpass itself is slenderness. Slenderness, defined as the ratio of the span of the overpass divided by the height, should fall within a certain range: a very low slenderness results in a heavy structure with a large thickness, whilst a very high slenderness results in a rather slender structure that may not seem safe anymore. The precise extent of this range depends on the type of structural system. Though there are no strict requirements regarding minimum or maximum slenderness, an estimate should be made on what is reasonable.

6.1.2. IFD principles framework

The performance of the alternatives on the matter of IFD principles is assessed using a Multi-Criteria Analysis. The MCA is performed by assessing the performance of the alternatives on eight categories. These categories are derived from section 3.1.3 and in conjunction enable an assessment on the performance regarding IFD principles. The categories are derived from the guidelines that do not translate into requirements (see section 5.1); some additional important factors are included as well. The categories are listed below, along with an explanation of their relevance. Below the list, the method of assessment is described for each category. The structures can eventually be divided into smaller, standardised parts to follow the IFD guidelines. Since the size of the resulting modules affects the outcomes of the MCA, the assessment is performed with two modules sizes: 4 m and 12 m. These sizes are not final, they just show how the module size impacts the outcomes of the assessment for a smaller and larger module size.

- *Number of different components* - A limited number of different components reduces complexity of construction and simplifies sorting of components during deconstruction.
- *Number of components* - A limited number of components creates a clearer construction process.
- *Number of connections* - A reduced number of connections results in less actions to be performed on-site.
- *Ease of changing overpass layout* - As one of the essential properties of an IFD structure, simple and limited actions to change the overpass layout are desired.
- *Mass of components* - Low mass of the different components allows for easier handling and manoeuvring on the construction site.
- *Independence - Parallel assembly* - Parallel assembly, the possibility to assemble different segments of a structure simultaneously and combine them later, decreases the construction time and simplifies the assembly process.
- *Ease of replacement of components* - Related to *Ease of changing overpass layout*, easy replacement of components increases the longevity of the structure when replacement is a realistic possibility.
- *Maintenance* - Less maintenance results in less activities to be executed during service of the structure and saves costs.

Number of different components
The determination of the number of different components is straightforward: components of a different material and with different cross-sections are a separate type of component. Connections are excluded.

Number of components
For the number of components, the different components are counted. Connections are not included.

Number of connections
As the connections themselves are not known at this stage, some assumptions need to be made. For interfaces between linear elements, it is evident that each interface between two modules requires one connection. In the case of concrete deck plates, in transverse direction the connection is created by means of the prestressing reinforcement. In longitudinal direction the connection is assumed to be incorporated in the underlying connection. For steel deck plates, the connection is assumed to be part of the connections of the underlying members.

Ease of changing overpass layout
This criterion is scored qualitatively, as it is difficult to determine relevant values for comparison. Ease of changing overpass layout in this context relates specifically to the addition of lanes, i.e., an extension in width of the overpass. A three-point scoring system is used: two points are awarded in case only edge panels need to be removed, one point if other connections are impacted, yet the main structural system can remain intact, zero points if the structural system is impacted.

Mass
The mass, calculated in kilograms, is determined by the average weight of all components. The mass of an individual component is multiplied by the number of components. The sum of these masses is divided by the total number of components, resulting in the average mass across all components. Prestressing reinforcement is excluded, as it is a connection element rather than a component.

Independence - Parallel assembly
Parallel assembly is scored qualitatively, again with a three-point system. When parallel assembly is fully possible, that is, if all parts of the structure can be assembled independently, a value of two is awarded. If there is some interdependency, a score of one is given, while for significant interdependency, most components are linked in some manner, a value of zero is given.

Ease of replacement
As for parallel assembly, this category is scored qualitatively. The focus is on replacement of components that are not part of the main span-bridging structure, in particular deck plates, as the replacement of the main structure is difficult for any structure. Two points are awarded if replacement can be done without impact on other components, one point if there is impact, yet not on the main structure, and zero points if the replacement directly impacts the main structure. In case all components are part of the main structure, a score of zero is awarded as well.

Maintenance
The maintenance that is considered is related to periodic, preventive maintenance of the structural elements of the overpass. Included is only the maintenance of the steel, as for the steel maintenance is clearly defined and takes place repetitively. Other maintenance is expected to be more accidental of nature and similar for all alternatives. Therefore, it is not included. The total amount of maintenance, in m^2, is the product of the area on which the maintenance is applied and the number of times maintenance is applied over the design life of 200 years. The maintenance interval is assumed to be 15 years, as discussed in 6.1.1.

Normalisation and weights
The values of the categories need to be converted to a value between one and zero, to allow for a fair comparison. This is done by so-called 'Linear Max'-normalisation, which uses formula 6.1 in case high values indicate a better score, and formula 6.2 in case low values indicate a better score [70].

$$n_{ij} = \frac{r_{ij}}{r_{max}} \tag{6.1}$$

$$n_{ij} = 1 - \frac{r_{ij}}{r_{max}} \tag{6.2}$$

This method normalises data based on the best possible value a category can have and not necessarily on the best value among the alternatives. To illustrate with an example, if the highest performance on maintenance is 9000 m^2 and the lowest performance is 10000 m^2, their respective values are 0,10 and 0. This takes into account that although 9000 m^2 is better than 10000 m^2, it is far from the potential best, which would be no maintenance at all. For the qualitative categories, the maximum and minimum values will be held at two and zero respectively, even if they are not among the assigned values for a category.

The method assumes that zero is the best possible score. However, for certain categories this is not the case. Therefore, for the categories *Number of components*, *Number of different components* and *Mass of components* a value of one is assumed as the best possible score by applying a corrected version of formula 6.2, shown in formula 6.3.

$$n_{ij} = 1 - \frac{r_{ij} - 1}{r_{max} - 1} \tag{6.3}$$

Scores are calculated by multiplying the value for each category by a weight factor, which is assumed to be 1 for all categories. The sum of all scores for each alternative results in the total score.

6.2. Assessment results

6.2.1. Environmental impact assessment

In order to perform the assessment on the environmental impact, the materials and processes need to be known. For each alternative, appendix C shows a table with the materials and processes and their quantities. These quantities have been used as input for the environmental impact calculation.

Figure 6.2 shows the result of the assessment in the form of the ECI, expressed in euros. For each of the layouts the ECI is shown for each alternative. As the designs are based on modules, some layouts have the same impact, since they use the same number of modules. It is obtained that the Composite alternative performs best across all layouts, whereas the Orthotropic alternative consistently has the highest impact. Figure 6.3 shows the summed impact across all different layouts. It is evident that the Composite alternative has the best performance. The impact is calculated over different life-cycle phases, which are combined in modules (see Figure 6.1). Figure 6.4 shows the impact from the 4x1 layout, divided into the different life-cycle modules. The total impact reported is the net result: module D is negative and thus reduces the impact. It can be seen that for all alternatives module A is responsible for the largest impact, between 85-90%. Module B in this instance refers only to the impact of the material used for maintenance.

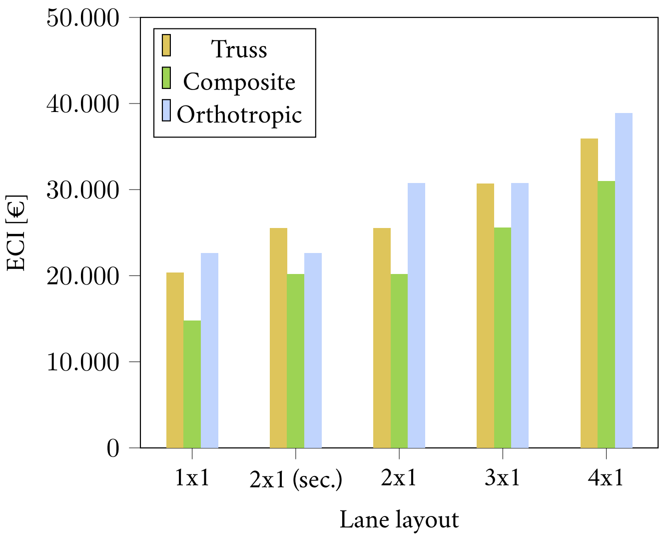


Figure 6.2: Environmental impact per road layout

Figure 6.5 shows the contribution of the different elements within the environmental analysis to the total impact of the alternative. It can be seen that for the Orthotropic alternative nearly 50% of the impact comes from the deck (deck plate and stiffeners), which, considering the fact that it is made of steel, is an important reason for it having a higher environmental impact. Maintenance also plays a role. The Composite alternative has a more or less equal impact for the deck and steel girders. For the Truss alternative a limited impact of the deck is seen, making that the main elements are the source of the impact. As explained in section 6.1.1, the transport is calculated for a distance of 200 km. Evidently, this

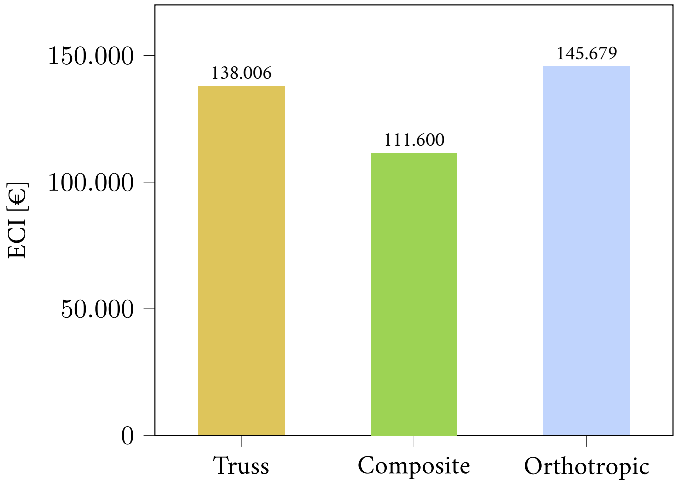


Figure 6.3: Total environmental impact per alternative

number can vary, either due to different transportation distances or due to more or less re-use cycles of the structure. However, as for all alternatives the transport accounts for only a few percent of the total impact, variations will have limited impact on the results.

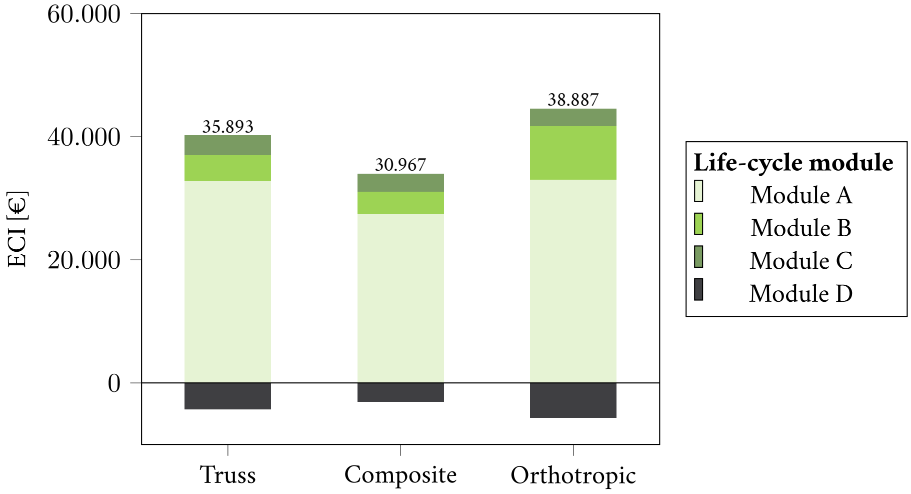


Figure 6.4: Environmental impact of 4x1 layout, divided in life-cycle modules

An important factor of the impact that has not been considered yet is the substructure. Considering that the total weight of the Orthotropic alternative is lower than that of the Composite alternative, this influences the results of the assessment. Although the substructure is not designed, an indication can be given of the impact the weight reduction has on the environmental impact. Firstly, it is assumed that, for a steel bridge or overpass, the impact of the substructure is equivalent to 25% of the superstructure, as an LCA study by Beco [63] shows. This concerns only the production phase, i.e., the LCA modules A1-3. Evidently, the exact value is dependent on the specific structure, yet this percentage can serve as an estimate. Then, considering the total mass of both structures (700000 kg for the Composite and 275000 kg for the Orthotropic alternative), it is seen that the mass of the Orthotropic structure is equivalent to 39% of the Composite structure. The following calculations show the difference in total load on the substructure:

$$F_{tot,comp} = F_{sw} + F_{var} = 1,25 \cdot 9,81 \cdot 700 + 1,5 \cdot ((10,35 \cdot 3 + 3,5 \cdot 6 + 2,5 \cdot 14,2) \cdot 32 + 600 + 400 + 200) = 14600 \text{ kN}$$

$$F_{tot,orth} = F_{sw} + F_{var} = 1,25 \cdot 9,81 \cdot 255 + 1,5 \cdot ((10,35 \cdot 3 + 3,5 \cdot 6 + 2,5 \cdot 14,2) \cdot 32 + 600 + 400 + 200) = 9100 \text{ kN}$$

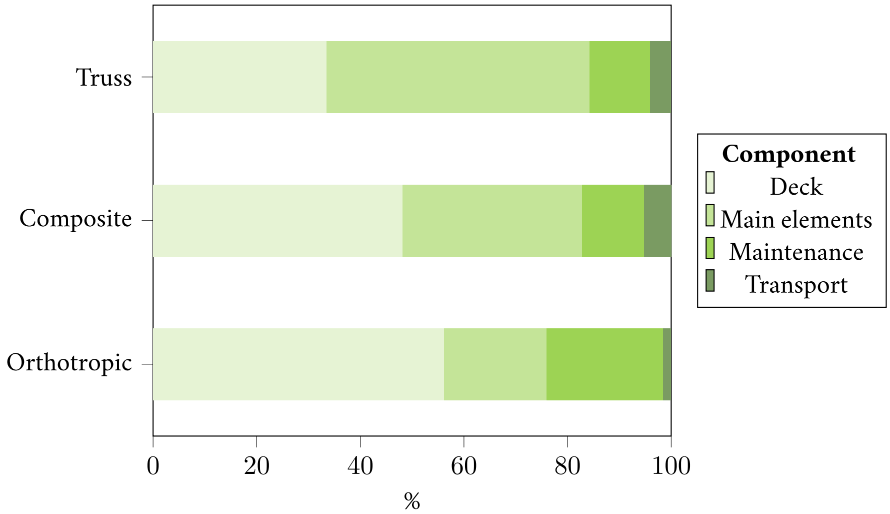


Figure 6.5: Environmental impact: contribution of different components to total impact

The Orthotropic alternative has a load equivalent to 62% of the Composite alternative. This means that the impact of the superstructure could be decreased by 38%. Considering the impact of all substructures is equal to 25% of the impact of the Orthotropic alternative, Table 6.1 is compiled. For the Truss alternative, which has a mass of 630000 kg, a similar calculation results in a load reduction of 6%. The results show that, although the difference decreases, there still exists a margin of 9% between the impact of the Composite and Orthotropic alternatives. The Truss alternative, however, has been surpassed by the Orthotropic alternative, which has a 5% lower impact. Figure 6.6 graphically shows the combined impact of the superstructure and substructure.
In conclusion, considering the production phase, the substructure has an effect that favours the lighter orthotropic structure, yet it is not sufficiently large to change the outcome of the assessment. Apart from the weight of the structure, other factors play a role in the design of the substructure, which may again favour the Composite alternative. Consequently, also considering the higher impact due to maintenance for the Orthotropic alternative, the Composite alternative is still the alternative with the lowest impact.

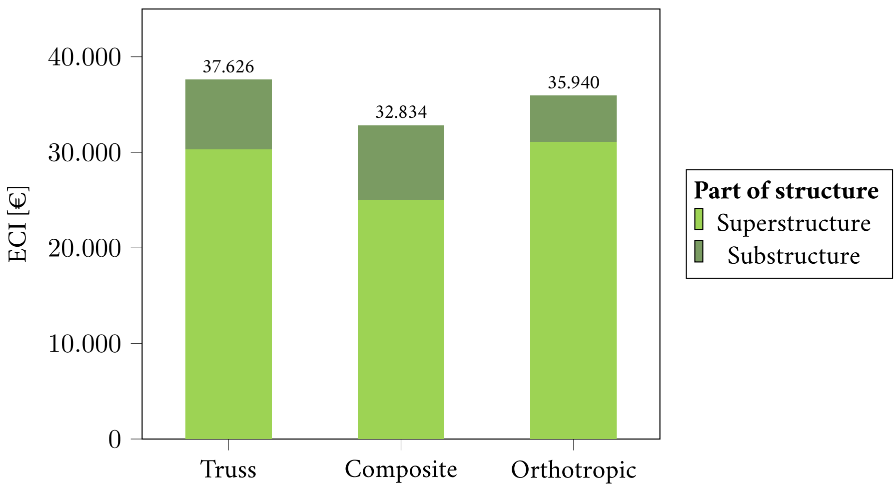


Figure 6.6: Combined environmental impact of superstructure and substructure, LCA-phases A1-3

Table 6.1: ECI values [€] for superstructure and substructure, LCA-phases A1-3

	Superstructure	Substructure	Total [A1-3]
Truss	30.314	7.312	37.626
Composite	25.055	7.779	32.834
Orthotropic	31.117	4.823	35.940

6.2.2. IFD principles

For each of the MCA categories, the values for the three alternatives have been determined. Table 6.2 shows the values for each of the assessment criteria. For the calculation of these values, appendix D can be consulted. With the normalisation approach as described, Table 6.3 is created. All values have been converted into scores between zero and one.

Figure 6.7 shows the total scores, for weight factors of 1, of the four alternatives. For smaller module sizes, the Composite and Orthotropic alternative perform nearly equally. However, if the module size is significantly larger, the Orthotropic alternative clearly behaves the best, though the Composite alternative still shows good behaviour. The main difference between the two alternatives comes from the reduced number of connections that is required.

The Truss alternative clearly has the lowest score. The main reason for this low score is the dependence in the structural system, which complicates replacement and extensions, and limits parallel assembly. The large number of (different) components is also a disadvantage. This does mean that the mass of the components is relatively low. In terms of connections, the truss structure also performs good, since a substantial number of connections combines multiple elements.

Strong points of the Composite alternative are the possibility for parallel assembly, explained by the nature of the system, and the small number of different components that are needed. The weak points are the aforementioned number of connections (mainly coming from the prestressing tendons and shear connectors) and the mass of the components. The

Table 6.2: MCA: values per category

	Unit	Truss		Composite		Orthotropic	
Module size →		*4 m*	*12 m*	*4 m*	*12 m*	*4 m*	*12 m*
Nr. of different components	#	5		2		1	
Nr. of components	#	175	104	112	42	48	18
Nr. of connections	#	232	161	577	542	754	244
Ease of changing overpass layout	*qual.*	0		1		2	
Mass of components	kg	3588	6037	6240	16640	5288	14100
Independence - PA	*qual.*	1		2		2	
Ease of replacement	*qual.*	0		1		0	
Maintenance	m^2	16911		14914		35331	

Table 6.3: MCA: scores per category

	Truss		Composite		Orthotropic	
Module size →	*4 m*	*12 m*	*4 m*	*12 m*	*4 m*	*12 m*
Nr. of different components	0,00		0,75		1,00	
Nr. of components	0,00	0,00	0,36	0,60	0,73	0,83
Nr. of connections	0,69	0,70	0,23	0,00	0,00	0,55
Ease of changing overpass layout	0,00		0,50		1,00	
Mass of components	0,43	0,64	0,00	0,00	0,15	0,15
Independence - PA	0,50		1,00		1,00	
Ease of replacement	0,00		0,50		0,00	
Maintenance	0,52		0,58		0,00	

mass of the individual components is rather high due to the concrete deck, which has a higher thickness than the Truss alternative, and the fact that the modules itself are of considerable size.

The Orthotropic alternative has a good score in particular due to the fact that only one module is used. As a result it is easy to modify and assembly is simplified. However, this comes with disadvantages, as the mass of the components becomes rather large and replacement of a component is complex because the structural system is always affected. Since the alternative is made completely of steel, the maintenance area is also larger than for the other two alternatives.

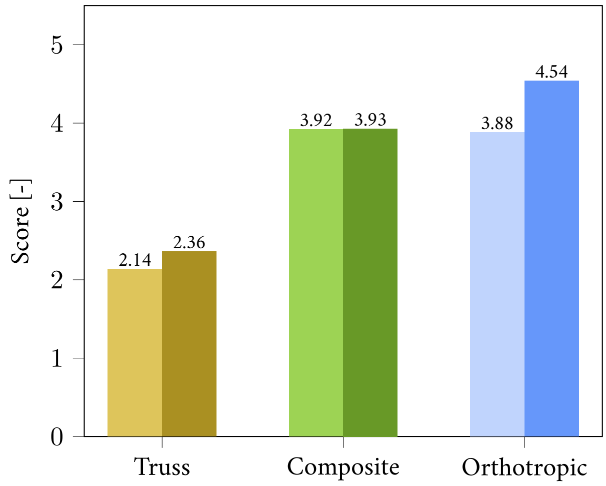


Figure 6.7: MCA scores, for module size 4 m (light) and 12 m (dark)

6.3. Conclusion

The three alternatives described in chapter 5 have been assessed on their performance regarding environmental impact and following IFD principles. The environmental impact assessment is in favour of the Composite alternative, which consistently has the lowest impact, even when a hypothetical substructure is included. On the IFD principles, the Orthotropic alternative shows the best behaviour for larger modules, followed by the Composite alternative. For smaller modules they perform equally. Considering the good performance on both environmental impact and IFD principles, the Composite alternative is concluded to be the best overall design for the application investigated within this research.

IV

Detailed Design

7
Connection Options

Three different interfaces are distinguished in the composite overpass that require attention. These are the shear connection between steel girders and concrete deck plates, the steel girder connection between girder segments and the connection between concrete deck plates. Firstly, requirements and guidelines that are applicable to all these connections are listed. Then, based on these requirements, the different options are investigated.

7.1. Requirements

To ensure demountability is possible and feasible, several requirements are formulated which should be met by the designed connections. The following requirements are defined:

- Use mechanical connections, preferably without connectors, otherwise with connectors or integral connections. In case chemical connections are proven to be demountable, they can be considered equivalent to non-chemical connections [19].
- Prevent the occurrence of damage to other parts of the structure during disassembly [19].
- Connections should not be enclosed by other objects [71].
- Disassembly of connections should be safe [71].
- Design joints and connectors to be able to sustain repeated assembly and disassembly [22].

Apart from requirements, guidelines can be defined, which increase the demountability of a connection and facilitate a faster and more simplified assembly and disassembly process:

- The time required for disassembly should be minimised [71].
- The number of actions required to disassemble the connection should be minimised [71].
- The number of (different) connections should be minimised [22].
- Aim for limited complexity in the connections [23].
- Ensure good accessibility to connections [22].

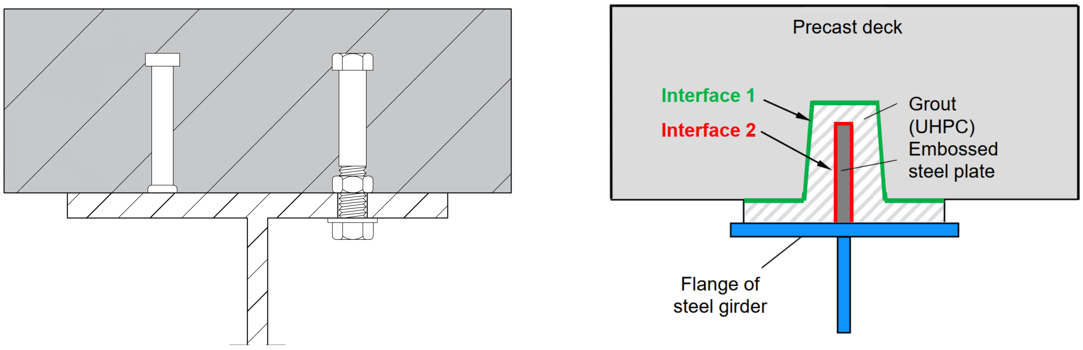
Besides IFD requirements, tolerances also impose limitations on a structure. Tolerances are of importance for the assembly of the structure, particularly for connections in prefabricated structures. From the point of view of mechanical performance, the tolerances should be minimised. Production, however, requires some tolerance to allow for small deviations during the production of components. All components are standardised and mass produced. This means that it is expected to be economically feasible to optimise the production process to create small tolerances, for instance by manufacturing a high-precision mould. Furthermore, the fact that the interfaces between the components will always be the same due to the use of identical components increases the possibility for optimisation of the production process.

In terms of tolerances, separate tolerances are distinguished for both the steel and the concrete. With regard to bolt holes in a steel connection, EN 1090 prescribes that the hole diameter should be 2 mm larger than the bolt, assuming a normal size hole [72]. It is assumed that this is sufficient, given the considerations mentioned and the fact that this is successfully applied in the modular structure shown in Figure 3.7. For concrete, normally tolerances are larger than for steel. Yet, as all panels are the same, it is economically feasible to optimise the mould required for production of the panels, so that small tolerances can be achieved. Therefore, it is decided to assume a slightly larger, yet still limited, tolerance of 4 mm. This margin is chosen because this value is often used in the tests on the shear connectors, to which is referred in section 8.1.3. Accordingly, it is also applied on the bolt holes for the shear connectors within the steel.

7.2. Shear connection

A connection between the steel girder and the concrete deck is required to transfer shear forces and to create composite action. The most common type of connection is a mechanical connection in the form of welded elements, mostly studs. The problem with welded elements is that they are not demountable, which is why other types of connectors need to be used to allow for reusability. Bolted connections are well suited for demountability and are increasing in relevance. They exist in the form of conventional bolts, with load transfer by bearing, and as friction connections, where load transfer is by friction. Figure 7.1a shows both a welded stud and a bolted connector.

Alternatively, connections utilising adhesives are possible. Figure 7.1b shows an example of a developed adhesive connection in combination with a continuous plate welded to the steel. Grout is used to connect the concrete and steel. The main benefit of this connection is the absence of individual connectors and fast assembly. It should be noted that, besides through adhesion, forces are also transferred by friction and interlocking. The disadvantage is that demountability of the grout is not proven. Since the grout is essential for the transfer of forces, the application of non-adhesive grout is not expected to result in good behaviour. Hence, it is decided to focus on a connection created with individual shear connectors.



(a) Welded stud (left) and bolted connector (right)

(b) Strip shear connection [73]

Figure 7.1: Examples of shear connection methods

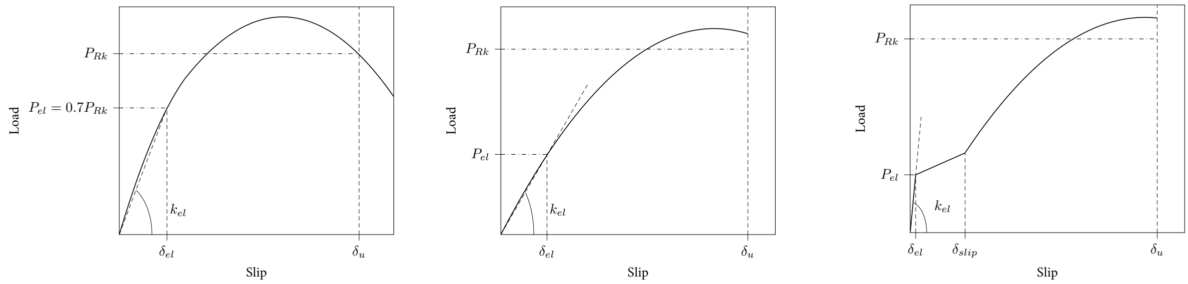
7.2.1. General behaviour

For analysis of shear connectors, the most insightful feature is the load-slip behaviour, which describes the deformation of a connector in response to the application of a load. As the behaviour of demountable connectors is different compared to welded studs, it is important to understand the differences. Figure 7.2 shows the qualitative load-slip behaviour of three types of connectors: conventional welded studs, demountable connectors without preload and demountable connectors with preload. The figures are indicative of the behaviour and are used as a matter of comparison. The behaviour of individual connectors may, therefore, differ from the generalised behaviour shown in the figures.

ULS vs. SLS

For an analysis in either ULS or SLS, different assumptions need to be made. For ULS values close to the ultimate resistance can be taken, yet for SLS a limit needs to be imposed. For the welded studs this is defined through tests as a resistance of $0.7P_{Rk}$. For demountable connectors, however, this relation is not always valid, as they have different behaviour. Hence, a limit is formulated based on the re-usability. In order to be able to reuse the elements from the structure after a use cycle, it is necessary to prevent the occurrence of damage or irreversible deformation in the structure. This is ensured by the prevention of inelastic behaviour, as also suggested by the Steel Construction Institute [74]. By imposing such a limit, it is assured that the components can be reused without the need for inspection and that it is possible to disassemble the connections.

For each of the connectors that are discussed the behaviour is different, as is the point up to which plastic deformation is prevented. As a safe limit it is decided to restrict connector forces in SLS to their elastic limit. In case the connectors are not preloaded, this relates to the part of the load-slip curve that is linear, which indicates elastic behaviour as shown in Figure 7.2c. In case of preloaded connections, the elastic limit is taken as equivalent to the domain in which the forces are transferred by friction, the first branch in Figure 7.2c. Although the behaviour afterwards may be partially elastic, the occurrence of slip after the friction resistance has been overcome may lead to unfavourable behaviour, such as a loss of resistance or plastic deformation, and should be prevented. This approach is also suggested in some design codes [75].



(a) Conventional welded stud

(b) Demountable non-preloaded connector

(c) Friction-based connector

Figure 7.2: Indicative load-slip behaviour of different shear connectors

It is acknowledged that the proposed limit can be conservative for certain connectors, for it is not necessarily the case that the structure deforms plastically directly after the elastic limit of the connector has been surpassed. Still, it is not known for all connectors up to which point plastic deformation is prevented and whether disassembly of the connector and reuse of elements is possible. Therefore, as the current limit ensures for all connectors that no plastic deformation takes place, it is considered that the described approach is suitable for the design.

Preload loss

A point of attention for preloaded connectors is the amount of preload in the bolts and in particular the reduction in load due to preload loss. Although it is not part of the scope of this research to perform a detailed design of the connection, it is important to assess whether preload loss is a limiting factor in the design or if it can be managed when taken into account. Nijgh [76] listed several causes of preload loss. The mitigation of preload loss focuses on two properties of the connection: the connector and the surface. With regard to the connector, appropriate detailing can effectively mitigate some of the causes of preload loss and, naturally, should be considered for the detailed design of the connection. The second aspect is the surface, where, by means of the mechanism of embedment, plastic deformation of the surface coating results in relaxation. Though it is evident that a surface coating is required, the right installation methods can cover losses that occur due to these effects [77].

Apart from the steel parts, the concrete is also of importance, for creep and shrinkage effects reduce the preload force. Although it is not part of this research to assess the magnitude of preload loss due to creep and shrinkage of the concrete, it has been found that measures can be taken to mitigate these losses. Examples of such measures are the use of high-strength concrete and the application of a proper installation procedure [78].

In conclusion, measures exist that can mitigate or potentially fully cover preload loss. The need for these measures is to be demonstrated by a detailed design of the connectors.

Initial slip

The initial slip of a connector is usually defined as the slip that a connector experiences before the elastic design resistance of the connector is reached, denoted by δ_{el} in Figure 7.2a and 7.2b. The initial slip is limited due to the good initial stiffness. For preloaded bolted connectors, though, initial slip is often referred to as the slip that occurs directly after the friction resistance is overcome. In Figure 7.2c this is the range $\delta_{slip} - \delta_{el}$. The stiffness of the connector in this stage can differ: for some connectors the stiffness is more or less equal to the third stage, whilst for some connectors no stiffness in this stage has been recorded. This slip occurs due to the clearance between the bolt and bolt hole. In favour of fatigue life, initial slip in preloaded connections needs to be prevented. It should be noted that initial slip has no effect on the ultimate resistance of bolted connectors [79].

Composite action and ductility

The degree of composite action is also a relevant property of a composite structure. In case of full composite action all forces can be transferred between the steel and concrete resulting in full interaction. If not all forces can be transferred, partial interaction occurs. Full interaction results in better cross-sectional properties, yet it requires more connectors and may not always be required. For the shear connectors full composite action means that all forces can be transferred between the steel and concrete. This either means that connectors should be ductile enough to allow other connectors to reach their ultimate resistance before failure or that the placement of the connectors should be optimised to follow the shear force behaviour. The degree of composite action is also influenced by the stiffness of the connectors. A low connector stiffness results in reduced interaction and as a result a reduced stiffness of the assembly. Consequently, flexible connectors should follow the shear force distribution more closely to limit deformations.

Related to the composite action is the ductility of the connector. A connector is ductile if it exhibits ideal plastic behaviour, that is, it features a plastic plateau. In the Eurocode a connector is considered ductile if it can maintain its characteristic resistance P_{Rk} up to a slip capacity δ_u of 6 mm (see Figure 7.2a). This is under the assumption that P_{Rk} is reached at limited slip. Demountable shear connectors tend to not show behaviour similar to welded studs and can thus, following the Eurocode definition, not be classified as ductile connectors. Using the classification proposed by the Steel Construction Institute [74] the connectors are classified as non-ductile with sufficient deformation capacity, since the majority of the connectors have an ultimate deformation δ_u exceeding 6 mm. Normally, non-ductile connectors do not allow for redistribution of loads to other connectors, given that they fail directly after reaching their ultimate resistance. For the demountable shear connectors, however, redistribution is possible up to a certain degree, due to the deformation capacity that exists. Consequently, for the ULS it is allowed to design for plastic resistance, under the condition that the design resistance as retrieved from the Eurocode is slightly reduced [74].

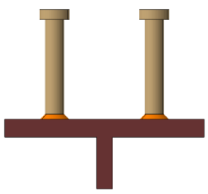
Normally, a minimum degree of shear interaction is required to prevent premature failure of the shear connectors. Again, this requirement is based on welded studs and can, therefore, not directly be applied on demountable connectors. As a replacement of this condition it is replaced with a check on elastic behaviour in SLS, which already is the current approach for the SLS verification [74].

Fatigue life
Naturally, good fatigue life is desired for applications in bridges and overpasses and especially for an overpass that should be usable for 200 years. Almost all bolted connectors have a fatigue life better than welded studs, due to the fact that welds are more vulnerable to cyclic loading. Fatigue resistance can be increased further by means of preload. The stress variations in a bolt reduce when a preload force is applied, resulting in improved fatigue life. Movements of the bolts inside holes should also be prevented.

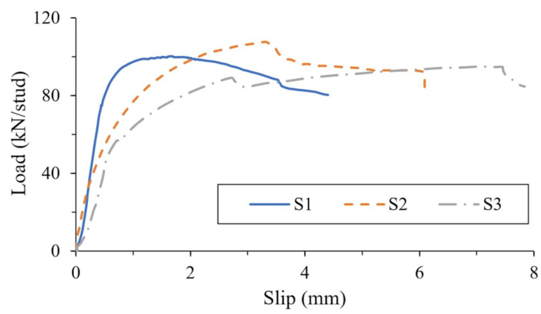
7.2.2. Connector types

Due to the increasing interest in the use of demountable shear connectors, numerous types of connectors have been developed recently. Several of these connectors are briefly described. The load-slip behaviours of the different connectors are illustrated, with the remark that they are not directly comparable for all connectors, since the dimensions and strength of the connectors can differ. After the discussion of the different connectors, an overview is given where it is reasoned which connectors have the most potential, based on practical considerations.

Welded headed stud
Welded headed studs, shown in Figure 7.3a, are the conventional solution for shear connectors. They are widely used in the construction industry. Given the growing relevance of sustainability and, consequently, of disassembly and reuse of components, the non-demountability of the welded studs is an increasingly important disadvantage. Another point of concern for welded studs is the relatively low fatigue strength of the connector. Figure 7.3b shows the load-slip behaviour of welded headed stud connectors. The load-slip behaviour of welded studs is characterised by a rapid increase of resistance, followed by an increase of deformation for a more or less constant load. This translates in a good initial stiffness, as limited initial slip is required before the ultimate resistance is achieved. The ultimate slip capacity is often considered to be 6 mm, proving that welded studs can exhibit ductile behaviour.



(a) Illustration of welded headed stud [80]

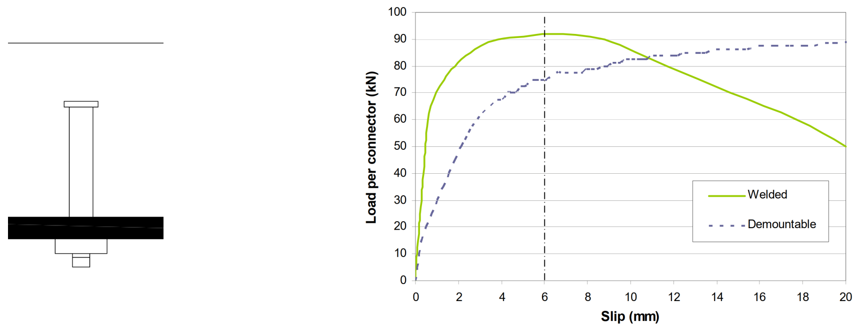


(b) Load-slip behaviour of welded headed stud [81]

Figure 7.3: Welded headed stud

Demountable headed stud
Demountable headed studs (DHS) are very similar in shape to conventional headed studs, with the exception that they are connected by their threaded end and a nut, as shown by Figure 7.4a.

The behaviour of the demountable headed stud is different from that of welded headed studs, which is shown by Figure 7.4b. The connector has a similar capacity and is more ductile, yet has a lower initial stiffness and as such the initial slip is considerably larger than for welded studs [82]. Fatigue behaviour of the demountable headed studs has not been tested, yet it can be expected to be better than for welded studs, due to the absence of welds.



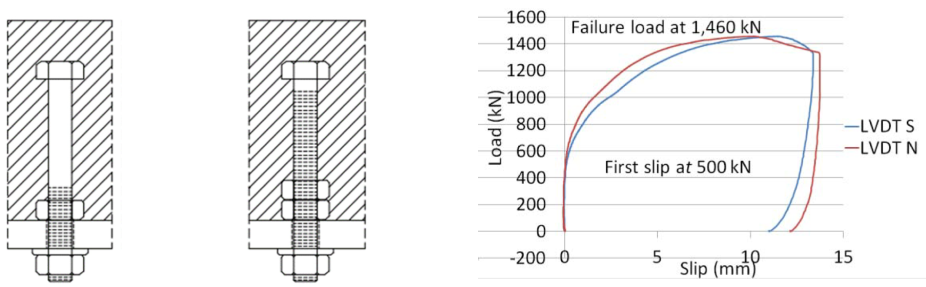
(a) Illustration of a DHS [adapted from D20] **(b)** Load-slip behaviour of welded stud and DHS [82]

Figure 7.4: Demountable headed stud

Embedded nut bolt
Embedded nut bolts are bolts that are connected with a nut and feature one or two additional nuts at the flange, referred to as respectively single-embedded nut bolts (SENB) and double-embedded nut bolts (DENB). Figure 7.5a shows an illustration of an SENB and Figure 7.5b of a DENB. The effect of the second nut on aspects such as stiffness seems to be limited, as is shown by analyses by [83] and [79]. Thus, the behaviour of the SENB and DENB can be considered comparable.

Figure 7.5c shows a typical load-slip curve of an embedded nut connector, in this case for an SENB. The connector is preloaded and the results are shown for a connection with a total of eight identical connectors. The resistance is similar to welded studs [79]. The ductility, however, is slightly lower and especially the stiffness is the property that is inferior to conventional studs. Initial slip also takes place due to the clearance between the bolt and bolt hole. Fatigue behaviour has been tested for preloaded DENBs and has proved to be significantly better than for conventional studs [84]. It was reasoned that this might be explained by the reduced bending of the bolt. Since the stiffness of SENBs and DENBs have shown to be very similar, the bending reduction should be similar too, leading to good fatigue behaviour for both DENBs and SENBs.

An alternative is a bolt without an embedded nut. While some properties are similar to SENBs, the stiffness is considerably lower [79, 83], excluding them as a feasible option.



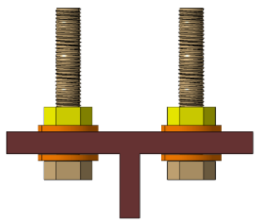
(a) SENB [85] **(b)** DENB [85] **(c)** Load-slip behaviour SENB [86]

Figure 7.5: Embedded nut bolt connectors

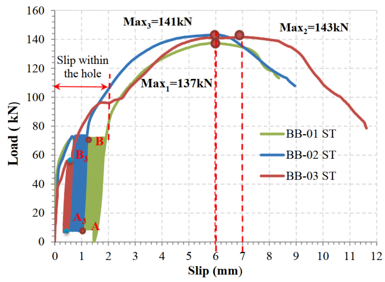
Blind bolt

Figure 7.6a shows an illustration of a blind bolt (BB). The connector consists of a bolt with its head under the steel flange and an additional bolt on top of the flange, embedded in the concrete. The absence of a head or nut on the concrete end of the bolt forms the distinction with the SENB connector.

With respect to conventional studs, blind bolts have a higher resistance and show sufficient ductility [87], as is illustrated by Figure 7.6b. Not dissimilar from embedded nut connectors, the stiffness is considerably lower compared to welded studs and initial slip is noticed due to the clearance between bolt and bolt hole. Fatigue behaviour of blind bolts, on the other hand, has shown to be better than for welded studs [87].



(a) Illustration of blind bolt [80]



(b) Load-slip behaviour of blind bolt [80]

Figure 7.6: Blind bolt

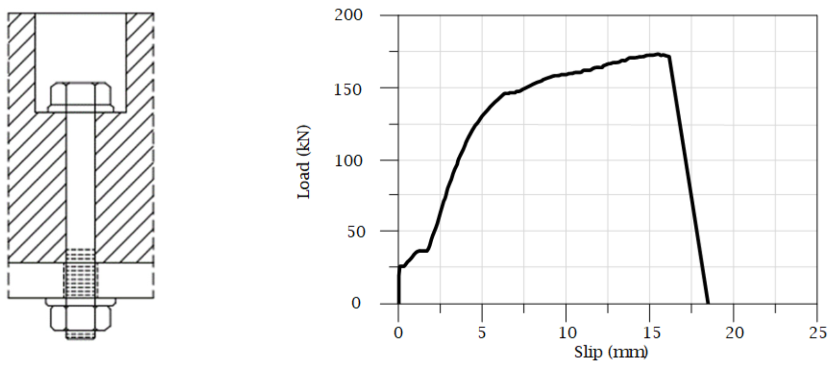
An alternative to a blind bolt is an adhesive anchor connection, which is in fact a blind bolt where the embedded nut has been removed. The resistance of this connection is similar, yet the stiffness is significantly lower [84]. Considering fatigue resistance, the fatigue life is, like for blind bolts, better than for welded studs. The rather low stiffness, however, makes that blind bolts are favoured over adhesive anchors. Other types of blind bolts, such as Ajax Oneside or Lindapter Hollo-bolts, have shown to have insufficient fatigue life, making them unsuitable for use in high-cycle-fatigue applications [88].

High-strength friction grip bolt

High-strength friction grip bolt (HSFGB) connections are the most basic type of friction connection. Figure 7.7a shows the layout of the connection. The bolts are installed through a hole in the concrete and then preloaded to transfer forces by means of friction.

The resistance of the HSFGB is higher than for welded studs [89]. This is also shown by the load-slip behaviour in Figure 7.7b. Initial stiffness of the HSFGB is also better, yet when friction is overcome slip occurs and afterwards the stiffness of the bolt is lower. Noteworthy is that after loss of friction resistance the bolts do not experience a sudden loss of resistance, yet see a continuous, though small, increase of resistance until bearing occurs. This behaviour is consistent with most friction connections. The ductility is good and might even be very large, as shown by [84]. Moreover, the fatigue behaviour is considerably better than for conventional studs.

Points of attention for this type of connection are the effect of the preload force on the concrete, as this introduces high compressive stress around the bolt. Furthermore, the compressive force on the concrete leads to creep and shrinkage effects in the concrete, which in turn can result in preload loss. Preload loss in general is an important aspect to consider for preloaded bolts.

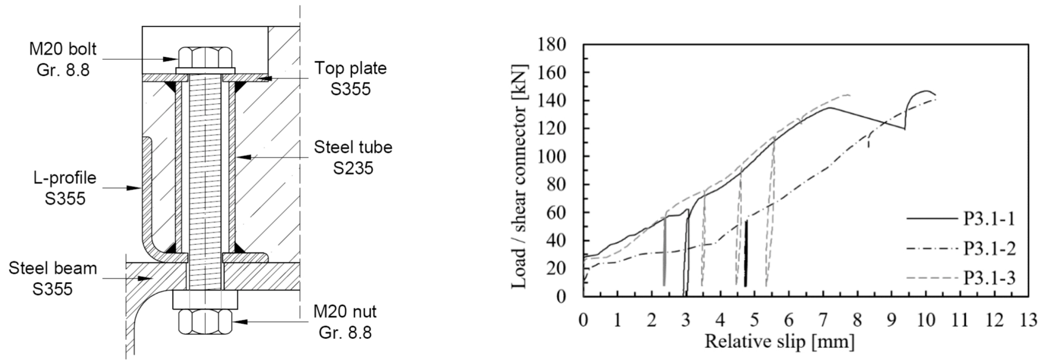


(a) Illustration of HSFGB [85] **(b)** Load-slip behaviour HSFGB, adapted from [89]

Figure 7.7: High-strength friction grip bolt connection

Cylinder HSFGB
A connection with improved behaviour on the aforementioned points of attention is a modified version of the HSFGB connection, the so-called Cylinder system in Figure 7.8a: a steel cylinder is placed in a hole in the concrete and in the cylinder the bolt is placed. The main advantage of this system is that the forces are introduced on the steel, rather than on the concrete, and as a result creep and shrinkage effects are eliminated and thus preload losses are reduced [90]. Additionally, the cylinder serves as protection for the concrete.

In terms of behaviour, the regular HSFGB and cylinder system are very similar. Comparing test results from [90] and [89], regular HSFGBs have slightly more resistance. Given that the test parameters are not completely similar, no real conclusions can be drawn on this matter. The ductility also appears to be smaller than for the regular HSFGB. This, though, might be explained by the concrete class: The cylinder system has a higher concrete class than the regular HSFGB connection and, considering that Pavlović [79] showed that higher concrete classes show more brittle behaviour, this may cause failure at lower deformations. Fatigue has not been tested separately for this connection, yet behaviour similar to HSFGBs can be expected.

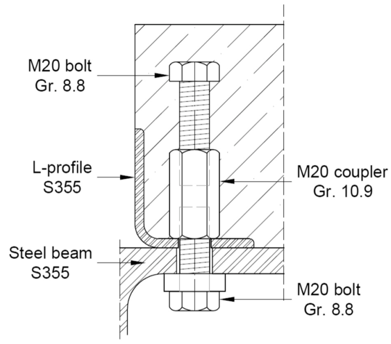


(a) Cylinder system illustration [91] **(b)** Load-slip behaviour Cylinder system [91]

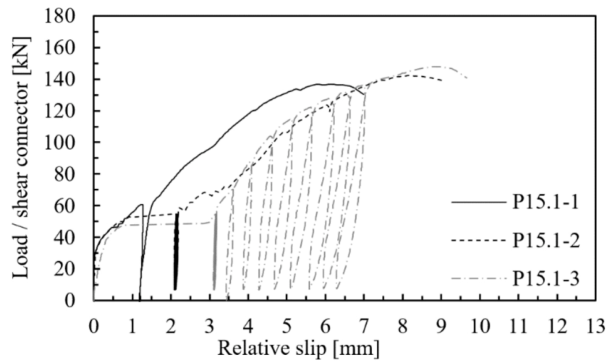
Figure 7.8: Cylinder system: adapted version of HSFGB

Embedded coupler device
Figure 7.9 shows an embedded coupler device connection (ECD): a connection consisting of two bolts and a coupler device. One bolt is embedded in the concrete and connected to the coupler device. The second bolt connects to the coupler device from under the steel flange. Due to the connection of the second bolt to the coupler, it can be removed easily and without resulting in protruding parts.

The resistance of the connection is higher than, or at least similar to, conventional studs and its ductility is also good [90]. The stiffness is lower, though, and slip occurs after the friction resistance is overcome, as is the case for HSFGB connections. On fatigue life no tests have been done, but given that preloading of the bolts is applied, it could be expected that good fatigue life can be achieved.



(a) Illustration of ECD without resin [91]

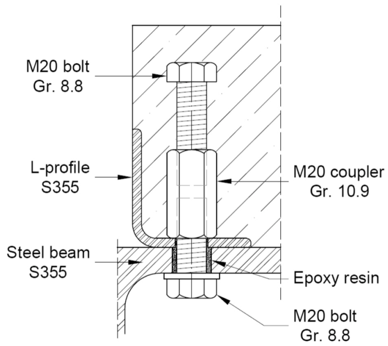


(b) Load-slip behaviour of ECD without resin [91]

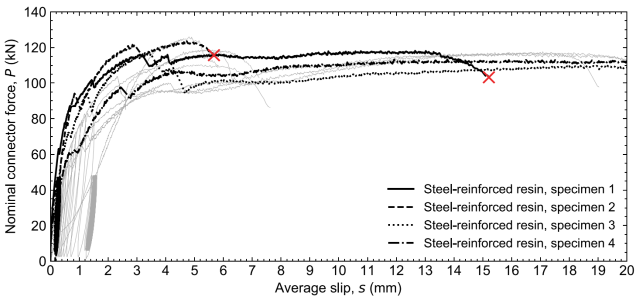
Figure 7.9: Embedded coupler device, without resin

Injected embedded coupler device
A variation on the ECD connection is the addition of resin in the void between the bolt and the steel flange, displayed in Figure 7.10a. The addition of resin allows for larger tolerances, as slip is prevented by the resin. A conventional type of resin can be used for the connection. However, an innovation has been developed where small steel particles are added to the resin to enhance its properties, referred to as injected steel-reinforced resin (iSRR). The iSRR leads to more favourable behaviour: the stiffness is improved compared to conventional resins (by approximately 50% according to Nijgh [92]) and long-term behaviour and fatigue behaviour are better [93]. Accordingly, the reinforced resin is preferred over the non-reinforced resin [76].

More specifically, iSRR connections have good shear resistance and stiffness. In combination with preload, the connection also has a high initial stiffness and a lower slip to reach high resistance. In case of omission of preload, the resistance of the injected connection is slightly lower compared to a preloaded non-injected connection [92]. The fatigue resistance is good [88], provided that preload is applied. It is possible to demount the connection, even though resin is used; Nijgh [76] showed that when it has been ensured that the resin does not adhere to the steel, demounting is possible. This can be achieved by the application of a release agent.



(a) Illustration of ECD iSRR [91]



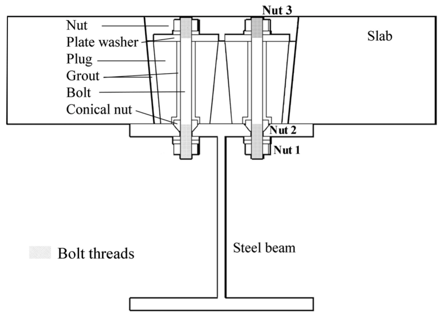
(b) Load-slip behaviour of ECD iSRR [92]

Figure 7.10: Embedded coupler device, with injected steel-reinforced resin

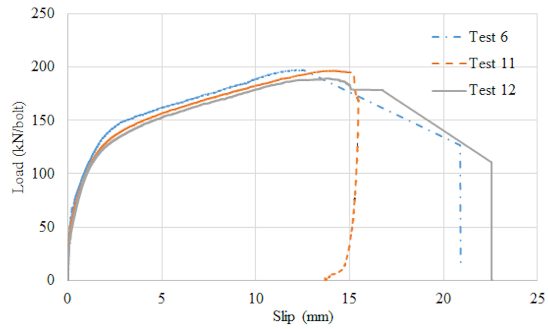
Locking-nut shear connector
The locking-nut shear connector (LNSC) is a novel design of a connector. It consists of two bolts with plugs around them, illustrated by Figure 7.11. The full assembly is then grouted in the concrete slab.

The connection has a high resistance due to its specific design [75]. The slip capacity is also better than for conventional studs, as, due to the conical nut and countersunk hole in the steel flange, slip in the bolt hole is prevented. As a result, low initial slip can be achieved. The stiffness in the lower loading regime is comparable to conventional studs, yet conventional studs can sustain higher loads at that stiffness. Disassembly can be done by means of either removing the lower bolt or by loosening the top bolt and removing the concrete along with the plug. Fatigue tests have not been performed yet. Still, as the bolts are preloaded, good fatigue life is plausible. Fatigue life of this connection has not been tested.

The optimised design also has a clear disadvantage in that the connection is rather complex. In combination with the large number of different components, this makes (dis)assembly more difficult. With regard to reuse, the design has a disadvantage as well. As the bolt, the bolt hole and the plug position are adjusted to one another, a perfect fit is created in the first use phase, whilst potential deviations are covered by the application of grout. For re-use phases, however, very strict tolerances are required if the connection is directly reused. These tolerances might be too strict to be feasible, as it can be expected that deviations will occur in the exact position of the bolt holes with respect to the concrete plugs.



(a) Illustration of LNSC [75]



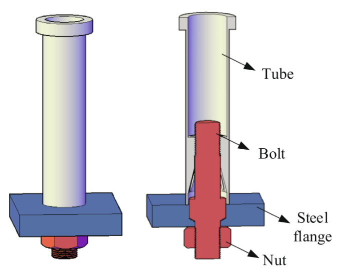
(b) Load-slip behaviour of LNSC [75]

Figure 7.11: Locking-nut shear connector

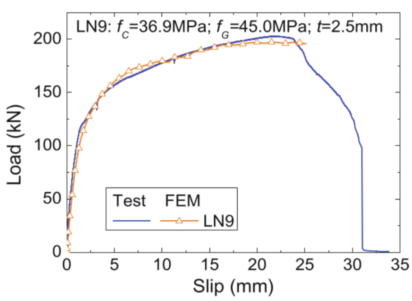
Locking-bolt demountable shear connector
Locking-bolt demountable shear connectors (LBDSC) are newly developed connections. In Figure 7.12 can be seen that they consist of a threaded bolt with an embedded trapezoidal nut, placed in a countersunk hole in the steel flange. It is fastened with a nut under the flange. At the top of the bolt a tube, resembling a stud, can be connected and filled with grout. The top of the tube should be level with the concrete surface, to enable demounting of the connection from the top. Demounting through the bottom nut is also possible.

With respect to welded studs, the resistance and slip capacity are better, whilst the stiffness for the lower loading regime of the connector is similar [94]. Like the locking-nut shear connector, sudden slip that occurs in, for instance, friction bolt connections is eliminated by the conical nut and countersunk hole and high initial stiffness is achieved. The fatigue behaviour of the connection is unknown, though, and given the discontinuities in the design, stress concentrations might develop and reduce the fatigue life. Moreover, although preload is said not to be required, it might be favourable to apply to increase fatigue life.

The largest problem with this design are the tolerances. As the tube, bolt and bolt hole in the flange are all adjusted to one another, they need to be assembled before the pockets in the concrete are cast. This ensures that in the first use cycle the connections are all perfectly aligned. For the re-use phases, however, it can be expected that small deviations in the exact position of the connector in the concrete can occur, which will not necessarily align with the bolt positions. Therefore, perfect positioning of all connectors is required, which is not feasible.



(a) Illustration of LBDSC [94]



(b) Load-slip behaviour of LBDSC [94]

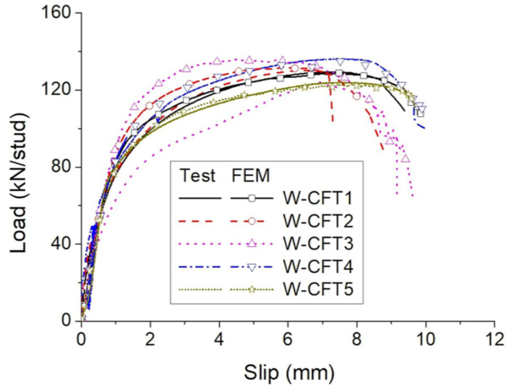
Figure 7.12: Locking-bolt demountable shear connector

Welded demountable shear connector

A variation on the LBDSC is the welded demountable shear connector (WDSC). It is shown in Figure 7.13. Instead of a bolted connection to the steel flange, the bolt is welded to the flange. The tube connection remains unchanged and follows the same principle.

The connection has better shear resistance and similar stiffness to conventional studs and shows ductile behaviour [81]. Fatigue life has been evaluated and, although it is better than for conventional studs, it is inferior to several other options [95]. This might be explained by the presence of welds. As for the bolted version, tolerances are expected to be an issue for re-use cycles.

(a) Illustration of WDSC, adapted from [81]



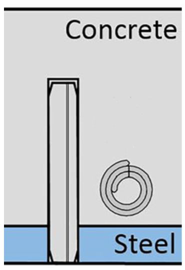
(b) Load-slip behaviour of WDSC [81]

Figure 7.13: Welded demountable shear connector

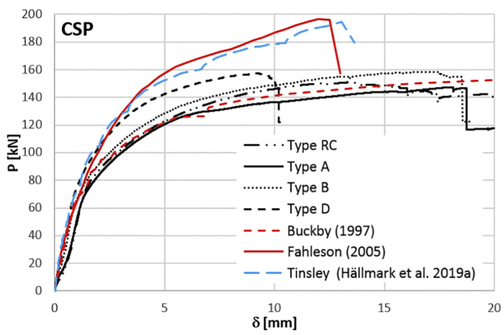
Coiled spring pin

The coiled spring pin (CSP) is a connector that is different from the bolted connectors. It consists of a rolled steel plate, which is placed inside a hole that is slightly smaller than the diameter of the CSP. Due to the fact that the CSP is compressed, a spring force develops, which forms the connection between the connected elements. The advantage of such a connector is that it does not require any additional elements, such as nuts in the case of bolts, and it is easy to install, as no preload or injection is necessary. Fatigue life of the CSP is comparable to welded studs, but considerably lower than the fatigue life of most of the bolted connectors [96].

The demountability of this connector is not straightforward, though. Originally proposed as a post-installed strengthening measure for composite decks, the connector is installed in a blind hole, for which it is difficult to remove the connector damage-free. Still, it may be possible to remove the CSP. An approach could be to include a profile in the centre of the CSP or at its end to which a device can be connected to pull out the connector. A second option could be to make a through-hole, allowing for the CSP to be pushed out at the top of the deck. Another point of attention is the alignment of the holes. To develop a spring force the connector needs perfect alignment. Whilst such tolerances would be too strict, a solution that may have potential but needs testing would be to make an oversized hole in the steel flange and use injection.



(a) Illustration of CSP [96]



(b) Load-slip behaviour of CSP [97]

Figure 7.14: Coiled spring pin

Overview
To reduce the number of possible connections, it is assessed whether the connectors are suitable for use in an IFD overpass. For each of the connectors several practical considerations exist that are listed in Table 7.1.

Table 7.1: Practical considerations for the connectors

Connector	Advantages	Disadvantages
DHS		- Protrudes from plate - Connector cannot be replaced
SENB		- Protrudes from plate - Connector cannot be replaced
BB		- Protrudes from plate - Connector cannot be replaced
HSFGB	+ Can be demounted from the top + Connector is replaceable	- Requires two-side access
Cylinder	+ Can be demounted from the top	- Requires two-side access - Manufacturing is complex - Cylinder is not replaceable
ECD (no resin)		- Coupler and embedded connector cannot be replaced
ECD (iSRR)	+ Larger tolerances can be achieved	- Coupler and embedded connector cannot be replaced - Requires injection of resin
LNSC	+ Can be demounted from the top + Connection is replaceable + Large tolerances can be achieved	- Grout needs curing time - Installation requires two-side access - Need for grouting for each use cycle - Manufacturing is complex
LBDSC	+ Can be demounted from the top + Connector is replaceable	- Requires two-side access - Grout needs curing time - Need for grouting for each use cycle - Strict tolerances for reuse
WDSC	+ Can be demounted from the top	- Protrudes from girder - Grout needs curing time - Need for grouting for each use cycle - Welded part cannot be replaced - Strict tolerances for reuse
CSP	+ Connector is replaceable	- Strict tolerances for reuse

Based on Table 7.1 a number of connectors can be excluded due to certain practical limitations. Three practical considerations are valued as the most important:

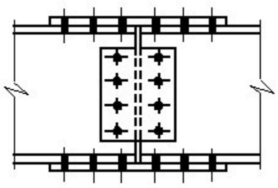
- Protrusion from the deck plate: the protrusion from the deck plate is considered an important limitation for reuse. This creates a vulnerability during transportation and disassembly, which can lead to damage and render the module unusable. Taking note of the requirements in section 7.1 that focus on prevention of damage and the need for repeated disassembly, this limitation is undesirable in an IFD overpass. As a result, the DHS, SENB and BB connectors are dismissed as options.
- Strict tolerances for reuse: it is acknowledged that some tolerances are necessary for the use of prefabricated components. For some connectors, however, the tolerances need to be considerably lower than for other connectors, due to their optimised design. It is considered unfeasible to demand such strict tolerances, leading to the conclusion that these connectors cannot be part of the design. This is the case for the LBDSC, WDSC and CSP connectors.
- Application of grout: the application of grout has one important downside in that it requires curing time. Hence, it imposes limitations on the assembly process, which is why it is decided to dismiss it as an option for the shear connectors. This applies to the LNSC connector.

Following the exclusion of these connectors, four connectors remain, which are considered to be the most suitable for an IFD overpass. These are the HSFGB, Cylinder, ECD (no resin) and ECD (iSRR). For these connectors their behaviour in the structure is investigated using the mechanical properties determined using test results from literature.

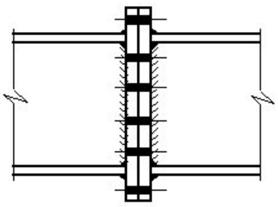
7.3. Steel girder connection

The connection between the steel girder segments is made with a bolted connection, as they are particularly useful for demountable connections, where other types of connections, such as welds, are not demountable.

With regard to the type of connection, there are two types: connections loaded in shear and loaded in tension, shown in Figures 7.15a and 7.15b. For shear connections, the Eurocode distinguishes three categories: bearing, slip-resistant at SLS and slip-resistant at ULS, categories A, B and C respectively. Category A is not applicable, due to the low fatigue resistance. The difference between category B and C relates to the effect the occurrence of slip will have on a structure. For the connection is located in the main girders, slip is not allowed and rigidity is required, which means that a category C is needed. In terms of classification of the stiffness of the joint, it should be a rigid joint. Tension connections also exist. Yet, as shear joints can be designed infinitely stiff, use bolts more efficiently as forces are better distributed over the bolts and have favourable fatigue behaviour, shear joints are the preferred option.



(a) Bolted connection with shear forces [98]



(b) Bolted connection with tension forces [98]

Figure 7.15: Types of bolted connections

Bolt types

With regard to the bolts, three types can be distinguished: regular bolts, preloaded bolts and injected bolts. Regular bolts are bolts used in conventional bolted connections where the load transfer is done via bearing of the contact surface of the bolt with the connected plates. As they do not require additional actions, they are easy to install. However, they have low fatigue resistance, as large force variations can occur in the bolts. This excludes the use of regular bolts. Preloaded or friction bolts are the logical choice for slip-resistant connections. The bolts are preloaded, which creates a clamping force on the connection. As a result the force transfer is through friction between the connected elements, rather than via bearing. When the friction resistance is overcome, the force transfer takes place by means of bearing of the bolts. Loosening of the connection due to vibrations is prevented by preloading the connection. The presence of the preload also reduces the stress variations in the bolt and activates a larger area to develop resistance, resulting in enhanced fatigue performance. Another advantage is that oversized holes can be used. Points of attention are the introduction of additional stress on other members and the loss of preload force.

Injection bolts are an alternative to preloaded bolts to create slip-resistant joints. At first friction takes the load, after which the injected resin and bolt take the load by bearing. In itself injection bolts are not demountable. If, however, measures are taken to prevent the resin to adhere to the steel, the connection can be demounted. Injection bolts have the advantage that larger clearances can be used, since the resin fills the void and prevents sudden slip in case of overload. Like for non-injected bolts, preloading should be applied, for the same reasons as mentioned earlier. The design resistance of preloaded injection bolts is higher than for regular preloaded bolts, leading to a smaller amount of bolts required. The increase is said to be 35% [76]. The resin also acts as protection for corrosion of the interior of the connection. Points of attention are related to long-term behaviour, e.g., creep of the resin.

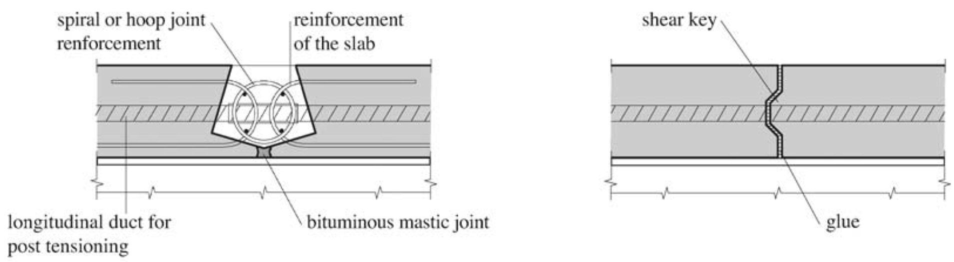
Although injection bolts have advantages over regular preloaded bolts. There are several disadvantages, in particular related to execution. It is evident that injection adds time to the installation process of the bolts. An additional installation time of 1 - 2 minutes per bolt can be expected. Consequently, even though less bolts are likely required, the increased installation time removes the advantage of using less injection bolts with respect to preloaded bolts. Another disadvantage is that injection complicates the assembly, since a special release agent needs to be applied in order to allow for future demountability. Considering the IFD guideline "The number of actions required to disassemble the connection should be minimised", injection is not favourable for promoting demountability of the connection. A third note is on the resin itself, which cannot be reused. This results in waste during disassembly and the continuous need for new resin upon every re-use cycle, which is a problem preloaded bolts do not have.

To conclude, given that there is no true benefit of a reduced number of injection bolts in terms of installation time and bearing in mind the increased complexity, preloaded bolts are favoured over injection bolts.

Fatigue behaviour
As the connection needs to be designed such that the friction limit of the bolts is not exceeded (category C), fatigue life is expected to be good. Following this condition the bolts are unlikely to be governing, for they receive limited stress changes. The fatigue design should focus on the stresses in the plate material of the connecting plates, which generally have high fatigue resistance and are unlikely to be governing for the design.

7.4. Deck connection

The connection between the prefabricated concrete panels also requires attention. The most conventional method for connecting prefabricated decks is to let reinforcement protrude from the deck panels and grout the opening between the two deck panels. The combination of grout and reinforcement ensures the force transfer. An example of such a connection is shown in Figure 7.16, joint a. It is evident that this type of connection is not demountable.
Another method for (partially) connecting concrete elements is using shear keys. A concrete element is designed in a specific shape that fits into another element providing a contact surface, particularly useful for the transfer of shear loads. A commonly used type of shear key (an internal key) is illustrated by joint b in Figure 7.16. Shear keys are nearly always used in combination with prestressing reinforcement, to ensure an effective contact surface. Another type of shear key is the recently developed overlapping shear key, shown in Figure 7.17. Due to the multiple overlapping keys vertical deformation is prevented. The downside to shear keys is that they can only transfer loads in up to two directions and, as such, care should be taken when they are applied. Adhesives may also be utilised. An example is a type of mortar that does not adhere to the concrete and that can easily be removed. The main application of this mortar is to ensure a smooth contact surface.



(a) Concreted joint (b) Glued joint

Figure 7.16: Examples of prefabricated concrete deck joints [99]

Another possible method is prestressing reinforcement. Prestressing reinforcement exerts a compressive force on the concrete, which, when high enough, can withstand the normal force in the concrete and eliminate tensile stresses.

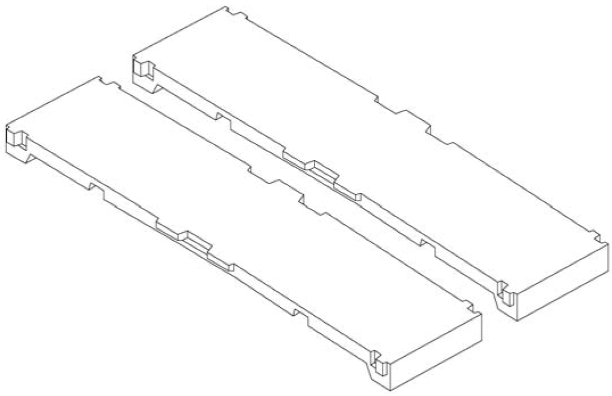


Figure 7.17: Overlapping shear keys [100]

Prestressing reinforcement is often used for connections between prefabricated concrete elements. This could be in the form of the connections in Figure 7.16, but it is also used for dry connections, i.e., without the need for grout. In terms of existing structures that use unbonded prestressing tendons to connect prefabricated concrete elements, a notable example is the Circular viaduct from Figure 3.2. The main benefit of prestressing reinforcement is that, when unbonded, it is not directly connected to the concrete. This means that the reinforcement can be de-tensioned, which allows for an easy removal of the reinforcement from the concrete. As a result, demountability and potentially even re-usability of the reinforcement is guaranteed.

New connections are also developed. An interesting concept is the connection shown in Figure 7.18. The connection consists of steel plates connected to the reinforcement in the concrete. These plates can then be connected to each other by bolts and welds to ensure all relevant forces can be transferred between the deck plates. The tests performed by Wang et al. [101] show that the connection has potential for use. It might be possible to remove the weld to make the connection demountable, but this has not been studied. There are some disadvantages, though, in that stress concentrations can be expected to develop, and, more importantly, it uses a substantial amount of material.

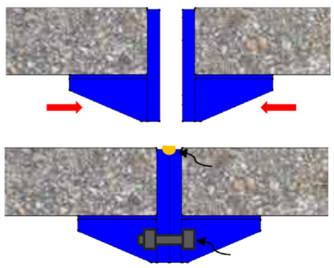


Figure 7.18: Fully-dry concrete deck connection [101]

Distinguishing that two joints between deck elements exist (longitudinal and transverse), for each of these joints a different connection is preferred. For the longitudinal joint, prestressing reinforcement is the most suitable, as it is easily demountable and ensures that the relevant forces (forces in the direction of the deck span) are transferred between the deck elements. The integrity of the system is also ensured when using prestressing reinforcement. For the transverse joint it is most important to transfer vertical forces. Hence, prestressing reinforcement is not directly necessary. Instead, shear keys are of better use, as their main purpose is to transfer vertical forces. If sufficiently strong, they are preferred over the connection shown in Figure 7.18, for shear keys use less material. In terms of the type of shear key, there is no clear benefit for either of the two types. Hence, the internal keys are preferred over the overlapping keys due to their more simplified form and the fact that they are more commonly used.

Couplers

Due to the need for a possibility to change the overpass layout, the prestressing reinforcement should also change in length. Evidently, this can be done by using a new prestressing tendon once the width of the overpass increases. Yet, it might be possible to divide the tendons in sections.

Couplers are used to link two prestressing tendons to create a longer tendon. This is mainly beneficial in the reduction of prestress losses, which is why couplers are often used in long-span structures. In terms of tensile strength, couplers are expected to match the tensile strength of the tendon.

There are some disadvantages to couplers, though:

- Couplers are larger in diameter than normal tendons. As a result, larger channels inside the concrete are required than would be necessary for uncoupled tendons. This causes a reduction in concrete area, which leads to an increase in compression and hence more sensitivity to creep. The extent of this effect is expected to be limited.
- The fatigue life of couplers is considerably less than that of tendons. Where tendons have a fatigue detail category of 150, couplers have a detail category of only 80 [102]. This remark may not be of high relevance for the specific situation discussed in this research, as limited to no stress fluctuations in the tendons are expected.
- Most importantly, the Eurocode states that couplers should not be placed in 50% or more of the tendons, unless any additional risk to structural safety can be proven to be non-existent [102]. Since the prestressing reinforcement is critical in maintaining structural integrity, a detailed analysis is required to prove whether it is allowed to use coupled tendons.

Since it is not clear whether all tendons can include couplers and it is favourable, from an IFD point of view, to minimise the number of different elements and the complexity of assembly, it has been decided not to include couplers and assume full-length tendons.

7.5. Conclusion

In this chapter the options regarding the three types of connections that are present in the design are investigated. With regard to the connection between the deck and the steel girder, several proposed connectors were investigated and four connectors were selected based on their suitability regarding reuse. For the steel girder connection it was found that a splice joint using shear loaded friction bolts is the preferred connection. The connection between the deck elements is different for each direction: longitudinal joints are formed by prestressing tendons and transverse joints are formed by shear keys. All these connections meet the requirements to ensure demountability, as they are mechanical connections (the injected connection is proven to be demountable too), they are accessible and they can be disassembled without causing damage to the structure.

8
Design Optimisation

This chapter describes the optimisation of the model. Building upon the dimensions as determined in section 5.4, a model is created to assess the effects of the different shear connectors. The design is then verified for all relevant limit states. In addition to the shear connection, the connection between the steel girder elements and the transverse connection in the deck are further elaborated on. Lastly, dimensions for the modules that form the designed overpass are determined.

8.1. Model

8.1.1. Model description

The model consists of simply supported girders, modelled as beam elements, and the concrete deck elements, modelled as shell elements. A section of a girder is shown as a schematic in Figure 8.1, whilst the full model features five girders, with a spacing of 4 m, that span 32 m. The girders are divided into four 8 m sections. The connection between the girder elements is rigid and, consequently, the girders can be modelled as continuous. The girder and deck elements are connected by the shear connectors: these are modelled as a set of infinitely rigid beam elements with a negligible mass. At the red nodes shown in Figure 8.1, the springs are placed, that allow for translation in the x- and y-direction.

The joint in the longitudinal direction, indicated by the blue lines in Figure 8.1, is positioned above the girder, as vertical forces need to be transferred to prevent differences in vertical deformation. When positioned between the girders, the connection with only prestressing reinforcement is not sufficient and an additional form of connection would be required, shear keys for example. Instead, when relocating the location of the joint towards the top of the beam, vertical forces are directly transferred to the beam and differences in vertical deformation will not exist. The applied prestressing reinforcement exerts a force large enough that the concrete is always in compression, creating a closed joint that is also able to transfer normal forces in the x-direction. With the connection as it is, it is not possible to transfer forces in the y-direction. It is reasoned that this is not necessary because each deck plate is connected to the girder by a separate row of shear connectors. As a result, the forces in y-direction can be transferred to the beam for each deck plate individually. In conclusion, the longitudinal joint is modelled as rigid in all directions except for the y-direction.

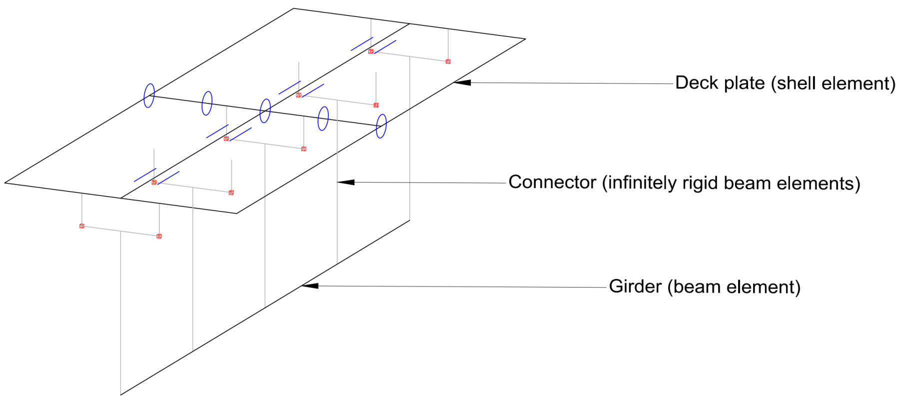


Figure 8.1: Schematic of elements in the model

As explained in section 7.4, the transverse connection is formed by shear keys. The connection is indicated by the blue circles in Figure 8.1. The shear keys allow for force transfer in the x- and z-direction; differential deformation in both these directions is restrained. Important is that the deck is verified to always be in compression, thus ensuring that the interfaces of different deck elements are always in compression. This leads to the conclusion that also in the y-direction the deck elements act is if they were continuous. Accordingly, a rigid connection between the deck elements with respect to translations can be assumed. Rotation between the plates (around the x-axis) is not restrained and is assumed to be a hinge.

8.1.2. General input

The input for the model is based directly on the design of the Composite alternative as described in section 5.4. Further optimisation on these dimensions is not performed. The same load models and loads are used as have been used for the verification of the alternatives. An exception to this are the traffic loads. Regarding the magnitude of the loading, the Dutch National Annex to the Eurocode prescribes formula 8.1 to alter the magnitude of the traffic loads, thus accounting for a certain degree of load increase over a long design life [103]. The formula takes the expected service life t and expected number of truck loads N_{obs} and converts them into a correction factor Ψ. For a design life of 200 years and an expected number of truck loads of $2 \cdot 10^6$ (a higher N_{obs} leads to a lower Ψ, so a lower value is used), Ψ is equal to 1,0162. This value is applied on all traffic loads.

$$\Psi = \left\{ \frac{ln(N_{obs} \cdot t)}{ln(N_{obs} \cdot 100)} \right\}^{0,45} \tag{8.1}$$

For details regarding the load models and other input, appendix A can be consulted.

8.1.3. Shear connection input

Static behaviour

To come to the input for the model, the results from the tests that have been performed and published in literature are used. In order to compare them equally, the circumstances under which tests have been performed need to be similar, as the performance of a connector is governed by a selection of variables. In Table 8.1 the specifications of the connectors are listed, which include the tensile strength of the connector f_u. Furthermore, the ultimate load at failure P_{ult}, the elastic stiffness k_{el} and the elastic load P_{el} are listed. The latter two of these parameters focus on the elastic range of the load-slip curve. They are determined following the definitions described in section 7.2.1. For the ECD (iSRR) the elastic limit P_{el} is taken as 40% of P_{ult} [92]. For the HSFGB, the tests reflect that there is virtually no slip before the friction limit is exceeded [89]. There is, however, no value reported regarding the actual stiffness that is achieved. Hence, it was necessary to estimate the magnitude of the stiffness based on the graph with test results from Kayir [89]. It is acknowledged that the value retrieved from the graph might be slightly off from the true value. Still, as the stiffness is considerably higher than for the other connectors, it is reasoned that the different behaviour of the HSFGB compared to the other connectors is well reflected.

Table 8.1: Relevant properties of shear connectors, retrieved from test results

Connector type	f_u [MPa]	Diameter [mm]	Preload [kN]	P_{ult} [kN]	k_{el} [kN/mm]	P_{el} [kN]	Source
HSFGB	800	19	61	169	560	26	[89]
Cylinder	800	20	100	145	250	26	[91]
ECD (no resin)	800	20	120	142	70	50	[91]
ECD (iSRR)	800	20	-	118	172	47	[92]

The connector that is used has the properties as shown in Table 8.2. It is also shown in Figure 8.2. It is noteworthy to mention that the dimensions of the top flange are determined taking into account required edge distances of the concrete and steel. The edge distance for the concrete is composed of a concrete cover of 55 mm, a practical reinforcement diameter of 14 mm and an assumed cover between the reinforcement and the hole of 12 mm. The edge distance for the steel towards the centre of the bolt hole should be at a minimum 1,2d_0, which is 34 mm. With d_0 equal to 28 mm, this results in a total minimum width for half the flange of 146 mm. Accordingly, a width of 150 mm (and a total width of 300 mm) is sufficient.

Table 8.2: Properties of used shear connector

Size	Bolt diameter [mm]	Hole diameter [mm]	Bolt grade	Preload* [kN]	Concrete class
M24	24	30	10.9	240	C45/55

* *Preload force only applicable to preloaded connectors.*

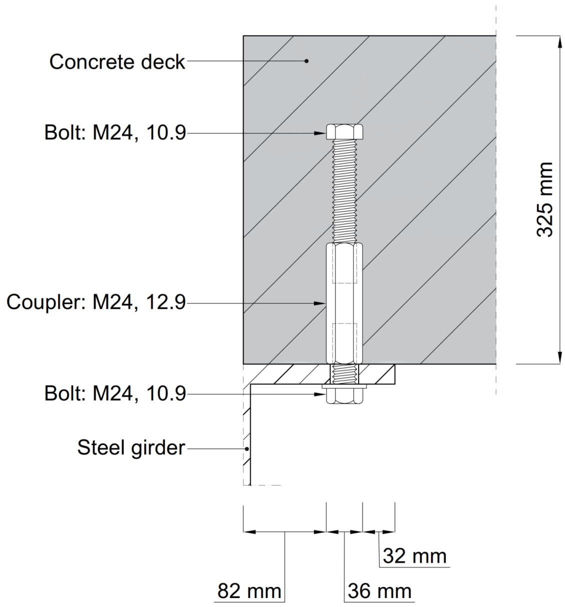


Figure 8.2: Dimensions of used shear connector

The connector that is used has different properties than the tested connectors from Table 8.1. To be able to still use the results from the tests, it is determined if and how the values of P_{el} and k_{el} need to be adjusted. For this, a parametric study by Liu et al. [104] on the influence of different properties on the behaviour of an HSFGB is used, as the load-slip behaviour of this connection is very similar to the ECD (no resin). Furthermore, the failure mode in for both connectors was shear fracture in the bolt. Hence, given the absence of a parametric study specifically on the ECD (no resin), this study has been found most comparable.

For the preloaded connections, P_{el} is the friction limit. As shown by Liu et al. [104], the magnitude of P_{el} is for the most part controlled by the preload force; bolt diameter and bolt grade in itself do not change the results. Notably, an increase in the bolt diameter and bolt grade is required to allow for larger preload forces. Following this, it is found that the value of P_{el} is well predicted by formula 8.2 from the Eurocode [105]. This is also illustrated by Kozma et al. [91], where the friction coefficient of the surface μ is the main source of variability for the differing test results. Therefore, it is possible to determine P_{el} using this formula. Since oversized holes are present, the value of k_s is 0,85, there is one friction surface ($n = 1$) and for the preload force $F_{p,c}$ the maximum limit of 70% of the total bolt resistance is respected. The μ-factor is assumed to be equal to 0,40, equivalent to category B surface treatment: zinc-treated and painted surfaces [72], which is considered to be feasible regarding manufacturing. Since no design formulas are proposed in the literature, partial safety factors are not yet used to allow for a fair comparison. The stiffness k_{el}, in contrast with the friction limit, does not change significantly due to a change in bolt diameter, bolt grade, concrete class or even preload force [104]. Consequently, the values as determined from the tests can be used.

$$P_{el} = k_s \cdot n \cdot \mu \cdot F_{p,C} \tag{8.2}$$

The ECD (iSRR) is not preloaded, so a different approach is needed. Based on the tests performed, Nijgh [92] proposes formula 8.3 to describe the average shear resistance of the connector, where A_s is the shear area of the connector. Although this originally applies to the ultimate resistance, it is used for the elastic resistance as well, considering that the elastic limit is in fact determined as 40% of the ultimate resistance. With regard to the stiffness k_{el}, the most influential property is the bolt diameter: the stiffness increases significantly when the bolt diameter is enlarged from M20 to M24, by 30% according to Nijgh [92]. Accordingly, the stiffness is increased by this percentage. There are more differences between the used properties and the properties tested by Nijgh [92]. Most notably, these are the concrete class, hole clearance and bolt grade. The extent to which these factors change, however, is significantly smaller than for the stiffness. Furthermore, the effects combined more or less cancel out each other, leading to the net result that the behaviour of the connector is not really impacted and these effects can be neglected.

$$P_u = 0,547 \cdot A_s \cdot f_{ub} \tag{8.3}$$

The changed properties of the used connectors are shown in Table 8.3.

Table 8.3: Input shear connectors for SLS analysis

Connector type	f_u [MPa]	Diameter [mm]	Preload [kN]	P_{el} [kN]	k_{el} [kN/mm]
HSFGB	1000	24	240	81	560
Cylinder	1000	24	240	81	250
ECD (no resin)	1000	24	240	81	70
ECD (iSRR)	1000	24	-	77	224

Fatigue behaviour

As the connectors are mostly recently developed, fatigue tests have not been performed for all types. The results for the connectors that have been tested (including connectors that have been excluded as options) are shown in Figure 8.3; all of the bolted connectors are preloaded. Since the number of tests is limited, it has not yet been possible to suggest S-N curves. What is directly visible is the significant improvement of the fatigue life of all bolted connectors in comparison with S-N curve of welded studs, presumably largely due to the absence of welds. Noteworthy are the so-called run-out tests, marked with the triangle. These are tests during which the specimen did not fail and cycles were stopped at a certain moment. For the HSFGB and DENB connector, the loads corresponding to these run-out tests are equivalent to or even higher than the friction limit. Thus, following these test results, the fatigue life of these connectors is infinite under the requirement that the friction limit is not exceeded in the FLS. While the BB connector has a slightly inferior fatigue life, it still follows the same pattern as the other connectors and has a run-out stress that is close to the friction limit.

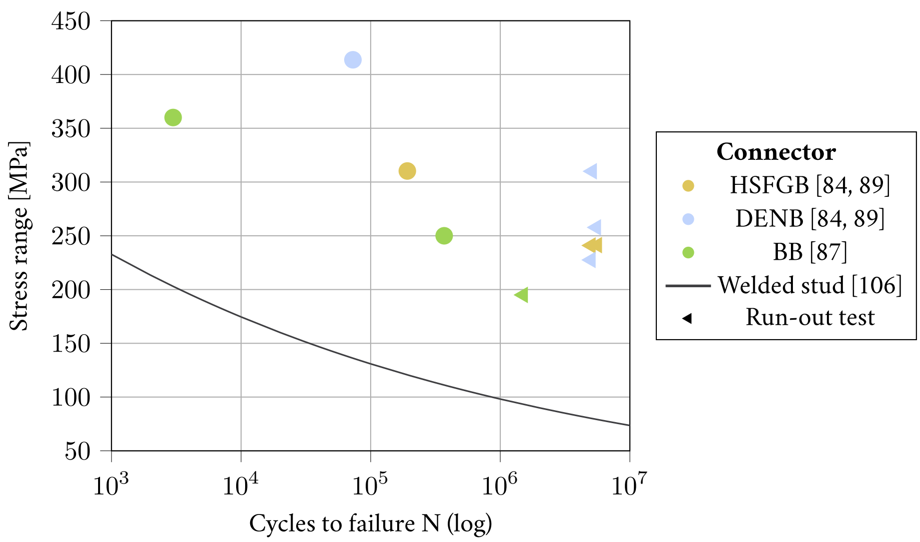


Figure 8.3: Fatigue tests of different connectors

When extrapolating these results to connectors that have not been tested, a trend seems to exist for preloaded connectors: a connector that is loaded at a maximum to its friction limit has an infinite fatigue life. Given the similar initial behaviour of all preloaded connectors, the statement that this applies to all preloaded connectors seems promising.

For the non-preloaded connection, i.e., the ECD with the steel-reinforced resin, no fatigue tests corresponding to the application within this research have been found. Consequently, it is not possible to come to an accurate prediction regarding the expected fatigue life of this connection. Notably, tests have been conducted on this type of connection, yet for a connection of steel to FRP. Results from these tests indicate good fatigue behaviour that is better than that of conventional injected connections [88, 93]. This suggests that the fatigue life of the connection itself is good, though tests for its application in a steel-concrete connection are required to substantiate this statement.

8.2. Analysis results

8.2.1. SLS

To determine which shear connector is the best, it is verified which connector layout is required in the design. It will become apparent that the SLS is governing, given the requirement of the elastic limit/friction limit. Accordingly, the deformation check is the verification that needs to be considered. The limit that needs to be respected is $L/300$, a conventional limit for deformations. For a span of 32 m and a margin on the unity check of 5%, the deformation limit w_{lim} is equal to 101,3 mm.

Independent of the type of connector, the largest part of the deformation comes from the construction stage where the steel girder needs to support itself and the concrete deck on top, which is not yet connected at this stage. The deformation can be determined directly from the girder deformation. The deformation u_{constr} under the self-weight of the steel and concrete amounts to 70,7 mm. This leaves a deformation margin of 30,6 mm for the use phase.

After the construction stage, the connectors are effective and the composite structure is responsible for supporting the dead load and variable loads. The composite structure then follows a pattern that approaches the pattern shown in Figure 8.4. It is clear that the critical locations are at the supports. An initial calculation shows that the forces at this location were rather high. To compensate for this a change is made. Instead of an equidistant spacing for the full beam, the spacing of the connectors is reduced up to 1 m from the support. The effect of this change is that there are more connectors at this location, which, as a result, attract less force. For the remaining part of the beam a larger spacing is applied. It is acknowledged that the spacing could be further optimised, but given the modularity of the deck and girders a regular design is strongly preferred.

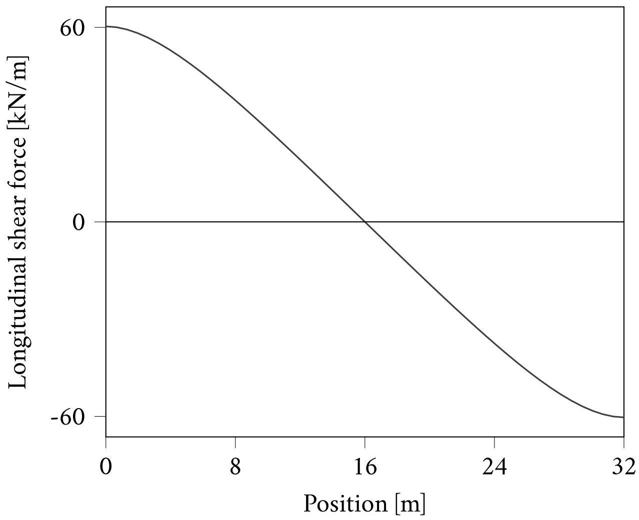


Figure 8.4: Theoretical distribution of longitudinal shear force

Due to the different properties of the connectors, the layouts of the shear connectors are different. Table 8.4 lists the actual layout for each of the connectors, whereas Figure 8.5 shows the layout as used in the model for a section of the girder, using spacing values of the ECD (no resin) connector. The layouts of the shear connectors have been designed such that the maximum force in the connectors is below the value of P_{el} from Table 8.3.

The deformation of the system for each of the connectors is within the margin of 30,3 mm, meaning all systems are satisfactory. It can also be concluded that a higher stiffness requires more connectors, yet results in a reduction of the deformation.

Table 8.4: Results on connector layout and deformation (SLS)

Connector	s_{1m} [mm]	s_{main} [mm]	w_{use} [mm]
HSFGB	60	300	21,9
Cylinder	90	330	22,7
ECD (no resin)	130	330	25,7
ECD (iSRR)	80	330	22,8

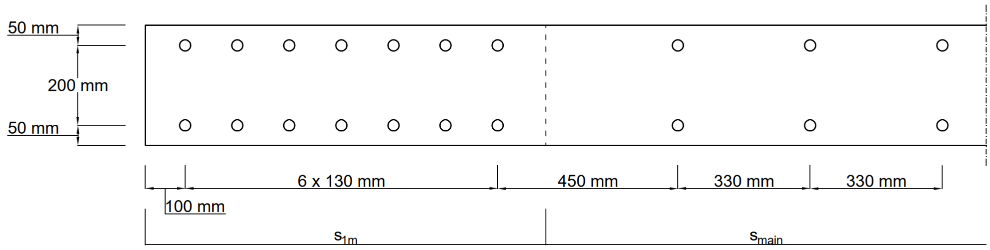


Figure 8.5: Connector layout as used in model (view of top flange girder)

Comparing the two extreme scenarios, the HSFGB and ECD (no resin), the trade-off exists in that a reduction in deformation can be achieved at the cost of more connectors. The benefit of the reduction in deformation is that the girder could be further optimised, resulting in a reduction on material. In short, a system with HSFGB connectors uses less material for the main girder, yet has more connectors, whilst an ECD (no resin) system uses more material, but less connectors.

With regard to optimisation of the girder, there is a small margin to allow for an increase in deformation of the girder, as the deformation limit is not yet reached. Still, as the total deformation also includes the construction phase, the potential net reduction in material cost is limited. The number of connectors is also of interest, since more connectors means that the material costs increase. Another relevant aspect of the connectors is the installation time. For the preloaded connectors this is expected to be equal, as the same actions are required. However, for the injected ECD connector the installation process is different. In order to compare the preloaded and injected connectors, the assembly costs are considered. For the preloaded connectors, the assembly costs are estimated at €2,50 per connector (cf. appendix H). The assembly costs of the injected connector have been estimated by Nijgh [92] at the same cost of €2,50. Accordingly, in terms of assembly no difference exists between the two types of connectors.

Aside from costs, for demountability in general guidelines exist (see section 7.1) that assist in a conclusion on the best solution. The use of a small number of connectors itself is a guideline, whilst that also means that the time required for disassembly is decreased, assuming similar (de-)installation times for each connector.

Consequently, it is concluded that it is favourable to minimise the number of connectors, regardless of the slightly larger material usage for the girder. Thus, given the current approach on the elastic limit, the ECD (no resin) is the preferred connector.

Other connectors

The four connectors that are included in the analysis have been chosen based on the fact that they are suitable for reuse; the behaviour of the connectors was not considered initially. Some connectors that are not included do have good properties, though. Hence, it is investigated how this could affect the design. The most interesting connectors are the LNSC and LBDSC, since they have good overall behaviour, in contrast with some other connectors, which have very low stiffness, for instance. The LBDSC is considered because it has a clear elastic limit formulated in literature and there is no need for preload, unlike the LNSC.

To calculate the ultimate resistance of the LBDSC connector He et al. [107] propose formula 8.4:

$$P_u = \min(\alpha_1 \cdot A_t \cdot \sqrt{E_c \cdot f_c'},\ \ \alpha_2 \cdot A_s \cdot f_u) \tag{8.4}$$

where A_t is the cross-sectional area of the grout-infilled tube, $f_c^{'}$ the compressive strength of concrete and A_s the cross-sectional area of the bolt. For α_1 a value of 0,30 is valid and for α_2 relation 8.5 holds.

$$\alpha_2 = 0,84 \cdot \left(\frac{20}{d}\right)^{0,84} \leq 1 \tag{8.5}$$

It is also suggested to impose a limit equal to 1/3 of the ultimate resistance to ensure demountability and reusability of all the elements. Thus, for an M24-connector of class 10.9 and concrete of class C45/55, the elastic limit P_{el} is equal to 85 kN. The stiffness of the connector is estimated at 156 kN/mm, based on parametric studies performed by He et al. [107]. The values are summarised in Table 8.5.

Table 8.5: Input shear connectors ECD (no resin) and LBDSC

Connector type	f_u [MPa]	**Diameter** [mm]	**Preload** [kN]	P_{el} [kN]	k_{el} [kN/mm]
ECD (no resin)	1000	24	240	81	70
LBDSC	1000	24	-	85	150

Using these values, it is determined what the connector layout is. The results are shown in Table 8.6, where they are compared with the ECD (no resin) connector. The results show that, as expected, fewer connectors are needed. The reduction is approximately 10%.

Table 8.6: Results on connector layout and deformation ECD (no resin) and LBDSC

Connector	s_{1m} [mm]	s_{main} [mm]	w_{use} [mm]
ECD (no resin)	130	330	25,7
LBDSC	110	390	24,6

From this analysis it can be concluded that connectors with a higher resistance can lead to less shear connectors. In the case of the LBDSC an increase in resistance of close to 5% leads to a reduction in the number of connectors of 10%, noted that the stiffness is also increased. However, the LBDSC is not well-suited for reuse due to its strict tolerances and the need for grout. Therefore, the ECD (no resin) still is the connector of choice. Another conclusion that can be drawn from this analysis is that a similar, possibly more pronounced effect can occur if the elastic limit of the ECD (no resin) connector is proved to be higher than what is currently assumed. It was shown by Kozma [90] that for the tested set-up (a four-point bending test) the beam elements are reusable when loaded up to the deflection limit of the beam. Still, other load regimes exist that result in higher forces on individual connectors, which could lead to plastic deformation in the beam elements. So, in order to conclude that for all serviceability loading regimes reusability of the components is possible, more tests need to be performed.

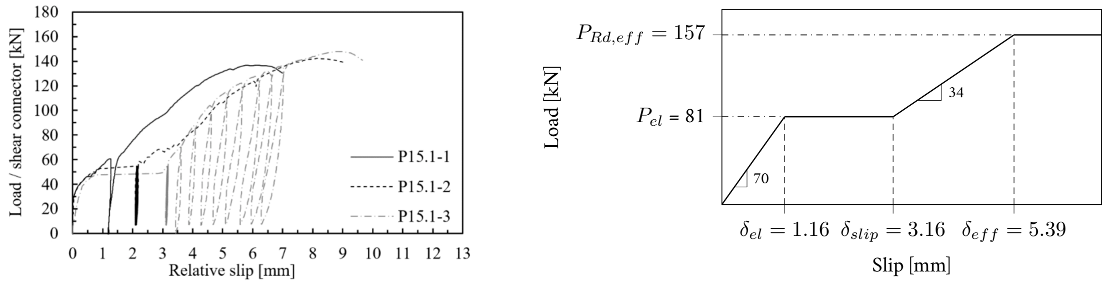
8.2.2. ULS

Plastic behaviour

The connector input as listed in Table 8.3 is related to elastic behaviour of the shear connectors. For the ultimate limit state, however, plastic behaviour is expected. In the model this can be accounted for by the use of a non-linear spring instead of a linear spring. The input for the non-linear spring comes from the load-slip curve of the connector. As for the elastic behaviour, the curve as determined by the test results needs to be adapted, given the changed connector properties. The ECD (no resin) connector is a friction-based connector (cf. Figure 7.2c) meaning three branches of the load-slip curve need to be defined. Figure 8.6a shows the original load-slip behaviour and Figure 8.6b shows the simplified load-slip curve that is derived from it. The first branch is related to the elastic part and its values have previously been determined. The second branch is the part describing the slip in the hole due to the present clearance. For the same clearance is used, a slip of 2 mm (as reported by Kozma et al. [91]) is adopted. No load increase is accounted for during this stage. The third stage is the plastic deformation of the connector. It has been previously explained that the demountable shear connectors do not exhibit an ideal plastic plateau, yet show some ductile behaviour. As a result, Steel Construction Institute [74] state that the conventional verification on plastic resistance may be utilised, yet with a connector design resistance of $P_{Rd,eff}$. With formula 8.6 $P_{Rd,eff}$ is calculated [74, 106]. k_{flex} in this formula is equal to 0,85.

$$P_{Rd,eff} = k_{flex} \cdot P_{Rd} = k_{flex} \cdot \frac{0,9 \cdot P_{ult}}{1,25} \tag{8.6}$$

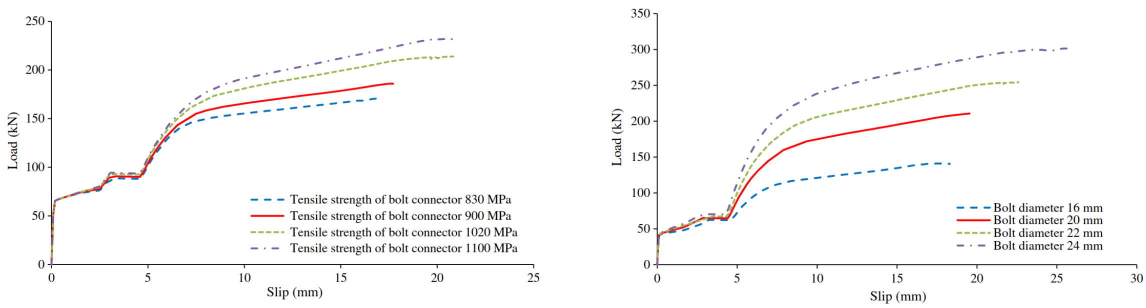
This means that $P_{Rd,eff} = 0,612P_{ult}$. With $P_{Rd,eff}$ as limit for the resistance, only the initial part of the third branch of the load-slip curve is of importance; any resistance after $P_{Rd,eff}$ may not be accounted for. In Figure 8.6a it can be seen that the behaviour over the initial part of the third branch is close-to linear. Thus, this third branch is approximated as a linear branch. The stiffness over this part is estimated at 30 kN/mm. The most important properties that differ for the designed ECD (no resin) connector compared to the test specimen are the bolt diameter and bolt grade. For the stiffness, from Figure 8.7a it can be seen that the bolt grade has limited influence on the behaviour for the initial part of the third branch. The bolt diameter, on the other hand, has an influence in that the stiffness increases, as can be concluded from Figure 8.7b. The increase in stiffness is determined as the difference between the 20 mm and 24 mm curve. The interval considered is between the end of the initial slip and $P_{Rd,eff}$. The increase is estimated at 13%. As $P_{Rd,eff}$ is based on P_{ult}, the value of P_{ult} also needs adjustment. An increase of both the bolt diameter and bolt grade (from 8.8 to 10.9) results in a higher P_{ult}. From Figures 8.7a and 8.7b, the increase has been found to be 43% and 26% respectively. The resulting values are highlighted in Figure 8.6b.



(a) Load-slip behaviour from tests [91] (repetition of Figure 7.9b)

(b) Simplified load-slip curve *(Stiffness in kN/mm)*

Figure 8.6: Load-slip curves ECD (no resin)



(a) Influence of bolt grade on load-slip behaviour

(b) Influence of bolt diameter on load-slip behaviour

Figure 8.7: Results from parametric study HSFGB [104]

Results

With the non-linear spring defined, the model can be verified for the ULS. The focus is on the global behaviour of the system, as this is the behaviour that is clearly different than is assumed for the calculations in the alternative phase.

The total stresses for the system are a combination of the stresses deriving from the construction and use phases. The stresses in the construction phase have previously been determined in appendix B.2. As the system of a simply supported beam has not changed, these stresses can still be used. The stresses in the use phase have been determined with the model,

Table 8.7: Global normal stresses ULS

	Construction	Use	Total	*UC*
Stress bottom flange [MPa]	134,1	148,9	283,0	0,80
Stress top flange [MPa]	-255,6	-49,4	-305,0	0,86
Stress deck [MPa]	0	-21,2	-21,2	0,71

including non-linear springs. The calculation results are shown in appendix F. From the analysis it is also clear that a substantial margin exist between the connector forces and $P_{Rd,eff}$. All resulting stresses in the steel and concrete as well as the unity checks are listed in Table 8.7. The unity checks are all sufficient, thus showing that the design still meets the ULS criteria.

8.2.3. FLS

As concluded in section 8.1.3, the tested connectors, which were preloaded, have infinite fatigue life for forces up to their friction limit. Given that the ECD (no resin) connector is also preloaded and considering the absence of fatigue tests, it is assumed that this also applies to the ECD (no resin) connector. Since the load situation from the FLS results in lower connector forces than the SLS, this condition is easily met, meaning that the connectors have sufficient fatigue life.

From the hand calculations it was concluded that fatigue of the bottom flange-web connection of the girder was close to critical. Therefore, this detail needs to be verified once more, given that the behaviour of the system is different. In F the stresses in the girder under the fatigue load are shown. At the location of the bottom flange-web connection a maximum stress variation $\Delta\sigma_{Ed}$ of 15,6 MPa is reported. With the fatigue limit σ_L equal to 34,9 MPa (see appendix B.2), the following unity check is calculated:

$$UC_{fat,girder} = \frac{\Delta\sigma_{Ed}}{\sigma_L} = \frac{15,6}{34,9} = 0,45$$

It can be concluded that the fatigue resistance is sufficient. Noteworthy is that there exists a considerable difference in stress calculated by the hand calculations and the model. This is explained by a redistribution of loads to adjacent beams within the model, resulting in a substantial reduction in loads on the governing girder.

8.2.4. Effects of module length

For the dimensions of the modules are not yet known, the exact positions of the connections and thus the partial hinges in the model are unknown as well. It has been investigated whether this has an influence on the results from the model. In the model the joints are placed 8 m apart, meaning four modules are required to create the span. To see what the effect is of these joints, the current scenario has been compared to a scenario with rigid joints, i.e., simulating a continuous deck. Most important is the deformation, as this is what has been the basis of the SLS analysis. In comparison with a fully rigid deck, the deformation increases by 1% for 8 m modules, which comes down to three joints. Consequently, it is expected that other configurations (i.e., more or differently placed joints) will not result in a meaningful deviation from the current model. The effect on the stress in the steel and concrete has also been investigated. It shows that the stresses increase by approximately 4%, comparing the scenario with partial hinges with the rigid joints scenario. This increase is of such an extent that it cannot be ruled out that larger stresses will be reported for different module sizes. Nonetheless, the extent to which the stresses are larger is expected to be limited and there is sufficient margin on the unity checks for ULS and FLS. Accordingly, the conclusions from the ULS and FLS will not change.

The reported small differences in behaviour that also indicate that the implementation of modularity in the deck is not really disadvantageous in terms of structural behaviour. The connections ensure that most of the forces can be transferred as would be the case in a continuous deck. For the forces that cannot be transferred, differences between the modular deck and a continuous deck exist, yet these are fairly small and do not have a significant impact on the design of the structure.

8.3. Connection design

Apart from the shear connection, two connections need further attention. These are the splice connection between the steel girder segments and the shear key connection between the concrete deck plates in transverse direction.

8.3.1. Steel girder connection

As explained in section 7.3, the connection needs to be of type C and is best created using preloaded bolts that transfer forces in shear. This can be done with a conventional splice connection. For the design of the connection, IDEA StatiCa is used. The connection is designed for stresses equivalent to 95% of the material strength. The connection is not designed to be stronger than the connected elements (+100%), since the ULS loads on the structure are not governing and, therefore, stresses are below 95% of the material strength. Thus, it is possible to design a more economic connection, whilst effectively still being stronger than the expected loads would require. By using friction bolts loaded in shear, the stiffness of the connection is, as required, rigid.

Figure 8.8 shows the connection. The girders are connected at both flanges and the web with preloaded bolts of type M30, strength 10.9. Since minimising the number of different types of connectors is an IFD guideline, the M30 bolt is the only bolt size that is used in this connection. The preload force is limited to 70% of the ultimate strength, following the Eurocode. All splice plates are S355. Appendix G shows the drawings of the connection. It should be noted that the web splice plate could be modified to reduce the material needed, though this is not done yet.

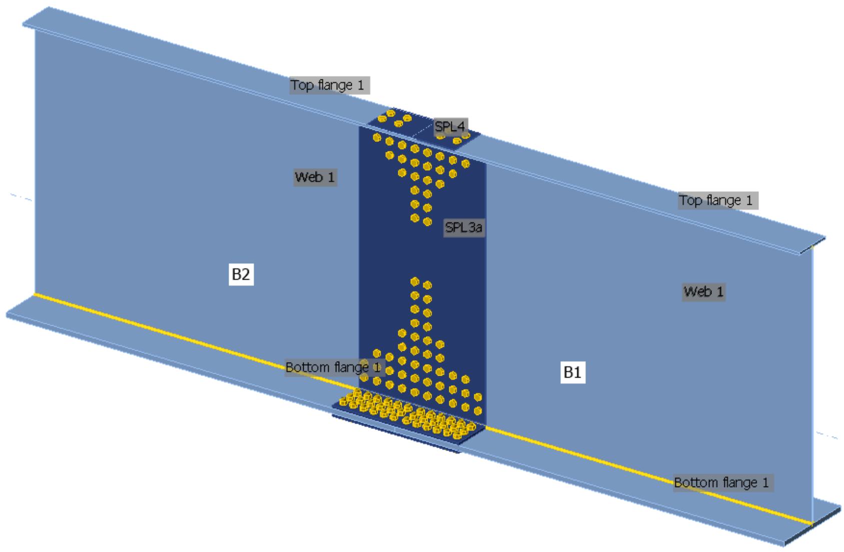


Figure 8.8: Steel girder connection, 3D view

Regarding the fatigue resistance of the connection, for the connection is of type C, the bolts automatically have sufficient fatigue resistance. The splice plates within the connection have been verified based on the moment in the girder resulting from the fatigue load and have sufficient fatigue life as well. In short, fatigue resistance of the connection elements is sufficient.

With the majority of bolts loaded close to their maximum resistance, it is expected that the solution is representative and close to the optimal solution. It is thus shown that a design can be made that reflects the behaviour that is assumed in the model.

8.3.2. Shear keys

The joint between the concrete deck plates in transverse direction is connected by shear keys. It is determined whether they can create a sufficiently strong connection to transfer vertical forces.

The principle of applying shear keys to transfer forces between prefabricated concrete elements has also been applied in the Circular viaduct (Figure 3.2). Formula 8.7 is used to calculate the resistance [108]. This formula is based on EN-1992-1-1, though some modifications have been made.

$$v_{Rd,i} = 0,5 \cdot f_{ctd} + \left(0,9 \cdot \frac{A_{sk}}{A_{tot}} + 0,42 \cdot \frac{A_{tot} - A_{sk}}{A_{tot}}\right) \cdot \sigma_n \leq 0,5 \cdot \nu \cdot f_{cd} \tag{8.7}$$

where:

- A_{sk} Area of the base of the shear keys.
- A_{tot} Total area.
- σ_n Stress caused by the minimal external normal force acting simultaneously with the shear force.
- ν Strength reduction factor, equal to 0,49.

The formula consists of a cohesion and a friction component. The first component is the cohesion, which is determined by the concrete class. The friction (the second component) is dependent on an external normal force. Usually, this is interpreted as a prestressing force, yet this is not present in the longitudinal direction. There still exists a normal force, though, which is the result of the dead load on the structure. Since this normal force is transferred through the interfaces, it can be considered as the external normal force. The total resistance should be higher than the maximum stresses at the interface. This maximum stress is the result from wheel loads from Eurocode Load Model 2 positioned directly next to the interface. It is assumed that the load spreads over an area of 682 x 682 mm (wheel size + spread width with an asphalt thickness of 141 mm). Figure 8.9 shows the shear stresses that occur at the interface. Important is to consider the difference between the two sides of the interface; the difference in stress is the stress the connection needs to transfer. The stresses are computed assuming a joint where only the rotation between the deck elements is free.

From Figure 8.9 it can be derived that the average stress that needs to be transferred is, on average, 0,2 MPa. This is valid for an area of 682 x 325 mm, with 325 mm being the height of the deck. The stress at the interface is rather small. It is believed that this is largely due to the positioning of the joint parallel to the span direction. The consequence of this is that stresses induced by local loads do not have to be transferred through the joint to arrive at the main girder, thus reducing the stress at the joint.

As the concrete class is C45/55, f_{ctd} is 1,77 MPa. In terms of the shear keys, multiple dimensions are possible. Figure 8.10 shows a possible layout of the shear keys, following Eurocode 2 requirements [102]. Using these dimensions, it is calculated that the resistance of an area of 682 x 325 (two shear keys) is 1,9 MPa. Thus, it is obtained that the resistance of the shear keys is largely sufficient to resist the stresses induced by wheel loads.

It is noteworthy to mention that the structure is designed such that all interfaces, i.e., all shear key connections, are in compression. This means that the shear keys are always able to transfer forces, both through cohesion and friction. To ensure an adequate contact surface, non-adhesive mortar can be applied. The fatigue behaviour of the shear keys is also of interest. Although a verification has not been performed, the expectation is that fatigue will not be governing for the design given the relatively low stresses that occur because the joint is parallel with the span direction.

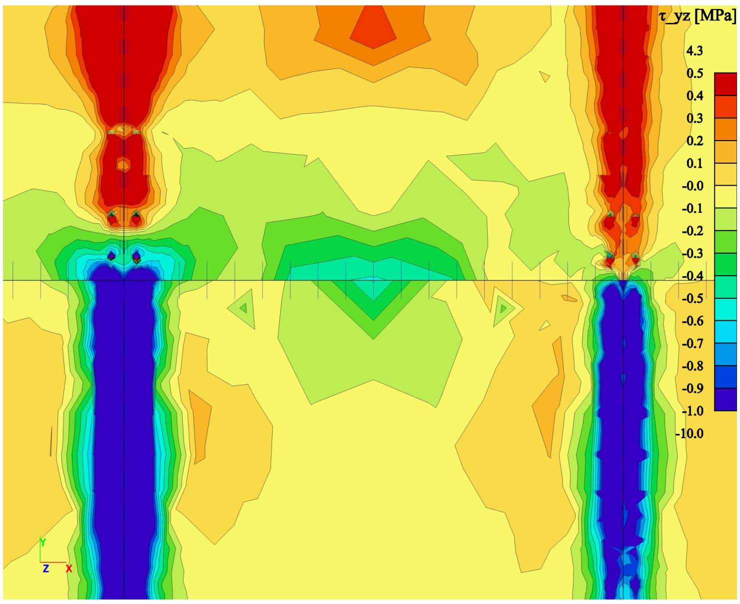


Figure 8.9: Shear stress at joint interface due to local wheel load

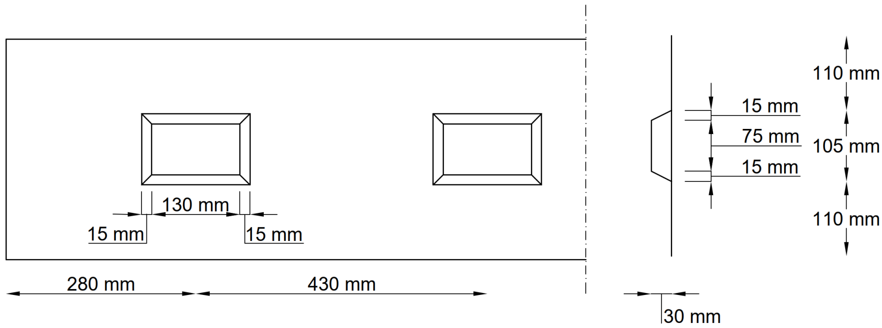


Figure 8.10: Possible dimensions for shear keys

8.4. Module dimensions

Now the overpass is designed and verified, it can be determined what the dimensions of the modules should be. Of interest are the width, height and length of the modules.

For the dimensions of the modules the maximum dimensions for transport need to be taken into account. By itself, the length of the elements is not a point of concern. In combination with the height or weight it requires some attention, though. According to the Dutch law, long-term permits may be issued if the height of the transport including its cargo is under 4,25 m and the width under 3,5 m [109]. Several transportation companies have these permits, meaning that these dimensions can be followed. Considering the greater allowable height, it is more practical to transport elements vertically. In order to transport elements of (up to) 4 m, it is required to make use of special trailers that have a sufficiently low cargo floor that can allow for the transportation of these elements. Using these trailers, elements with lengths up to 15 m can be transported. The maximum dimensions of the modules can, therefore, be 4 m x 3,5 m x 15 m. Manufacturing dimensions are generally larger and are not a point of concern.

8.4.1. Module width

The width of the elements is of concern for the deck elements; the width of the girders is naturally determined by their profile and is sufficiently small. The width of the deck elements should follow the grid of the structure, i.e., the girders. Since the deck elements span the distance between the girders, the width of these elements is 4 m. This dimension has been determined during the preliminary design phase and was part of the optimisation.

8.4.2. Module height

The height of the elements is in principle determined by the structural behaviour, which is directly related to the span. Nevertheless, it is possible to change the height by the creation of multiple modules. For a large span range of 12-32 m is considered, modules with a smaller height can be created for use within smaller spans. This is relevant in particular for the girders; the deck thickness is bound by other factors that are span independent and cannot be reduced.

From the point of view of material efficiency, it is favourable to optimise the height for each span. On the other hand, in favour of the potential for reusability, availability and flexibility, a minimum number of modules is desirable. Hence, a compromise needs to be found. It is suggested that there should be two modules with different heights. This results in sufficient flexibility as each height can be used for a set span range, whilst the material efficiency is improved for shorter spans. Naturally, more heights can be distinguished, yet this would come at the cost of a reduced flexibility and reusability, which is considered unfavourable.

To determine the heights of the modules, the sustainability dimension ”social” is considered. As explained in section 6.1.1, this dimension is most relevant in the form of the aesthetics of the overpass, and more specifically the slenderness. Hence, the slenderness should be optimised. It is decided to divide the span range of 12-32 m into a range of 12-19 m and a range of 20-32 m, as this is the division that results in the highest slenderness for the shortest span within each range. For both span ranges, a different girder height is defined. The girder height of the 12-19 m span range is estimated based on the deformation, which has shown to be the governing criterion. Equation 8.8 describes the deformation criterion of a simply supported system under a distributed load, since this causes nearly all the deformation.

Table 8.8: Span ranges and module height

Span range [m]	Element type	Girder height [mm]	Total height [mm]	Minimum slenderness
20-32	Regular	2058	2383	8,4
20-32	Guardrail	1292	1617	12,4
12-19	Regular	1090	1415	8,5
12-19	Guardrail	820	1145	10,5

$$w = \frac{5}{384} \cdot \frac{q \cdot L^4}{EI} = L/300 = w_{lim} \tag{8.8}$$

It can be seen that the numerator decreases by a factor of 4 for a reduction in span. The deformation limit also decreases for a smaller span, yet by a factor of 1. The denominator decreases by a factor of 3 when the height is reduced (the height is present in the moment of inertia *I*). If reductions on both sides are equal, then it is ensured that the deformation stays below the limit. The net result is that the left-hand side and right-hand side both decrease by a factor of 1 if the span is reduced, meaning that the same reduction can be applied to both the span and the height. For a span of 19 m, the left-hand side reduces with a factor of 19/32 and so does the right-hand side. The reduced height is then 19/32 of 2383, which is 1415 mm. This is summarised in Table 8.8, where it is also shown that the slenderness for the smallest span in the range is nearly equal for both heights. For the guardrail section the same approach is used. The only difference is that the stress is governing instead of the deformation. This leads to a situation where the inertia still decreases with a factor of 3, yet the nominator, which is the bending moment, decreases only by a factor of 2. For a unity check on stress, the design stress decreases by a factor of 1 (the left-hand side in an equation), whilst the resistance (the right-hand side) stays the same. The resulting dimensions of these sections are also shown in Table 8.8.

It is acknowledged that the dimensions of the smaller modules are estimations. A detailed calculation is required to more accurately determine which height the module should have. Nevertheless, it provides a good indication of the degree of reduction that is possible and shows that the appearance of the overpass on shorter spans is improved.

8.4.3. Module length

The length of the modules determines the range of spans that can be created. To increase the range of possible arrangements, it is decided that it is favourable to propose two different modules, each with a different length. To find the optimal length of these modules, several aspects are of importance. The following advantages and disadvantages of smaller modules and more connections can be distinguished. The disadvantages are derived from previously listed IFD guidelines.

+ Reduced mass: less-heavy equipment
+ On-site handling is more convenient
+ More configurations are possible

- Increased (dis)assembly time
- More (dis)assembly actions required

For some aspects it is possible to quantify to which extent they play a role by utilising the economic dimension of sustainability, i.e., calculating the costs. Accordingly, a cost calculation has been done on the structure, including the connections. Table 8.9 shows a selection of relevant costs. The background behind these costs can be found in appendix H.

Reduced mass

The effect of the reduced mass is expected to be related to assembly, specifically in the form of the need for heavy equipment if large modules are used. Based on the data from Table 8.9, it can be seen that the costs related to assembly are only 8% of the total costs. Hence, the effect of the assembly on the total costs, which includes the use of equipment, is small. In conclusion, the benefit of a reduced mass is limited.

Increased (dis)assembly time

In terms of assembly time, the connections are of particular interest. The assembly costs for the connection are 9,5% of the total costs. This leads to a conclusion that in terms of installation costs there is limited benefit from less connections. Nonetheless, the fact that more time is needed is a disadvantage in itself.

Table 8.9: Costs of girder and girder connection

Element	Type of cost	Cost [€]
Girder (32m)	Materials and production	70641
	Assembly	8020
	Transport	5534
	Total	**84195**
Connection (1x)	Materials and production	3032
	Assembly	267
	Total	**3299**

More configurations are possible
Given that the majority of the costs, for both the girders and the connections, stems from the material that is used, the material efficiency is the most insightful aspect. This is covered by the possible configurations. Figure 8.11 shows conceptually how the module size affects the structure. Smaller modules result in more possible configurations: A combination of two- and three-block modules allows for the creation of a five-block configuration, whilst a set of three and four-block modules cannot. This means that, to achieve a five-block configuration, a six-block configuration needs to be constructed, leading to increased material usage. There is also a disadvantage in that more connections are required: for a four-block configuration, one connection is required using two two-block modules, whilst a four-block module does not require a connection.

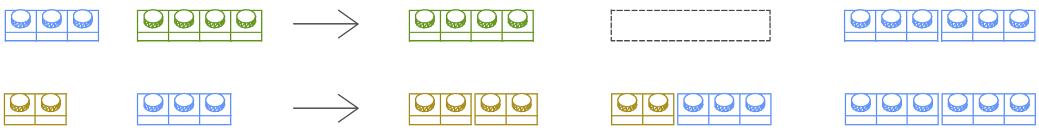


Figure 8.11: Conceptual overview module sizes

To find the module length, the first step is to consider modules with a length of $60x$ cm. The 60 cm interval is an interval that is often used in current construction practice. Since interfaces with other structures or with secondary elements are expected in the length direction, it is a logical choice to apply this restriction on the module length. Considering the 60 cm interval in module lengths, the minimum distance between two configurations is 60 cm (in Figure 8.11 this is equivalent to the fact that only a three-block and a four-block configuration are possible). However, this would require small modules and a large number of connections, making this unfavourable. The next option is a gap of 120 cm (e.g., going from a four-block to a six-block configuration in Figure 8.11). A set of modules that would have a maximum distance of 120 cm between two configurations is 5,4 m & 6,6 m. For reference, a configuration of 22,8 m can be constructed (3 x 5,4 + 1 x 6,6) and the next possible configuration is then 24 m (2 x 5,4 + 2 x 6,6). With these two modules on average a total of 4 modules is required for spans in the range of 20-32 m. For module sets with a maximum difference of 1,8 m, the reduction in number of connections is not significant enough to offset the increase in material usage. Accordingly, modules with a 1,2 m difference are favoured over those with a 1,8 m difference. The next step is a 2,4 m difference. For this difference, modules of 6,6 m & 10,8 m are an option. These modules require an average number of 3 modules per girder. For a 3 m difference, no clear benefit is achieved with respect to the 2,4 m difference. Beyond a 3 m difference, it is considered that the difference is too large and the options regarding configurations are too limited.

In summary, the two best options are the 1,2 m difference modules and the 2,4 m difference modules. In terms of costs, the difference is negligible. This is proved using Table 8.9. It is calculated that 1 m of girder costs €2631, which makes that 1,25 m of girder costs the same as one connection (€3299). Practically, this means that if the number of connections is reduced by 1, the total length of a girder can increase by 1,25 m without increasing the costs. This is, approximately, the situation for the two considered module sets. Therefore, the decisive aspect is considered to be the number of actions required to (dis)assemble the connection. It is reasoned that this aspect is more important than easier handling during execution, since the difference in module size is limited. Besides this aspect, installation time is also seen as important. In conclusion, it is suggested for the modules to have lengths of 6,6 m and 10,8 m.

For the span range of 12-19 m, a similar approach is used. For a 1,2 m difference, a module set of 4,2 m & 5,4 m is possible, requiring on average 3 modules. For a 2,4 m difference, modules of 4,2 m & 10,8 m suffice, requiring an average of 2 modules to form a span. Following the same argumentation as for the larger span range, the 4,2 m & 10,8 m modules are favoured.

8.4.4. Overview

All dimensions of the modules are determined. In total, there are four girder modules and four deck modules per span range. Figures 8.12 and 8.13 show the modules of the 20-32 m range for respectively the regular sections and the guardrail sections. The modules for the regular and guardrail sections for the 12-19 m range are shown in Figures 8.14 and 8.15, respectively. As can be seen, the width of the guardrail sections is 3,6 m. Whereas initially the width was 1,6 m (illustrated by Figure 5.1), this has been changed to 3,6 m, for it is favourable for the load-bearing behaviour if the interface between two deck elements is located above a girder instead of in between two girders. It is noteworthy to mention that the regular deck module of length 10,8 m can be used for both span ranges, since the thickness is the same for all deck elements. Besides the dimensions of the modules, the proposed connector layout for the 6,6 m module is illustrated in Figure 8.16. Since the girder modules are symmetric, half the module is shown in the figure. The connector layout follows the same pattern for modules of other dimensions, where only the distance to the centre connector (420 mm) can differ.

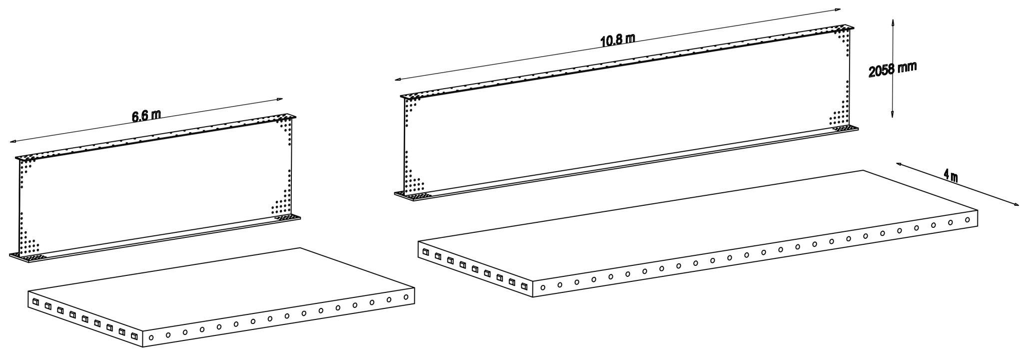


Figure 8.12: Regular modules for span range 20-32 m

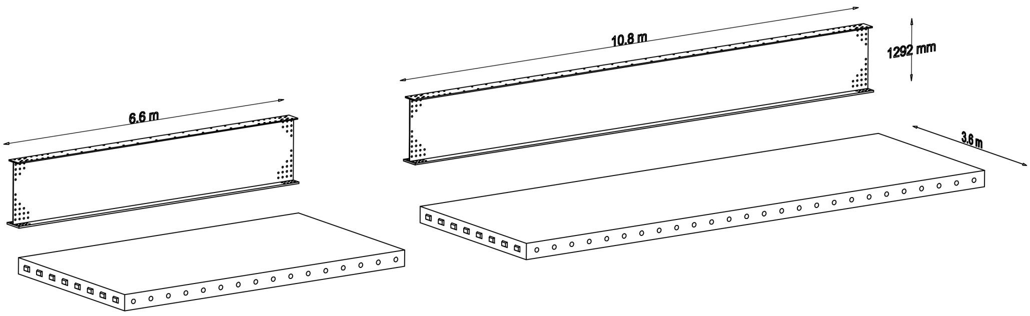


Figure 8.13: Guardrail modules for span range 20-32 m

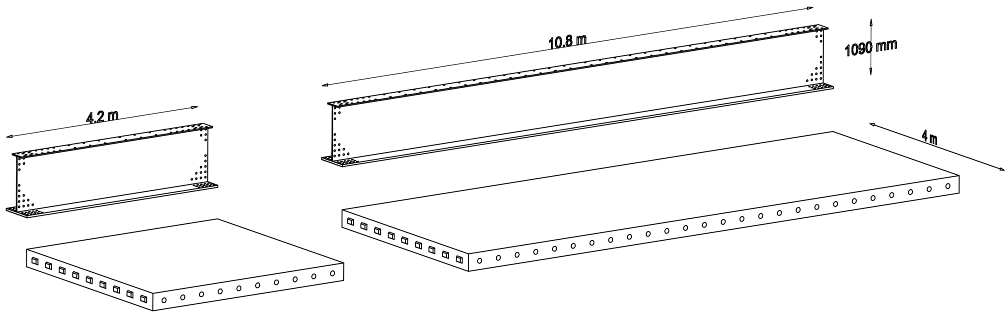


Figure 8.14: Regular modules for span range 12-19 m

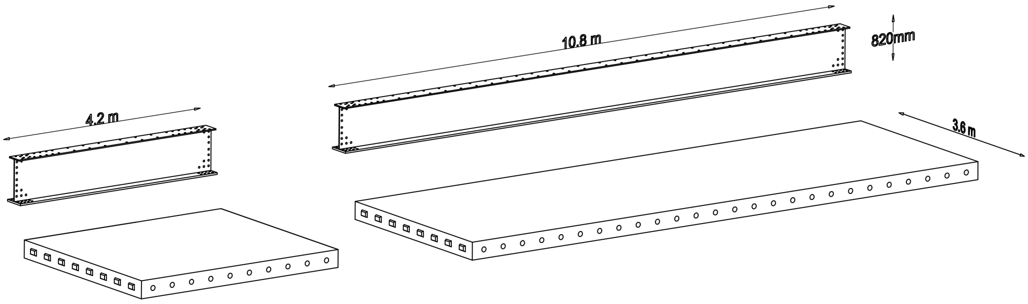


Figure 8.15: Guardrail modules for span range 12-19 m

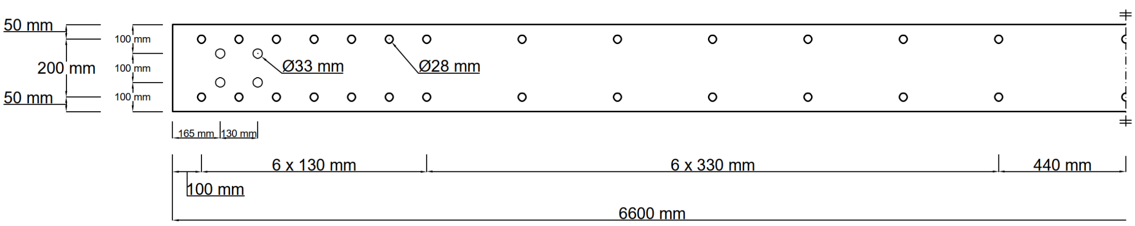


Figure 8.16: Shear onnector layout for a 6,6 m module

Adaptations to the design

Though the modules have fixed dimensions, there are some changes to be made to optimise the design for the specific situation it will be used in. The first optimisation concerns the shear connector. Due to the symmetry of the modules, the closely spaced part of the layout is present in locations not at the support. At these locations it is expected that a larger spacing can be used, which means that certain connector holes can be left empty. This offers the benefit of reduced costs due to lower material and installation costs. A reduction in the number of connectors is also possible for spans shorter than the maximum span. For the layout is determined specifically for the maximum span, it may be possible to increase the spacing in case shorter spans are under consideration.

It is important to provide adequate protection for empty holes, though. The holes in the concrete are of particular concern, since deterioration processes, such as corrosion, can take place when not protected properly. To solve this problem various solutions can be proposed. Two possible solutions could be the use of a 'dummy' connector, a connector that can be placed in the hole but does not transfer loads, or the use of non-adhesive grout.

A reduction in bolts is also possible for the steel girder connections. Like the connectors, these are designed for the maximum possible loads. Since the maximum loads may differ for different configurations and different locations within the overpass, a reduction in the number of bolts used in the splice connection may be applied in those situations.

Though designed for highway loads, the design could also be used for other applications, where lower loads are expected. In case of a reduction of the magnitude of the loads, different measures can be taken: the number of connectors can be reduced, both relating to the number of bolts in the girder connection and to the number of shear connectors. It could also be an option to reduce the number of prestressing tendons. A third option is to deviate from the existing span ranges. In case of lower loads, it could be possible that longer spans can be created with the modules, which in turn would open up the design to even more applications. Naturally, the possibility of these measures being taken depends on the extent of the load reduction and requires verification. Another aspect on which the number of use cases for the overpass can be increased is the maximum width of the overpass. The overpass is verified for a maximum width of 23,2 m. However, from the structural behaviour there is no direct restriction for the application of an overpass wider than 23,2 m. The load distribution in the longitudinal direction is not significantly affected by a larger width, nor is the load-bearing behaviour in the transverse direction. As a result, there might be possibilities for larger widths. A verification of the design for larger widths should be done to prove whether this is indeed possible.

On the matter of strengthening, it is previously explained that specific strengthening measures are excluded from the design. Nonetheless, the possibility to strengthen the design still exists. One of the possibilities is to increase the number of prestressing tendons. Since there exists some margin on the compressive stresses in the concrete and the prestressing ducts are sufficiently large, it is possible to increase the prestressing load up to 40%. For reinforcement of the girders, other measures are possible, e.g., welding additional plates to the girders or even post-installation of connectors; however, these types of measures are not accounted for in the design and thus require modifications to the elements.

8.5. Conclusion

In this chapter the design has been further developed, leading to more detailed connections and proposals for dimensions.

With regard to the shear connectors, the SLS verification is governing, leading to the conclusion that the ECD connector without resin is best suitable for the application due to its lower stiffness. The layout of the connectors follows the pattern of a small spacing up to 1 m from the support and a larger spacing for the rest of the span. For the connection between the girder elements a design has been made that can withstand the forces in the girders. The feasibility of the transverse connection between the deck elements has also been proved by analysing the stresses in the deck and the resistance of a possible shear key connection. Lastly, dimensions have been proposed for the modules. The width of all modules is equal to 4 m. For the height, two different modules are suggested, each for a certain span range, to increase the material efficiency and improve the slenderness of the system. The length of the modules has been determined taking into account the costs of the girders and the connections, resulting in two sets of two modules, one for each of the span ranges.

V

Results

9
Discussion

This research shows that a steel-concrete composite structure is the best option for the design of a sustainable overpass according to IFD principles. The use of prestressing tendons, shear keys and demountable shear connectors, specifically ECD connectors without resin, makes it possible for the structure to be divided into modules and ensures the demountability and modularity of the design. To discuss the implications of the achieved results and possible limitations, this chapter is structured by the phases that exist within this study.

9.1. Preliminary design

Environmental impact assessment
The study identifies that a composite structure is the most sustainable structural system for an IFD overpass. This is in line with the typical range of application of the three structural systems, where, often based on regular costs, the composite structure is the most logical choice for shorter spans. The environmental impact assessment also shows that the environmental costs of different types of superstructures can differ significantly. In combination with the fact that the environmental impact of substructures is limited in comparison with superstructures, as shown by [63], this illustrates that an assessment of the environmental impact of different structures should focus primarily on the superstructure. Another statement that can be made based on the results is that the majority of the impact stems from the production phase (module A). This means that an investment is made in the short-term which needs to be valued appropriately in the long-term. The reuse of components, through for instance IFD design, is an effective way of achieving this and should, therefore, be of consideration during the design of new infrastructure.

The reliability of the ECI is influenced by the uncertainty that is inherent to the calculation of environmental impact. Most prominently, this concerns the estimation of long-term impact (modules C and D), as it is difficult to predict what will happen to the materials at their end-of-life, in particular for a lifespan of 200 years. Still, the impact of this uncertainty on the results is limited, varying from 7% to at most 15%. As has been shown in the ECI calculation, the composition is dominated by module A impact. Since this concerns the production phase (i.e., the foreseeable future), it is more predictable, and thus the uncertainty is significantly smaller. Moreover, as the percentage of the total impact that comes from modules C and D is comparable across all materials, any deviations are not expected to have a significant impact on the comparison.

IFD principles assessment
The Orthotropic alternative scored best in the MCA describing the structure's performance on IFD principles. This is explained to a large extent by the limited number of components that are needed to form the structure, the need for a smaller number of connections and the ease of changing the layout. These properties are also present in the modular structure presented in Figure 3.7. The inferior performance of the Truss alternative, on the other hand, is largely due to it having a lot of different components and the fact that changes to the structure, whether replacements or changes to the layout, are difficult to perform. Based on the MCA scores it can be identified which aspects are most impactful in developing an IFD structure.

- Whilst a truss is a dependent system because of the fact that the deck structure relies on only two trusses, composite and orthotropic deck structures are more independent, as they feature multiple girders that independently form a separate segment of the structure. The benefits of this are related to the possibilities for parallel assembly and the ease of replacement, but changing the layout of the structure is also simplified. To conclude, independence is an important feature of an IFD structure.

- The good performance of the Orthotropic alternative is in part explained by the fact that it features essentially one, relatively large component, which means the number of connections is limited. Besides, by designing for only a couple of elements that are preferably large, a simplified (dis)assembly process is developed. Therefore, the use of large standardised components contributes to the development of an IFD structure.

It is acknowledged that the results from the MCA are dependent on the categories considered: the inclusion or exclusion of certain categories naturally influences the outcome. Nevertheless, as the categories represent different aspects of IFD, the MCA score is expected to reflect well the overall performance on IFD. A different scoring procedure is also possible. Though this can affect the scores for the alternatives, it is not expected to impact the relative outcome of the assessment: a fully qualitative assessment would still favour the Orthotropic alternative.

9.2. Detailed design

Model
To be able to model the structure, it was necessary to simplify some aspects of the model. Most notably, these are the shear connectors. Instead of modelling the actual shear connectors, they are modelled as springs. Whereas this results in some difference in the behaviour of the connectors, both the forces in the connectors and the deformation of the composite girder correspond well with what is expected from theory, as shown by the validation in appendix E.

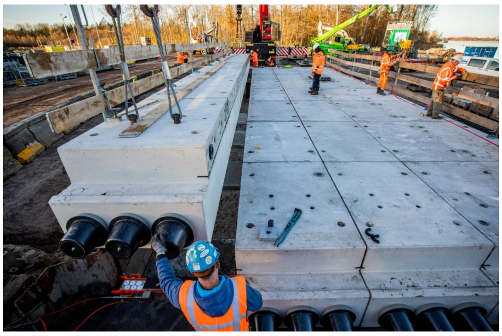
Shear connectors
The approach for the design of the shear connection focused on ensuring reusability of the overpass and its components by preventing the occurrence of plastic deformation. This has been accounted for by imposing an elastic limit on the connectors. The analysis on the shear connectors shows that, possibly somewhat unexpectedly, the connectors with a lower stiffness are favourable over the connectors with a higher stiffness. However, when considering the shear force distribution in combination with the use of the elastic limit for the connectors, this statement logically holds true. The application of this elastic limit also implies that improvement of the behaviour of the shear connection is the most impactful in the elastic range. For preloaded connectors, the focus should be on the friction resistance, whilst non-preloaded connectors benefit from the ability to undergo more elastic deformation. Another point of improvement is the elastic limit itself. The current limit is a safe limit that ensures reusability under all circumstances, but it could be argued that it is conservative. Nevertheless, in the absence of an accurate description of the elastic limit for all discussed connectors, the current limit was found to be the most appropriate.

With regard to the mechanical behaviour of the connectors, the properties are all determined based on limited test results and a parametric study. Though that it was not part of the scope to perform tests, it is evident that more test results will enhance the accuracy of the findings. Nonetheless, given what is available at the time of writing, the analysis can provide valuable and meaningful insights, especially regarding the relative performance of the considered connectors.

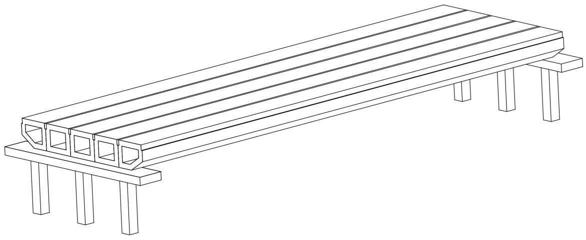
Shear keys
The design utilises shear keys to transfer horizontal and vertical forces between the deck elements. The verification on the shear keys showed that it is possible to develop sufficient resistance using the compressive force present due to dead loads. An important condition for this connection to work is that there always exists a compressive force in the interface. Where commonly shear keys are applied in combination with prestressing reinforcement, this study shows that, based on a simplified verification model, prestressing reinforcement may not always be required to create a shear key connection. Thus, the use of dry connections between concrete elements may gain further interest for use in current practice.

9.3. Sustainability benefits

To illustrate where the benefits of the developed design are in comparison with conventional solutions, two comparisons are made on the environmental impact. Figures 9.1a, 9.1b and 9.2 show the Circular viaduct, the conventional concrete overpass and the composite overpass, the overpasses that serve as comparison.



(a) Example of the circular viaduct [12]



(b) Impression of the conventional concrete overpass

Figure 9.1: Concrete overpasses used for comparison

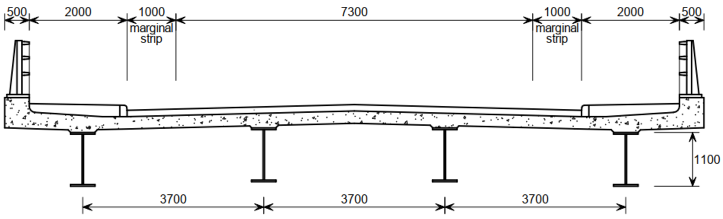


Figure 9.2: Cross-section of conventional composite overpass [110]

The first comparison is with a conventional concrete overpass (Concrete overpass) that consists of box girders (SKK girders specifically) and the previously mentioned Circular viaduct, an overpass that has similar design principles as the IFD overpass. The box girder overpass has a design life of 100 years and the Circular viaduct a design life of 200 years. The reference overpasses are 7,5 m (one lane) in width and 22,5 m long (to cross a span of 20 m). These overpasses are designed for the same application as the IFD overpass and are thus well comparable. Data on the material quantities required for both concrete overpasses is retrieved from an LCA-investigation into these two overpasses performed by NIBE Research [111] and listed in appendix C.3.

The second comparison is with a design of a conventional multi-girder steel-concrete composite overpass (Composite overpass), which is similar to the IFD overpass. The conventional composite overpass is a continuous structure that crosses two spans of 28 m and has a width of 14,3 m (two lanes plus footways) and has a design life of 120 years. The spans are formed by three girder segments: two of 21,7 m and one of 12,6 m. The conventional composite overpass is designed for the same loads as the IFD overpass. There are some differences in design assumptions, in particular the consequence class (CC2 instead of CC3) and fatigue cycles ($1x10^6$ cycles instead of infinite cycles). This means that it should be taken into account that the conventional overpass is designed for a slightly less demanding application. The data on the material quantities is retrieved from Steel Construction Institute [110] and listed in appendix C.3.

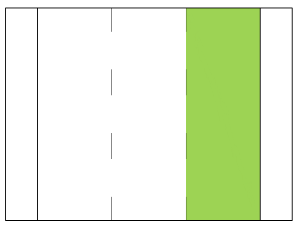
The comparisons are made based on a number of different scenarios. Important is to distinguish between the functional life and the design life. The design life (how long the structure can last) generally is 100 years for conventional overpasses and 200 years for the proposed IFD design. The functional life depends on whether the structure can meet the functional requirements and can differ for each overpass. In practice, the functional life and design life tend not to match: before the design life is reached a situation arises where the functional requirements are not met anymore. In the majority of situations that this is the case the capacity of the structure is insufficient. The average time after which this currently happens is 40 years [112].

Figure 9.3 shows conceptually the changes that occur for each scenario. In appendix C.4 a more detailed description of the changes to the structures is provided. The following scenarios are distinguished:

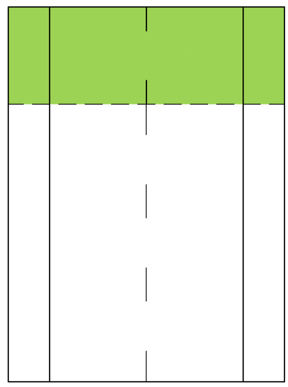
0. Reference scenario: for all structures the functional life is equal to the design life. A reference period of 200 years is considered, equal to the design life of the IFD overpass.
1. Extension of the width of the overpass: an additional lane is added to all structures. This simulates a situation where the capacity of the overpass is insufficient and requires an extension, relating to the principle of flexibility

of IFD. The reference period is 100 years for the concrete overpass comparison and 120 years for the composite overpass comparison. For both this is equal to their design life. The interval at which an extension is applied is 40 years. For the conventional overpasses, the extension involves partial replacement of the structure.

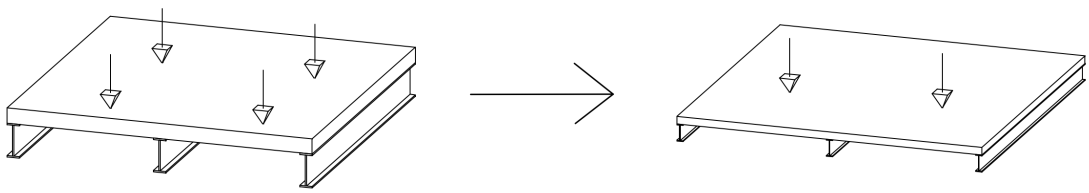
2. Extension of the length of the overpass: the length of the structure is extended, relating to the principle of flexibility. This situation can occur due to different reasons, such as the addition of a lane within the road under the overpass. As for scenario 1, the reference periods are respectively 100 years and 120 years for the concrete overpass and composite overpass comparisons and the replacement interval is 40 years. For the conventional overpasses, the extension involves full replacement of the structure.
3. Relocation: for this scenario it is assumed that the superstructure is relocated and used for an application with lower loads, for example a bicycle bridge, which is approximated by reducing the material quantities and thus the impact of the structure by 50%. This relates to the principle of demountability of IFD. The reference period is 200 years, equal to the design life of the IFD overpass. In this scenario the relocation interval is assumed to be 80 years. This is longer than the 40 years replacement interval, as it is expected that this scenario will occur less frequently. This scenario can also be considered an illustration of different situations. An example could be the replacement of 50% of the deck structure due to deterioration, which is a scenario that is very similar to relocation.



(a) Scenario 1: Extension of the width



(b) Scenario 2: Extension of the length



(c) Scenario 3: Relocation

Figure 9.3: Conceptual changes for scenarios

It should be noted that the scenarios display only the environmental impact of the superstructures and not of substructures. A point of attention is the reference period. For scenarios 1 and 2 a reference period of 100/120 years is used. This because the focus is on the influence of an extension of the overpass and it is expected that it is not likely for an extension to occur more than twice. Hence, a shorter reference period illustrates only the effects of layout changes and not of any other change (e.g. reconstruction), which is already described in other scenarios. Related to this, it is decided not to specify the end-of-life use of the overpasses, other than effects described by module D. All materials that are removed from the structure and are not directly reused again are considered to undergo the end-of-life process as described in the LCA analysis on the material, which is mostly recycling of raw materials. Consequently, any high-quality use of the removed elements from the overpasses, i.e., the reuse of full components, is unaccounted for. Due to the large uncertainty that exists regarding high-quality end-of-life use, it is considered not feasible to include this. An exception to this are IFD overpass modules that are used for a short period and then replaced, since they are intended for reuse and likely to be reused. For these elements, the impact is limited to the period they were used in the overpass.

9.3.1. Concrete overpasses comparison

Figure 9.4 shows the comparison between the concrete overpasses and the IFD overpass for scenario 0, the reference scenario. This scenario shows that in terms of the construction of one overpass, the Concrete overpass has the least impact. Yet, when a second overpass is constructed after 100 years, the Concrete overpass clearly has the highest ECI. Between the two modular overpasses, the Circular viaduct and IFD overpass, the IFD overpass has less impact over the full reference period, regardless of the maintenance that raises its ECI over time.

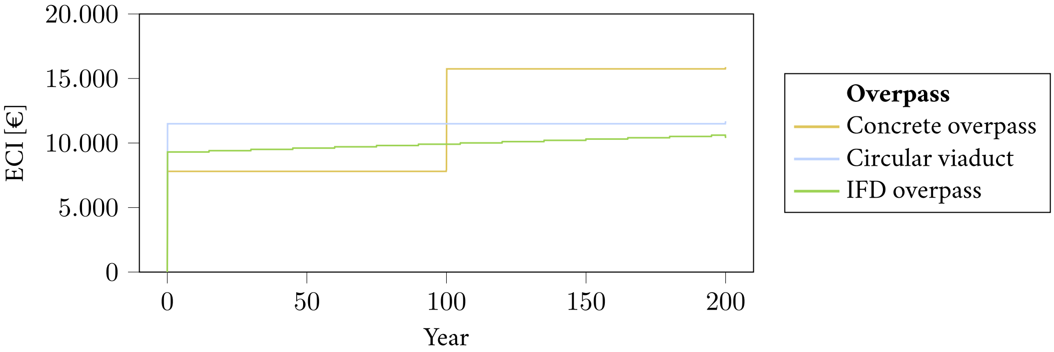


Figure 9.4: Concrete overpass comparison: Scenario 0

Scenario 1 is shown in Figure 9.5. It shows that the difference between the concrete and IFD overpass decreases slightly, but not significantly. An explanation for this is that, although the Concrete overpass requires the removal and reconstruction of some elements, whereas for the IFD overpass no replacement or reconstruction is necessary, the assumption is made that all prestressing reinforcement is removed. Whilst it might be possible to reuse the prestressing tendons, for this scenario it is assumed that the tendons are completely replaced. This effect makes that the impacts of an extension are comparable, whereas reuse of the tendons (e.g., extension of the already present tendons) would result in lower impact of the extension of the IFD overpass. The main benefit is in the fact that the IFD overpass does not require a second extension. Since the dimensions of the modules of the IFD overpass for this situation make that the structure after the first cycle is wide enough for the addition of the second lane, there is no need for the addition of more modules and hence no increase in ECI is reported. For reference, if a second extension is done, the ECI is slightly larger than for the conventional concrete overpass. The Circular viaduct follows the same pattern as the IFD overpass, yet with a higher ECI due to the larger construction costs.

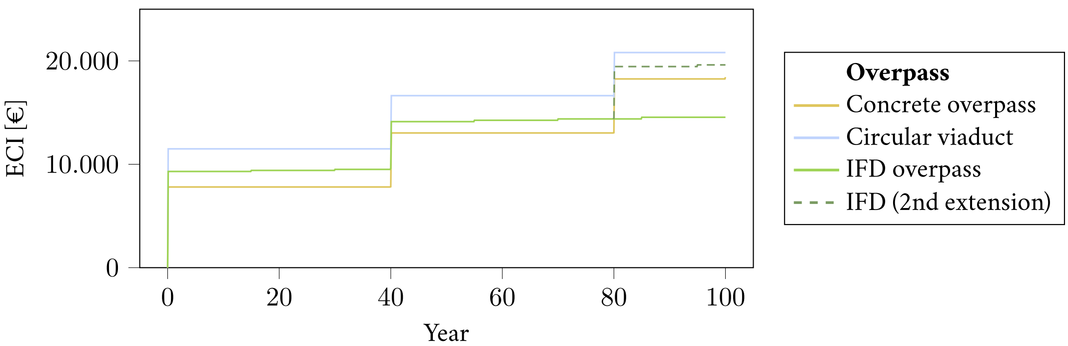


Figure 9.5: Concrete overpass comparison: Scenario 1

The pattern for scenario 2 is more pronounced in comparison with scenario 1, as illustrated by Figure 9.6. The modular structure makes that both the IFD overpass and the Circular viaduct can be adapted to a substantially lower environmental cost than the Concrete overpass: after only one extension both have a lower ECI than the Concrete overpass. The temporary reduction in the ECI of the IFD overpass is due to the fact that modules are replaced that are only used for 40 years and that are, therefore, still suitable for reuse after they are disassembled. Accordingly, only the impact for the 40 years of use is accounted for by applying an ECI reduction when these modules are no longer used.

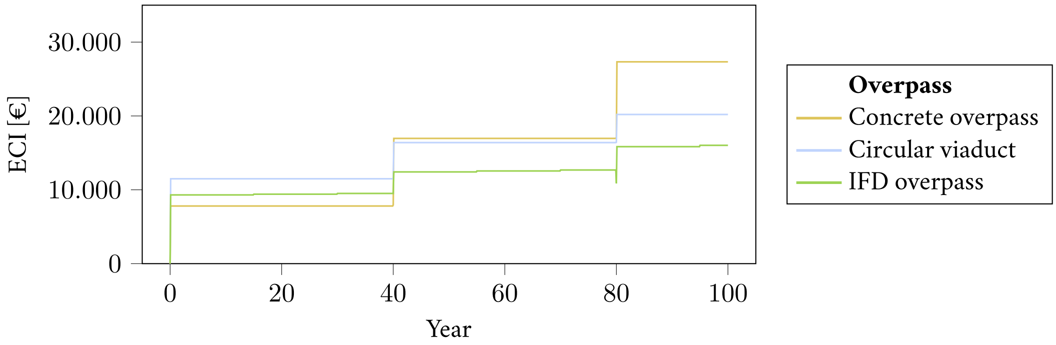


Figure 9.6: Concrete overpass comparison: Scenario 2

Scenario 3 is visualised in Figure 9.7. Again, the Concrete overpass starts off at a lower ECI, yet after one relocation cycle the IFD overpass becomes the overpass with the lowest impact. The differences remain small though, because of maintenance, the reduced impact of the reconstructed overpass and the shorter design life of the final Concrete overpass (in use from 160 years onwards). In case the reconstructed overpasses are used for the same application as the first overpass, the impact of a reconstruction increases substantially. It is evident that the IFD design will then be the most favourable.

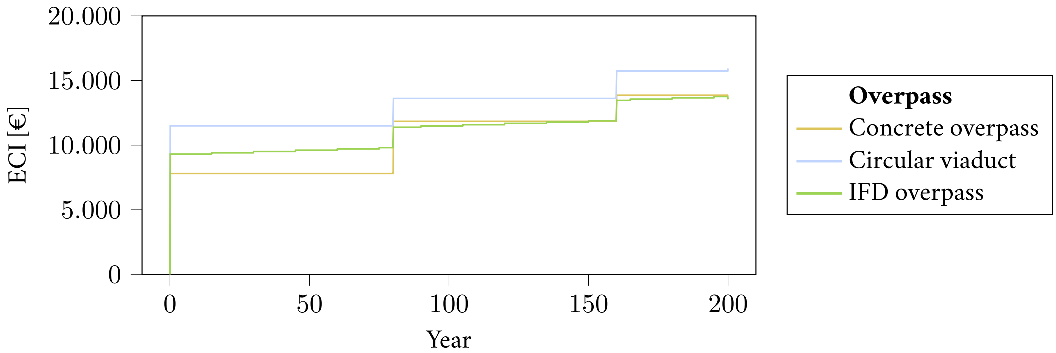


Figure 9.7: Concrete overpass comparison: Scenario 3

9.3.2. Composite overpass comparison

The initial impact of both the Composite overpass and the IFD overpass (IFD overpass) is very similar, as illustrated by Figure 9.8. Naturally, one full replacement after 100 years makes that the Composite overpass is the overpass with the highest ECI.

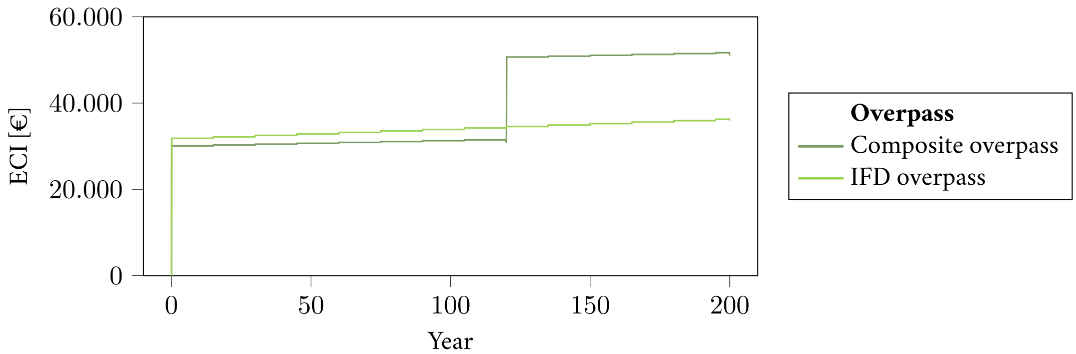


Figure 9.8: Composite overpass comparison: Scenario 0

For scenario 1, the Composite overpass is in favour, as illustrated by Figure 9.9. It can be seen that the addition of one lane results in less impact for this overpass. There are two important reasons for this. The first reason is that in order to add a lane to the Composite overpass, only a small part of the deck (the part that forms the end section) needs to be reconstructed, which for the Concrete overpass earlier was not the case. The second and most important reason has to do with the full removal and replacement of the prestressing tendons. This causes a significant additional impact upon extension. Reuse of the tendons will have a favourable effect and would have the effect that the impact of both overpasses is more or less equal.

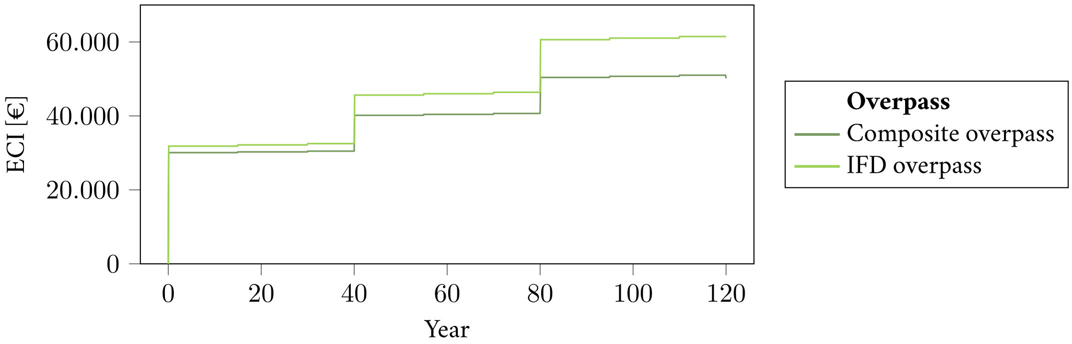


Figure 9.9: Composite overpass comparison: Scenario 1

Scenario 2 is illustrated by Figure 9.10. The extension is applied to only one of the two spans. Since the Composite overpass girders are composed of three segments, it is assumed that only one of these girder segments needs to be replaced to extend the overpass, instead of the full overpass. Still, even though this is possible, the IFD overpass is clearly in favour compared to the Composite overpass.

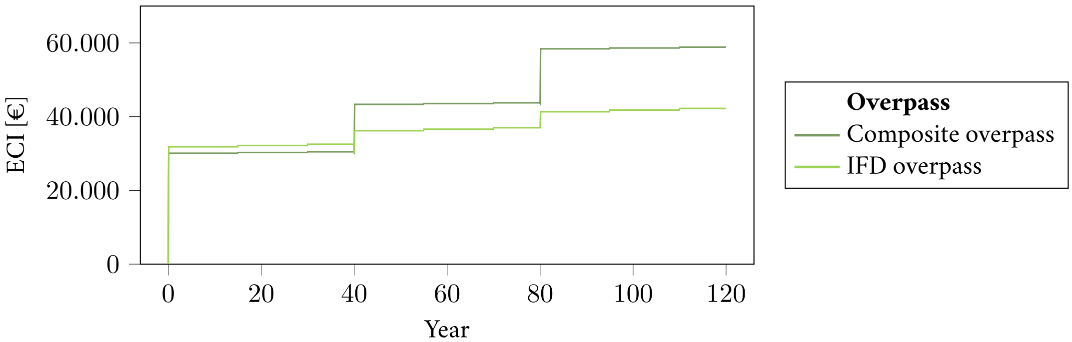


Figure 9.10: Composite overpass comparison: Scenario 2

Figure 9.11 shows that, again, the IFD overpass is favourable after one relocation cycle. Even though the lighter loads on the structure allow for the Composite overpass to be constructed with a reduced impact of 50%, the disassembly and reassembly of the IFD overpass has a lower impact.

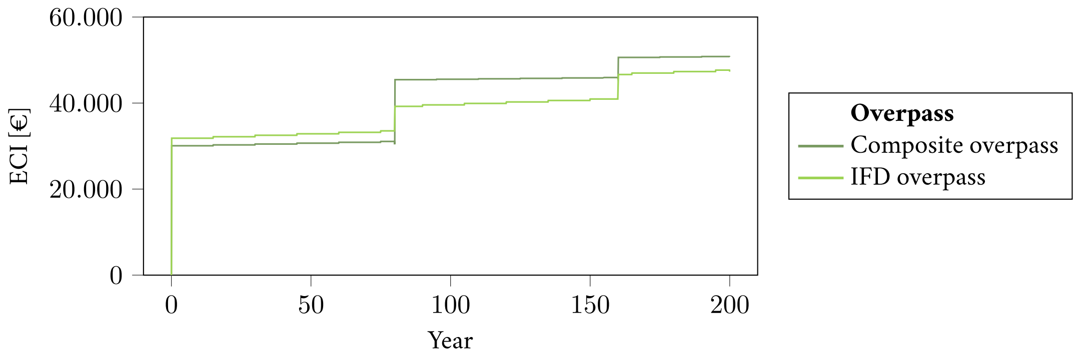


Figure 9.11: Composite overpass comparison: Scenario 3

9.3.3. Possibilities for environmental impact reduction

The comparison shows that the environmental impact is low enough for the IFD design to be competitive in certain situations. Yet, although the most sustainable structural system is used, there is potential for further reduction of the impact. The focus is on improvements in the short-term.

The largest source of environmental impact of the design is steel. Though the impact of the steel production itself may not be easily reduced in the short-term, use of recycled steel can reduce the impact as less raw materials are needed. Since it was found in section 4.1 that there is no loss of quality for steel recycling, this may be a viable option.

The second-largest source of impact is the concrete. As for steel, a more sustainable production process is an improvement for the long-term. Hence, the most potential in the short-term is in the use of recycled materials for the production of concrete and the application of more sustainable cement. With cement being the source of most of the impact of concrete, this is where the largest reduction is possible. In the design it is assumed that CEM III is used, which is already more sustainable than CEM I concrete, due to the lower clinker content. There may, however, be room for more improvement. This is illustrated by the fact that the production of CEM III/C has a 35% lower impact than the production of CEM III/B, which presumably is the type of cement used in the design [113]. Since CEM III/C is not really used at the moment, it needs to be investigated whether this would be possible.

Another important aspect is the prestressing steel. In scenario 1, it is assumed that the prestressing steel is fully replaced after one extension. This partially explains why the IFD design has a higher impact than the conventional composite design. Hence, reuse of the prestressing steel in some form improves the ECI of the IFD design in case of extension in the width direction.

Within the current design it is also possible to reduce the impact. This mainly concerns the shear connectors and the girder connection. Both connections have been designed for the critical loading situation. Not all locations or designs, however, are subject to this loading situation. As a result there may be possibilities to use fewer shear connectors in case a shorter span is required, or to reduce the number of bolts in the girder connection for locations where the loads are less critical. This saves on environmental impact, costs and assembly time.

9.3.4. Conclusion

Based on the comparisons several conclusions can be drawn on when the IFD overpass is beneficial and when the other solutions are favourable.

- The IFD overpass has a higher or at most equal initial impact compared to conventional solutions. When the impact due to maintenance is included, this difference increases further.
- In most scenarios, the flexibility of the IFD overpass means that, often already after one change to the layout of the overpass, it is the option with the lowest impact. This effect is enhanced after a second change cycle. An exception to this is the extension of the width of the overpass (scenario 1) for the composite overpass: the conventional composite overpass is designed such that an extension of the width is possible without the need for major changes.
- The demountability in combination with the long lifespan of the IFD overpass makes that the environmental impact is lower on the long-term compared to conventional solutions. The extent to which the benefit exists depends on the application after the first use cycle.

- For all scenarios the IFD overpass outperforms the Circular viaduct. The behaviour of the two overpasses in terms of environmental impact is the same, yet the higher impact due to production and assembly makes that the Circular viaduct consistently has a higher environmental cost.
- Besides the environmental impact, the use of raw materials is important for sustainable practice too. Since the impact of module A and the use of raw materials are strongly connected - raw material supply and processing is described by modules A1-A3 - the environmental impact due to module A indicates to which extent raw materials are used. In addition to that, the majority of the total impact stems from module A. Therefore, the outcomes of the comparisons also illustrate to what extent raw materials are used. In conclusion, the benefits of IFD in relation to the ECI also apply to the use of raw materials.

10
Concluding Remarks

This chapter presents the conclusion of the performed research as well as recommendations for future research. The first section focuses on the conclusions, by considering the research objectives and questions. The second section describes several relevant recommendations.

10.1. Conclusion

This research aimed to develop a design for an overpass where the focus was on IFD principles and sustainability. The three central themes of this research, described by the sub-questions, are the preliminary design and IFD principles, the connections and dimensions, and the sustainability benefits.

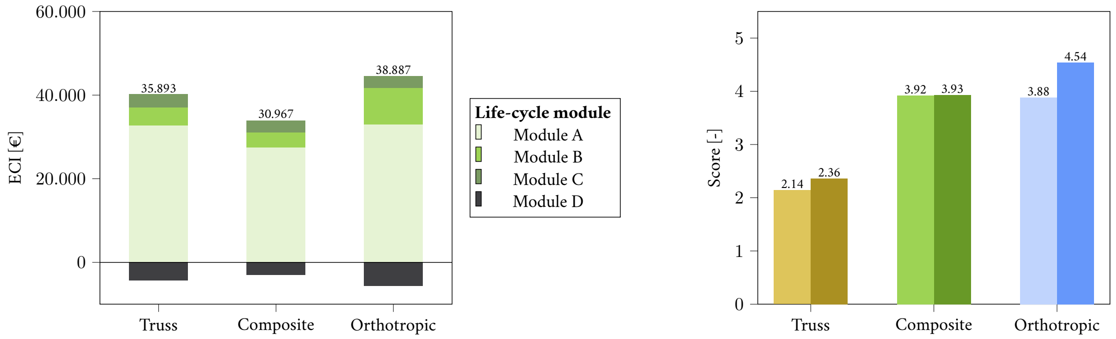
Preliminary design

The three principles of IFD are Industrial, Flexible and Demountable. Industrial describes the need for the use of prefabricated, standardised components with the aim for efficient material use. Flexible is a multi-interpretable term and has a central goal of ensuring that a structure can be changed in order to meet changing circumstances. A design approach similar to IFD, DfD/A, describes flexible by three characteristics: versatility, convertibility and expandability. Demountable has the straightforward goal of ensuring reusability of components and structures. Demountability concerns a number of different aspects, which are ease of access, independence, support reuse, simplicity and standardisation.

To incorporate the different principles into a design, the principles are translated into guidelines. For industrial, the focus of these guidelines is on modularity and prefabrication. For flexibility, two DfD/A characteristics are relevant. Convertibility guidelines relate to the possibility to accommodate a change of loading. Layout changes due to a change of functional requirements are the central theme for expandability guidelines. Numerous guidelines to improve demountability are formulated. The most relevant guidelines concern the use of demountable connections, designing for durability and longevity and minimising the number of connections and components.

The first step towards finding the most suitable structural system was to investigate the options regarding materials. The materials steel, concrete, timber and FRP were investigated on their current use, recyclability and durability. It was concluded that steel is the material that is most suitable for an IFD overpass, since it is easily standardised, the recycling potential is high and durability can be very good. For its good durability and large number of options regarding connections concrete was found to be a good option for use as a secondary material. Following steel as the main material, a truss structure, a steel-concrete composite structure and a steel girder structure with an orthotropic deck were found to be the most promising structural systems.

For these three structural systems, designs were made and optimised to minimise the environmental impact. Within these designs IFD requirements were included, which state that the designs need to be modular, made from prefabricated and standardised components, adjustable in dimensions and using demountable connections. The design alternatives were then assessed on their performance regarding sustainability, in the form of environmental impact, and IFD principles. The IFD principles were assessed using an MCA, with criteria focusing on the number of connections and components, independence, mass and maintenance. Figure 10.1a shows the results of the environmental impact, expressed in the ECI. The results indicate that, in terms of environmental costs, the Composite alternative has the lowest impact. This is true for both the total impact as well as the impact from the production and installation of the overpass (module A). On the notion of IFD principles, Figure 10.1b presents the results for the assessment. The outcome is that for smaller modules the scores are equal, whilst for larger modules the Orthotropic alternative is favoured over the Composite. The conclusion is that, combining both assessments, the Composite alternative has the best overall performance.



(a) ECI of 4x1 layout, divided in life-cycle modules (repetition of Figure 6.4)

(b) MCA scores, for module size 4 m (light) and 12 m (dark) (repetition of Figure 6.7)

Figure 10.1: Results from the performance assessment of the design alternatives

Connections and module dimensions

Within the Composite design three connections are distinguished. The first connection is the shear connection between the deck and the girders. For this connection the initial step was to investigate the different options that exists for a demountable shear connection. The HSFGB, Cylinder, ECD (no resin) and ECD (iSRR) are found to be the most suitable for reuse applications. From literature properties were determined for these connectors, which needed to be scaled using a parametric study in order to allow for the use larger connectors. Then, a model was created to determine which of the connectors is the best for the application. Since for reuse purposes the forces in the connector for the SLS should remain below the friction limit, the governing criterion is deformation. Based on this criterion, it was determined that the ECD (no resin) is the best connector, as it requires the least amount of connectors without meaningful concessions regarding strength and stiffness.

The second connection is between the steel girder elements. It was found that a splice connection with shear loaded friction bolts is the most suitable option. In the model the connection was assumed as rigid. It was later verified that a design can be made for such a rigid connection that can successfully transfer the forces.

The third connection is between the concrete deck elements. After it was determined that this connection is best created by shear keys, it was shown that shear keys are sufficiently strong to be a feasible option.

With the connections known, it was determined what dimensions the modules should have. Based on aesthetics, in the form of slenderness, it was suggested that two span ranges are distinguished, each with a different girder height. For each of these span ranges two module lengths are proposed, allowing for the formation of multiple span configurations. These modules lengths are based on the number of connections that are needed to construct the beam and the costs affiliated with the connections and the girders.

Environmental impact comparison

The proposed design has several benefits over conventional overpasses when considering the environmental impact. The overall picture is that the initial investment of an IFD overpass is higher than for conventional overpasses. However, after some changes to the overpass, in particular substantial changes, the IFD overpass is the favourable option due to its flexibility, demountability and reusability. These are the situations in which the IFD design is the most effective. It was also concluded that the proposed IFD design outperforms the Circular viaduct due to its lower impact from production

Final design

The end result of the research is the design that is developed for an IFD overpass. Figure 10.2 shows the concept. The concept exists of multiple girder modules that can be connected via bolted connections to form a full girder. These girders are combined with a concrete deck to create an overpass. The concrete deck elements are linked by shear keys and connected to the girders with demountable shear connectors. Finally, the individual girders and deck elements are combined into one structure by the application of prestressing reinforcement.

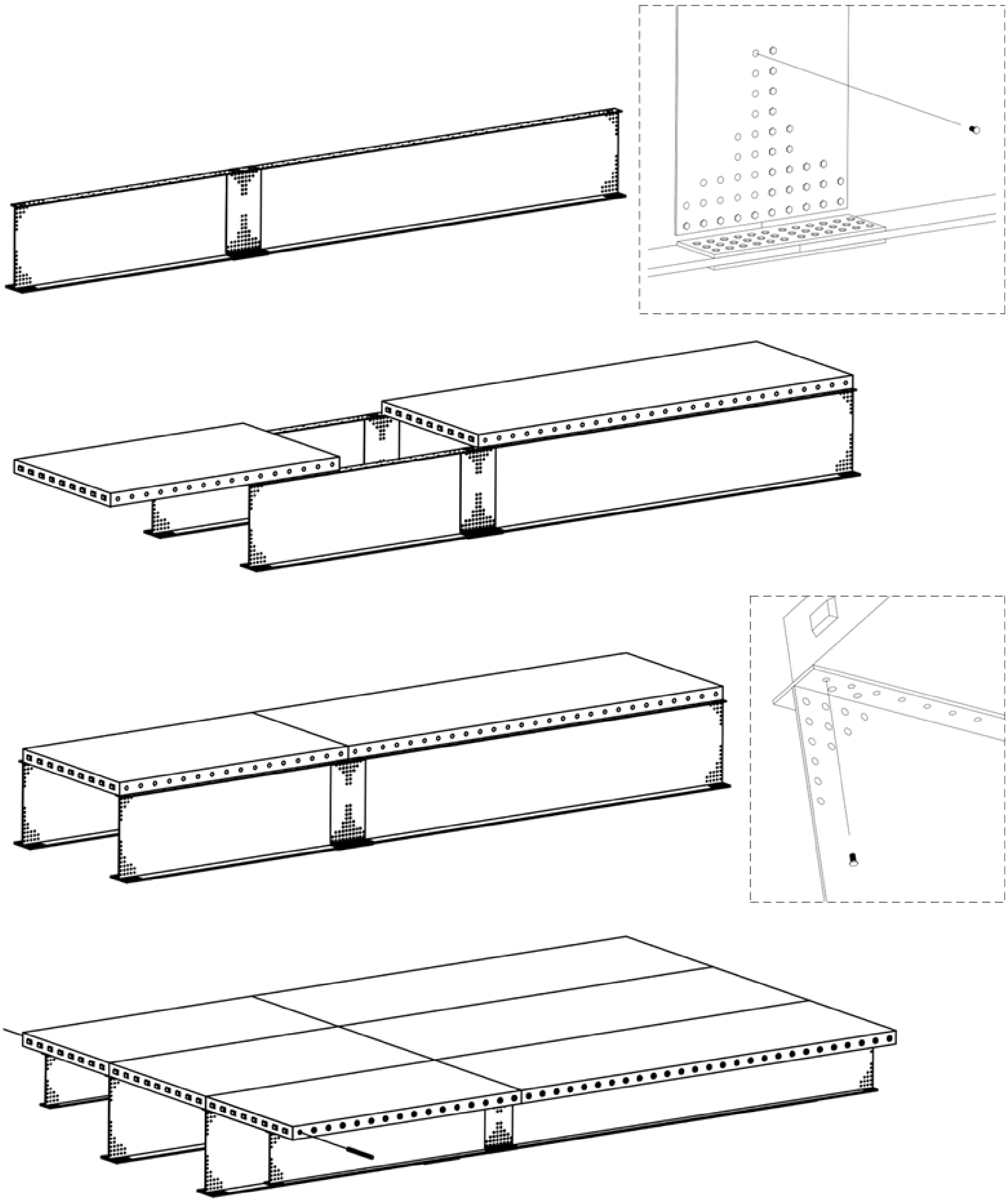


Figure 10.2: Illustration of the final design

The central theme in the research has been to ensure that the designed concept adheres to the IFD principles. The first principle of industrial is present in the use of modules to create the overpass. These modules are all prefabricated and can be produced on a mass scale. Flexibility is accounted for by ensuring the design is convertible and expandable. The ability to change the dimensions of the overpass, both in length and width, accommodates potential changes in traffic intensity and allows for adaptations to the road layout. Demountability is incorporated in the design through various aspects. Most prominently present in the design is the use of connections that can be easily disassembled. The reduction of the number of connections has also been a goal in the design. In addition to the connections, the use of durable materials and the design for longevity contributes to the reuse of the demountable components, as does the use of standardised components. Next to IFD, sustainability has also played an important role in the research. The design has been made sustainable by selecting the most sustainable structural system and optimising its dimensions based on the environmental impact. Other aspects of sustainability, such as costs and aesthetics, have also been applied to further increase the sustainability of the design.

In conclusion, the design shows that it is possible to develop an overpass that complies with IFD principles by using a small selection of modular elements and demountable connections. During the design process, different aspects of sustainability can be addressed to come to a sustainable end result.

10.2. Recommendations for further research

Since a limited time was available to perform the research, it was necessary to formulate a scope and make assumptions. Based on the scope and assumptions, a selection can be made of aspects that are not included in this research, but which are of particular interest to serve as the topic for further research.

The design focuses on the preliminary design of the overpass. This means that not all aspects have been worked out and some detailing needs to be performed. Hence, it is suggested to perform a detailed design for the overpass, based on the current results.

Within this study, it was decided to focus on concrete as the material for the deck, as there is more literature on connections with concrete rather than with materials like timber and FRP. However, it can be interesting to investigate other materials, such as timber and FRP. Since these materials offer some advantages over concrete, exploring them could lead to alternative solutions. The focus of such an investigation should be on the connection between deck modules as well as the shear connection between the deck and girder.

For this research, use has been made of test results on shear connectors. Since there is only a limited number of tests, it will be beneficial for the accuracy of the description of the load-slip behaviour if more tests are performed on the considered shear connectors. Of particular interest are tests on connectors with different properties, including the properties as used in this research. Furthermore, fatigue tests on the demountable shear connectors, such as the ECD (no resin), should be performed to better understand the fatigue behaviour of the connectors. It is also interesting to perform research regarding the optimisation of the shear connectors. Firstly, this concerns the ECD (no resin) connector, for which a research objective could be to increase the friction resistance or to accurately describe the point at which plastic deformation first occurs within one of the elements of the connection. Secondly, other connectors can be the subject of future research. An example is the LBDSC, which has good behaviour, but is less favourable for reuse. Consequently, changes to the LBDSC that increase the potential for reuse are also an interesting subject for future research.

10.3. Recommendations for use

Following the results from this research, several recommendations can be formulated on the application of IFD and its principles, the connections and the design in general.

Based on the MCA, two recommendations are formulated, which are expected to be the most influential in designing an IFD structure:

- *Aim to create independence in the structural system.*
  In the context of this research independence relates to preventing the use of (load-bearing) components that rely on other components to function, or, alternatively, minimising integration of components. Apart from this definition, other aspects of independence are of importance too, such as accessibility of connections and separation of components with different lifespans.
- *Aim to use a small selection of large elements.*
  The use of large elements reduces the number of elements and connections and simplifies the assembly process.

The presented design has potential for use due to its flexibility and high degree of demountability. Two of the elements that form the design are thought to be particularly interesting:

- Regarding shear connectors, it is recommended to consider demountable shear connectors when designing a composite structure. Demountable shear connectors show good behaviour and have advantages over welded studs, such as the better fatigue life. Furthermore, due to the different options that exist, a form of optimisation is possible in choosing the best connector for the application. Evidently, the demountability of the connectors is an advantage in terms of reuse.
- Shear keys have shown to be a viable option for a demountable connection between concrete elements, even without prestressing reinforcement. Accordingly, the use of shear keys can be an interesting alternative for use

in concrete structures without prestressing, provided that the connection is always in compression. The most promising application is in locations where small loads are expected in the shear keys.

The assessment of the sustainability benefits allows for the formulation of recommendations regarding the use of IFD design. These recommendations are generally applicable for IFD structures, provided they have an application similar to the developed overpass.

- *Aim for a design life that is similar to the (expected) functional life.*
  The high impact of the production and construction of an overpass shows that this has a significant impact on how sustainable a design is. Accordingly, a reduction on the impact in the production stage is the most impactful. This is best done by optimising the design for its function and not constructing a structure that is too robust for its intended functional life. The ECI (MKI) can be a useful tool to perform an analysis on the sustainability of a design through an assessment on its environmental impact.
- *Consider IFD design as an alternative when (substantial) changes to the structure are expected.*
  The extent to which the environmental impact of the IFD overpass is lower than the conventional designs after changes to the layout highlights the benefits of using an IFD design. Especially in the case of large changes to the structure, IFD design is beneficial.
- *Consider IFD design as an alternative when it can be expected that the structure will be demounted and/or reused.*
  The assessment has demonstrated that the ability to disassemble and reuse components can lead to a significant reduction in environmental impact.
- *If there exists no direct motivation for the use of IFD design, reconsider the need for its application.*
  For IFD structures to be viable, they need to compensate for the higher initial impact. In case there is no possibility for compensation, conventional solutions will, in principal, be the most sustainable solutions. Consequently, IFD design may not be the most logical choice if the benefits of IFD are not exploited and a different sustainable design strategy may better suit the purpose. In case IFD design is applied though, ensuring high potential for reuse of the components can aid in mitigating the larger initial impact.

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A

Design Principles

To be able to perform the design verification, design principles need to be determined. This includes assumptions, material properties, loads and the layout. These principles apply to both the alternatives and the final design.

Design assumptions
Some general assumptions are made in order to perform the verification of the alternatives. These are listed below:

- All connections, unless specified differently, are considered to be clamped connections. This allows for the assumption that the components form continuous elements. An exception is the Truss alternative: the connections in the truss are assumed to be pinned connections.
- Optimisation is performed up to unity checks in the range of 0,90-0,95. The upper limit of 0,95 is used to maintain some margin with respect to the ultimate resistance of the elements.
- For the fatigue verification, FLM4a is used. Even though the load model consists of five different trucks, only one truck is used for the verification. This is because truck number three from Figure A.2 has shown to be the truck that results in the highest loads on the main span. Normally, the calculation focuses on damage accumulation. However, as the amount of loading cycles is at such an extent that infinite fatigue life is required, only the governing truck is relevant.
- To ensure sufficient durability of concrete, EN 1992-1-1 prescribes a lower limit for the concrete class for given exposure classes to ensure sufficient protection of the reinforcement. Assuming exposure class XD3 is valid, the concrete class should be at a minimum C35/45 [102]. Hence, this is the lower limit for the concrete class.
- Cross-section classes have been checked for all elements: all elements have cross-section class 1, 2 or 3.

Material properties
Material factors are listed in Table A.1. The material properties that have been used in the design verification are the following:

Table A.1: Material factors

Concrete		**Steel**		**Reinforcement**		**Prestress**	
γ_C	1,5	γ_{M0}	1	γ_s	1,15	γ_S	1
$\gamma_{C,fat}$	1,5	γ_{M1}	1			γ_P	1
		γ_{Ff}	1				
		$\gamma_{Mf}*$	1,45				

* *For the orthotropic deck a value of 1,15 can be used [13].*

Concrete

Class	C45/55
Density	2500 kg/m^3
Young's modulus	36283 N/mm^2

Steel

Class	S355 *or* S460
Density	7850 kg/m^3
Young's modulus	210000 N/mm^2

Steel reinforcement

Class	B500
Density	7850 kg/m^3
Young's modulus	200000 N/mm^2

Prestressing steel

Class	Y1860
Density	7810 kg/m^3
Young's modulus	195000 N/mm^2

Loads

Figure A.1 shows LM1 (Load Model 1). The values for the loads and α-factors are listed in Table A.2.

Figure A.2 shows the trucks that should be considered and Figure A.3 shows the arrangement of the wheels for the different axles. The third truck is the truck that is found to result in the governing loading situation.

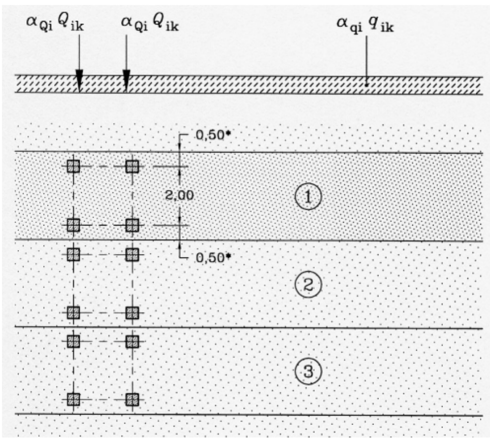


Figure A.1: Load Model 1 [114]

Table A.2: Load values from LM1 [114]

	q_k [kN/m^2]	α_k	$q_k\alpha_k$ [kN/m^2]	Q_k [kN]
Lane 1	9	1,15	10,35	300
Lane 2	2,5	1,4	3,5	200
Lane 3	2,5	1,4	3,5	100
Other	2,5	1	2,5	0

Type voertuig		Verkeerstype				
Afbeelding van de vrachtwagen	Afstand tussen de assen m	Gelijkwaardige aslast kN	Lange afstand % [a]	Middellange afstand % [a]	Lokaal verkeer % [a]	Wiel-type
	4,5	70 130	20,0	50,0	80,0	A B
	4,20 1,30	70 120 120	5,0	5,0	5,0	A B B
	3,20 5,20 1,30 1,30	70 150 90 90 90	40,0	20,0	5,0	A B C C C
	3,40 6,00 1,80	70 140 90 90	25,0	15,0	5,0	A B C C
	4,80 3,60 4,40 1,30	70 130 90 80 80	10,0	10,0	5,0	A B C C C

[a] Percentage vrachtwagens.

Figure A.2: Selection of trucks from FLM4a [103]

The load factors and combination factors for the load combinations are listed in Table A.3 and A.4 respectively.

Table A.3: Load factors for ULS and FLS [115]

Load factor	Value
$\gamma_{g,superior1}$	1,4
$\gamma_{g,superior2}$	1,25
$\gamma_{g,inferior}$	0,9
$\gamma_{P,inferior}$	1,0
$\gamma_{P,superior}$	1,2
$\gamma_{q,traffic}$	1,5
$\gamma_{q,other}$	1,65
γ_{Ff}	1,0

Table A.4: Combination factors for variable loads [115]

Combination factor	Value
$\psi_{0,traffic}$	0,8
$\psi_{1,traffic}$	0,8
$\psi_{2,traffic}$	0,4
$\psi_{0,temperature}$	0,3
$\psi_{1,temperature}$	0,8
$\psi_{2,temperature}$	0

The following secondary structures and corresponding loads are distinguished:

- Asphalt layer: a minimum thickness of 141 mm is required and the volumetric weight of asphalt is equal to 23,0 kN/m^3 [13]. This results in a load of 3,24 kN/m^2.
- Guardrail and railing: For the guardrail and railing a combined load of 3,5 kN/m is assumed.
- Ducts: A load of 2 kN/m^2 is assumed for ducts in or under the deck.

Temperature loads are determined using the National Annex to Eurocode 1991-1-5 [116]. For details regarding the approach (such as the deck types), the Eurocode (EC) can be consulted. The following temperature loads are defined:

- Thermal expansion coefficient concrete — $\alpha_{T,c} = 1 \cdot 10^{-5}$ K^{-1}
- Thermal expansion coefficient steel — $\alpha_{T,s} = 1,2 \cdot 10^{-5}$ K^{-1}
- Steel girder *(EC type 1b)* — ΔT_1 = 15 °C
- Steel-concrete composite girder *(EC type 2, simplified)* — ΔT_1 = 13 °C
- Concrete deck *(EC type 2, normal)* — ΔT_1 = 13 $°C$, ΔT_2 = 4 °C

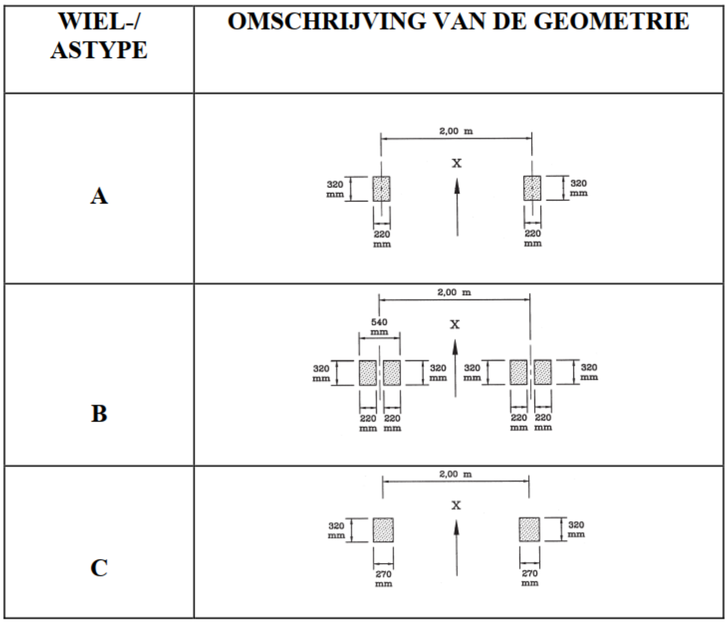


Figure A.3: Axle arrangements for trucks from FLM4a [114]

Layout

Figure A.4 shows the highway (3+1)x1-layout, from which all other highway layouts can be derived by removing the parallel lane and block line and one or more regular lanes. This layout has been determined following regulations in the ROA [14]. The 2x1-layout for the secondary road is shown in Figure A.5. This layout is determined following the HWO Stroomwegen [15]. For both layouts the guardrail section is a combination of an inspection area of 0,5 m, a railing of 0,5 m and the guardrail itself measuring 0,6 m.

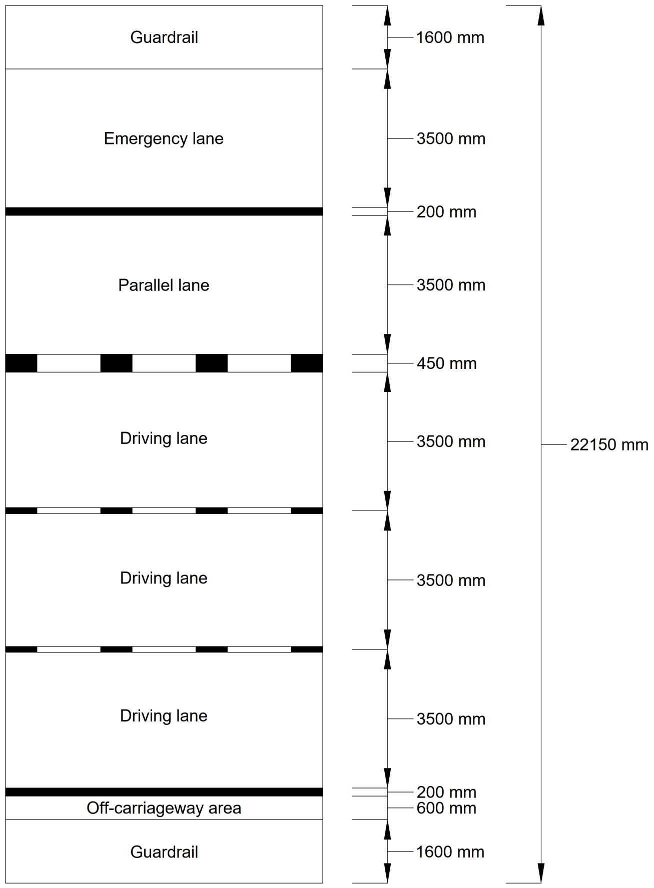


Figure A.4: Highway road: (3+1)x1-layout

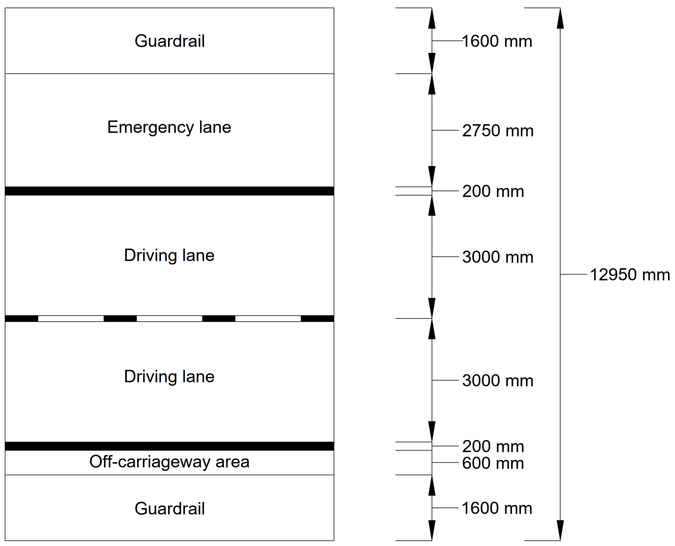


Figure A.5: Secondary road: 2x1-layout

B

Design Alternatives: Verification

This appendix describes the verification of the design alternatives as described in chapter 5.

B.1. Truss

The cross-sectional properties for the Truss alternative are derived from the profiles as described in section 5.3. The steel class is S460.

ULS

For the ULS several checks have been performed for the truss, the crossbeams, the stringers and the deck. Evidently, buckling checks are included. Notably, the bottom chord is always in tension, removing the need for a buckling check.

Self-weight truss	$q_{eg} = 7,2 \text{ kN/m}$
Crossbeam load on truss	$F_{cb} = 708,6 \text{ kN}$
Variable load	*Full LM1*
Design load	$N_{Ed,bot} = 9051 \text{ kN}$
	$N_{Ed,top} = 9954 \text{ kN}$
	$N_{Ed,diag} = 6495 \text{ kN}$
Buckling factor	$\chi = \frac{1}{\phi + \sqrt{\phi^2 - \lambda^2}}$
	$\phi = 0,5 \cdot (1 + \alpha \cdot (\lambda - 0,2) + \lambda^2$
	$\alpha = 0,13$
	$\lambda = \frac{L_{crit}}{i \cdot \lambda_1}$
	$\lambda_1 = \pi \cdot \sqrt{\frac{E}{f_y}}$
	$\chi_{top} = 0,96$
	$\chi_{diag} = 0,93$
Resistance bottom chord	$N_{t,Rd} = \frac{A \cdot f_y}{\gamma_{M0}} = 9936 \text{ kN}$
Resistance top chord	$N_{b,Rd,bot} = \frac{\chi_top \cdot A \cdot f_y}{\gamma_{M1}} = 12068 \text{ kN}$
Resistance diagonal	$N_{b,Rd,diag} = \frac{\chi_diag \cdot A \cdot f_y}{\gamma_{M1}} = 7127 \text{ kN}$
UC_{top}	$\frac{N_{Ed,top}}{N_{t,Rd}} = 0,82$
UC_{bot}	$\frac{N_{Ed,bot}}{N_{b,Rd,bot}} = 0,91$
UC_{diag}	$\frac{N_{Ed,diag}}{N_{b,Rd,diag}} = 0,91$

The truss has been designed without bracing/crossbeams at the top. As a result, a check on the stability of the truss is required. This is done based on a U-frame model.

Buckling factor	$\chi_{op} = \min(\chi_{LT}; \chi_{diag}) = 0,93$
	$\chi_{LT} = 1,0$
Characteristic resistance	$N_{Rk} = A \cdot f_y = 12558$ kN
$UC_{U-frame}$	$\frac{\chi_{op} \cdot N_{Ed,top}}{N_{Rk} \cdot \gamma_{M1}} = 0,85$

The crossbeam has been verified on bending and shear forces.

Self-weight	$q_{eg} = 55,9$ kN/m
Variable load	$q_{k1} = 55,2$ kN/m
	$q_{k2} = 18,7$ kN/m
	$q_{kr} = 13,4$ kN/m
Design load	$M_{Ed} = 10400$ kNm
	$V_{Ed} = 2768$ kN
Moment resistance	$M_{pl,Rd} = \frac{W_{pl} \cdot f_{y,red}}{\gamma_{M0}} = 11300$ kNm
	Reduction in yield strength due to crossbeam thickness exceeding 40 mm
Shear resistance	$V_{pl,Rd} = \frac{A_v \cdot f_y}{\sqrt{3} \cdot \gamma_{M0}} = 9630$ kN
	$A_v = \max(A - 2 \cdot b \cdot t_f + (t_w + 2 \cdot r) \cdot t_f; (h - 2 \cdot t_f - 2 \cdot r) \cdot t_w) = 36257$ mm^2
$UC_{bending}$	$\frac{M_{Ed}}{M_{pl,Rd}} = 0,92$
UC_{shear}	$\frac{V_{Ed}}{V_{pl,Rd}} = 0,29$

The stringers are, similar to the crossbeams, verified for bending and shear forces.

Self-weight	$q_{eg} = 24,5$ kN/m
Variable load	$q_{k1} = 25,9$ kN/m
Design load	$M_{Ed} = 556$ kNm
	$V_{Ed} = 717$ kN
Moment resistance	$M_{pl,Rd} = \frac{W_{pl} \cdot f_y}{\gamma_{M0}} = 6570$ kNm
Shear resistance	$V_{pl,Rd} = \frac{A_v \cdot f_y}{\sqrt{3} \cdot \gamma_{M0}} = 1270$ kN
	$A_v = \max(A - 2 \cdot b \cdot t_f + (t_w + 2 \cdot r) \cdot t_f; (h - 2 \cdot t_f - 2 \cdot r) \cdot t_w) = 4768$ mm^2
$UC_{bending}$	$\frac{M_{Ed}}{M_{pl,Rd}} = 0,85$
UC_{shear}	$\frac{V_{Ed}}{V_{pl,Rd}} = 0,57$

The concrete deck is symmetric, resulting in equal properties for both the top and bottom. The prestressing force is the same for all cross-sections. The reinforcement is continuous over the support and as a result covers the tensile forces. At midspan, since this is the assumed location of the interface between two plates, there is no reinforcement. Theoretically, no reinforcement is required since the deck is prestressed and is designed such that no tension occurs. Still, some practical reinforcement with the dimensions ∅12-170 is included.

The prestressing tendons are composed of six strands, each with an equivalent diameter of 15,2 mm and a cross-sectional area of 140 mm. The tendons are spaced 400 mm apart. The loss in prestress force over time has been accounted for by using a reduced stress in the prestressing strands at $t = \infty$. The assumed stress $\sigma_{p,\infty}$ equals 1080 MPa. As this is an assumption, the result will be slightly conservative.

Self-weight	$M_{eg,sup} = 3,4$ kNm
	$M_{eg,mid} = 1,7$ kNm
Variable load	$M_{var,sup} = 41,7$ kNm
	$M_{var,mid} = 27,5$ kNm
Temperature load	$M_{temp} = 74,2$ kNm
Design load	$M_{sup} = 50,8$ kNm
	$M_{mid} = 29,8$ kNm
Normal stress due to prestress	$\sigma_{cp} = -9,07$ MPa
Normal stress due to bending	$\sigma_{cb,sup} = \pm 7,16$ MPa
Normal stress due to bending	$\sigma_{cb,mid} = \pm 10,44$ MPa
$UC_{bot,sup}$	$\frac{-\sigma_{cb,sup}+\gamma_P \cdot \sigma_{cp}}{f_{cd}} = 0,65$
$UC_{top,mid}$	$\frac{-\sigma_{cb,mid}+\gamma_P \cdot \sigma_{cp}}{f_{cd}} = 0,54$
$UC_{bot,mid}$	$(\sigma_{cb,sup} + \sigma_{cp}) = -1,91 < 0$ MPa

It has been verified whether shear reinforcement is required. For the verification, a cover of 55 mm is used, as explained in section 5.1.

Effective depth	$d = 250 - 55 - 12/2 = 189$ mm
Shear resistance	$V_{Rd,c} = (v_{min} + k_1 \cdot \sigma_{cp}) \cdot b_w \cdot d = 202$ kN
	$v_{min} = 0,035 \cdot k^{3/2} \cdot f_{ck}^{1/2} = 0,66$ MPa
	$k = 1 + \sqrt{\frac{200}{d}} = 2 \leq 2$
	$\sigma_{cp} = 0,2 \cdot f_{cd} = 6$ MPa
	$b_w = 682$ mm
Design load	$V_{Ed} = 190$ kN
UC	$\frac{V_{Ed}}{V_{Rd,c}} = 0,94$

SLS

The deformation of the crossbeam is verified. The crossbeam is assumed to be clamped at both ends. For the variable load an equivalent distributed load has been determined.

Permanent load	$q_{perm} = 55,9$ kN/m
Variable load	$q_{var} = 41,0$ kN/m
Deformation	$w = \frac{1}{384} \cdot \frac{(q_{perm}+q_{var}) \cdot L^4}{EI} = 31,6$ mm
Deformation limit	$w_{lim} = \frac{L}{300} = 77,3$ mm
UC	$\frac{w}{w_{lim}} = 0,41$

As prestressing reinforcement is used, it should be verified whether tensile stresses are present in the SLS. For the midspan location this is not the case, as it is already verified for the ULS that there is no tension. For the support location this is verified.

Permanent load	$q_{perm} = 9,5$ kN/m
Variable load	$q_{k1} = 7,1$ kN/m
	$q_{k2} = 2,4$ kN/m
	$q_{kr} = 1,7$ kN/m
Temperature load	$q_{temp} = 0,37$ kN/mm
Design load	$M_{Ed} = 60,1$ kNm
Normal stress due to prestress	$\sigma_{cp} = -9,07$ MPa
Normal stress due to bending	$\sigma_{cb,sup} = \pm 8,46$ MPa
$UC_{top,sup}$	$\frac{-\sigma_{cb,sup}+\sigma_{cp}}{f_{cd}} = -0,62 < 0$ MPa

FLS

The fatigue load is determined using FLM 4a. Loads are determined for a 602 mm wide strip over which the load spreads (considering an asphalt layer thickness of 141 mm, a spreading angle of 45° and a wheel width of 320 mm). The verification focuses on whether the resistance of the concrete to fatigue is sufficient. This is the case if the inequality below is fulfilled. The verification is performed for the governing moment, which is at the midspan location. As no shear reinforcement is present, a check is also done on the shear forces. As a conservative assumption reinforcement has not been included in the section modulus.

Permanent load	$M_{perm} = 3,0$ kNm
Fatigue load	$M_{fat} = 17,7$ kNm
Section modulus	$W_{c,fat} = \frac{1}{6} \cdot 602 \cdot 250^2 = 6,27 \cdot 10^6$ mm³
Fatigue strength	$f_{cd,fat} = 20,9$ MPa
Stress ratio	$R_{equ} = \frac{E_{cd,min,equ}}{E_{cd,max,equ}} = 0,77$
Maximum compressive stress level	$E_{cd,max,equ} = \frac{\sigma_{cd,max,equ}}{f_{cd,fat}} = 0,59$
Minimum compressive stress level	$E_{cd,min,equ} = \frac{\sigma_{cd,min,equ}}{f_{cd,fat}} = 0,46$
Maximum compressive stress	$\sigma_{cd,max,equ} = -\frac{M_{perm}+M_{fat}}{W_c} + \sigma_{cp} = -12,4$ MPa
Minimum compressive stress	$\sigma_{cd,min,equ} = -\frac{M_{perm}}{W_c} + \sigma_{cp} = -9,6$ MPa
UC	$E_{cd,min,equ} + 0,43\sqrt{1 - R_{equ}} = 0,80 \leq 1$

Permanent load	$V_{perm} = 14,3$ kN
Fatigue load	$V_{fat} = 39,1$ kN
Maximum shear force	$V_{Ed,max} = V_{perm} + V_{fat} = 53,4$ kN
Minimum shear force	$V_{Ed,min} = V_{perm} = 14,3$ kN
Shear resistance	$V_{Rd,c} = 202$ kN
UC	$\frac{\lvert V_{Ed,max}\rvert}{\lvert V_{Rd,c}\rvert} = 0,27 \leq 0,5 - \frac{\lvert V_{Ed,min}\rvert}{\lvert V_{Rd,c}\rvert} = 0,43$

Due to the central placement of the prestressing reinforcement, limited to no stress fluctuations occurs in the tendons. As a result, fatigue is not governing for the prestressing reinforcement.

The steel crossbeam has also been verified on fatigue. For the truss members fatigue is not governing due to the high detail class and favourable loading pattern.

Detail Category 160	$\Delta\sigma_C = 125$ MPa
EN1993-1-9: Table 8.1, DC2 [117]	
Cut-off limit	$\Delta\sigma_L = 44,7$ MPa
Design load	$M_{Ed} = 799$ kN
Design stress	$\Delta\sigma_{Ed} = \frac{M_{Ed} \cdot na_{cmp}}{I_{inf}} = 36,0$ MPa
UC	$\frac{\Delta\sigma_{Ed}}{\Delta\sigma_L} = 0,81$

B.2. Composite

Cross-sectional properties

To determine the cross-sectional properties, the assumption has been made that full composite action exists between the steel and concrete. The steel class used in this alternative is S355. Since fatigue proves to be governing, a higher steel class, as has been used in the Truss alternative, is not possible.

Effective width	$b_{eff} = 2 \cdot \min(L_e/8; b_i) = 2000$ mm
Neutral axis steel cross-section	$na_s = 708$ mm (from bottom)
Neutral axis concrete cross-section	$na_c = 162,5$ mm
Neutral axis composite cross-section	$na_{cmp} = 1906$ mm (from bottom)
Moment of inertia concrete	$I_c = 1,14 \cdot 10^{10}$ mm^4
Moment of inertia steel	$I_s = 3,51 \cdot 10^{10}$ mm^4
Moment of inertia composite	$I_{inf} = 1,54 \cdot 10^{11}$ mm^4
First moment of area steel	$S_s = 2,04 \cdot 10^7$ mm
Beam stiffness	$EI = 3,22 \cdot 10^{16}$ Nmm^2
Section modulus concrete	$W_c = \frac{1}{6} \cdot 682 \cdot 325^2 = 1,20 \cdot 10^7$ mm^3

ULS - Construction stage

The verification of the girder in the construction stage has been performed with the assumption that no contribution exists between the concrete and steel during the construction, i.e., unpropped construction. The loads present at this stage are the self-weight of the steel and concrete.

Self-weight	$q_{eg} = 36,9$ kN/m
Variable load	$q_{var} = 0$ kN/m
Design load	$M_{Ed} = 6621$ kNm
Stress top flange	$\sigma_{s,top} = 296,3$ MPa
Stress bottom flange	$\sigma_{s,bot} = 141,4$ MPa
UC	$\max(\frac{\sigma_{s,i}}{f_y \cdot \gamma_{M0}}) = 0,83$

ULS - Use stage

For the use stage, loads from the construction stage are combined with live loads and the dead load on the structure. The temperature load acts over the height of the cross-section, i.e., as a horizontal load. The stresses in the cross-section are composed of the stresses in the construction phase and additional stresses from, e.g., the variable load. The assumption that self-weight of the steel and concrete is supported by just the steel girder is still valid.

Self-weight on girder	$q_{eg} = 37,1$ kN/m
Dead load	$q_{dl} = 13,0$ kN/m
Variable load	$q_{var} = 34,6$ kN/m
Temperature load	$q_{temp} = \alpha_{T,concrete} \cdot \int_0^h \Delta T_1(x) \cdot E_c = 0,76$ kN/mm
Design load	$M_{Ed} = M_{eg} + M_{var} + M_{temp} = 15677$ kNm
	$V_{Ed} = V_{eg} + V_{var} = 2609$ kN
Normal stress steel top flange	$\sigma_{s,top} = 269,3$ MPa
Normal stress steel bottom flange	$\sigma_{s,bot} = 314,6$ MPa
Normal stress concrete top flange	$\sigma_{c,top} = -8,4$ MPa
Shear stress web	$\tau_{web} = \frac{V_{Ed} \cdot b}{S_s \cdot I_s} = 108,5$ MPa
$UC_{ns,s}$	$\max(\frac{\sigma_{s,i}}{(f_y \cdot \gamma_{M0})}) = 0,89$
$UC_{ns,c}$	$\frac{\sigma_c}{f_{cd}} = 0,28$
$UC_{ss,s}$	$\frac{\sigma_c}{\frac{f_y \cdot \gamma_{M0}}{\sqrt{3}}} = 0,53$

Shear buckling of the web is verified using the same design force as is used for the shear stress.

Reduction factor	$\chi = \frac{1{,}37}{0{,}7+\lambda_w} = 0,50$
	$\lambda_w = \sqrt{\frac{f_{yd}}{k_\tau \cdot \sigma_E \cdot \sqrt{3}}} = 2,03$
	$k_{tau} = 5,36$
	$\sigma_E = 9,3$ MPa
Resistance	$V_{bw,Rd} = \frac{\chi \cdot f_{yd} \cdot h_{web} \cdot t_{web}}{\sqrt{3} \cdot \gamma_{M1}} = 2881$ kN
Shear force	$V_{Ed} = 2609$ kN
UC	$\frac{V_{Ed}}{v_{bw,Rd}} = 0,91$

Transverse buckling of the web is verified assuming a combined load of two wheels (in reality they are 1.2 m apart) acting as one point load on the web.

Reduction factor	$\chi = \frac{0{,}5}{\lambda_F}$
	$\lambda_F = \sqrt{\frac{l_y \cdot t_{web} \cdot f_{yd}}{F_{cr}}} = 0,33$
	$F_{cr} = 0,9 \cdot k_F \cdot E_s \cdot t_{web}^3 \cdot h_{web} = 830$ kN
	$k_F = 3,2$
	$l_y = l_e + \sqrt{m_1 + m_2} \cdot t_{fl,top} = 390$ mm
	$l_e = 93$ mm
	$m_1 = 21,4$
	$m_2 = 200$
Resistance	$F_{Rd} = \frac{\chi \cdot f_{yd} \cdot h_{web} \cdot t_{web}}{\sqrt{3} \cdot \gamma_{M1}} = 634$ kN
Vertical force	$F_{Ed} = \gamma_{q,traffic} \cdot Q_{k,1} = 450$ kN
UC	$\frac{F_{Ed}}{F_{Rd}} = 0,71$

The prestressing tendons are composed of eight strands, each with an equivalent diameter of 15,7 mm and a cross-sectional area of 150 mm. The tendons are spaced 400 mm apart. The loss in prestress force over time has been accounted for by using a reduced stress in the prestressing strands at $t = \infty$. The assumed stress $\sigma_{p,\infty}$ equals 1080 MPa. As this is an assumption, the result will be slightly conservative.

Self-weight	$M_{eg,sup} = 10,3$ kNm
	$M_{eg,mid} = 5,2$ kNm
Variable load	$M_{var,sup} = 76,1$ kNm
	$M_{var,mid} = 61,7$ kNm
Temperature load	$M_{temp} = 28,1$ kNm
Design load	$M_{sup} = 144$ kNm
	$M_{mid} = 115$ kNm
Normal stress due to prestress	$\sigma_{cp} = -10,0$ MPa
Normal stress due to bending	$\sigma_{cb,sup} = \pm 12,0$ MPa
Normal stress due to bending	$\sigma_{cb,mid} = \pm 9,5$ MPa
$UC_{bot,sup}$	$\frac{-\sigma_{cb,sup} + \gamma_P \cdot \sigma_{cp}}{f_{cd}} = 0,81$
$UC_{top,mid}$	$\frac{-\sigma_{cb,mid} + \gamma_P \cdot \sigma_{cp}}{f_{cd}} = 0,72$
$UC_{bot,mid}$	$(\sigma_{cb,sup} + \sigma_{cp}) = -0,24 < 0$ MPa

It has been verified whether shear reinforcement is required.

Effective depth	$d = 325 - 55 - 12/2 = 264$ mm
Shear resistance	$V_{Rd,c} = (v_{min} + k_1 \cdot \sigma_{cp}) \cdot b_w \cdot d = 270$ kN
	$v_{min} = 0,035 \cdot k^{3/2} \cdot f_{ck}^{1/2} = 0,60$ MPa
	$k = 1 + \sqrt{\frac{200}{d}} = 1,87 \leq 2$
	$\sigma_{cp} = 0,2 \cdot f_{cd} = 6$ MPa
	$b_w = 682$ mm
Design load	$V_{Ed} = 256$ kN
UC	$\frac{V_{Ed}}{V_{Rd,c}} = 0,946$

SLS

The deformation of the system is verified for the use stage. For the point load it is assumed that from a tandem load placed above the girder, 88% of the load is supported by that girder.

Permanent load construction phase	$q_{perm,c} = 37,1$ kN/m
Permanent load use phase	$q_{perm,u} = 13,0$ kN/m
Variable load	$q_{var} = 12,6$ kN/m
	$F_{Ed} = 0,88 \cdot Q_{k,1} = 528$ kN
Deformation construction phase	$w_{constr} = \frac{5}{384} \cdot \frac{q_{perm,c} \cdot L^4}{EI} = 68,9$ mm
Deformation use phase	$w_{use} = \frac{5}{384} \cdot \frac{(q_{perm,u} + q_{var}) \cdot L^4}{EI} + \frac{1}{64} \cdot \frac{F_{Ed} \cdot L^3}{EI}$
	$= 31,3$ mm
Deformation limit	$w_{lim} = \frac{L}{300} = 106,7$ mm
UC	$\frac{w_{constr} + w_{use}}{w_{lim}} = 0,94$

It is verified whether tensile stresses are present in the SLS. For the midspan location this is not the case, as it is already verified for the ULS that there is no tension. For the support location this is verified.

Permanent load	$q_{perm} = 7,8$ kN/m
Variable load	$q_{k1} = 7,1$ kN/m
	$q_{k2} = 2,4$ kN/m
	$q_{kr} = 1,7$ kN/m
Temperature load	$q_{temp} = 0,52$ kN/mm
Design load	$M_{Ed} = 117$ kNm
Normal stress due to prestress	$\sigma_{cp} = -10,0$ MPa
Normal stress due to bending	$\sigma_{cb,sup} = \pm 9,7$ MPa
$UC_{top,sup}$	$\frac{-\sigma_{cb,sup} + \sigma_{cp}}{f_{cd}} = -0,24 < 0$ MPa

FLS

The fatigue load is determined using FLM4a. Loads are determined for a 602 mm wide strip over which the load spreads. The verification focuses on whether the resistance of the concrete to fatigue is sufficient. This is the case if the inequality below is fulfilled. The verification is performed for the governing moment, which is at the midspan location. As no shear reinforcement is present, a check is also done on the shear forces.

Permanent load	$M_{perm} = 4,6$ kNm
Fatigue load	$M_{fat} = 24,6$ kNm
Section modulus	$W_{c,fat} = \frac{1}{6} \cdot 602 \cdot 325^2 = 1,06 \cdot 10^7$ mm^3
Fatigue strength	$f_{cd,fat} = 20,9$ MPa
Stress ratio	$R_{equ} = \frac{E_{cd,min,equ}}{E_{cd,max,equ}} = 0,82$
Maximum compressive stress level	$E_{cd,max,equ} = \frac{\sigma_{cd,max,equ}}{f_{cd,fat}} = 0,61$
Minimum compressive stress level	$E_{cd,min,equ} = \frac{\sigma_{cd,min,equ}}{f_{cd,fat}} = 0,50$
Maximum compressive stress	$\sigma_{cd,max,equ} = -\dfrac{M_{perm} + M_{fat}}{W_c} + \sigma_{cp}$
	$= -12,7$ MPa
Minimum compressive stress	$\sigma_{cd,min,equ} = -\frac{M_{perm}}{W_c} + \sigma_{cp} = -10,4$ MPa
UC	$E_{cd,min,equ} + 0,43\sqrt{1 - R_{equ}} = 0,79 \leq 1$

Permanent load	$V_{perm} = 27,4$ kN
Fatigue load	$V_{fat} = 54,6$ kN
Maximum shear force	$V_{Ed,max} = V_{perm} + V_{fat} = 82,0$ kN
Minimum shear force	$V_{Ed,min} = V_{perm} = 27,4$ kN
Shear resistance	$V_{Rd,c} = 238$ kN
UC	$\frac{\lvert V_{Ed,max}\rvert}{\lvert V_{Rd,c}\rvert} = 0,34 \leq 0,5 - \frac{\lvert V_{Ed,min}\rvert}{\lvert V_{Rd,c}\rvert} = 0,39$

The steel girder is verified on fatigue, with the focus on the connection between the bottom flange and the web.

Detail Category 125	$\Delta\sigma_C = 125$ MPa
EN1993-1-9: Table 8.2, DC1/2 [117]	
Cut-off limit	$\Delta\sigma_L = 34,9$ MPa
Design load	$M_{Ed} = 2693$ kN
Design stress	$\Delta\sigma_{Ed} = \frac{M_{Ed} \cdot na_{cmp}}{I_{inf}} = 32,8$ MPa
UC	$\frac{\Delta\sigma_{Ed}}{\Delta\sigma_L} = 0,94$

B.3. Orthotropic

Cross-sectional properties

To determine the cross-sectional properties of the deck, effective widths and buckling effects need to be taken into account. Moreover, a difference exists in the properties for the ULS and SLS. All results follow from the geometry of the overpass and are calculated based on the approach as described in EN-1993-1-5.

For the girder the effects of plate-like and column-like buckling are taken into account. For the calculation of $I_{g,ULS}$ the influence of the deck has been neglected.

ULS	
	$A_c, eff, loc = 91281 \text{ mm}^2$
	$b_{eff,w} = 227 \text{ mm}$
Plate-like behaviour	$\rho = 0,62$
Column-like behaviour	$\chi = 0,86$
	$\xi = 0$
	$\rho_c = (\rho - \chi) \cdot \xi \cdot (2 - \xi) + \chi = 0,86$
	$A_{c,eff} = \rho_c \cdot A_{c,eff,loc} + \Sigma b_{edge,eff} \cdot t$
	$= 82793 \text{ mm}^2$
	$b_{edge,eff} = 125 \text{ mm}$
Effective area	$A_{eff} = A_{c,eff} \cdot \beta^k = 82457 \text{ mm}^2$
	$\beta^k = 0,996$
Neutral axis (bottom)	$na_{g,ULS} = 1517 \text{ mm}$
Moment of inertia	$I_{g,ULS} = 1,27 \cdot 10^{11} \text{ mm}^4$
SLS	
Effective area	$A_{eff} = A_{c,eff} \cdot \beta_1 = 78997 \text{ mm}^2$
	$\beta_1 = 0,954$
Neutral axis (bottom)	$na_{g,SLS} = 1501 \text{ mm}$
Moment of inertia	$I_{g,SLS} = 1,25 \cdot 10^{11} \text{ mm}^4$
First moment of area	$S_g = 5,95 \cdot 10^7 \text{ mm}^3$

For the crossbeam the effective properties have been determined taking into account effective width. The location for which the properties have been determined is at the support.

ULS	
Effective width	$b_{eff} = b_0 \cdot \beta^k = 999 \text{ mm}$
	$b_0 = 2000 \text{ mm}$
	$\beta^k = 0,50$
Neutral axis (bottom)	$na_{CB,ULS} = 232 \text{ mm}$
Moment of inertia	$I_{CB,ULS} = 1,99 \cdot 10^9 \text{ mm}^4$
SLS	
Effective width	$b_{eff} = b_0 \cdot \beta = 593 \text{ mm}$
	$b_0 = 2000 \text{ mm}$
	$\beta = 0,30$
Neutral axis (bottom)	$na_{CB,SLS} = 290 \text{ mm}$
Moment of inertia	$I_{CB,SLS} = 1,58 \cdot 10^9 \text{ mm}^4$
First moment of area	$S_{cb} = 2,38 \cdot 10^6 \text{ mm}^3$

The effective properties of the stiffeners have been determined taking into account the effective width of the stiffener. The dimensions of the stiffeners are such that local buckling effects can be neglected.

Midspan	
	$b_{eff,bf} = 50$ mm
	$b_{eff,deck,in} = 123$ mm
	$b_{eff,deck,out} = 123$ mm
Neutral axis (top)	$na_{stf,mid} = 67$ mm
Moment of inertia	$I_{stf,mid} = 1,42 \cdot 10^8$ mm^4
Support	
	$b_{eff,bf} = 47$ mm
	$b_{eff,deck,in} = 93$ mm
	$b_{eff,deck,out} = 93$ mm
Neutral axis (top)	$na_{stf,sup} = 91$ mm
Moment of inertia	$I_{stf,sup} = 1,33 \cdot 10^8$ mm^4

ULS

The normal stress in the girder and deck in longitudinal direction are determined. For the deck this is due to global and local bending, which cause interaction at a position in between cross-beams and close to midspan of the girder.

Self-weight	$q_{eg} = 34,4$ kN/m
Variable load	$q_{var,gl} = 38,1$ kN/m
	$q_{var,loc} = 5,2$ kN/m
Temperature load	$q_{temp,deck} = 0,74$ kN/mm
	$q_{temp,web} = 8,71$ kN/mm
Design load	$M_{Ed,gl} = 20430$ kNm
	$M_{Ed,loc} = 167$ kNm
Normal stress	$\sigma_{gl,fl} = \frac{M_{Ed,gl} \cdot na_{g,ULS}}{I_{g,ULS}} = 240$ MPa
	$\sigma_{gl,deck} = \frac{M_{Ed,gl} \cdot (h_g - na_{g,ULS})}{I_{g,ULS}} = -115$ MPa
	$\sigma_{loc} = \frac{M_{Ed,loc} \cdot na_{stf}}{I_{stf,ULS}} = -107$ MPa
UC_{flange}	$\frac{\sigma_{gl,fl}}{f_y \cdot \gamma_{M0}} = 0,68$
UC_{deck}	$\frac{\sigma_{gl,deck} + \sigma_{loc}}{f_y \cdot \gamma_{M0}} = 0,63$

Shear buckling of the web is verified for the shear force at the support. The same loads as for the normal force are valid.

Reduction factor	$\chi = \frac{1,37}{0,7 + \lambda_w} = 0,53$
	$\lambda_w = \sqrt{\frac{f_{yd}}{k_\tau \cdot \sigma_E \cdot \sqrt{3}}} = 1,56$
	$k_{tau} = 6,54$
	$\sigma_E = 12,8$ MPa
Resistance	$V_{bw,Rd} = \frac{\chi \cdot f_{yd} \cdot h_{web} \cdot t_{web}}{\sqrt{3} \cdot \gamma_{M1}} = 4289$ kN
Shear force	$V_{Ed} = 2414$ kN
UC	$\frac{V_{Ed}}{v_{bw,Rd}} = 0,56$

Transverse buckling of the web is verified assuming a combined load of two wheels (in reality they are 1.2 m apart) acting as one point load on the web.

Reduction factor	$\chi = \frac{0,5}{\lambda_F} = 0,33$
	$\lambda_F = \sqrt{\frac{l_y \cdot t_{web} \cdot f_{yd}}{F_{cr}}} = 1,49$
	$F_{cr} = 0,9 \cdot k_F \cdot E_s \cdot t_{web}^3 \cdot h_{web} = 1558$ kN
	$k_F = 3,1$
	$l_y = l_e + \sqrt{m_1 + m_2} \cdot t_{fl,top} = 544$ mm
	$l_e = 135$ mm
	$m_1 = 277$
	$m_2 = 375$
Resistance	$F_{Rd} = \frac{\chi \cdot f_{yd} \cdot h_{web} \cdot t_{web}}{\sqrt{3} \cdot \gamma_{M1}} = 1163$ kN
Vertical force	$F_{Ed} = \gamma_{q,traffic} \cdot Q_{k,1} = 450$ kN
UC	$\frac{F_{Ed}}{F_{Rd}} = 0,39$

The crossbeams and stiffeners are verified for normal stresses. For the crossbeam the location at the support of the element is governing; for the stiffener this is the midspan location.

Self-weight	$q_{eg,cb} = 23,4$ kN/m
Variable load	$q_{k1,cb} = 41,2$ kN/m
	$q_{k2,cb} = 14$ kN/m
	$q_{kr,cb} = 10$ kN/m
Design load	$M_{Ed,cb} = 659$ kNm
Normal stress	$\sigma_{cb,fl} = \frac{M_{Ed,cb} \cdot na_{cb,ULS}}{I_{cb,ULS}} = \pm 159$ MPa
UC	$\frac{\sigma_{cb,fl}}{f_y \cdot \gamma_{M0}} = 0,45$

Self-weight	$q_{eg,stf} = 1,1$ kN/m
Variable load	$q_{var,stf} = 5,2$ kN/m
Design load	$M_{Ed,stf} = 167$ kNm
Normal stress	$\sigma_{stf} = \frac{M_{Ed,stf} \cdot na_{stf,ULS,mid}}{I_{stf,ULS,mid}} = \pm 316$ MPa
UC	$\frac{\sigma_{stf}}{f_y \cdot \gamma_{M0}} = 0,89$

SLS

The deformation of the main girder has been verified. For the variable load an equivalent distributed load has been determined.

Permanent load	$q_{perm} = 63,2$ kN/m
Variable load	$q_{var} = 71,3$ kN/m
Deformation	$w = \frac{5}{384} \cdot \frac{(q_{perm} + q_{var}) \cdot L^4}{EI} = 68,4$ mm
Deformation limit	$w_{lim} = \frac{L}{300} = 106,7$ mm
UC	$\frac{w}{w_{lim}} = 0,64$

With regard to the stiffener, its stiffness has been found sufficiently large to match the minimum stiffness required, following Figure B.1.

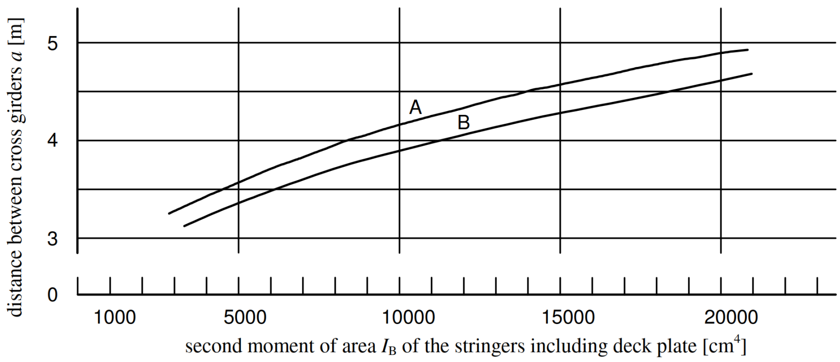


Figure B.1: Graph for minimum stiffness of longitudinal stiffeners [118]

FLS

The steel girder and crossbeam have been verified on fatigue for bending and shear stresses.

Detail Category 125	$\Delta\sigma_C = 125$ MPa
EN1993-1-9: Table 8.2, DC1/2 [117]	
Cut-off limit	$\Delta\sigma_L = 34,9$ MPa
Design load	$M_{Ed,g} = 2816$ kNm
Design stress	$\Delta\sigma_{Ed,g} = \frac{M_{Ed,g} \cdot z}{I_{g,SLS}} = 32,9$ MPa
	$z = na_{g,SLS} - t_{fl,g} = 1461$ mm
$UC_{g,b}$	$\frac{\Delta\sigma_{Ed,g}}{\Delta\sigma_L} = 0,94$

Shear	
Detail Category 100	$\Delta\tau_C = 100$ MPa
EN1993-1-9: Table 8.1, DC6 [117]	
Cut-off limit	$\Delta\tau_L = 31,5$ MPa
Design load	$V_{Ed,g} = 385$ kN
Design stress	$\tau_{Ed,g} = \frac{V_{Ed,g} \cdot S_g}{I_{g,SLS} \cdot t_{g,web}} = 10,2$ MPa
$UC_{g,s}$	$\frac{\tau_{Ed,g}}{\tau_L} = 0,32$

Bending	
Detail Category 125	$\Delta\sigma_C = 125$ MPa
EN1993-1-9: Table 8.2, DC1/2 [117]	
Cut-off limit	$\Delta\sigma_L = 34,9$ MPa
Design load	$M_{Ed,cb} = 106$ kNm
Design stress	$\Delta\sigma_{Ed,cb} = \frac{M_{Ed,cb} \cdot z}{I_{cb,SLS}} = 25,8$ MPa
	$z = na_{cb,SLS} - t_{fl,cb} = 268$ mm
$UC_{cb,b}$	$\frac{\Delta\sigma_{Ed,cb}}{\Delta\sigma_L} = 0,74$

Shear	
Detail Category 100	$\Delta\tau_C = 100$ MPa
EN1993-1-9: Table 8.1, DC6 [117]	
Cut-off limit	$\Delta\tau_L = 31,5$ MPa
Design load	$V_{Ed,cb} = 181$ kN
Design stress	$\tau_{Ed,cb} = \frac{V_{Ed,cb} \cdot S_{cb}}{I_{cb,SLS} \cdot t_{cb,web}} = 27,8$ MPa
$UC_{cb,s}$	$\frac{\tau_{Ed,cb}}{\tau_L} = 0,88$

Apart from the main elements, the welded details present in the orthotropic deck are verified, since these are often governing. With regard to the subscripts listed in the calculations, the element that comes first is the element in which the stress is considered; the second element indicates with which element the connection has been made.
The first detail that has been verified is the connection between the deck and the stiffener. This location is considered for the position between the crossbeams and above the crossbeams. In the deck interaction of stresses occurs: the bending of the crossbeam over the main girders and the bending of the deck over the stiffener both result in a tensile stress. Although there is no stiffener directly at the location of the main girder, the bending moment is, slightly conservatively, taken from that location.

Detail category 125	$\Delta\sigma_C = 125$ MPa
ROK: DC 1a [13]	
Cut-off limit	$\Delta\sigma_L = 44,0$ MPa
Design load crossbeam bending	$M_{cb-stf,cb} = 76,2$ kNm
Design stress crossbeam bending	$\Delta\sigma_{cb-stf,cb} = \frac{M_{cb-stf} \cdot na_{cb,SLS}}{I_{cb,SLS}} = 20,1$ MPa
Design stress stiffener midspan	$\Delta\sigma_{cb-stf,stf,mid} = 21,1$ MPa
$UC_{cb-stf,mid}$	$\frac{\Delta\sigma_{cb-stf,cb} + \Delta\sigma_{cb-stf,stf,mid}}{\Delta\sigma_L} = 0,94$

Detail category 200	$\Delta\sigma_C = 200$ MPa
ROK: DC 1c [13]	
Cut-off limit	$\Delta\sigma_L = 47,0$ MPa
Design stress stiffener support	$\sigma_{cb-stf,stf,sup} = 21,4$ MPa
$UC_{cb-stf,sup}$	$\frac{\Delta\sigma_{cb-stf,cb} + \Delta\sigma_{cb-stf,stf,sup}}{\Delta\sigma_L} = 0,88$

Detail Category 180	$\Delta\sigma_C = 180$ MPa
ROK: DC 2a [13]	
Cut-off limit	$\Delta\sigma_L = 63,3$ MPa
Design stress stiffener	$\Delta\sigma_{stf-cb,stf} = 17,5$ MPa
UC_{stf-cb}	$\frac{\Delta\sigma_{stf-cb,stf}}{\Delta\sigma_L} = 0,28$

Another detail is the weld between the stiffener and the crossbeam.

Detail Category 160	$\Delta\sigma_C = 160$ MPa
ROK: DC 3c [13]	
Cut-off limit	$\Delta\sigma_L = 56,3$ MPa
Design load	$M_{stf-cb} = 22,1$ kNm
Design stress	$\Delta\sigma_{stf-cb} = \frac{M_{stf-cb} \cdot (h_{stf} - na_{stf,cb})}{I_{stf,cb}} = 40,8$ MPa
UC_{stf-cb}	$\frac{\Delta\sigma_{stf-cb}}{\Delta\sigma_L} = 0,72$

The connection between the crossbeam and deck is also verified. For the stress in the deck the load is assumed to come from a wheel load on top of the crossbeam.

Detail Category 100	$\Delta\sigma_C = 100$ MPa
ROK: DC 6a [13]	
Cut-off limit	$\Delta\sigma_L = 35,2$ MPa
Design load	$N_{cb-deck} = 170$ N/mm
Design stress	$\Delta\sigma_{cb-deck} = \frac{N_{cb-deck}}{t_{cb,web}} = 12,2$ MPa
$UC_{cb-deck}$	$\frac{\Delta\sigma_{cb-deck}}{\Delta\sigma_L} = 0,35$

Details that have not been verified are either covered by other verifications or it is assumed that they will not be governing. This includes the welds themselves.

B.4. Guardrail section

As previously explained, guardrail sections are considered as distinct modules. Though most of the dimensions of these modules need to be the same as for the main part of the structure (due to geometrical restraints), a small number of dimensions can be optimised. This is due to the fact that these modules receive less loads. Table B.1 shows the changes that have been made to the main modules to come to the dimensions of the guardrail sections. The dimensions are determined using the same calculations as for the main part of the structure.

Table B.1: Changed dimensions of the guardrail sections

Alternative	**Dimension**	**Original** [mm]	**Changed** [mm]
Truss	$e_{stringer}$	2500	2050
Composite	$h_{girder,web}$	2000	1240
	e_{girder}	4000	3200
	$b_{fl,bot}$	660	400
	$t_{fl,bot}$	38	32
Orthotropic	$h_{girder,web}$	2190	1350
	e_{girder}	5000	3300
	$t_{girder,web}$	18	14
	$b_{girder,fl}$	660	410
	$t_{girder,fl}$	40	30
	e_{stf}	250	200
	$b_{stf,top}$	250	200

C

Environmental Impact Calculations

C.1. Materials and processes - Design alternatives

Tables C.1 to C.3 show the material quantities and the processes that are taken into account to perform the analysis. The majority of the data is retrieved from the NMD [119]. If other sources are used, the source is added.

Table C.1: Materials and processes for environmental impact assessment: Truss

Element	Material	Unit	Value	*Name from NMD*
Deck	Concrete C45/55	m^3	177,4	*Betonmortel voor GWW C35/45 CEM III 2391* kg/m^3 *compleet*
				Category 3 data
	Reinforcement steel	tonne	15,5	*Wapeningsstaal*
				Category 3 data
	Pretensioning steel	tonne	12,2	*Voorspanstaal ligger*
				Category 3 data
Girder	Steel	kg	156666	*Zwaar constructiestaal GWW 7820* kg/m^3*, incl. conservering [120]*
	Zinc primer	m^2	16911	*From EPD: [67]*
Transport	Truck transport	tkm	125568	*Transport met vrachtwagen, EURO 6, diesel*
				Category 3 data

Table C.2: Materials and processes for environmental impact assessment: Composite

Element	Material	Unit	Value	*Name from NMD*
Deck	Concrete C45/55	m^3	229,5	*Betonmortel voor GWW C35/45 CEM III 2391* kg/m^3 *compleet*
				Category 3 data
	Reinforcement steel	tonne	15,4	*Wapeningsstaal*
				Category 3 data
	Pretensioning steel	tonne	17,4	*Voorspanstaal ligger*
				Category 3 data
Girder	Steel	kg	92371	*Zwaar constructiestaal GWW 7820* kg/m^3*, incl. conservering [120]*
	Zinc primer	m^2	14914	*From EPD: [67]*
Transport	Truck transport	tkm	139773	*Transport met vrachtwagen, EURO 6, diesel*
				Category 3 data

Table C.3: Materials and processes for environmental impact assessment: Orthotropic

Element	Material	Unit	Value	*Name from NMD*
Girder + Deck	Steel	kg	253800	*Zwaar constructiestaal GWW 7820 kg/m^3, incl. conservering [120]*
	Zinc primer	m^2	35331	*From EPD: [67]*
Transport	Truck transport	tkm	50760	*Transport met vrachtwagen, EURO 6, diesel*
				Category 3 data

C.2. Conversion factors

The data not directly retrieved from the NMD is in part reported in different equivalent units. In order to be able to perform calculations with these data, the values need to be converted into the corresponding unit. Table C.4 shows the categories for which conversion is required, along with the conversion factor.

Table C.4: Unit conversion factors environmental impact categories

Category	Old unit-eq	New unit-eq	Conversion factor	Source
POCP	kg NMVOC	kg NO_x	5,56	[121]
	kg NO_x	kg C_2H_4	0,36	[121]
AP	mol H^+	kg NH_3	0,33	[122]
	kg NH_3	kg SO_2	1,88	[122]
ADPF	MJ	kg Sb	4,81E-04	[123]
EP-freshwater	kg P	kg PO_4	3,06	[124]
EP-terrestrial	mole N	g N	14,007	*Molar mass*
EP-m/EP-t	g N	kg PO_4	4,2E-04	[124]
HTTP-c	CTUh	kg 1,4-DCB*	3,27E+06	[125]
HTTP-nc	CTUh	kg 1,4-DCB*	1,10E+07	[125]
FAETP	CTUe	kg 1,4-DCB*	1,02E-03	[125]

**DCB stands for dichlorobenzene*

The monetisation factors applied for conversion of the impact into a monetary value are listed in Table C.5. The monetisation factor itself is listed for each impact category, as is the unit that this category uses.

Table C.5: Monetisation factors environmental impact categories [123]

Category	Unit-eq	Monetisation factor [€/kg]
GWP	kg CO_2	0,05
ODP	kg CFC-11*	30
AP	kg SO_2	4
EP	kg PO_4	9
POCP	kg C_2H_4	2
ADPE	kg Sb	0,16
ADPF	kg Sb	0,16
HTTP	kg 1,4-DCB*	0,09
FAETP	kg 1,4-DCB*	0,03

**CFC stands for chlorofluorocarbon*

**DCB stands for dichlorobenzene*

C.3. Materials and processes - Reference overpasses

Table C.6 and C.7 show the mass of the reference overpasses for all materials.

Table C.6: Mass [kg] for concrete reference overpasses [111]

Material	**STVI**	**CIVI**
Concrete (C60/75)	181830	266552
Reinforcement	12375	22540
Prestressing	9060	9108

Table C.7: Mass [kg] for composite reference overpass [110]

Material	**Mass** [kg]
Concrete (C40/50)	500500
Reinforcement	53768
Girders	96105
Bracing	4423
Bolts	150
Splice plates	1023
Shear studs	1246

To calculate the ECI the environmental impact data of the different materials needs to be known. Table C.8 lists the material data along with the source of the data.

Table C.8: Materials and processes for environmental impact assessment: Reference overpasses

Material	**Unit**	*Name from NMD*
Concrete C60/75*	m^3	*Betonmortel voor GWW C55/67 CEM III/A*
Concrete C40/50*	m^3	*Betonmortel voor GWW C35/45 CEM III 2391* kg/m^3 *compleet*
		Category 3 data
Reinforcement steel	tonne	*Wapeningsstaal*
		Category 3 data
Pretensioning steel	tonne	*Voorspanstaal ligger*
		Category 3 data
Steel	kg	*Zwaar constructiestaal GWW 7820* kg/m^3*, incl. conservering [120]*
Zinc primer	m^2	*From EPD: [67]*

* *The exact concrete class was not found in the NMD. The closest available class is used.*

C.4. Sustainability comparison approach

With the materials and environmental impact data from the previous section, it is possible to perform the calculations for the scenarios from section 9.3. The calculation of the ECI itself is the same as previously explained, how the ECI values are used to make the ECI-over-time plots is what is explained in this section.

General approach

In principle, the approach is nearly the same for all of the different overpasses. At time=0, the impact of the production and construction (module A) is applied. Then, at the end of the functional life of the overpass, modules C and D are applied, which describe the disassembly process and potential benefits beyond the system boundaries. In case the reference period is longer than the functional life, this cycle is repeated. In situations where parts of a structure are removed, on these parts modules C and D are also applied. For overpasses which feature steel components, the impact of one maintenance cycle is added every 15 years.

Scenario 0

For scenario 0, the general approach is followed. For the Concrete overpass one full replacement is applied after 100 years, whilst the Circular viaduct and IFD overpass feature one cycle. The Composite overpass also features a replacement cycle, yet the impact of the second structure is reduced to 2/3 (80/120 years) of the initial impact, to compensate for the fact that the structure can be designed for a shorter design life.

Scenario 1

Scenario 1 starts with the general approach. Then, after 40 years one lane is added to all the structures. The minimum lane width required for the addition of one lane is 3,5 m. Figures C.1 and C.2 show graphically which changes are required to the original overpasses in order to add a lane. The red elements indicate elements that are removed and demolished, green elements are elements that are added to the structure and blue elements are elements that are removed yet suitable for reuse. The exact approach is explained for each overpass separately:

- Concrete overpass: assuming an average beam width of 1,25 m, first an edge beam is removed. Then, three beams and a new edge beam are added in cycle 1. For cycle 2, again three beams and an edge beam are added.
- Circular viaduct: first, the prestressing reinforcement in transverse direction is removed (43% of the total), assuming no reuse. Since the modules of the Circular viaduct are 1,5 m in width, three modules are added and new prestressing reinforcement is installed. For cycle 2 this is repeated, yet with only two modules.

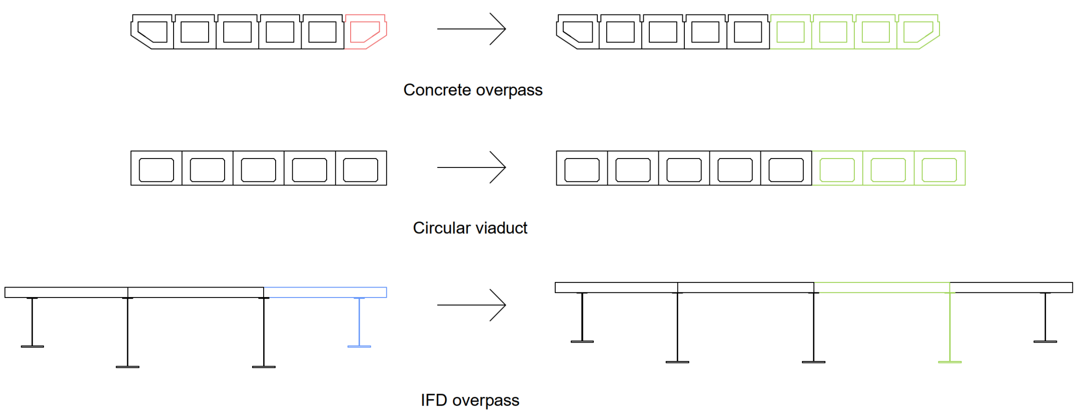


Figure C.1: Scenario 1: Changes to overpasses of concrete comparison

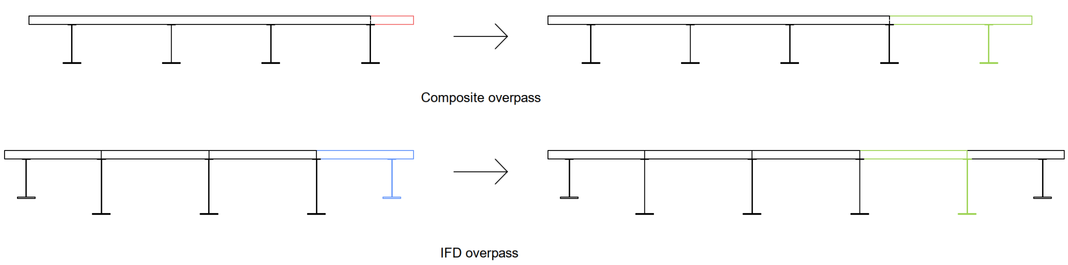


Figure C.2: Scenario 1: Changes to overpasses of composite comparison

- IFD overpass: the prestressing reinforcement and the edge beam are at first removed. The edge beam removal (or disassembly) is accounted for using the assembly costs of the edge beam, i.e., the costs from modules A4-5. Secondly, one module of 4 m is added, along with the edge beam and the application of new prestressing reinforcement. There is no need for additional modules for a second extension, so no additional impact is reported. Maintenance is assumed to be applied during the replacement to ensure that all elements receive maintenance at the same time, having the effect that a new maintenance cycle is needed 15 years after the replacement. In Figure C.1 there is also a line indicating the IFD overpass with a second extension. For this situation the process of the first extension is followed.
- Composite overpass: since the conventional steel-composite overpass features no edge beam, only a part of the concrete deck needs to be removed to allow for the addition of girders. It is assumed that 1,5 m of deck need to be removed. Next, one girder is added along with 5,2 m of concrete deck (3,7 m spacing between girders + 1,5 m edge). This is repeated for replacement cycle 2. Maintenance is assumed to be applied during the replacement. A new maintenance cycle is then needed 15 years after the replacement.

Scenario 2

Like scenario 1, scenario 2 features a layout change after 40 and 80 years. The reason for this change is assumed to be the addition of a lane beneath the overpass, resulting in the need to extend the overpass itself by a minimum of 3,5 m. The change is applied at the same end of the overpass both times. Figures C.3 and C.4 illustrate the changes graphically.

- Concrete overpass: for it is not possible to extend the conventional beam overpass, it is completely removed and replaced by a new overpass that is 3,5 m longer for each cycle.
- Circular viaduct: To start, the longitudinal prestressing reinforcement (57% of total) and the end module are removed. Then, two modules of 2,5 m in length are added, along with the previously used end module and new prestressing reinforcement. For cycle 2 this is repeated, yet with the addition of just 1 module.
- IFD overpass (concrete overpass comparison): the layout of the IFD overpass can be adjusted simply by the addition of one module of 6,6 m. For the second cycle, the best solution in terms of ECI is the removal of this 6,6 m module and the addition of a third 10,8 m module. For the 10,8 m module full costs are applied. Since the 6,6 m module is still available for use elsewhere, the cost of this module is accounted for by adjusting its impact to its use period. This means that upon disassembly, next to disassembly costs, 80% (40 years out of 200 years) of the initial impact is applied as a discount, resulting in a reduction of the ECI. Maintenance is assumed to be applied during the replacement, having the effect that a new maintenance cycle is needed 15 years after the replacement.
- Composite overpass: the original design of the composite overpass consists of three girder segments. Hence, it is assumed that it is possible to remove one of these segments and replace it with a longer segment. This is what is done twice, by extending the segment by 3,5 m. Maintenance on the remaining structure is assumed to be applied during the replacement, having the effect that a new maintenance cycle is needed 15 years after the replacement.
- IFD overpass (composite overpass comparison): for the first cycle it is more advantageous to remove the 6,6 m module and replace it by a 10,8 m module. For the second cycle it is sufficient to add a 6,6 m module. In terms of the impact of these changes, the same approach is used as for the IFD overpass in the concrete overpass comparison.

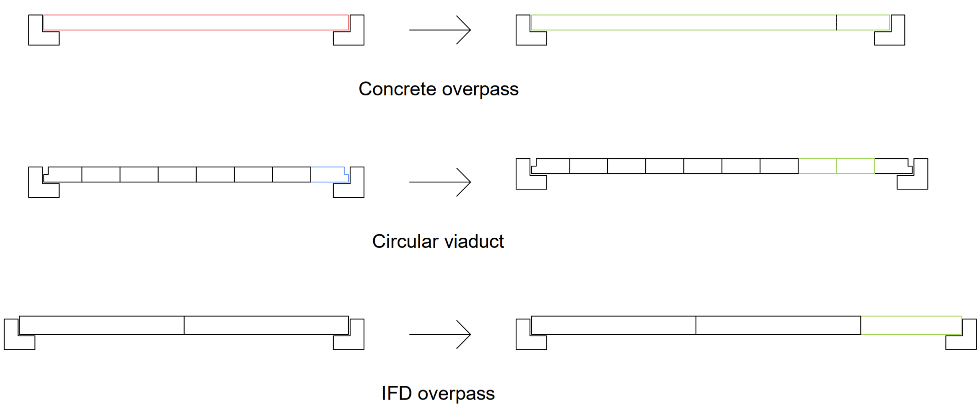


Figure C.3: Scenario 2: Changes to overpasses of concrete comparison

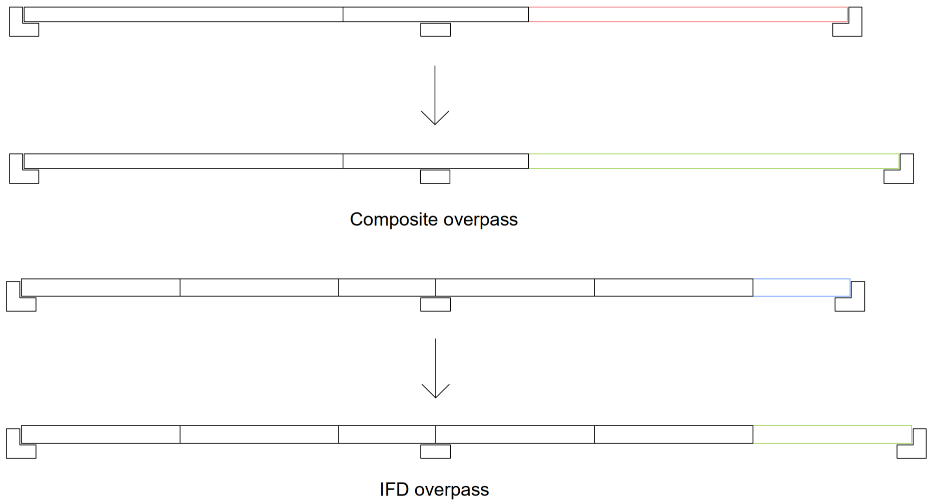


Figure C.4: Scenario 2: Changes to overpasses of composite comparison

Scenario 3
Scenario 3 again starts with the general approach. After 80 and 160 years the structure is needed at a different location. If possible, the old superstructure is relocated. If not, the old superstructure is removed and a new one is constructed, with an impact that is equivalent to 50% of the original structure.

- Concrete overpass: since the structure is not demountable, it is removed and replaced by an overpass with 50% lower impact. The impact of the third overpass (after 160 years) is reduced by 75% because it also has half the design life.
- Circular viaduct: one relocation of the overpass is accounted for by applying twice the impact from modules A4-5 for the full structure, thus simulating disassembly and reassembly of the overpass.
- IFD overpass: the same approach as for the Circular viaduct is used.
- Composite overpass: the approach for the Composite overpass is the same as for the Concrete overpass, with the exception that the impact of the third overpass is reduced by 83%, as the original design life of the Composite overpass is 120 years.

D

MCA Calculations

This appendix describes the calculation of the input for the MCA score calculations. The results of these calculations form the direct input of Table 6.3.
As explained in section 6.2.2, the MCA has been performed for a module size of 4 m and 12 m. It is acknowledged that not all dimensions are divisible by these numbers. In that case, the number is rounded up. In case it is required for a structure to be divided into modules, the module dimensions are based on the regularity in the layout.

Number of different components
Table D.1 shows the number of different components for each alternative.

Table D.1: Values Number of different components

	Truss	Composite	Orthotropic
Nr. of different components	5	2	1

Truss
For the Truss alternative the following components can be distinguished: top chords, bottom chords, diagonals, crossbeams and stringer-deck modules. The stringers and deck are considered as one module, as this reduces the number of components and connections.

Composite
The Composite alternative consists of two different components: the girders and the deck plates.

Orthotropic
The Orthotropic alternative has only one component.

Number of components
Table D.2 lists the total number of components for each of the alternatives.

Table D.2: Values Number of components

	Truss	Composite	Orthotropic
Nr. of components	104	112	48
	175	42	18

Truss
The number of components of the truss itself is assumed to be determined by the nodes: each element spans between the nodes. This means the 32 m long bottom chord of the truss consists of 6 5,335 m segments. The top chord is 28 m long and has 5 segments. There are total of 12 diagonals. With two trusses at each side, this means all values need to be multiplied by 2. With regard to the crossbeams, there are 7 of them in the 32 m span, having a spacing of 5,335 m. For the width of 23,2 m, a total of either 7 or 4 segments is required (2 separate segments are included for the guardrail sections). The stringer-deck modules are 2,5 x 4 or 12 m, where 2,5 is the spacing between individual stringer. The width is smaller

than 4 or 12 m, as this ensures a one-size module. This means that for the width 10 modules are required, resulting in a total of 80 and 30 modules respectively. The total number of modules is then 104 and 175 respectively.

Composite
The Composite alternative essentially consists of 4 x 4 or 4 x 12 m modules, composed of a separated girder and deck section. For the 4 m segment width this translates into 5 sections for the 20 m width plus two for the guardrail sections. For a length of 32 m and a width of 23,2 m in total 112 or 42 of these modules are required respectively (including separate sections for the guardrail).

Orthotropic
The components of the Orthotropic alternative are 5 x 4 or 5 x 12 m modules, composed of a separated girder and deck section. With a width of 5 m, the number of modules is 6 (2 guardrail sections). For a length of 32 m 48 and 18 of these modules are required for respectively 4 m and 12 m.

Number of connections
Table D.3 shows the number of connections for each alternative.

Table D.3: Values Number of connections

	Module size [m]	**Truss**	**Composite**	**Orthotropic**
Nr. of connections	4	232	577	754
	12	161	542	244

Truss
All points where truss members align require a connection. For two trusses, this amounts to 26 connections. With 7 crossbeams that are divided into 7 or 4 segments, a total of 8 or 5 connections per crossbeam are required, since they are connected to the truss at their ends. A total of 10 stringers are present. Each stringer requires 7 or 2 connections. The prestressing reinforcement for this alternative is spaced at 400 mm, resulting in a total of 80 tendons. In total, this combines to 232 and 161 connections for 4 m and 12 m respectively.

Composite
A total of 7 girders, each requiring 7 or 2 connections between the segments, results in 49 or 14 connections. The connection between the deck and the girder is done with shear connectors, which are assumed to be spaced at 500 mm. Each m thus has 2 connectors. For each girder this means 64 connections with the deck. The prestressing reinforcement forms the connection in the transverse direction. With a spacing of 400 mm, a total of 80 tendons is required. This combines to a total of 577 or 542 connections for 4 m and 12 m segments respectively.

Orthotropic
There are 6 girders each requiring 7 or 2 connections, for 4 m segments and 12 m segments respectively. A total of 8 crossbeams, spaced at 4 m, is present. The number of connections per crossbeam is 5, resulting in 40 connections in total. Every meter of deck features 2 stiffeners, which are all assumed to require two connections (at both webs of the stiffener). There are a total of 40 plus 8 (guardrail sections) is 48 stiffeners. They are divided like the girders, hence coming to a total of 772 or 192 connections for the stiffeners. This combines to a total of 754 or 244 connections respectively.

Ease of changing overpass layout
Table D.4 lists the qualitative scores for the category of Ease of changing overpass layout.

Table D.4: Values Ease of changing overpass layout

	Truss	**Composite**	**Orthotropic**
Ease of changing overpass layout	0	1	2

Truss
In order to add additional lanes, it is necessary to remove one truss before the crossbeam can be extended. It is evident that this impacts the main structure, resulting in a score of zero.

Composite
To add additional lanes, it is required to remove the guardrail section, which in turn requires de-stressing of the prestressing reinforcement. Still, as this can be done in segments, it will not impact the main structure: a score of one is assigned.

Orthotropic
The addition of a lane for this alternative only requires the removal of the guardrail section, which is why a score of two is assigned.

Mass of components
Table D.5 lists the average mass of the components for all the alternatives.

Table D.5: Values Mass of components

	Module size [m]	**Truss**	**Composite**	**Orthotropic**
Mass of components [kg]	4	3588	6240	5288
	12	6037	16640	14100

Truss
The mass of components is calculated as the averaged weight of all components. Table D.6 shows the mass of the individual components. In the deck prestressing reinforcement and regular reinforcement are included. When multiplied with the total length or area of these components the total mass is acquired. The average mass is then the total mass divided by the total number of components. The average mass amounts to 3473 and 5844 kg for 4 m and 12 m segments respectively.

Table D.6: Mass of components: Truss

	Mass	**Unit**
Truss top chord	214	kg/m
Truss bottom chord	170	kg/m
Truss diagonal	130	kg/m
Crossbeam	576	kg/m
Stringer	76	kg/m
Deck	597	kg/m^2

Composite
The mass of the regular components is reported in Table D.7. For the guardrail, the values are shown in Table D.8. In the deck prestressing reinforcement and regular reinforcement are included. The average mass is calculated to be 6035 and 16093 kg.

Table D.7: Mass of components: Composite

	Mass	**Unit**
Girder	464	kg/m
Deck	813	kg/m

Table D.8: Mass of components: Composite (guardrail)

	Mass	**Unit**
Girder	284	kg/m
Deck	813	kg/m

Orthotropic
The Orthotropic alternative consists of only one component, meaning that the average mass is derived from the mass of this component. For the regular section the mass of one section of width 5 m and 4 m length is 6657 kg and for the guardrail section, with width 1,6 m, it is 2549 kg per 4 m length. Combined, this results in an average mass of 5288 or 14100 kg for 4 m and 12 m segments respectively.

Independence - Parallel assembly
Table D.9 lists the qualitative scores for the category of Independence - Parallel assembly.

Table D.9: Values Independence - Parallel assembly

	Truss	Composite	Orthotropic
Independence - Parallel assembly	1	2	2

Truss
A number of components can be assembled in parallel, crossbeams for instance, but there still exists an interdependency between trusses and crossbeams, leading to a score of one.

Composite
Parallel assembly is possible for the Composite alternative, as each girder, along with the deck on top, can be assembled independently. The girders can then be combined to form the full structure. A score of two is awarded.

Orthotropic
Since the orthotropic deck has identical sections, it is evident that it can be assembled in parallel. Hence, a score of two is applied.

Ease of replacement
Table D.10 shows the qualitative scores for the category of Ease of replacement.

Table D.10: Values Ease of replacement

	Truss	Composite	Orthotropic
Ease of replacement	0	1	0

Truss
In order to replace a deck plate or a stringer, the prestressing reinforcement needs to be temporarily removed. As the truss will most likely block some of the anchorage points of the prestressing tendons, the truss itself needs to be removed as well, which has a significant impact on the structure. Therefore, a score of zero is awarded.

Composite
The replacement of a deck plate for this alternative requires the removal of the prestressing reinforcement. However, as the girders and the deck are separated, the girders are unaffected and the main structure remains intact. This means that a score of one is awarded.

Orthotropic
All components of the Orthotropic alternative, including the deck, are part of the main structure. Evidently, the main structure is impacted in case of replacement, resulting in a score of 0.

Maintenance
Table D.11 lists the total area of maintenance for each of the three alternatives.

Table D.11: Values Maintenance

	Truss	Composite	Orthotropic
Maintenance [m^2]	16911	14914	35331

Truss
Maintenance is calculated by multiplying the total area to be maintained by the number of times the maintenance takes place. Table D.12 shows the data for the calculation of the area. The perimeter and the total length of the members are multiplied to determine the total area. For the crossbeam and the stringer the top of the top flange is excluded from the perimeter, as this is covered by the deck. The interval for maintenance is assumed to be 15 years, meaning that in 200 years a total of 13 times maintenance is required. Multiplying this by the area results in a total of 16911 m^2 of area to be maintained.

Composite
The perimeter of the main girder, minus the top of top flange, is 5,708 m. For the guardrail girder this is 3,656 m. With a

Table D.12: Maintenance area: Truss

	Perimeter [m]	**Total length** [m]	**Area** [m^2]
Truss top chord	1,8	53,3	95,9
Truss bottom chord	1,8	64	115,1
Truss diagonal	1,4	127,6	178,6
Crossbeam	3,14	162,4	509,6
Stringer	1,26	320	401,6
Total			1301

maintenance interval of 15 years and a total of 160 m of main girder and 64 m of guardrail girder, the total area amounts to 14914 m^2.

Orthotropic
Table D.13 shows the area of the members of the Orthotropic alternative, divided into the three major parts of the structure. With 13 maintenance periods, the total to be maintained area is 34910 m^2.

Table D.13: Maintenance area: Orthotropic

	Perimeter [m]	**Total length** [m]	**Area** [m^2]
Deck + Stiffeners	43,88	32	1404
Main girder	5,80	128	743
Main girder (guardrail)	3,57	64	228
Crossbeam	1,85	185,6	343
Total			2718

E
Model Validation

This appendix describes the validation of the SCIA model as described in section 8.1. The validation focuses on situations with a full and a partial shear connection between the steel and concrete.

E.1. Full shear connection

A full shear connection means that all forces between the steel and concrete can be transferred. It is validated if the model is an accurate representation of a structure with full composite action and whether the way in which the shear connectors are modelled impacts the outcome.

In the model, this is simulated by assuming a near-infinite stiffness for the springs. The transversal joints have also been modified to simulate a rigid connection. As it was the assumption for the calculations done for the design alternative Composite that there was full composite action, the calculations listed in appendix B can be used for the validation. The validation has been performed for a distributed load of 10 kN/m, equivalent to a surface load of 2,5 kN/m^2. All dimensions are the same as for the Composite alternative.

Table E.1 shows the values computed for both the model and the hand calculations. There appears to be a trend in that the model yields slightly higher values than the hand calculations do, though the difference is consistently small.

Table E.1: Validation full shear connection

	Unit	**Model**	**Hand calculations**
$\sigma_{s,bot}$	[MPa]	16,1	15,9
$\sigma_{s,top}$	[MPa]	-1,5	-1,3
$\sigma_{c,top}$	[MPa]	-0,8	-0,7
w_{use}	[mm]	4,6	4,2

E.2. Partial shear connection

Partial shear interaction describes a situation where not all forces are transferred from the concrete to the steel. This is the case for the proposed design. Validation is performed using an elastic analysis, which is the case for the SLS situation discussed in section 8.2.1.

The model is validated using a differential equation that describes a composite beam with elastic interaction. The differential equation is shown in equation E.1 and E.2, along with the five equalities required to solve the equation. Figure E.1 shows schematically the reasoning behind these equations.

$$\frac{d^6 w}{dx^6} - \alpha^2 \frac{d^4 w}{dx^4} = -\frac{\alpha^2}{EI_\infty} q \tag{E.1}$$

$$\alpha^2 = K \left(\frac{1}{E_1 A_1} + \frac{1}{E_2 A_2} + \frac{r^2}{EI_0} \right) \tag{E.2}$$

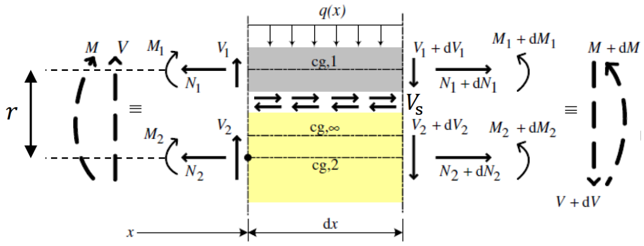


Figure E.1: Explanation of parameters in differential equation [126]

$$\frac{dV}{dx} = -q$$
$$N_1 + N_2 = 0$$
$$M = M_1 + M_2 - N_1 \cdot r$$
$$V = \frac{dM}{dx}$$
$$V_s = K \cdot s = -\frac{dN_1}{dx} = \frac{dN_2}{dx}$$

The validation is done with the same assumptions as for full shear interaction. For the model, one isolated beam is considered, as this is most comparable to the situation the differential equation describes. In terms of input, a spacing of 500 mm between the connectors and a stiffness of the shear connectors of 80 kN/mm is used.

Figures E.2 and E.3 show the deformation of the beam for the model and the differential equation. As expected, both have symmetric deformation. It is also evident that with a deformation of 5,9 and 6,0 mm respectively, the results are similar.

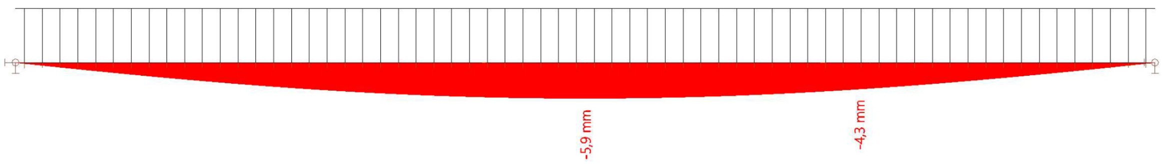


Figure E.2: Girder deformation from SCIA model

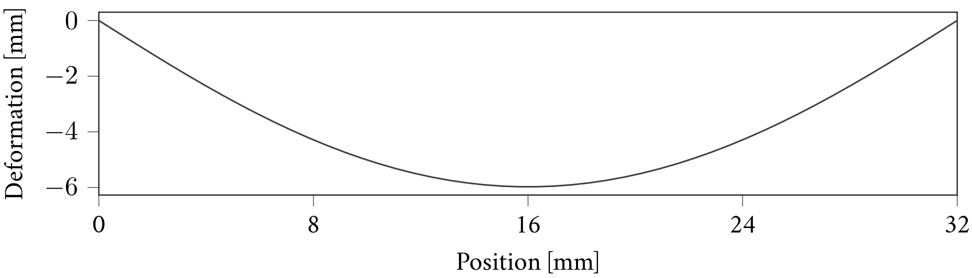


Figure E.3: Girder deformation from differential equation

Figure E.4 shows the shear forces for the sets of two connectors at the same position along the beam, i.e., the sum of the forces in the individual connectors. Figure E.5 shows the shear force distribution from the differential equation. It can be seen that the shear forces follow the pattern that is expected from the shear force distribution. In terms of magnitude, the model yields a force of 32,58 kN in the first connector from the support. When integrating the differential equation over the interval 0-0,5 m (from the support), the shear force that would be taken by the first connector is calculated, which is equal to 30,12 kN.

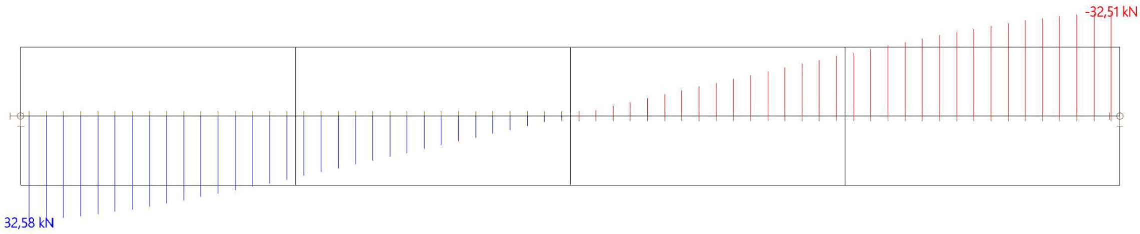


Figure E.4: Shear force per set of connectors from SCIA model

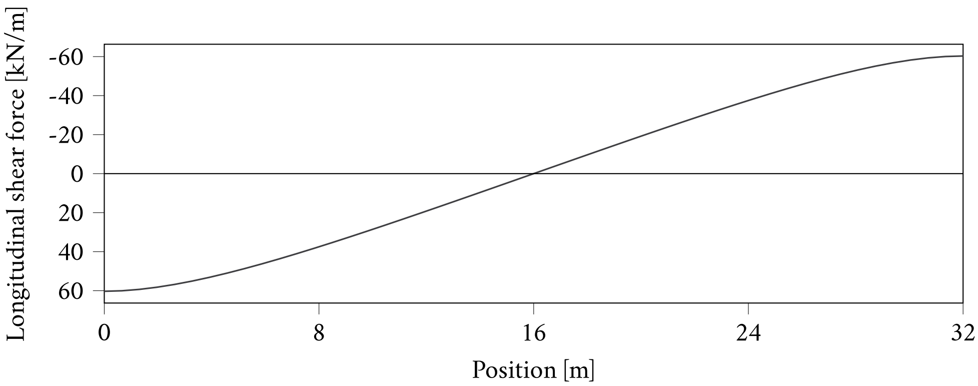


Figure E.5: Longitudinal shear force distribution from differential equation

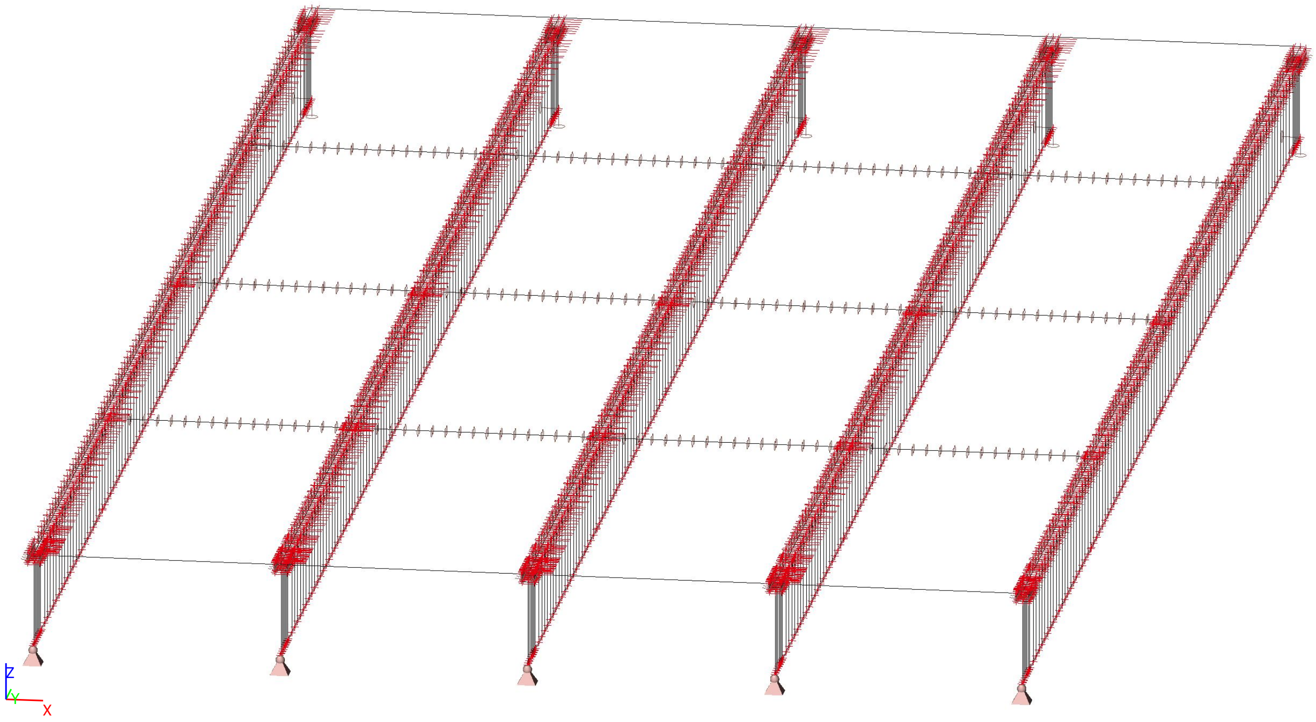
F

Calculation Report - System Model

1. Table of contents

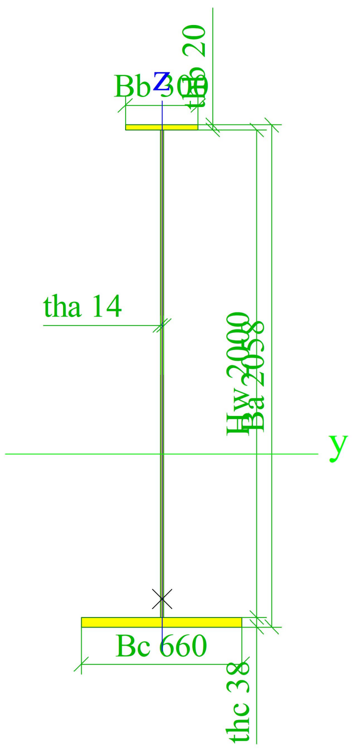
2. Geometry

2.1. Overview



2.2. Cross-sections

CS3		
Type	Iwn	
Detailed	2058; 14; 300; 20; 660; 38; 2000; 8	
Formcode	101 - Asymmetric I section	
Shape type	Thin-walled	
Item material	S 355	
Fabrication	welded	
Colour		
Flexural buckling y-y, Flexural buckling z-z	b	c
A [m^2]	5,9080e-02	
A_y [m^2], A_z [m^2]	3,0532e-02	2,8671e-02
A_L [m^2/m], A_D [m^2/m]	6,0080e+00	6,0080e+00
$c_{Y.UCS}$ [mm], $c_{Z.UCS}$ [mm]	330	708
α [deg]	0,00	
I_y [m^4], I_z [m^4]	3,5065e-02	9,5586e-04
i_y [mm], i_z [mm]	770	127
$W_{el.y}$ [m^3], $W_{el.z}$ [m^3]	2,5974e-02	2,8965e-03
$W_{pl.y}$ [m^3], $W_{pl.z}$ [m^3]	3,9116e-02	4,6862e-03
$M_{pl.y.+}$ [Nm], $M_{pl.y.-}$ [Nm]	13886070,46	13886070,46
$M_{pl.z.+}$ [Nm], $M_{pl.z.-}$ [Nm]	1663601,00	1663601,00
d_y [mm], d_z [mm]	0	-594
I_t [m^4], I_w [m^6]	1,4728e-05	1,7653e-04
$β_y$ [mm], $β_z$ [mm]	1641	0

Picture	
	

Explanations of symbols	
Formcode	h - Height s - Web thickness bt - Flange width top bb - Flange width bottom tt - Flange thickness top tb - Flange thickness bottom r - Radius at flange root
A	Area
A_y	Shear Area in principal y-direction
A_z	Shear Area in principal z-direction
A_L	Circumference per unit length
A_D	Drying surface per unit length
$c_{Y.UCS}$	Centroid coordinate in Y-direction of Input axis system
$c_{Z.UCS}$	Centroid coordinate in Z-direction of Input axis system
$I_{Y.LCS}$	Second moment of area about the YLCS axis
$I_{Z.LCS}$	Second moment of area about the ZLCS axis
$I_{YZ.LCS}$	Product moment of area in the LCS system
α	Rotation angle of the principal axis system
I_y	Second moment of area about the principal y-axis
I_z	Second moment of area about the principal z-axis
i_y	Radius of gyration about the principal y-axis

Explanations of symbols	
i_z	Radius of gyration about the principal z-axis
$W_{el.y}$	Elastic section modulus about the principal y-axis
$W_{el.z}$	Elastic section modulus about the principal z-axis
$W_{pl.y}$	Plastic section modulus about the principal y-axis
$W_{pl.z}$	Plastic section modulus about the principal z-axis
$M_{pl.y.+}$	Plastic moment about the principal y-axis for a positive My moment
$M_{pl.y.-}$	Plastic moment about the principal y-axis for a negative My moment
$M_{pl.z.+}$	Plastic moment about the principal z-axis for a positive Mz moment
$M_{pl.z.-}$	Plastic moment about the principal z-axis for a negative Mz moment
d_y	Shear center coordinate in principal y-direction measured from the centroid
d_z	Shear center coordinate in principal z-direction measured from the centroid
I_t	Torsional constant
I_w	Warping constant
$β_y$	Mono-symmetry constant about the principal y-axis
$β_z$	Mono-symmetry constant about the principal z-axis

2.3. Nodes

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N539	2,000	1,250	1,512
N567	2,000	8,250	1,512
N597	2,000	15,750	1,512
N662	-2,000	0,000	1,512
N663	2,000	0,000	1,512
N664	2,000	8,000	1,512
N665	-2,000	8,000	1,512
N666	2,000	16,000	1,512
N667	-2,000	16,000	1,512
N668	2,000	24,000	1,512
N669	-2,000	24,000	1,512
N670	2,000	32,000	1,512

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N671	-2,000	32,000	1,512
N740	6,000	1,250	1,512
N768	6,000	8,250	1,512
N798	6,000	15,750	1,512
N863	6,000	0,000	1,512
N864	6,000	8,000	1,512
N865	6,000	16,000	1,512
N866	6,000	24,000	1,512
N867	6,000	32,000	1,512
N936	10,000	1,250	1,512
N964	10,000	8,250	1,512
N994	10,000	15,750	1,512
N1059	10,000	0,000	1,512
N1060	10,000	8,000	1,512
N1061	10,000	16,000	1,512
N1062	10,000	24,000	1,512
N1063	10,000	32,000	1,512
N1081	14,000	9,250	0,000
N1114	14,000	25,750	0,000
N1255	14,000	0,000	1,512
N1256	14,000	8,000	1,512
N1257	14,000	16,000	1,512
N1258	14,000	24,000	1,512
N1259	14,000	32,000	1,512
N1389	-2,000	1,250	1,512
N1403	-2,000	8,250	1,512
N1418	-2,000	15,750	1,512
N1472	13,900	1,330	1,512
N1548	13,900	8,250	1,512
N1622	13,900	15,750	1,512
N1660	10,000	9,250	0,000
N1693	10,000	25,750	0,000
N1900	10,100	1,330	1,512
N1914	10,100	8,250	1,512
N1929	10,100	15,750	1,512
N1964	9,900	1,330	1,512
N1978	9,900	8,250	1,512
N2015	9,900	15,750	1,512
N2043	6,000	9,250	0,000
N2076	6,000	25,750	0,000
N2283	6,100	1,330	1,512
N2297	6,100	8,250	1,512
N2312	6,100	15,750	1,512
N2347	5,900	1,330	1,512
N2361	5,900	8,250	1,512
N2398	5,900	15,750	1,512
N2426	2,000	9,250	0,000
N2459	2,000	25,750	0,000
N2666	2,100	1,330	1,512
N2680	2,100	8,250	1,512
N2695	2,100	15,750	1,512
N2730	1,900	1,330	1,512
N2744	1,900	8,250	1,512
N2781	1,900	15,750	1,512
N2809	-2,000	9,250	0,000
N2842	-2,000	25,750	0,000
N3049	-1,900	1,330	1,512
N3063	-1,900	8,250	1,512
N3078	-1,900	15,750	1,512
N3191	13,900	1,500	1,512
N3268	13,900	8,000	1,512
N3363	13,900	16,000	1,512
N3378	14,000	17,500	0,000
N3601	10,100	1,500	1,512
N3602	9,900	1,500	1,512
N3607	6,100	1,500	1,512
N3608	5,900	1,500	1,512
N3613	2,100	1,500	1,512
N3614	1,900	1,500	1,512

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
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N3917	6,100	8,000	1,512
N3918	5,900	8,000	1,512
N3927	-1,900	8,000	1,512
N4292	10,100	16,000	1,512
N4293	9,900	16,000	1,512
N4297	6,100	16,000	1,512
N4298	5,900	16,000	1,512
N4302	2,100	16,000	1,512
N4303	1,900	16,000	1,512
N4307	-1,900	16,000	1,512
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N4363	6,000	17,500	0,000
N4371	2,000	17,500	0,000
N4379	-2,000	17,500	0,000
N5051	1,900	7,875	1,512
N5054	2,100	7,875	1,512
N5057	1,900	8,125	1,512
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N6423	1,900	8,000	1,512
N7250	13,900	0,000	1,512
N7265	10,100	0,125	1,512
N7266	9,900	0,125	1,512
N7277	6,100	0,125	1,512
N7278	5,900	0,125	1,512
N7289	2,100	0,125	1,512
N7290	1,900	0,125	1,512
N7301	-1,900	0,125	1,512
N7311	14,000	0,120	0,000
N7314	14,000	0,100	1,350
N7315	13,900	0,100	1,350
N7316	14,100	0,100	1,350
N7318	14,100	0,100	1,512
N7319	13,900	0,100	1,512
N7822	10,000	0,120	0,000
N7823	10,100	0,000	1,512
N7824	9,900	0,000	1,512
N7826	10,100	0,100	1,512
N7827	9,900	0,100	1,512
N8060	6,000	0,120	0,000
N8061	6,100	0,000	1,512
N8062	5,900	0,000	1,512
N8064	6,100	0,100	1,512
N8065	5,900	0,100	1,512
N8298	2,000	0,120	0,000
N8299	2,100	0,000	1,512
N8300	1,900	0,000	1,512
N8302	2,100	0,100	1,512
N8303	1,900	0,100	1,512
N8536	-2,000	0,120	0,000
N8537	-1,900	0,000	1,512
N8540	-1,900	0,100	1,512
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N8893	10,100	0,100	1,350
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N9298	6,100	0,100	1,350
N9701	2,000	0,100	1,350
N9702	1,900	0,100	1,350
N9703	2,100	0,100	1,350
N10106	-2,000	0,100	1,350
N10107	-2,100	0,100	1,350
N10108	-1,900	0,100	1,350
N10504	-2,100	0,100	1,512
N11176	13,900	31,900	1,512

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N11180	5,900	31,900	1,512
N11181	2,100	31,900	1,512
N11182	1,900	31,900	1,512
N11183	-1,900	31,900	1,512
N11244	13,900	1,200	1,512
N11246	10,100	1,200	1,512
N11247	9,900	1,200	1,512
N11249	6,100	1,200	1,512
N11250	5,900	1,200	1,512
N11252	2,100	1,200	1,512
N11253	1,900	1,200	1,512
N11255	-1,900	1,200	1,512
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N11871	10,100	8,100	1,512
N11872	9,900	8,100	1,512
N11874	6,100	8,100	1,512
N11875	5,900	8,100	1,512
N11877	2,100	8,100	1,512
N11878	1,900	8,100	1,512
N11880	-1,900	8,100	1,512
N12584	13,900	15,900	1,512
N12586	10,100	15,900	1,512
N12587	9,900	15,900	1,512
N12589	6,100	15,900	1,512
N12590	5,900	15,900	1,512
N12592	2,100	15,900	1,512
N12593	1,900	15,900	1,512
N12595	-1,900	15,900	1,512
N12614	13,900	16,200	1,512
N12616	10,100	16,200	1,512
N12617	9,900	16,200	1,512
N12619	6,100	16,200	1,512
N12620	5,900	16,200	1,512
N12622	2,100	16,200	1,512
N12623	1,900	16,200	1,512
N12625	-1,900	16,200	1,512
N14001	13,900	1,400	1,512
N14003	10,100	1,400	1,512
N14004	9,900	1,400	1,512
N14006	6,100	1,400	1,512
N14007	5,900	1,400	1,512
N14009	2,100	1,400	1,512
N14010	1,900	1,400	1,512
N14012	-1,900	1,400	1,512
N14031	13,900	1,600	1,512
N14033	10,100	1,600	1,512
N14034	9,900	1,600	1,512
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N14039	2,100	1,600	1,512
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N14750	10,000	7,600	0,000
N14753	6,000	7,600	0,000
N14756	2,000	7,600	0,000
N14759	-2,000	7,600	0,000
N15529	14,000	14,200	0,000
N15532	10,000	14,200	0,000
N15535	6,000	14,200	0,000
N15538	2,000	14,200	0,000
N15541	-2,000	14,200	0,000
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N15734	10,100	15,800	1,512
N15735	9,900	15,800	1,512
N15737	6,100	15,800	1,512

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N15743	-1,900	15,800	1,512
N16324	14,000	20,800	0,000
N16327	10,000	20,800	0,000
N16330	6,000	20,800	0,000
N16333	2,000	20,800	0,000
N16336	-2,000	20,800	0,000
N17119	14,000	27,400	0,000
N17122	10,000	27,400	0,000
N17125	6,000	27,400	0,000
N17128	2,000	27,400	0,000
N17131	-2,000	27,400	0,000
N18202	14,000	4,300	0,000
N18205	10,000	4,300	0,000
N18208	6,000	4,300	0,000
N18211	2,000	4,300	0,000
N18214	-2,000	4,300	0,000
N18473	13,900	7,900	1,512
N18475	10,100	7,900	1,512
N18476	9,900	7,900	1,512
N18478	6,100	7,900	1,512
N18479	5,900	7,900	1,512
N18481	2,100	7,900	1,512
N18482	1,900	7,900	1,512
N18484	-1,900	7,900	1,512
N18693	14,000	10,900	0,000
N18696	10,000	10,900	0,000
N18699	6,000	10,900	0,000
N18702	2,000	10,900	0,000
N18705	-2,000	10,900	0,000
N19045	13,900	15,700	1,512
N19047	10,100	15,700	1,512
N19048	9,900	15,700	1,512
N19050	6,100	15,700	1,512
N19051	5,900	15,700	1,512
N19053	2,100	15,700	1,512
N19054	1,900	15,700	1,512
N19056	-1,900	15,700	1,512
N19662	14,000	24,100	0,000
N19665	10,000	24,100	0,000
N19668	6,000	24,100	0,000
N19671	2,000	24,100	0,000
N19674	-2,000	24,100	0,000
N20153	14,000	30,700	0,000
N20156	10,000	30,700	0,000
N20159	6,000	30,700	0,000
N20162	2,000	30,700	0,000
N20165	-2,000	30,700	0,000
N20189	13,900	1,540	1,512
N20191	10,100	1,540	1,512
N20192	9,900	1,540	1,512
N20194	6,100	1,540	1,512
N20195	5,900	1,540	1,512
N20197	2,100	1,540	1,512
N20198	1,900	1,540	1,512
N20200	-1,900	1,540	1,512
N20444	14,000	3,970	0,000
N20447	10,000	3,970	0,000
N20450	6,000	3,970	0,000
N20453	2,000	3,970	0,000
N20456	-2,000	3,970	0,000
N20761	14,000	6,940	0,000
N20764	10,000	6,940	0,000
N20767	6,000	6,940	0,000
N20770	2,000	6,940	0,000
N20773	-2,000	6,940	0,000
N20870	13,900	8,020	1,512

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N20872	10,100	8,020	1,512
N20873	9,900	8,020	1,512
N20875	6,100	8,020	1,512
N20876	5,900	8,020	1,512
N20878	2,100	8,020	1,512
N20879	1,900	8,020	1,512
N20881	-1,900	8,020	1,512
N20900	13,900	8,290	1,512
N20902	10,100	8,290	1,512
N20903	9,900	8,290	1,512
N20905	6,100	8,290	1,512
N20906	5,900	8,290	1,512
N20908	2,100	8,290	1,512
N20909	1,900	8,290	1,512
N20911	-1,900	8,290	1,512
N21065	14,000	9,910	0,000
N21068	10,000	9,910	0,000
N21071	6,000	9,910	0,000
N21074	2,000	9,910	0,000
N21077	-2,000	9,910	0,000
N21382	14,000	12,880	0,000
N21385	10,000	12,880	0,000
N21388	6,000	12,880	0,000
N21391	2,000	12,880	0,000
N21394	-2,000	12,880	0,000
N21699	14,000	15,850	0,000
N21701	13,900	15,850	1,512
N21702	10,000	15,850	0,000
N21703	10,100	15,850	1,512
N21704	9,900	15,850	1,512
N21705	6,000	15,850	0,000
N21706	6,100	15,850	1,512
N21707	5,900	15,850	1,512
N21708	2,000	15,850	0,000
N21709	2,100	15,850	1,512
N21710	1,900	15,850	1,512
N21711	-2,000	15,850	0,000
N21712	-1,900	15,850	1,512
N22016	14,000	18,820	0,000
N22019	10,000	18,820	0,000
N22022	6,000	18,820	0,000
N22025	2,000	18,820	0,000
N22028	-2,000	18,820	0,000
N22320	14,000	21,790	0,000
N22323	10,000	21,790	0,000
N22326	6,000	21,790	0,000
N22329	2,000	21,790	0,000
N22332	-2,000	21,790	0,000
N22637	14,000	24,760	0,000
N22640	10,000	24,760	0,000
N22643	6,000	24,760	0,000
N22646	2,000	24,760	0,000
N22649	-2,000	24,760	0,000
N22954	14,000	27,730	0,000
N22957	10,000	27,730	0,000
N22960	6,000	27,730	0,000
N22963	2,000	27,730	0,000
N22966	-2,000	27,730	0,000
N25651	14,000	1,330	0,000
N25652	10,000	1,330	0,000
N25653	6,000	1,330	0,000
N25654	2,000	1,330	0,000
N25655	-2,000	1,330	0,000
N25671	14,000	1,660	0,000
N25673	13,900	1,660	1,512
N25674	10,000	1,660	0,000
N25675	10,100	1,660	1,512
N25676	9,900	1,660	1,512
N25677	6,000	1,660	0,000

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N25678	6,100	1,660	1,512
N25679	5,900	1,660	1,512
N25680	2,000	1,660	0,000
N25681	2,100	1,660	1,512
N25682	1,900	1,660	1,512
N25683	-2,000	1,660	0,000
N25684	-1,900	1,660	1,512
N25701	14,000	1,990	0,000
N25704	10,000	1,990	0,000
N25707	6,000	1,990	0,000
N25710	2,000	1,990	0,000
N25713	-2,000	1,990	0,000
N25731	14,000	2,320	0,000
N25734	10,000	2,320	0,000
N25737	6,000	2,320	0,000
N25740	2,000	2,320	0,000
N25743	-2,000	2,320	0,000
N25761	14,000	2,650	0,000
N25764	10,000	2,650	0,000
N25767	6,000	2,650	0,000
N25770	2,000	2,650	0,000
N25773	-2,000	2,650	0,000
N25791	14,000	2,980	0,000
N25794	10,000	2,980	0,000
N25797	6,000	2,980	0,000
N25800	2,000	2,980	0,000
N25803	-2,000	2,980	0,000
N25821	14,000	3,310	0,000
N25824	10,000	3,310	0,000
N25827	6,000	3,310	0,000
N25830	2,000	3,310	0,000
N25833	-2,000	3,310	0,000
N25851	14,000	3,640	0,000
N25854	10,000	3,640	0,000
N25857	6,000	3,640	0,000
N25860	2,000	3,640	0,000
N25863	-2,000	3,640	0,000
N25915	14,000	4,630	0,000
N25918	10,000	4,630	0,000
N25921	6,000	4,630	0,000
N25924	2,000	4,630	0,000
N25927	-2,000	4,630	0,000
N25945	14,000	4,960	0,000
N25948	10,000	4,960	0,000
N25951	6,000	4,960	0,000
N25954	2,000	4,960	0,000
N25957	-2,000	4,960	0,000
N25975	14,000	5,290	0,000
N25978	10,000	5,290	0,000
N25981	6,000	5,290	0,000
N25984	2,000	5,290	0,000
N25987	-2,000	5,290	0,000
N26005	14,000	5,620	0,000
N26008	10,000	5,620	0,000
N26011	6,000	5,620	0,000
N26014	2,000	5,620	0,000
N26017	-2,000	5,620	0,000
N26035	14,000	5,950	0,000
N26038	10,000	5,950	0,000
N26041	6,000	5,950	0,000
N26044	2,000	5,950	0,000
N26047	-2,000	5,950	0,000
N26065	14,000	6,280	0,000
N26068	10,000	6,280	0,000
N26071	6,000	6,280	0,000
N26074	2,000	6,280	0,000
N26077	-2,000	6,280	0,000
N26095	14,000	6,610	0,000
N26098	10,000	6,610	0,000

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N26101	6,000	6,610	0,000
N26104	2,000	6,610	0,000
N26107	-2,000	6,610	0,000
N26142	14,000	7,270	0,000
N26145	10,000	7,270	0,000
N26148	6,000	7,270	0,000
N26151	2,000	7,270	0,000
N26154	-2,000	7,270	0,000
N26189	14,000	7,930	0,000
N26191	13,900	7,930	1,512
N26192	10,000	7,930	0,000
N26193	10,100	7,930	1,512
N26194	9,900	7,930	1,512
N26195	6,000	7,930	0,000
N26196	6,100	7,930	1,512
N26197	5,900	7,930	1,512
N26198	2,000	7,930	0,000
N26199	2,100	7,930	1,512
N26200	1,900	7,930	1,512
N26201	-2,000	7,930	0,000
N26202	-1,900	7,930	1,512
N26219	14,000	8,260	0,000
N26221	13,900	8,260	1,512
N26222	10,000	8,260	0,000
N26223	10,100	8,260	1,512
N26224	9,900	8,260	1,512
N26225	6,000	8,260	0,000
N26226	6,100	8,260	1,512
N26227	5,900	8,260	1,512
N26228	2,000	8,260	0,000
N26229	2,100	8,260	1,512
N26230	1,900	8,260	1,512
N26231	-2,000	8,260	0,000
N26232	-1,900	8,260	1,512
N26249	14,000	8,590	0,000
N26252	10,000	8,590	0,000
N26255	6,000	8,590	0,000
N26258	2,000	8,590	0,000
N26261	-2,000	8,590	0,000
N26279	14,000	8,920	0,000
N26282	10,000	8,920	0,000
N26285	6,000	8,920	0,000
N26288	2,000	8,920	0,000
N26291	-2,000	8,920	0,000
N26326	14,000	9,580	0,000
N26329	10,000	9,580	0,000
N26332	6,000	9,580	0,000
N26335	2,000	9,580	0,000
N26338	-2,000	9,580	0,000
N26373	14,000	10,240	0,000
N26376	10,000	10,240	0,000
N26379	6,000	10,240	0,000
N26382	2,000	10,240	0,000
N26385	-2,000	10,240	0,000
N26403	14,000	10,570	0,000
N26406	10,000	10,570	0,000
N26409	6,000	10,570	0,000
N26412	2,000	10,570	0,000
N26415	-2,000	10,570	0,000
N26450	14,000	11,230	0,000
N26453	10,000	11,230	0,000
N26456	6,000	11,230	0,000
N26459	2,000	11,230	0,000
N26462	-2,000	11,230	0,000
N26480	14,000	11,560	0,000
N26483	10,000	11,560	0,000
N26486	6,000	11,560	0,000
N26489	2,000	11,560	0,000
N26492	-2,000	11,560	0,000

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N26510	14,000	11,890	0,000
N26513	10,000	11,890	0,000
N26516	6,000	11,890	0,000
N26519	2,000	11,890	0,000
N26522	-2,000	11,890	0,000
N26540	14,000	12,220	0,000
N26543	10,000	12,220	0,000
N26546	6,000	12,220	0,000
N26549	2,000	12,220	0,000
N26552	-2,000	12,220	0,000
N26570	14,000	12,550	0,000
N26573	10,000	12,550	0,000
N26576	6,000	12,550	0,000
N26579	2,000	12,550	0,000
N26582	-2,000	12,550	0,000
N26617	14,000	13,210	0,000
N26620	10,000	13,210	0,000
N26623	6,000	13,210	0,000
N26626	2,000	13,210	0,000
N26629	-2,000	13,210	0,000
N26647	14,000	13,540	0,000
N26650	10,000	13,540	0,000
N26653	6,000	13,540	0,000
N26656	2,000	13,540	0,000
N26659	-2,000	13,540	0,000
N26677	14,000	13,870	0,000
N26680	10,000	13,870	0,000
N26683	6,000	13,870	0,000
N26686	2,000	13,870	0,000
N26689	-2,000	13,870	0,000
N26724	14,000	14,530	0,000
N26727	10,000	14,530	0,000
N26730	6,000	14,530	0,000
N26733	2,000	14,530	0,000
N26736	-2,000	14,530	0,000
N26754	14,000	14,860	0,000
N26757	10,000	14,860	0,000
N26760	6,000	14,860	0,000
N26763	2,000	14,860	0,000
N26766	-2,000	14,860	0,000
N26784	14,000	15,190	0,000
N26787	10,000	15,190	0,000
N26790	6,000	15,190	0,000
N26793	2,000	15,190	0,000
N26796	-2,000	15,190	0,000
N26814	14,000	15,520	0,000
N26817	10,000	15,520	0,000
N26820	6,000	15,520	0,000
N26823	2,000	15,520	0,000
N26826	-2,000	15,520	0,000
N26861	14,000	16,180	0,000
N26863	13,900	16,180	1,512
N26864	10,000	16,180	0,000
N26865	10,100	16,180	1,512
N26866	9,900	16,180	1,512
N26867	6,000	16,180	0,000
N26868	6,100	16,180	1,512
N26869	5,900	16,180	1,512
N26870	2,000	16,180	0,000
N26871	2,100	16,180	1,512
N26872	1,900	16,180	1,512
N26873	-2,000	16,180	0,000
N26874	-1,900	16,180	1,512
N26891	14,000	16,510	0,000
N26894	10,000	16,510	0,000
N26897	6,000	16,510	0,000
N26900	2,000	16,510	0,000
N26903	-2,000	16,510	0,000
N26921	14,000	16,840	0,000

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N26924	10,000	16,840	0,000
N26927	6,000	16,840	0,000
N26930	2,000	16,840	0,000
N26933	-2,000	16,840	0,000
N26951	14,000	17,170	0,000
N26954	10,000	17,170	0,000
N26957	6,000	17,170	0,000
N26960	2,000	17,170	0,000
N26963	-2,000	17,170	0,000
N26998	14,000	17,830	0,000
N27001	10,000	17,830	0,000
N27004	6,000	17,830	0,000
N27007	2,000	17,830	0,000
N27010	-2,000	17,830	0,000
N27028	14,000	18,160	0,000
N27031	10,000	18,160	0,000
N27034	6,000	18,160	0,000
N27037	2,000	18,160	0,000
N27040	-2,000	18,160	0,000
N27058	14,000	18,490	0,000
N27061	10,000	18,490	0,000
N27064	6,000	18,490	0,000
N27067	2,000	18,490	0,000
N27070	-2,000	18,490	0,000
N27105	14,000	19,150	0,000
N27108	10,000	19,150	0,000
N27111	6,000	19,150	0,000
N27114	2,000	19,150	0,000
N27117	-2,000	19,150	0,000
N27135	14,000	19,480	0,000
N27138	10,000	19,480	0,000
N27141	6,000	19,480	0,000
N27144	2,000	19,480	0,000
N27147	-2,000	19,480	0,000
N27165	14,000	19,810	0,000
N27168	10,000	19,810	0,000
N27171	6,000	19,810	0,000
N27174	2,000	19,810	0,000
N27177	-2,000	19,810	0,000
N27195	14,000	20,140	0,000
N27198	10,000	20,140	0,000
N27201	6,000	20,140	0,000
N27204	2,000	20,140	0,000
N27207	-2,000	20,140	0,000
N27225	14,000	20,470	0,000
N27228	10,000	20,470	0,000
N27231	6,000	20,470	0,000
N27234	2,000	20,470	0,000
N27237	-2,000	20,470	0,000
N27272	14,000	21,130	0,000
N27275	10,000	21,130	0,000
N27278	6,000	21,130	0,000
N27281	2,000	21,130	0,000
N27284	-2,000	21,130	0,000
N27302	14,000	21,460	0,000
N27305	10,000	21,460	0,000
N27308	6,000	21,460	0,000
N27311	2,000	21,460	0,000
N27314	-2,000	21,460	0,000
N27349	14,000	22,120	0,000
N27352	10,000	22,120	0,000
N27355	6,000	22,120	0,000
N27358	2,000	22,120	0,000
N27361	-2,000	22,120	0,000
N27379	14,000	22,450	0,000
N27382	10,000	22,450	0,000
N27385	6,000	22,450	0,000
N27388	2,000	22,450	0,000
N27391	-2,000	22,450	0,000

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N27409	14,000	22,780	0,000
N27412	10,000	22,780	0,000
N27415	6,000	22,780	0,000
N27418	2,000	22,780	0,000
N27421	-2,000	22,780	0,000
N27439	14,000	23,110	0,000
N27442	10,000	23,110	0,000
N27445	6,000	23,110	0,000
N27448	2,000	23,110	0,000
N27451	-2,000	23,110	0,000
N27469	14,000	23,440	0,000
N27472	10,000	23,440	0,000
N27475	6,000	23,440	0,000
N27478	2,000	23,440	0,000
N27481	-2,000	23,440	0,000
N27499	14,000	23,770	0,000
N27502	10,000	23,770	0,000
N27505	6,000	23,770	0,000
N27508	2,000	23,770	0,000
N27511	-2,000	23,770	0,000
N27546	14,000	24,430	0,000
N27549	10,000	24,430	0,000
N27552	6,000	24,430	0,000
N27555	2,000	24,430	0,000
N27558	-2,000	24,430	0,000
N27593	14,000	25,090	0,000
N27596	10,000	25,090	0,000
N27599	6,000	25,090	0,000
N27602	2,000	25,090	0,000
N27605	-2,000	25,090	0,000
N27623	14,000	25,420	0,000
N27626	10,000	25,420	0,000
N27629	6,000	25,420	0,000
N27632	2,000	25,420	0,000
N27635	-2,000	25,420	0,000
N27670	14,000	26,080	0,000
N27673	10,000	26,080	0,000
N27676	6,000	26,080	0,000
N27679	2,000	26,080	0,000
N27682	-2,000	26,080	0,000
N27700	14,000	26,410	0,000
N27703	10,000	26,410	0,000
N27706	6,000	26,410	0,000
N27709	2,000	26,410	0,000
N27712	-2,000	26,410	0,000
N27730	14,000	26,740	0,000
N27733	10,000	26,740	0,000
N27736	6,000	26,740	0,000
N27739	2,000	26,740	0,000
N27742	-2,000	26,740	0,000
N27760	14,000	27,070	0,000
N27763	10,000	27,070	0,000
N27766	6,000	27,070	0,000
N27769	2,000	27,070	0,000
N27772	-2,000	27,070	0,000
N27824	14,000	28,060	0,000
N27827	10,000	28,060	0,000
N27830	6,000	28,060	0,000
N27833	2,000	28,060	0,000
N27836	-2,000	28,060	0,000
N27854	14,000	28,390	0,000
N27857	10,000	28,390	0,000
N27860	6,000	28,390	0,000
N27863	2,000	28,390	0,000
N27866	-2,000	28,390	0,000
N27884	14,000	28,720	0,000
N27887	10,000	28,720	0,000
N27890	6,000	28,720	0,000
N27893	2,000	28,720	0,000

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N27896	-2,000	28,720	0,000
N27914	14,000	29,050	0,000
N27917	10,000	29,050	0,000
N27920	6,000	29,050	0,000
N27923	2,000	29,050	0,000
N27926	-2,000	29,050	0,000
N27944	14,000	29,380	0,000
N27947	10,000	29,380	0,000
N27950	6,000	29,380	0,000
N27953	2,000	29,380	0,000
N27956	-2,000	29,380	0,000
N27974	14,000	29,710	0,000
N27977	10,000	29,710	0,000
N27980	6,000	29,710	0,000
N27983	2,000	29,710	0,000
N27986	-2,000	29,710	0,000
N28004	14,000	30,040	0,000
N28007	10,000	30,040	0,000
N28010	6,000	30,040	0,000
N28013	2,000	30,040	0,000
N28016	-2,000	30,040	0,000
N28034	14,000	30,370	0,000
N28037	10,000	30,370	0,000
N28040	6,000	30,370	0,000
N28043	2,000	30,370	0,000
N28046	-2,000	30,370	0,000
N28065	13,900	30,700	1,512
N28066	10,100	30,700	1,512
N28067	9,900	30,700	1,512
N28068	6,100	30,700	1,512
N28069	5,900	30,700	1,512
N28070	2,100	30,700	1,512
N28071	1,900	30,700	1,512
N28072	-1,900	30,700	1,512
N29847	13,900	0,200	1,512
N29849	10,100	0,200	1,512
N29850	9,900	0,200	1,512
N29852	6,100	0,200	1,512
N29853	5,900	0,200	1,512
N29855	2,100	0,200	1,512
N29856	1,900	0,200	1,512
N29858	-1,900	0,200	1,512
N29877	13,900	0,300	1,512
N29879	10,100	0,300	1,512
N29880	9,900	0,300	1,512
N29882	6,100	0,300	1,512
N29883	5,900	0,300	1,512
N29885	2,100	0,300	1,512
N29886	1,900	0,300	1,512
N29888	-1,900	0,300	1,512
N29907	13,900	0,400	1,512
N29909	10,100	0,400	1,512
N29910	9,900	0,400	1,512
N29912	6,100	0,400	1,512
N29913	5,900	0,400	1,512
N29915	2,100	0,400	1,512
N29916	1,900	0,400	1,512
N29918	-1,900	0,400	1,512
N29937	13,900	0,500	1,512
N29939	10,100	0,500	1,512
N29940	9,900	0,500	1,512
N29942	6,100	0,500	1,512
N29943	5,900	0,500	1,512
N29945	2,100	0,500	1,512
N29946	1,900	0,500	1,512
N29948	-1,900	0,500	1,512
N29967	13,900	0,600	1,512
N29969	10,100	0,600	1,512
N29970	9,900	0,600	1,512

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N29972	6,100	0,600	1,512
N29973	5,900	0,600	1,512
N29975	2,100	0,600	1,512
N29976	1,900	0,600	1,512
N29978	-1,900	0,600	1,512
N29997	13,900	0,720	1,512
N29999	10,100	0,720	1,512
N30000	9,900	0,720	1,512
N30002	6,100	0,720	1,512
N30003	5,900	0,720	1,512
N30005	2,100	0,720	1,512
N30006	1,900	0,720	1,512
N30008	-1,900	0,720	1,512
N30027	13,900	0,800	1,512
N30029	10,100	0,800	1,512
N30030	9,900	0,800	1,512
N30032	6,100	0,800	1,512
N30033	5,900	0,800	1,512
N30035	2,100	0,800	1,512
N30036	1,900	0,800	1,512
N30038	-1,900	0,800	1,512
N30057	13,900	0,880	1,512
N30059	10,100	0,880	1,512
N30060	9,900	0,880	1,512
N30062	6,100	0,880	1,512
N30063	5,900	0,880	1,512
N30065	2,100	0,880	1,512
N30066	1,900	0,880	1,512
N30068	-1,900	0,880	1,512
N30087	13,900	1,000	1,512
N30089	10,100	1,000	1,512
N30090	9,900	1,000	1,512
N30092	6,100	1,000	1,512
N30093	5,900	1,000	1,512
N30095	2,100	1,000	1,512
N30096	1,900	1,000	1,512
N30098	-1,900	1,000	1,512
N30141	13,900	0,190	1,512
N30143	10,100	0,190	1,512
N30144	9,900	0,190	1,512
N30146	6,100	0,190	1,512
N30147	5,900	0,190	1,512
N30149	2,100	0,190	1,512
N30150	1,900	0,190	1,512
N30152	-1,900	0,190	1,512
N30171	13,900	0,280	1,512
N30173	10,100	0,280	1,512
N30174	9,900	0,280	1,512
N30176	6,100	0,280	1,512
N30177	5,900	0,280	1,512
N30179	2,100	0,280	1,512
N30180	1,900	0,280	1,512
N30182	-1,900	0,280	1,512
N30201	13,900	0,370	1,512
N30203	10,100	0,370	1,512
N30204	9,900	0,370	1,512
N30206	6,100	0,370	1,512
N30207	5,900	0,370	1,512
N30209	2,100	0,370	1,512
N30210	1,900	0,370	1,512
N30212	-1,900	0,370	1,512
N30231	13,900	0,480	1,512
N30233	10,100	0,480	1,512
N30234	9,900	0,480	1,512
N30236	6,100	0,480	1,512
N30237	5,900	0,480	1,512
N30239	2,100	0,480	1,512
N30240	1,900	0,480	1,512
N30242	-1,900	0,480	1,512

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N30261	13,900	0,550	1,512
N30263	10,100	0,550	1,512
N30264	9,900	0,550	1,512
N30266	6,100	0,550	1,512
N30267	5,900	0,550	1,512
N30269	2,100	0,550	1,512
N30270	1,900	0,550	1,512
N30272	-1,900	0,550	1,512
N30291	13,900	0,620	1,512
N30293	10,100	0,620	1,512
N30294	9,900	0,620	1,512
N30296	6,100	0,620	1,512
N30297	5,900	0,620	1,512
N30299	2,100	0,620	1,512
N30300	1,900	0,620	1,512
N30302	-1,900	0,620	1,512
N30321	13,900	0,730	1,512
N30323	10,100	0,730	1,512
N30324	9,900	0,730	1,512
N30326	6,100	0,730	1,512
N30327	5,900	0,730	1,512
N30329	2,100	0,730	1,512
N30330	1,900	0,730	1,512
N30332	-1,900	0,730	1,512
N30351	13,900	0,840	1,512
N30353	10,100	0,840	1,512
N30354	9,900	0,840	1,512
N30356	6,100	0,840	1,512
N30357	5,900	0,840	1,512
N30359	2,100	0,840	1,512
N30360	1,900	0,840	1,512
N30362	-1,900	0,840	1,512
N30381	13,900	0,910	1,512
N30383	10,100	0,910	1,512
N30384	9,900	0,910	1,512
N30386	6,100	0,910	1,512
N30387	5,900	0,910	1,512
N30389	2,100	0,910	1,512
N30390	1,900	0,910	1,512
N30392	-1,900	0,910	1,512
N30433	13,900	1,720	1,512
N30435	10,100	1,720	1,512
N30436	9,900	1,720	1,512
N30438	6,100	1,720	1,512
N30439	5,900	1,720	1,512
N30441	2,100	1,720	1,512
N30442	1,900	1,720	1,512
N30444	-1,900	1,720	1,512
N30463	13,900	2,080	1,512
N30465	10,100	2,080	1,512
N30466	9,900	2,080	1,512
N30468	6,100	2,080	1,512
N30469	5,900	2,080	1,512
N30471	2,100	2,080	1,512
N30472	1,900	2,080	1,512
N30474	-1,900	2,080	1,512
N30493	13,900	2,440	1,512
N30495	10,100	2,440	1,512
N30496	9,900	2,440	1,512
N30498	6,100	2,440	1,512
N30499	5,900	2,440	1,512
N30501	2,100	2,440	1,512
N30502	1,900	2,440	1,512
N30504	-1,900	2,440	1,512
N30523	13,900	2,800	1,512
N30525	10,100	2,800	1,512
N30526	9,900	2,800	1,512
N30528	6,100	2,800	1,512
N30529	5,900	2,800	1,512

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N30531	2,100	2,800	1,512
N30532	1,900	2,800	1,512
N30534	-1,900	2,800	1,512
N30553	13,900	3,160	1,512
N30555	10,100	3,160	1,512
N30556	9,900	3,160	1,512
N30558	6,100	3,160	1,512
N30559	5,900	3,160	1,512
N30561	2,100	3,160	1,512
N30562	1,900	3,160	1,512
N30564	-1,900	3,160	1,512
N30583	13,900	3,520	1,512
N30585	10,100	3,520	1,512
N30586	9,900	3,520	1,512
N30588	6,100	3,520	1,512
N30589	5,900	3,520	1,512
N30591	2,100	3,520	1,512
N30592	1,900	3,520	1,512
N30594	-1,900	3,520	1,512
N30613	13,900	3,880	1,512
N30615	10,100	3,880	1,512
N30616	9,900	3,880	1,512
N30618	6,100	3,880	1,512
N30619	5,900	3,880	1,512
N30621	2,100	3,880	1,512
N30622	1,900	3,880	1,512
N30624	-1,900	3,880	1,512
N30643	13,900	4,240	1,512
N30645	10,100	4,240	1,512
N30646	9,900	4,240	1,512
N30648	6,100	4,240	1,512
N30649	5,900	4,240	1,512
N30651	2,100	4,240	1,512
N30652	1,900	4,240	1,512
N30654	-1,900	4,240	1,512
N30673	13,900	4,600	1,512
N30675	10,100	4,600	1,512
N30676	9,900	4,600	1,512
N30678	6,100	4,600	1,512
N30679	5,900	4,600	1,512
N30681	2,100	4,600	1,512
N30682	1,900	4,600	1,512
N30684	-1,900	4,600	1,512
N30702	13,900	4,960	1,512
N30703	10,100	4,960	1,512
N30704	9,900	4,960	1,512
N30705	6,100	4,960	1,512
N30706	5,900	4,960	1,512
N30707	2,100	4,960	1,512
N30708	1,900	4,960	1,512
N30709	-1,900	4,960	1,512
N30728	13,900	5,320	1,512
N30730	10,100	5,320	1,512
N30731	9,900	5,320	1,512
N30733	6,100	5,320	1,512
N30734	5,900	5,320	1,512
N30736	2,100	5,320	1,512
N30737	1,900	5,320	1,512
N30739	-1,900	5,320	1,512
N30758	13,900	5,680	1,512
N30760	10,100	5,680	1,512
N30761	9,900	5,680	1,512
N30763	6,100	5,680	1,512
N30764	5,900	5,680	1,512
N30766	2,100	5,680	1,512
N30767	1,900	5,680	1,512
N30769	-1,900	5,680	1,512
N30788	13,900	6,040	1,512
N30790	10,100	6,040	1,512

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N30791	9,900	6,040	1,512
N30793	6,100	6,040	1,512
N30794	5,900	6,040	1,512
N30796	2,100	6,040	1,512
N30797	1,900	6,040	1,512
N30799	-1,900	6,040	1,512
N30818	13,900	6,400	1,512
N30820	10,100	6,400	1,512
N30821	9,900	6,400	1,512
N30823	6,100	6,400	1,512
N30824	5,900	6,400	1,512
N30826	2,100	6,400	1,512
N30827	1,900	6,400	1,512
N30829	-1,900	6,400	1,512
N30848	13,900	6,760	1,512
N30850	10,100	6,760	1,512
N30851	9,900	6,760	1,512
N30853	6,100	6,760	1,512
N30854	5,900	6,760	1,512
N30856	2,100	6,760	1,512
N30857	1,900	6,760	1,512
N30859	-1,900	6,760	1,512
N30878	13,900	7,120	1,512
N30880	10,100	7,120	1,512
N30881	9,900	7,120	1,512
N30883	6,100	7,120	1,512
N30884	5,900	7,120	1,512
N30886	2,100	7,120	1,512
N30887	1,900	7,120	1,512
N30889	-1,900	7,120	1,512
N30908	13,900	7,480	1,512
N30910	10,100	7,480	1,512
N30911	9,900	7,480	1,512
N30913	6,100	7,480	1,512
N30914	5,900	7,480	1,512
N30916	2,100	7,480	1,512
N30917	1,900	7,480	1,512
N30919	-1,900	7,480	1,512
N30938	13,900	7,840	1,512
N30940	10,100	7,840	1,512
N30941	9,900	7,840	1,512
N30943	6,100	7,840	1,512
N30944	5,900	7,840	1,512
N30946	2,100	7,840	1,512
N30947	1,900	7,840	1,512
N30949	-1,900	7,840	1,512
N30968	13,900	8,200	1,512
N30970	10,100	8,200	1,512
N30971	9,900	8,200	1,512
N30973	6,100	8,200	1,512
N30974	5,900	8,200	1,512
N30976	2,100	8,200	1,512
N30977	1,900	8,200	1,512
N30979	-1,900	8,200	1,512
N30998	13,900	8,560	1,512
N31000	10,100	8,560	1,512
N31001	9,900	8,560	1,512
N31003	6,100	8,560	1,512
N31004	5,900	8,560	1,512
N31006	2,100	8,560	1,512
N31007	1,900	8,560	1,512
N31009	-1,900	8,560	1,512
N31027	13,900	8,920	1,512
N31028	10,100	8,920	1,512
N31029	9,900	8,920	1,512
N31030	6,100	8,920	1,512
N31031	5,900	8,920	1,512
N31032	2,100	8,920	1,512
N31033	1,900	8,920	1,512

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N31034	-1,900	8,920	1,512
N31053	13,900	9,280	1,512
N31055	10,100	9,280	1,512
N31056	9,900	9,280	1,512
N31058	6,100	9,280	1,512
N31059	5,900	9,280	1,512
N31061	2,100	9,280	1,512
N31062	1,900	9,280	1,512
N31064	-1,900	9,280	1,512
N31083	13,900	9,640	1,512
N31085	10,100	9,640	1,512
N31086	9,900	9,640	1,512
N31088	6,100	9,640	1,512
N31089	5,900	9,640	1,512
N31091	2,100	9,640	1,512
N31092	1,900	9,640	1,512
N31094	-1,900	9,640	1,512
N31113	13,900	10,000	1,512
N31115	10,100	10,000	1,512
N31116	9,900	10,000	1,512
N31118	6,100	10,000	1,512
N31119	5,900	10,000	1,512
N31121	2,100	10,000	1,512
N31122	1,900	10,000	1,512
N31124	-1,900	10,000	1,512
N31143	13,900	10,360	1,512
N31145	10,100	10,360	1,512
N31146	9,900	10,360	1,512
N31148	6,100	10,360	1,512
N31149	5,900	10,360	1,512
N31151	2,100	10,360	1,512
N31152	1,900	10,360	1,512
N31154	-1,900	10,360	1,512
N31173	13,900	10,720	1,512
N31175	10,100	10,720	1,512
N31176	9,900	10,720	1,512
N31178	6,100	10,720	1,512
N31179	5,900	10,720	1,512
N31181	2,100	10,720	1,512
N31182	1,900	10,720	1,512
N31184	-1,900	10,720	1,512
N31203	13,900	11,080	1,512
N31205	10,100	11,080	1,512
N31206	9,900	11,080	1,512
N31208	6,100	11,080	1,512
N31209	5,900	11,080	1,512
N31211	2,100	11,080	1,512
N31212	1,900	11,080	1,512
N31214	-1,900	11,080	1,512
N31233	13,900	11,440	1,512
N31235	10,100	11,440	1,512
N31236	9,900	11,440	1,512
N31238	6,100	11,440	1,512
N31239	5,900	11,440	1,512
N31241	2,100	11,440	1,512
N31242	1,900	11,440	1,512
N31244	-1,900	11,440	1,512
N31263	13,900	11,800	1,512
N31265	10,100	11,800	1,512
N31266	9,900	11,800	1,512
N31268	6,100	11,800	1,512
N31269	5,900	11,800	1,512
N31271	2,100	11,800	1,512
N31272	1,900	11,800	1,512
N31274	-1,900	11,800	1,512
N31293	13,900	12,160	1,512
N31295	10,100	12,160	1,512
N31296	9,900	12,160	1,512
N31298	6,100	12,160	1,512

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N31299	5,900	12,160	1,512
N31301	2,100	12,160	1,512
N31302	1,900	12,160	1,512
N31304	-1,900	12,160	1,512
N31323	13,900	12,520	1,512
N31325	10,100	12,520	1,512
N31326	9,900	12,520	1,512
N31328	6,100	12,520	1,512
N31329	5,900	12,520	1,512
N31331	2,100	12,520	1,512
N31332	1,900	12,520	1,512
N31334	-1,900	12,520	1,512
N31352	13,900	12,880	1,512
N31353	10,100	12,880	1,512
N31354	9,900	12,880	1,512
N31355	6,100	12,880	1,512
N31356	5,900	12,880	1,512
N31357	2,100	12,880	1,512
N31358	1,900	12,880	1,512
N31359	-1,900	12,880	1,512
N31378	13,900	13,240	1,512
N31380	10,100	13,240	1,512
N31381	9,900	13,240	1,512
N31383	6,100	13,240	1,512
N31384	5,900	13,240	1,512
N31386	2,100	13,240	1,512
N31387	1,900	13,240	1,512
N31389	-1,900	13,240	1,512
N31408	13,900	13,600	1,512
N31410	10,100	13,600	1,512
N31411	9,900	13,600	1,512
N31413	6,100	13,600	1,512
N31414	5,900	13,600	1,512
N31416	2,100	13,600	1,512
N31417	1,900	13,600	1,512
N31419	-1,900	13,600	1,512
N31438	13,900	13,960	1,512
N31440	10,100	13,960	1,512
N31441	9,900	13,960	1,512
N31443	6,100	13,960	1,512
N31444	5,900	13,960	1,512
N31446	2,100	13,960	1,512
N31447	1,900	13,960	1,512
N31449	-1,900	13,960	1,512
N31468	13,900	14,320	1,512
N31470	10,100	14,320	1,512
N31471	9,900	14,320	1,512
N31473	6,100	14,320	1,512
N31474	5,900	14,320	1,512
N31476	2,100	14,320	1,512
N31477	1,900	14,320	1,512
N31479	-1,900	14,320	1,512
N31498	13,900	14,680	1,512
N31500	10,100	14,680	1,512
N31501	9,900	14,680	1,512
N31503	6,100	14,680	1,512
N31504	5,900	14,680	1,512
N31506	2,100	14,680	1,512
N31507	1,900	14,680	1,512
N31509	-1,900	14,680	1,512
N31528	13,900	15,040	1,512
N31530	10,100	15,040	1,512
N31531	9,900	15,040	1,512
N31533	6,100	15,040	1,512
N31534	5,900	15,040	1,512
N31536	2,100	15,040	1,512
N31537	1,900	15,040	1,512
N31539	-1,900	15,040	1,512
N31558	13,900	15,400	1,512

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N31560	10,100	15,400	1,512
N31561	9,900	15,400	1,512
N31563	6,100	15,400	1,512
N31564	5,900	15,400	1,512
N31566	2,100	15,400	1,512
N31567	1,900	15,400	1,512
N31569	-1,900	15,400	1,512
N31588	13,900	15,760	1,512
N31590	10,100	15,760	1,512
N31591	9,900	15,760	1,512
N31593	6,100	15,760	1,512
N31594	5,900	15,760	1,512
N31596	2,100	15,760	1,512
N31597	1,900	15,760	1,512
N31599	-1,900	15,760	1,512
N31618	13,900	16,120	1,512
N31620	10,100	16,120	1,512
N31621	9,900	16,120	1,512
N31623	6,100	16,120	1,512
N31624	5,900	16,120	1,512
N31626	2,100	16,120	1,512
N31627	1,900	16,120	1,512
N31629	-1,900	16,120	1,512
N31648	13,900	16,480	1,512
N31650	10,100	16,480	1,512
N31651	9,900	16,480	1,512
N31653	6,100	16,480	1,512
N31654	5,900	16,480	1,512
N31656	2,100	16,480	1,512
N31657	1,900	16,480	1,512
N31659	-1,900	16,480	1,512
N31677	13,900	16,840	1,512
N31678	10,100	16,840	1,512
N31679	9,900	16,840	1,512
N31680	6,100	16,840	1,512
N31681	5,900	16,840	1,512
N31682	2,100	16,840	1,512
N31683	1,900	16,840	1,512
N31684	-1,900	16,840	1,512
N31703	13,900	17,200	1,512
N31705	10,100	17,200	1,512
N31706	9,900	17,200	1,512
N31708	6,100	17,200	1,512
N31709	5,900	17,200	1,512
N31711	2,100	17,200	1,512
N31712	1,900	17,200	1,512
N31714	-1,900	17,200	1,512
N31733	13,900	17,560	1,512
N31735	10,100	17,560	1,512
N31736	9,900	17,560	1,512
N31738	6,100	17,560	1,512
N31739	5,900	17,560	1,512
N31741	2,100	17,560	1,512
N31742	1,900	17,560	1,512
N31744	-1,900	17,560	1,512
N31763	13,900	17,920	1,512
N31765	10,100	17,920	1,512
N31766	9,900	17,920	1,512
N31768	6,100	17,920	1,512
N31769	5,900	17,920	1,512
N31771	2,100	17,920	1,512
N31772	1,900	17,920	1,512
N31774	-1,900	17,920	1,512
N31793	13,900	18,280	1,512
N31795	10,100	18,280	1,512
N31796	9,900	18,280	1,512
N31798	6,100	18,280	1,512
N31799	5,900	18,280	1,512
N31801	2,100	18,280	1,512

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N31802	1,900	18,280	1,512
N31804	-1,900	18,280	1,512
N31823	13,900	18,640	1,512
N31825	10,100	18,640	1,512
N31826	9,900	18,640	1,512
N31828	6,100	18,640	1,512
N31829	5,900	18,640	1,512
N31831	2,100	18,640	1,512
N31832	1,900	18,640	1,512
N31834	-1,900	18,640	1,512
N31853	13,900	19,000	1,512
N31855	10,100	19,000	1,512
N31856	9,900	19,000	1,512
N31858	6,100	19,000	1,512
N31859	5,900	19,000	1,512
N31861	2,100	19,000	1,512
N31862	1,900	19,000	1,512
N31864	-1,900	19,000	1,512
N31883	13,900	19,360	1,512
N31885	10,100	19,360	1,512
N31886	9,900	19,360	1,512
N31888	6,100	19,360	1,512
N31889	5,900	19,360	1,512
N31891	2,100	19,360	1,512
N31892	1,900	19,360	1,512
N31894	-1,900	19,360	1,512
N31913	13,900	19,720	1,512
N31915	10,100	19,720	1,512
N31916	9,900	19,720	1,512
N31918	6,100	19,720	1,512
N31919	5,900	19,720	1,512
N31921	2,100	19,720	1,512
N31922	1,900	19,720	1,512
N31924	-1,900	19,720	1,512
N31943	13,900	20,080	1,512
N31945	10,100	20,080	1,512
N31946	9,900	20,080	1,512
N31948	6,100	20,080	1,512
N31949	5,900	20,080	1,512
N31951	2,100	20,080	1,512
N31952	1,900	20,080	1,512
N31954	-1,900	20,080	1,512
N31973	13,900	20,440	1,512
N31975	10,100	20,440	1,512
N31976	9,900	20,440	1,512
N31978	6,100	20,440	1,512
N31979	5,900	20,440	1,512
N31981	2,100	20,440	1,512
N31982	1,900	20,440	1,512
N31984	-1,900	20,440	1,512
N32002	13,900	20,800	1,512
N32003	10,100	20,800	1,512
N32004	9,900	20,800	1,512
N32005	6,100	20,800	1,512
N32006	5,900	20,800	1,512
N32007	2,100	20,800	1,512
N32008	1,900	20,800	1,512
N32009	-1,900	20,800	1,512
N32028	13,900	21,160	1,512
N32030	10,100	21,160	1,512
N32031	9,900	21,160	1,512
N32033	6,100	21,160	1,512
N32034	5,900	21,160	1,512
N32036	2,100	21,160	1,512
N32037	1,900	21,160	1,512
N32039	-1,900	21,160	1,512
N32058	13,900	21,520	1,512
N32060	10,100	21,520	1,512
N32061	9,900	21,520	1,512

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N32063	6,100	21,520	1,512
N32064	5,900	21,520	1,512
N32066	2,100	21,520	1,512
N32067	1,900	21,520	1,512
N32069	-1,900	21,520	1,512
N32088	13,900	21,880	1,512
N32090	10,100	21,880	1,512
N32091	9,900	21,880	1,512
N32093	6,100	21,880	1,512
N32094	5,900	21,880	1,512
N32096	2,100	21,880	1,512
N32097	1,900	21,880	1,512
N32099	-1,900	21,880	1,512
N32118	13,900	22,240	1,512
N32120	10,100	22,240	1,512
N32121	9,900	22,240	1,512
N32123	6,100	22,240	1,512
N32124	5,900	22,240	1,512
N32126	2,100	22,240	1,512
N32127	1,900	22,240	1,512
N32129	-1,900	22,240	1,512
N32148	13,900	22,600	1,512
N32150	10,100	22,600	1,512
N32151	9,900	22,600	1,512
N32153	6,100	22,600	1,512
N32154	5,900	22,600	1,512
N32156	2,100	22,600	1,512
N32157	1,900	22,600	1,512
N32159	-1,900	22,600	1,512
N32178	13,900	22,960	1,512
N32180	10,100	22,960	1,512
N32181	9,900	22,960	1,512
N32183	6,100	22,960	1,512
N32184	5,900	22,960	1,512
N32186	2,100	22,960	1,512
N32187	1,900	22,960	1,512
N32189	-1,900	22,960	1,512
N32208	13,900	23,320	1,512
N32210	10,100	23,320	1,512
N32211	9,900	23,320	1,512
N32213	6,100	23,320	1,512
N32214	5,900	23,320	1,512
N32216	2,100	23,320	1,512
N32217	1,900	23,320	1,512
N32219	-1,900	23,320	1,512
N32238	13,900	23,680	1,512
N32240	10,100	23,680	1,512
N32241	9,900	23,680	1,512
N32243	6,100	23,680	1,512
N32244	5,900	23,680	1,512
N32246	2,100	23,680	1,512
N32247	1,900	23,680	1,512
N32249	-1,900	23,680	1,512
N32268	13,900	24,040	1,512
N32270	10,100	24,040	1,512
N32271	9,900	24,040	1,512
N32273	6,100	24,040	1,512
N32274	5,900	24,040	1,512
N32276	2,100	24,040	1,512
N32277	1,900	24,040	1,512
N32279	-1,900	24,040	1,512
N32298	13,900	24,400	1,512
N32300	10,100	24,400	1,512
N32301	9,900	24,400	1,512
N32303	6,100	24,400	1,512
N32304	5,900	24,400	1,512
N32306	2,100	24,400	1,512
N32307	1,900	24,400	1,512
N32309	-1,900	24,400	1,512

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N32327	13,900	24,760	1,512
N32328	10,100	24,760	1,512
N32329	9,900	24,760	1,512
N32330	6,100	24,760	1,512
N32331	5,900	24,760	1,512
N32332	2,100	24,760	1,512
N32333	1,900	24,760	1,512
N32334	-1,900	24,760	1,512
N32353	13,900	25,120	1,512
N32355	10,100	25,120	1,512
N32356	9,900	25,120	1,512
N32358	6,100	25,120	1,512
N32359	5,900	25,120	1,512
N32361	2,100	25,120	1,512
N32362	1,900	25,120	1,512
N32364	-1,900	25,120	1,512
N32383	13,900	25,480	1,512
N32385	10,100	25,480	1,512
N32386	9,900	25,480	1,512
N32388	6,100	25,480	1,512
N32389	5,900	25,480	1,512
N32391	2,100	25,480	1,512
N32392	1,900	25,480	1,512
N32394	-1,900	25,480	1,512
N32413	13,900	25,840	1,512
N32415	10,100	25,840	1,512
N32416	9,900	25,840	1,512
N32418	6,100	25,840	1,512
N32419	5,900	25,840	1,512
N32421	2,100	25,840	1,512
N32422	1,900	25,840	1,512
N32424	-1,900	25,840	1,512
N32443	13,900	26,200	1,512
N32445	10,100	26,200	1,512
N32446	9,900	26,200	1,512
N32448	6,100	26,200	1,512
N32449	5,900	26,200	1,512
N32451	2,100	26,200	1,512
N32452	1,900	26,200	1,512
N32454	-1,900	26,200	1,512
N32473	13,900	26,560	1,512
N32475	10,100	26,560	1,512
N32476	9,900	26,560	1,512
N32478	6,100	26,560	1,512
N32479	5,900	26,560	1,512
N32481	2,100	26,560	1,512
N32482	1,900	26,560	1,512
N32484	-1,900	26,560	1,512
N32503	13,900	26,920	1,512
N32505	10,100	26,920	1,512
N32506	9,900	26,920	1,512
N32508	6,100	26,920	1,512
N32509	5,900	26,920	1,512
N32511	2,100	26,920	1,512
N32512	1,900	26,920	1,512
N32514	-1,900	26,920	1,512
N32533	13,900	27,280	1,512
N32535	10,100	27,280	1,512
N32536	9,900	27,280	1,512
N32538	6,100	27,280	1,512
N32539	5,900	27,280	1,512
N32541	2,100	27,280	1,512
N32542	1,900	27,280	1,512
N32544	-1,900	27,280	1,512
N32563	13,900	27,640	1,512
N32565	10,100	27,640	1,512
N32566	9,900	27,640	1,512
N32568	6,100	27,640	1,512
N32569	5,900	27,640	1,512

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N32571	2,100	27,640	1,512
N32572	1,900	27,640	1,512
N32574	-1,900	27,640	1,512
N32593	13,900	28,000	1,512
N32595	10,100	28,000	1,512
N32596	9,900	28,000	1,512
N32598	6,100	28,000	1,512
N32599	5,900	28,000	1,512
N32601	2,100	28,000	1,512
N32602	1,900	28,000	1,512
N32604	-1,900	28,000	1,512
N32623	13,900	28,360	1,512
N32625	10,100	28,360	1,512
N32626	9,900	28,360	1,512
N32628	6,100	28,360	1,512
N32629	5,900	28,360	1,512
N32631	2,100	28,360	1,512
N32632	1,900	28,360	1,512
N32634	-1,900	28,360	1,512
N32652	13,900	28,720	1,512
N32653	10,100	28,720	1,512
N32654	9,900	28,720	1,512
N32655	6,100	28,720	1,512
N32656	5,900	28,720	1,512
N32657	2,100	28,720	1,512
N32658	1,900	28,720	1,512
N32659	-1,900	28,720	1,512
N32678	13,900	29,080	1,512
N32680	10,100	29,080	1,512
N32681	9,900	29,080	1,512
N32683	6,100	29,080	1,512
N32684	5,900	29,080	1,512
N32686	2,100	29,080	1,512
N32687	1,900	29,080	1,512
N32689	-1,900	29,080	1,512
N32708	13,900	29,440	1,512
N32710	10,100	29,440	1,512
N32711	9,900	29,440	1,512
N32713	6,100	29,440	1,512
N32714	5,900	29,440	1,512
N32716	2,100	29,440	1,512
N32717	1,900	29,440	1,512
N32719	-1,900	29,440	1,512
N32738	13,900	29,800	1,512
N32740	10,100	29,800	1,512
N32741	9,900	29,800	1,512
N32743	6,100	29,800	1,512
N32744	5,900	29,800	1,512
N32746	2,100	29,800	1,512
N32747	1,900	29,800	1,512
N32749	-1,900	29,800	1,512
N32768	13,900	30,160	1,512
N32770	10,100	30,160	1,512
N32771	9,900	30,160	1,512
N32773	6,100	30,160	1,512
N32774	5,900	30,160	1,512
N32776	2,100	30,160	1,512
N32777	1,900	30,160	1,512
N32779	-1,900	30,160	1,512
N32786	13,900	30,520	1,512
N32797	10,100	30,520	1,512
N32804	9,900	30,520	1,512
N32809	6,100	30,520	1,512
N32816	5,900	30,520	1,512
N32821	2,100	30,520	1,512
N32828	1,900	30,520	1,512
N32833	-1,900	30,520	1,512
N32840	14,000	1,660	1,350
N32841	13,900	1,660	1,350

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N32842	14,100	1,660	1,350
N32843	10,000	1,660	1,350
N32844	9,900	1,660	1,350
N32845	10,100	1,660	1,350
N32846	6,000	1,660	1,350
N32847	5,900	1,660	1,350
N32848	6,100	1,660	1,350
N32849	2,000	1,660	1,350
N32850	1,900	1,660	1,350
N32851	2,100	1,660	1,350
N32852	-2,000	1,660	1,350
N32853	-2,100	1,660	1,350
N32854	-1,900	1,660	1,350
N32855	14,100	1,660	1,512
N32856	-2,100	1,660	1,512
N32857	14,000	1,990	1,350
N32858	13,900	1,990	1,350
N32859	14,100	1,990	1,350
N32860	10,000	1,990	1,350
N32861	9,900	1,990	1,350
N32862	10,100	1,990	1,350
N32863	6,000	1,990	1,350
N32864	5,900	1,990	1,350
N32865	6,100	1,990	1,350
N32866	2,000	1,990	1,350
N32867	1,900	1,990	1,350
N32868	2,100	1,990	1,350
N32869	-2,000	1,990	1,350
N32870	-2,100	1,990	1,350
N32871	-1,900	1,990	1,350
N32872	14,100	1,990	1,512
N32873	13,900	1,990	1,512
N32874	10,100	1,990	1,512
N32875	9,900	1,990	1,512
N32876	6,100	1,990	1,512
N32877	5,900	1,990	1,512
N32878	2,100	1,990	1,512
N32879	1,900	1,990	1,512
N32880	-1,900	1,990	1,512
N32881	-2,100	1,990	1,512
N32882	14,000	2,320	1,350
N32883	13,900	2,320	1,350
N32884	14,100	2,320	1,350
N32885	10,000	2,320	1,350
N32886	9,900	2,320	1,350
N32887	10,100	2,320	1,350
N32888	6,000	2,320	1,350
N32889	5,900	2,320	1,350
N32890	6,100	2,320	1,350
N32891	2,000	2,320	1,350
N32892	1,900	2,320	1,350
N32893	2,100	2,320	1,350
N32894	-2,000	2,320	1,350
N32895	-2,100	2,320	1,350
N32896	-1,900	2,320	1,350
N32897	14,100	2,320	1,512
N32898	13,900	2,320	1,512
N32899	10,100	2,320	1,512
N32900	9,900	2,320	1,512
N32901	6,100	2,320	1,512
N32902	5,900	2,320	1,512
N32903	2,100	2,320	1,512
N32904	1,900	2,320	1,512
N32905	-1,900	2,320	1,512
N32906	-2,100	2,320	1,512
N32907	14,000	2,650	1,350
N32908	13,900	2,650	1,350
N32909	14,100	2,650	1,350
N32910	10,000	2,650	1,350

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N32911	9,900	2,650	1,350
N32912	10,100	2,650	1,350
N32913	6,000	2,650	1,350
N32914	5,900	2,650	1,350
N32915	6,100	2,650	1,350
N32916	2,000	2,650	1,350
N32917	1,900	2,650	1,350
N32918	2,100	2,650	1,350
N32919	-2,000	2,650	1,350
N32920	-2,100	2,650	1,350
N32921	-1,900	2,650	1,350
N32922	14,100	2,650	1,512
N32923	13,900	2,650	1,512
N32924	10,100	2,650	1,512
N32925	9,900	2,650	1,512
N32926	6,100	2,650	1,512
N32927	5,900	2,650	1,512
N32928	2,100	2,650	1,512
N32929	1,900	2,650	1,512
N32930	-1,900	2,650	1,512
N32931	-2,100	2,650	1,512
N32932	14,000	2,980	1,350
N32933	13,900	2,980	1,350
N32934	14,100	2,980	1,350
N32935	10,000	2,980	1,350
N32936	9,900	2,980	1,350
N32937	10,100	2,980	1,350
N32938	6,000	2,980	1,350
N32939	5,900	2,980	1,350
N32940	6,100	2,980	1,350
N32941	2,000	2,980	1,350
N32942	1,900	2,980	1,350
N32943	2,100	2,980	1,350
N32944	-2,000	2,980	1,350
N32945	-2,100	2,980	1,350
N32946	-1,900	2,980	1,350
N32947	14,100	2,980	1,512
N32948	13,900	2,980	1,512
N32949	10,100	2,980	1,512
N32950	9,900	2,980	1,512
N32951	6,100	2,980	1,512
N32952	5,900	2,980	1,512
N32953	2,100	2,980	1,512
N32954	1,900	2,980	1,512
N32955	-1,900	2,980	1,512
N32956	-2,100	2,980	1,512
N32957	14,000	3,310	1,350
N32958	13,900	3,310	1,350
N32959	14,100	3,310	1,350
N32960	10,000	3,310	1,350
N32961	9,900	3,310	1,350
N32962	10,100	3,310	1,350
N32963	6,000	3,310	1,350
N32964	5,900	3,310	1,350
N32965	6,100	3,310	1,350
N32966	2,000	3,310	1,350
N32967	1,900	3,310	1,350
N32968	2,100	3,310	1,350
N32969	-2,000	3,310	1,350
N32970	-2,100	3,310	1,350
N32971	-1,900	3,310	1,350
N32972	14,100	3,310	1,512
N32973	13,900	3,310	1,512
N32974	10,100	3,310	1,512
N32975	9,900	3,310	1,512
N32976	6,100	3,310	1,512
N32977	5,900	3,310	1,512
N32978	2,100	3,310	1,512
N32979	1,900	3,310	1,512

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N32980	-1,900	3,310	1,512
N32981	-2,100	3,310	1,512
N32982	14,000	3,640	1,350
N32983	13,900	3,640	1,350
N32984	14,100	3,640	1,350
N32985	10,000	3,640	1,350
N32986	9,900	3,640	1,350
N32987	10,100	3,640	1,350
N32988	6,000	3,640	1,350
N32989	5,900	3,640	1,350
N32990	6,100	3,640	1,350
N32991	2,000	3,640	1,350
N32992	1,900	3,640	1,350
N32993	2,100	3,640	1,350
N32994	-2,000	3,640	1,350
N32995	-2,100	3,640	1,350
N32996	-1,900	3,640	1,350
N32997	14,100	3,640	1,512
N32998	13,900	3,640	1,512
N32999	10,100	3,640	1,512
N33000	9,900	3,640	1,512
N33001	6,100	3,640	1,512
N33002	5,900	3,640	1,512
N33003	2,100	3,640	1,512
N33004	1,900	3,640	1,512
N33005	-1,900	3,640	1,512
N33006	-2,100	3,640	1,512
N33007	14,000	3,970	1,350
N33008	13,900	3,970	1,350
N33009	14,100	3,970	1,350
N33010	10,000	3,970	1,350
N33011	9,900	3,970	1,350
N33012	10,100	3,970	1,350
N33013	6,000	3,970	1,350
N33014	5,900	3,970	1,350
N33015	6,100	3,970	1,350
N33016	2,000	3,970	1,350
N33017	1,900	3,970	1,350
N33018	2,100	3,970	1,350
N33019	-2,000	3,970	1,350
N33020	-2,100	3,970	1,350
N33021	-1,900	3,970	1,350
N33022	14,100	3,970	1,512
N33023	13,900	3,970	1,512
N33024	10,100	3,970	1,512
N33025	9,900	3,970	1,512
N33026	6,100	3,970	1,512
N33027	5,900	3,970	1,512
N33028	2,100	3,970	1,512
N33029	1,900	3,970	1,512
N33030	-1,900	3,970	1,512
N33031	-2,100	3,970	1,512
N33032	14,000	4,300	1,350
N33033	13,900	4,300	1,350
N33034	14,100	4,300	1,350
N33035	10,000	4,300	1,350
N33036	9,900	4,300	1,350
N33037	10,100	4,300	1,350
N33038	6,000	4,300	1,350
N33039	5,900	4,300	1,350
N33040	6,100	4,300	1,350
N33041	2,000	4,300	1,350
N33042	1,900	4,300	1,350
N33043	2,100	4,300	1,350
N33044	-2,000	4,300	1,350
N33045	-2,100	4,300	1,350
N33046	-1,900	4,300	1,350
N33047	14,100	4,300	1,512
N33048	13,900	4,300	1,512
N33049	10,100	4,300	1,512
N33050	9,900	4,300	1,512
N33051	6,100	4,300	1,512
N33052	5,900	4,300	1,512
N33053	2,100	4,300	1,512
N33054	1,900	4,300	1,512
N33055	-1,900	4,300	1,512
N33056	-2,100	4,300	1,512
N33057	14,000	4,630	1,350
N33058	13,900	4,630	1,350
N33059	14,100	4,630	1,350
N33060	10,000	4,630	1,350
N33061	9,900	4,630	1,350
N33062	10,100	4,630	1,350
N33063	6,000	4,630	1,350
N33064	5,900	4,630	1,350
N33065	6,100	4,630	1,350
N33066	2,000	4,630	1,350
N33067	1,900	4,630	1,350
N33068	2,100	4,630	1,350
N33069	-2,000	4,630	1,350
N33070	-2,100	4,630	1,350
N33071	-1,900	4,630	1,350
N33072	14,100	4,630	1,512
N33073	13,900	4,630	1,512
N33074	10,100	4,630	1,512
N33075	9,900	4,630	1,512
N33076	6,100	4,630	1,512
N33077	5,900	4,630	1,512
N33078	2,100	4,630	1,512
N33079	1,900	4,630	1,512
N33080	-1,900	4,630	1,512
N33081	-2,100	4,630	1,512
N33082	14,000	4,960	1,350
N33083	13,900	4,960	1,350
N33084	14,100	4,960	1,350
N33085	10,000	4,960	1,350
N33086	9,900	4,960	1,350
N33087	10,100	4,960	1,350
N33088	6,000	4,960	1,350
N33089	5,900	4,960	1,350
N33090	6,100	4,960	1,350
N33091	2,000	4,960	1,350
N33092	1,900	4,960	1,350
N33093	2,100	4,960	1,350
N33094	-2,000	4,960	1,350
N33095	-2,100	4,960	1,350
N33096	-1,900	4,960	1,350
N33097	14,100	4,960	1,512
N33098	-2,100	4,960	1,512
N33099	14,000	5,290	1,350
N33100	13,900	5,290	1,350
N33101	14,100	5,290	1,350
N33102	10,000	5,290	1,350
N33103	9,900	5,290	1,350
N33104	10,100	5,290	1,350
N33105	6,000	5,290	1,350
N33106	5,900	5,290	1,350
N33107	6,100	5,290	1,350
N33108	2,000	5,290	1,350
N33109	1,900	5,290	1,350
N33110	2,100	5,290	1,350
N33111	-2,000	5,290	1,350
N33112	-2,100	5,290	1,350
N33113	-1,900	5,290	1,350
N33114	14,100	5,290	1,512
N33115	13,900	5,290	1,512
N33116	10,100	5,290	1,512
N33117	9,900	5,290	1,512
N33118	6,100	5,290	1,512
N33119	5,900	5,290	1,512
N33120	2,100	5,290	1,512
N33121	1,900	5,290	1,512
N33122	-1,900	5,290	1,512
N33123	-2,100	5,290	1,512
N33124	14,000	5,620	1,350
N33125	13,900	5,620	1,350
N33126	14,100	5,620	1,350
N33127	10,000	5,620	1,350
N33128	9,900	5,620	1,350
N33129	10,100	5,620	1,350
N33130	6,000	5,620	1,350
N33131	5,900	5,620	1,350
N33132	6,100	5,620	1,350
N33133	2,000	5,620	1,350
N33134	1,900	5,620	1,350
N33135	2,100	5,620	1,350
N33136	-2,000	5,620	1,350
N33137	-2,100	5,620	1,350
N33138	-1,900	5,620	1,350
N33139	14,100	5,620	1,512
N33140	13,900	5,620	1,512
N33141	10,100	5,620	1,512
N33142	9,900	5,620	1,512
N33143	6,100	5,620	1,512
N33144	5,900	5,620	1,512
N33145	2,100	5,620	1,512
N33146	1,900	5,620	1,512
N33147	-1,900	5,620	1,512
N33148	-2,100	5,620	1,512
N33149	14,000	5,950	1,350
N33150	13,900	5,950	1,350
N33151	14,100	5,950	1,350
N33152	10,000	5,950	1,350
N33153	9,900	5,950	1,350
N33154	10,100	5,950	1,350
N33155	6,000	5,950	1,350
N33156	5,900	5,950	1,350
N33157	6,100	5,950	1,350
N33158	2,000	5,950	1,350
N33159	1,900	5,950	1,350
N33160	2,100	5,950	1,350
N33161	-2,000	5,950	1,350
N33162	-2,100	5,950	1,350
N33163	-1,900	5,950	1,350
N33164	14,100	5,950	1,512
N33165	13,900	5,950	1,512
N33166	10,100	5,950	1,512
N33167	9,900	5,950	1,512
N33168	6,100	5,950	1,512
N33169	5,900	5,950	1,512
N33170	2,100	5,950	1,512
N33171	1,900	5,950	1,512
N33172	-1,900	5,950	1,512
N33173	-2,100	5,950	1,512
N33174	14,000	6,280	1,350
N33175	13,900	6,280	1,350
N33176	14,100	6,280	1,350
N33177	10,000	6,280	1,350
N33178	9,900	6,280	1,350
N33179	10,100	6,280	1,350
N33180	6,000	6,280	1,350
N33181	5,900	6,280	1,350
N33182	6,100	6,280	1,350
N33183	2,000	6,280	1,350
N33184	1,900	6,280	1,350
N33185	2,100	6,280	1,350
N33186	-2,000	6,280	1,350

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N33187	-2,100	6,280	1,350
N33188	-1,900	6,280	1,350
N33189	14,100	6,280	1,512
N33190	13,900	6,280	1,512
N33191	10,100	6,280	1,512
N33192	9,900	6,280	1,512
N33193	6,100	6,280	1,512
N33194	5,900	6,280	1,512
N33195	2,100	6,280	1,512
N33196	1,900	6,280	1,512
N33197	-1,900	6,280	1,512
N33198	-2,100	6,280	1,512
N33199	14,000	6,610	1,350
N33200	13,900	6,610	1,350
N33201	14,100	6,610	1,350
N33202	10,000	6,610	1,350
N33203	9,900	6,610	1,350
N33204	10,100	6,610	1,350
N33205	6,000	6,610	1,350
N33206	5,900	6,610	1,350
N33207	6,100	6,610	1,350
N33208	2,000	6,610	1,350
N33209	1,900	6,610	1,350
N33210	2,100	6,610	1,350
N33211	-2,000	6,610	1,350
N33212	-2,100	6,610	1,350
N33213	-1,900	6,610	1,350
N33214	14,100	6,610	1,512
N33215	13,900	6,610	1,512
N33216	10,100	6,610	1,512
N33217	9,900	6,610	1,512
N33218	6,100	6,610	1,512
N33219	5,900	6,610	1,512
N33220	2,100	6,610	1,512
N33221	1,900	6,610	1,512
N33222	-1,900	6,610	1,512
N33223	-2,100	6,610	1,512
N33224	14,000	6,940	1,350
N33225	13,900	6,940	1,350
N33226	14,100	6,940	1,350
N33227	10,000	6,940	1,350
N33228	9,900	6,940	1,350
N33229	10,100	6,940	1,350
N33230	6,000	6,940	1,350
N33231	5,900	6,940	1,350
N33232	6,100	6,940	1,350
N33233	2,000	6,940	1,350
N33234	1,900	6,940	1,350
N33235	2,100	6,940	1,350
N33236	-2,000	6,940	1,350
N33237	-2,100	6,940	1,350
N33238	-1,900	6,940	1,350
N33239	14,100	6,940	1,512
N33240	13,900	6,940	1,512
N33241	10,100	6,940	1,512
N33242	9,900	6,940	1,512
N33243	6,100	6,940	1,512
N33244	5,900	6,940	1,512
N33245	2,100	6,940	1,512
N33246	1,900	6,940	1,512
N33247	-1,900	6,940	1,512
N33248	-2,100	6,940	1,512
N33249	14,000	7,270	1,350
N33250	13,900	7,270	1,350
N33251	14,100	7,270	1,350
N33252	10,000	7,270	1,350
N33253	9,900	7,270	1,350
N33254	10,100	7,270	1,350
N33255	6,000	7,270	1,350

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N33256	5,900	7,270	1,350
N33257	6,100	7,270	1,350
N33258	2,000	7,270	1,350
N33259	1,900	7,270	1,350
N33260	2,100	7,270	1,350
N33261	-2,000	7,270	1,350
N33262	-2,100	7,270	1,350
N33263	-1,900	7,270	1,350
N33264	14,100	7,270	1,512
N33265	13,900	7,270	1,512
N33266	10,100	7,270	1,512
N33267	9,900	7,270	1,512
N33268	6,100	7,270	1,512
N33269	5,900	7,270	1,512
N33270	2,100	7,270	1,512
N33271	1,900	7,270	1,512
N33272	-1,900	7,270	1,512
N33273	-2,100	7,270	1,512
N33274	14,000	7,600	1,350
N33275	13,900	7,600	1,350
N33276	14,100	7,600	1,350
N33277	10,000	7,600	1,350
N33278	9,900	7,600	1,350
N33279	10,100	7,600	1,350
N33280	6,000	7,600	1,350
N33281	5,900	7,600	1,350
N33282	6,100	7,600	1,350
N33283	2,000	7,600	1,350
N33284	1,900	7,600	1,350
N33285	2,100	7,600	1,350
N33286	-2,000	7,600	1,350
N33287	-2,100	7,600	1,350
N33288	-1,900	7,600	1,350
N33289	14,100	7,600	1,512
N33290	13,900	7,600	1,512
N33291	10,100	7,600	1,512
N33292	9,900	7,600	1,512
N33293	6,100	7,600	1,512
N33294	5,900	7,600	1,512
N33295	2,100	7,600	1,512
N33296	1,900	7,600	1,512
N33297	-1,900	7,600	1,512
N33298	-2,100	7,600	1,512
N33299	14,000	7,930	1,350
N33300	13,900	7,930	1,350
N33301	14,100	7,930	1,350
N33302	10,000	7,930	1,350
N33303	9,900	7,930	1,350
N33304	10,100	7,930	1,350
N33305	6,000	7,930	1,350
N33306	5,900	7,930	1,350
N33307	6,100	7,930	1,350
N33308	2,000	7,930	1,350
N33309	1,900	7,930	1,350
N33310	2,100	7,930	1,350
N33311	-2,000	7,930	1,350
N33312	-2,100	7,930	1,350
N33313	-1,900	7,930	1,350
N33314	14,100	7,930	1,512
N33315	-2,100	7,930	1,512
N33316	14,000	8,260	1,350
N33317	13,900	8,260	1,350
N33318	14,100	8,260	1,350
N33319	10,000	8,260	1,350
N33320	9,900	8,260	1,350
N33321	10,100	8,260	1,350
N33322	6,000	8,260	1,350
N33323	5,900	8,260	1,350
N33324	6,100	8,260	1,350

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N33325	2,000	8,260	1,350
N33326	1,900	8,260	1,350
N33327	2,100	8,260	1,350
N33328	-2,000	8,260	1,350
N33329	-2,100	8,260	1,350
N33330	-1,900	8,260	1,350
N33331	14,100	8,260	1,512
N33332	-2,100	8,260	1,512
N33333	14,000	8,590	1,350
N33334	13,900	8,590	1,350
N33335	14,100	8,590	1,350
N33336	10,000	8,590	1,350
N33337	9,900	8,590	1,350
N33338	10,100	8,590	1,350
N33339	6,000	8,590	1,350
N33340	5,900	8,590	1,350
N33341	6,100	8,590	1,350
N33342	2,000	8,590	1,350
N33343	1,900	8,590	1,350
N33344	2,100	8,590	1,350
N33345	-2,000	8,590	1,350
N33346	-2,100	8,590	1,350
N33347	-1,900	8,590	1,350
N33348	14,100	8,590	1,512
N33349	13,900	8,590	1,512
N33350	10,100	8,590	1,512
N33351	9,900	8,590	1,512
N33352	6,100	8,590	1,512
N33353	5,900	8,590	1,512
N33354	2,100	8,590	1,512
N33355	1,900	8,590	1,512
N33356	-1,900	8,590	1,512
N33357	-2,100	8,590	1,512
N33358	14,000	8,920	1,350
N33359	13,900	8,920	1,350
N33360	14,100	8,920	1,350
N33361	10,000	8,920	1,350
N33362	9,900	8,920	1,350
N33363	10,100	8,920	1,350
N33364	6,000	8,920	1,350
N33365	5,900	8,920	1,350
N33366	6,100	8,920	1,350
N33367	2,000	8,920	1,350
N33368	1,900	8,920	1,350
N33369	2,100	8,920	1,350
N33370	-2,000	8,920	1,350
N33371	-2,100	8,920	1,350
N33372	-1,900	8,920	1,350
N33373	14,100	8,920	1,512
N33374	-2,100	8,920	1,512
N33375	14,000	9,250	1,350
N33376	13,900	9,250	1,350
N33377	14,100	9,250	1,350
N33378	10,000	9,250	1,350
N33379	9,900	9,250	1,350
N33380	10,100	9,250	1,350
N33381	6,000	9,250	1,350
N33382	5,900	9,250	1,350
N33383	6,100	9,250	1,350
N33384	2,000	9,250	1,350
N33385	1,900	9,250	1,350
N33386	2,100	9,250	1,350
N33387	-2,000	9,250	1,350
N33388	-2,100	9,250	1,350
N33389	-1,900	9,250	1,350
N33390	14,100	9,250	1,512
N33391	13,900	9,250	1,512
N33392	10,100	9,250	1,512
N33393	9,900	9,250	1,512

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N33394	6,100	9,250	1,512
N33395	5,900	9,250	1,512
N33396	2,100	9,250	1,512
N33397	1,900	9,250	1,512
N33398	-1,900	9,250	1,512
N33399	-2,100	9,250	1,512
N33400	14,000	9,580	1,350
N33401	13,900	9,580	1,350
N33402	14,100	9,580	1,350
N33403	10,000	9,580	1,350
N33404	9,900	9,580	1,350
N33405	10,100	9,580	1,350
N33406	6,000	9,580	1,350
N33407	5,900	9,580	1,350
N33408	6,100	9,580	1,350
N33409	2,000	9,580	1,350
N33410	1,900	9,580	1,350
N33411	2,100	9,580	1,350
N33412	-2,000	9,580	1,350
N33413	-2,100	9,580	1,350
N33414	-1,900	9,580	1,350
N33415	14,100	9,580	1,512
N33416	13,900	9,580	1,512
N33417	10,100	9,580	1,512
N33418	9,900	9,580	1,512
N33419	6,100	9,580	1,512
N33420	5,900	9,580	1,512
N33421	2,100	9,580	1,512
N33422	1,900	9,580	1,512
N33423	-1,900	9,580	1,512
N33424	-2,100	9,580	1,512
N33425	14,000	9,910	1,350
N33426	13,900	9,910	1,350
N33427	14,100	9,910	1,350
N33428	10,000	9,910	1,350
N33429	9,900	9,910	1,350
N33430	10,100	9,910	1,350
N33431	6,000	9,910	1,350
N33432	5,900	9,910	1,350
N33433	6,100	9,910	1,350
N33434	2,000	9,910	1,350
N33435	1,900	9,910	1,350
N33436	2,100	9,910	1,350
N33437	-2,000	9,910	1,350
N33438	-2,100	9,910	1,350
N33439	-1,900	9,910	1,350
N33440	14,100	9,910	1,512
N33441	13,900	9,910	1,512
N33442	10,100	9,910	1,512
N33443	9,900	9,910	1,512
N33444	6,100	9,910	1,512
N33445	5,900	9,910	1,512
N33446	2,100	9,910	1,512
N33447	1,900	9,910	1,512
N33448	-1,900	9,910	1,512
N33449	-2,100	9,910	1,512
N33450	14,000	10,240	1,350
N33451	13,900	10,240	1,350
N33452	14,100	10,240	1,350
N33453	10,000	10,240	1,350
N33454	9,900	10,240	1,350
N33455	10,100	10,240	1,350
N33456	6,000	10,240	1,350
N33457	5,900	10,240	1,350
N33458	6,100	10,240	1,350
N33459	2,000	10,240	1,350
N33460	1,900	10,240	1,350
N33461	2,100	10,240	1,350
N33462	-2,000	10,240	1,350

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N33463	-2,100	10,240	1,350
N33464	-1,900	10,240	1,350
N33465	14,100	10,240	1,512
N33466	13,900	10,240	1,512
N33467	10,100	10,240	1,512
N33468	9,900	10,240	1,512
N33469	6,100	10,240	1,512
N33470	5,900	10,240	1,512
N33471	2,100	10,240	1,512
N33472	1,900	10,240	1,512
N33473	-1,900	10,240	1,512
N33474	-2,100	10,240	1,512
N33475	14,000	10,570	1,350
N33476	13,900	10,570	1,350
N33477	14,100	10,570	1,350
N33478	10,000	10,570	1,350
N33479	9,900	10,570	1,350
N33480	10,100	10,570	1,350
N33481	6,000	10,570	1,350
N33482	5,900	10,570	1,350
N33483	6,100	10,570	1,350
N33484	2,000	10,570	1,350
N33485	1,900	10,570	1,350
N33486	2,100	10,570	1,350
N33487	-2,000	10,570	1,350
N33488	-2,100	10,570	1,350
N33489	-1,900	10,570	1,350
N33490	14,100	10,570	1,512
N33491	13,900	10,570	1,512
N33492	10,100	10,570	1,512
N33493	9,900	10,570	1,512
N33494	6,100	10,570	1,512
N33495	5,900	10,570	1,512
N33496	2,100	10,570	1,512
N33497	1,900	10,570	1,512
N33498	-1,900	10,570	1,512
N33499	-2,100	10,570	1,512
N33500	14,000	10,900	1,350
N33501	13,900	10,900	1,350
N33502	14,100	10,900	1,350
N33503	10,000	10,900	1,350
N33504	9,900	10,900	1,350
N33505	10,100	10,900	1,350
N33506	6,000	10,900	1,350
N33507	5,900	10,900	1,350
N33508	6,100	10,900	1,350
N33509	2,000	10,900	1,350
N33510	1,900	10,900	1,350
N33511	2,100	10,900	1,350
N33512	-2,000	10,900	1,350
N33513	-2,100	10,900	1,350
N33514	-1,900	10,900	1,350
N33515	14,100	10,900	1,512
N33516	13,900	10,900	1,512
N33517	10,100	10,900	1,512
N33518	9,900	10,900	1,512
N33519	6,100	10,900	1,512
N33520	5,900	10,900	1,512
N33521	2,100	10,900	1,512
N33522	1,900	10,900	1,512
N33523	-1,900	10,900	1,512
N33524	-2,100	10,900	1,512
N33525	14,000	11,230	1,350
N33526	13,900	11,230	1,350
N33527	14,100	11,230	1,350
N33528	10,000	11,230	1,350
N33529	9,900	11,230	1,350
N33530	10,100	11,230	1,350
N33531	6,000	11,230	1,350

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N33532	5,900	11,230	1,350
N33533	6,100	11,230	1,350
N33534	2,000	11,230	1,350
N33535	1,900	11,230	1,350
N33536	2,100	11,230	1,350
N33537	-2,000	11,230	1,350
N33538	-2,100	11,230	1,350
N33539	-1,900	11,230	1,350
N33540	14,100	11,230	1,512
N33541	13,900	11,230	1,512
N33542	10,100	11,230	1,512
N33543	9,900	11,230	1,512
N33544	6,100	11,230	1,512
N33545	5,900	11,230	1,512
N33546	2,100	11,230	1,512
N33547	1,900	11,230	1,512
N33548	-1,900	11,230	1,512
N33549	-2,100	11,230	1,512
N33550	14,000	11,560	1,350
N33551	13,900	11,560	1,350
N33552	14,100	11,560	1,350
N33553	10,000	11,560	1,350
N33554	9,900	11,560	1,350
N33555	10,100	11,560	1,350
N33556	6,000	11,560	1,350
N33557	5,900	11,560	1,350
N33558	6,100	11,560	1,350
N33559	2,000	11,560	1,350
N33560	1,900	11,560	1,350
N33561	2,100	11,560	1,350
N33562	-2,000	11,560	1,350
N33563	-2,100	11,560	1,350
N33564	-1,900	11,560	1,350
N33565	14,100	11,560	1,512
N33566	13,900	11,560	1,512
N33567	10,100	11,560	1,512
N33568	9,900	11,560	1,512
N33569	6,100	11,560	1,512
N33570	5,900	11,560	1,512
N33571	2,100	11,560	1,512
N33572	1,900	11,560	1,512
N33573	-1,900	11,560	1,512
N33574	-2,100	11,560	1,512
N33575	14,000	11,890	1,350
N33576	13,900	11,890	1,350
N33577	14,100	11,890	1,350
N33578	10,000	11,890	1,350
N33579	9,900	11,890	1,350
N33580	10,100	11,890	1,350
N33581	6,000	11,890	1,350
N33582	5,900	11,890	1,350
N33583	6,100	11,890	1,350
N33584	2,000	11,890	1,350
N33585	1,900	11,890	1,350
N33586	2,100	11,890	1,350
N33587	-2,000	11,890	1,350
N33588	-2,100	11,890	1,350
N33589	-1,900	11,890	1,350
N33590	14,100	11,890	1,512
N33591	13,900	11,890	1,512
N33592	10,100	11,890	1,512
N33593	9,900	11,890	1,512
N33594	6,100	11,890	1,512
N33595	5,900	11,890	1,512
N33596	2,100	11,890	1,512
N33597	1,900	11,890	1,512
N33598	-1,900	11,890	1,512
N33599	-2,100	11,890	1,512
N33600	14,000	12,220	1,350

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N33601	13,900	12,220	1,350
N33602	14,100	12,220	1,350
N33603	10,000	12,220	1,350
N33604	9,900	12,220	1,350
N33605	10,100	12,220	1,350
N33606	6,000	12,220	1,350
N33607	5,900	12,220	1,350
N33608	6,100	12,220	1,350
N33609	2,000	12,220	1,350
N33610	1,900	12,220	1,350
N33611	2,100	12,220	1,350
N33612	-2,000	12,220	1,350
N33613	-2,100	12,220	1,350
N33614	-1,900	12,220	1,350
N33615	14,100	12,220	1,512
N33616	13,900	12,220	1,512
N33617	10,100	12,220	1,512
N33618	9,900	12,220	1,512
N33619	6,100	12,220	1,512
N33620	5,900	12,220	1,512
N33621	2,100	12,220	1,512
N33622	1,900	12,220	1,512
N33623	-1,900	12,220	1,512
N33624	-2,100	12,220	1,512
N33625	14,000	12,550	1,350
N33626	13,900	12,550	1,350
N33627	14,100	12,550	1,350
N33628	10,000	12,550	1,350
N33629	9,900	12,550	1,350
N33630	10,100	12,550	1,350
N33631	6,000	12,550	1,350
N33632	5,900	12,550	1,350
N33633	6,100	12,550	1,350
N33634	2,000	12,550	1,350
N33635	1,900	12,550	1,350
N33636	2,100	12,550	1,350
N33637	-2,000	12,550	1,350
N33638	-2,100	12,550	1,350
N33639	-1,900	12,550	1,350
N33640	14,100	12,550	1,512
N33641	13,900	12,550	1,512
N33642	10,100	12,550	1,512
N33643	9,900	12,550	1,512
N33644	6,100	12,550	1,512
N33645	5,900	12,550	1,512
N33646	2,100	12,550	1,512
N33647	1,900	12,550	1,512
N33648	-1,900	12,550	1,512
N33649	-2,100	12,550	1,512
N33650	14,000	12,880	1,350
N33651	13,900	12,880	1,350
N33652	14,100	12,880	1,350
N33653	10,000	12,880	1,350
N33654	9,900	12,880	1,350
N33655	10,100	12,880	1,350
N33656	6,000	12,880	1,350
N33657	5,900	12,880	1,350
N33658	6,100	12,880	1,350
N33659	2,000	12,880	1,350
N33660	1,900	12,880	1,350
N33661	2,100	12,880	1,350
N33662	-2,000	12,880	1,350
N33663	-2,100	12,880	1,350
N33664	-1,900	12,880	1,350
N33665	14,100	12,880	1,512
N33666	-2,100	12,880	1,512
N33667	14,000	13,210	1,350
N33668	13,900	13,210	1,350
N33669	14,100	13,210	1,350
N33670	10,000	13,210	1,350
N33671	9,900	13,210	1,350
N33672	10,100	13,210	1,350
N33673	6,000	13,210	1,350
N33674	5,900	13,210	1,350
N33675	6,100	13,210	1,350
N33676	2,000	13,210	1,350
N33677	1,900	13,210	1,350
N33678	2,100	13,210	1,350
N33679	-2,000	13,210	1,350
N33680	-2,100	13,210	1,350
N33681	-1,900	13,210	1,350
N33682	14,100	13,210	1,512
N33683	13,900	13,210	1,512
N33684	10,100	13,210	1,512
N33685	9,900	13,210	1,512
N33686	6,100	13,210	1,512
N33687	5,900	13,210	1,512
N33688	2,100	13,210	1,512
N33689	1,900	13,210	1,512
N33690	-1,900	13,210	1,512
N33691	-2,100	13,210	1,512
N33692	14,000	13,540	1,350
N33693	13,900	13,540	1,350
N33694	14,100	13,540	1,350
N33695	10,000	13,540	1,350
N33696	9,900	13,540	1,350
N33697	10,100	13,540	1,350
N33698	6,000	13,540	1,350
N33699	5,900	13,540	1,350
N33700	6,100	13,540	1,350
N33701	2,000	13,540	1,350
N33702	1,900	13,540	1,350
N33703	2,100	13,540	1,350
N33704	-2,000	13,540	1,350
N33705	-2,100	13,540	1,350
N33706	-1,900	13,540	1,350
N33707	14,100	13,540	1,512
N33708	13,900	13,540	1,512
N33709	10,100	13,540	1,512
N33710	9,900	13,540	1,512
N33711	6,100	13,540	1,512
N33712	5,900	13,540	1,512
N33713	2,100	13,540	1,512
N33714	1,900	13,540	1,512
N33715	-1,900	13,540	1,512
N33716	-2,100	13,540	1,512
N33717	14,000	13,870	1,350
N33718	13,900	13,870	1,350
N33719	14,100	13,870	1,350
N33720	10,000	13,870	1,350
N33721	9,900	13,870	1,350
N33722	10,100	13,870	1,350
N33723	6,000	13,870	1,350
N33724	5,900	13,870	1,350
N33725	6,100	13,870	1,350
N33726	2,000	13,870	1,350
N33727	1,900	13,870	1,350
N33728	2,100	13,870	1,350
N33729	-2,000	13,870	1,350
N33730	-2,100	13,870	1,350
N33731	-1,900	13,870	1,350
N33732	14,100	13,870	1,512
N33733	13,900	13,870	1,512
N33734	10,100	13,870	1,512
N33735	9,900	13,870	1,512
N33736	6,100	13,870	1,512
N33737	5,900	13,870	1,512
N33738	2,100	13,870	1,512
N33739	1,900	13,870	1,512
N33740	-1,900	13,870	1,512
N33741	-2,100	13,870	1,512
N33742	14,000	14,200	1,350
N33743	13,900	14,200	1,350
N33744	14,100	14,200	1,350
N33745	10,000	14,200	1,350
N33746	9,900	14,200	1,350
N33747	10,100	14,200	1,350
N33748	6,000	14,200	1,350
N33749	5,900	14,200	1,350
N33750	6,100	14,200	1,350
N33751	2,000	14,200	1,350
N33752	1,900	14,200	1,350
N33753	2,100	14,200	1,350
N33754	-2,000	14,200	1,350
N33755	-2,100	14,200	1,350
N33756	-1,900	14,200	1,350
N33757	14,100	14,200	1,512
N33758	13,900	14,200	1,512
N33759	10,100	14,200	1,512
N33760	9,900	14,200	1,512
N33761	6,100	14,200	1,512
N33762	5,900	14,200	1,512
N33763	2,100	14,200	1,512
N33764	1,900	14,200	1,512
N33765	-1,900	14,200	1,512
N33766	-2,100	14,200	1,512
N33767	14,000	14,530	1,350
N33768	13,900	14,530	1,350
N33769	14,100	14,530	1,350
N33770	10,000	14,530	1,350
N33771	9,900	14,530	1,350
N33772	10,100	14,530	1,350
N33773	6,000	14,530	1,350
N33774	5,900	14,530	1,350
N33775	6,100	14,530	1,350
N33776	2,000	14,530	1,350
N33777	1,900	14,530	1,350
N33778	2,100	14,530	1,350
N33779	-2,000	14,530	1,350
N33780	-2,100	14,530	1,350
N33781	-1,900	14,530	1,350
N33782	14,100	14,530	1,512
N33783	13,900	14,530	1,512
N33784	10,100	14,530	1,512
N33785	9,900	14,530	1,512
N33786	6,100	14,530	1,512
N33787	5,900	14,530	1,512
N33788	2,100	14,530	1,512
N33789	1,900	14,530	1,512
N33790	-1,900	14,530	1,512
N33791	-2,100	14,530	1,512
N33792	14,000	14,860	1,350
N33793	13,900	14,860	1,350
N33794	14,100	14,860	1,350
N33795	10,000	14,860	1,350
N33796	9,900	14,860	1,350
N33797	10,100	14,860	1,350
N33798	6,000	14,860	1,350
N33799	5,900	14,860	1,350
N33800	6,100	14,860	1,350
N33801	2,000	14,860	1,350
N33802	1,900	14,860	1,350
N33803	2,100	14,860	1,350
N33804	-2,000	14,860	1,350
N33805	-2,100	14,860	1,350
N33806	-1,900	14,860	1,350
N33807	14,100	14,860	1,512

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N33808	13,900	14,860	1,512
N33809	10,100	14,860	1,512
N33810	9,900	14,860	1,512
N33811	6,100	14,860	1,512
N33812	5,900	14,860	1,512
N33813	2,100	14,860	1,512
N33814	1,900	14,860	1,512
N33815	-1,900	14,860	1,512
N33816	-2,100	14,860	1,512
N33817	14,000	15,190	1,350
N33818	13,900	15,190	1,350
N33819	14,100	15,190	1,350
N33820	10,000	15,190	1,350
N33821	9,900	15,190	1,350
N33822	10,100	15,190	1,350
N33823	6,000	15,190	1,350
N33824	5,900	15,190	1,350
N33825	6,100	15,190	1,350
N33826	2,000	15,190	1,350
N33827	1,900	15,190	1,350
N33828	2,100	15,190	1,350
N33829	-2,000	15,190	1,350
N33830	-2,100	15,190	1,350
N33831	-1,900	15,190	1,350
N33832	14,100	15,190	1,512
N33833	13,900	15,190	1,512
N33834	10,100	15,190	1,512
N33835	9,900	15,190	1,512
N33836	6,100	15,190	1,512
N33837	5,900	15,190	1,512
N33838	2,100	15,190	1,512
N33839	1,900	15,190	1,512
N33840	-1,900	15,190	1,512
N33841	-2,100	15,190	1,512
N33842	14,000	15,520	1,350
N33843	13,900	15,520	1,350
N33844	14,100	15,520	1,350
N33845	10,000	15,520	1,350
N33846	9,900	15,520	1,350
N33847	10,100	15,520	1,350
N33848	6,000	15,520	1,350
N33849	5,900	15,520	1,350
N33850	6,100	15,520	1,350
N33851	2,000	15,520	1,350
N33852	1,900	15,520	1,350
N33853	2,100	15,520	1,350
N33854	-2,000	15,520	1,350
N33855	-2,100	15,520	1,350
N33856	-1,900	15,520	1,350
N33857	14,100	15,520	1,512
N33858	13,900	15,520	1,512
N33859	10,100	15,520	1,512
N33860	9,900	15,520	1,512
N33861	6,100	15,520	1,512
N33862	5,900	15,520	1,512
N33863	2,100	15,520	1,512
N33864	1,900	15,520	1,512
N33865	-1,900	15,520	1,512
N33866	-2,100	15,520	1,512
N33867	14,000	15,850	1,350
N33868	13,900	15,850	1,350
N33869	14,100	15,850	1,350
N33870	10,000	15,850	1,350
N33871	9,900	15,850	1,350
N33872	10,100	15,850	1,350
N33873	6,000	15,850	1,350
N33874	5,900	15,850	1,350
N33875	6,100	15,850	1,350
N33876	2,000	15,850	1,350

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N33877	1,900	15,850	1,350
N33878	2,100	15,850	1,350
N33879	-2,000	15,850	1,350
N33880	-2,100	15,850	1,350
N33881	-1,900	15,850	1,350
N33882	14,100	15,850	1,512
N33883	-2,100	15,850	1,512
N33884	14,000	16,180	1,350
N33885	13,900	16,180	1,350
N33886	14,100	16,180	1,350
N33887	10,000	16,180	1,350
N33888	9,900	16,180	1,350
N33889	10,100	16,180	1,350
N33890	6,000	16,180	1,350
N33891	5,900	16,180	1,350
N33892	6,100	16,180	1,350
N33893	2,000	16,180	1,350
N33894	1,900	16,180	1,350
N33895	2,100	16,180	1,350
N33896	-2,000	16,180	1,350
N33897	-2,100	16,180	1,350
N33898	-1,900	16,180	1,350
N33899	14,100	16,180	1,512
N33900	-2,100	16,180	1,512
N33901	14,000	16,510	1,350
N33902	13,900	16,510	1,350
N33903	14,100	16,510	1,350
N33904	10,000	16,510	1,350
N33905	9,900	16,510	1,350
N33906	10,100	16,510	1,350
N33907	6,000	16,510	1,350
N33908	5,900	16,510	1,350
N33909	6,100	16,510	1,350
N33910	2,000	16,510	1,350
N33911	1,900	16,510	1,350
N33912	2,100	16,510	1,350
N33913	-2,000	16,510	1,350
N33914	-2,100	16,510	1,350
N33915	-1,900	16,510	1,350
N33916	14,100	16,510	1,512
N33917	13,900	16,510	1,512
N33918	10,100	16,510	1,512
N33919	9,900	16,510	1,512
N33920	6,100	16,510	1,512
N33921	5,900	16,510	1,512
N33922	2,100	16,510	1,512
N33923	1,900	16,510	1,512
N33924	-1,900	16,510	1,512
N33925	-2,100	16,510	1,512
N33926	14,000	16,840	1,350
N33927	13,900	16,840	1,350
N33928	14,100	16,840	1,350
N33929	10,000	16,840	1,350
N33930	9,900	16,840	1,350
N33931	10,100	16,840	1,350
N33932	6,000	16,840	1,350
N33933	5,900	16,840	1,350
N33934	6,100	16,840	1,350
N33935	2,000	16,840	1,350
N33936	1,900	16,840	1,350
N33937	2,100	16,840	1,350
N33938	-2,000	16,840	1,350
N33939	-2,100	16,840	1,350
N33940	-1,900	16,840	1,350
N33941	14,100	16,840	1,512
N33942	-2,100	16,840	1,512
N33943	14,000	17,170	1,350
N33944	13,900	17,170	1,350
N33945	14,100	17,170	1,350

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N33946	10,000	17,170	1,350
N33947	9,900	17,170	1,350
N33948	10,100	17,170	1,350
N33949	6,000	17,170	1,350
N33950	5,900	17,170	1,350
N33951	6,100	17,170	1,350
N33952	2,000	17,170	1,350
N33953	1,900	17,170	1,350
N33954	2,100	17,170	1,350
N33955	-2,000	17,170	1,350
N33956	-2,100	17,170	1,350
N33957	-1,900	17,170	1,350
N33958	14,100	17,170	1,512
N33959	13,900	17,170	1,512
N33960	10,100	17,170	1,512
N33961	9,900	17,170	1,512
N33962	6,100	17,170	1,512
N33963	5,900	17,170	1,512
N33964	2,100	17,170	1,512
N33965	1,900	17,170	1,512
N33966	-1,900	17,170	1,512
N33967	-2,100	17,170	1,512
N33968	14,000	17,500	1,350
N33969	13,900	17,500	1,350
N33970	14,100	17,500	1,350
N33971	10,000	17,500	1,350
N33972	9,900	17,500	1,350
N33973	10,100	17,500	1,350
N33974	6,000	17,500	1,350
N33975	5,900	17,500	1,350
N33976	6,100	17,500	1,350
N33977	2,000	17,500	1,350
N33978	1,900	17,500	1,350
N33979	2,100	17,500	1,350
N33980	-2,000	17,500	1,350
N33981	-2,100	17,500	1,350
N33982	-1,900	17,500	1,350
N33983	14,100	17,500	1,512
N33984	13,900	17,500	1,512
N33985	10,100	17,500	1,512
N33986	9,900	17,500	1,512
N33987	6,100	17,500	1,512
N33988	5,900	17,500	1,512
N33989	2,100	17,500	1,512
N33990	1,900	17,500	1,512
N33991	-1,900	17,500	1,512
N33992	-2,100	17,500	1,512
N33993	14,000	17,830	1,350
N33994	13,900	17,830	1,350
N33995	14,100	17,830	1,350
N33996	10,000	17,830	1,350
N33997	9,900	17,830	1,350
N33998	10,100	17,830	1,350
N33999	6,000	17,830	1,350
N34000	5,900	17,830	1,350
N34001	6,100	17,830	1,350
N34002	2,000	17,830	1,350
N34003	1,900	17,830	1,350
N34004	2,100	17,830	1,350
N34005	-2,000	17,830	1,350
N34006	-2,100	17,830	1,350
N34007	-1,900	17,830	1,350
N34008	14,100	17,830	1,512
N34009	13,900	17,830	1,512
N34010	10,100	17,830	1,512
N34011	9,900	17,830	1,512
N34012	6,100	17,830	1,512
N34013	5,900	17,830	1,512
N34014	2,100	17,830	1,512

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N34015	1,900	17,830	1,512
N34016	-1,900	17,830	1,512
N34017	-2,100	17,830	1,512
N34018	14,000	18,160	1,350
N34019	13,900	18,160	1,350
N34020	14,100	18,160	1,350
N34021	10,000	18,160	1,350
N34022	9,900	18,160	1,350
N34023	10,100	18,160	1,350
N34024	6,000	18,160	1,350
N34025	5,900	18,160	1,350
N34026	6,100	18,160	1,350
N34027	2,000	18,160	1,350
N34028	1,900	18,160	1,350
N34029	2,100	18,160	1,350
N34030	-2,000	18,160	1,350
N34031	-2,100	18,160	1,350
N34032	-1,900	18,160	1,350
N34033	14,100	18,160	1,512
N34034	13,900	18,160	1,512
N34035	10,100	18,160	1,512
N34036	9,900	18,160	1,512
N34037	6,100	18,160	1,512
N34038	5,900	18,160	1,512
N34039	2,100	18,160	1,512
N34040	1,900	18,160	1,512
N34041	-1,900	18,160	1,512
N34042	-2,100	18,160	1,512
N34043	14,000	18,490	1,350
N34044	13,900	18,490	1,350
N34045	14,100	18,490	1,350
N34046	10,000	18,490	1,350
N34047	9,900	18,490	1,350
N34048	10,100	18,490	1,350
N34049	6,000	18,490	1,350
N34050	5,900	18,490	1,350
N34051	6,100	18,490	1,350
N34052	2,000	18,490	1,350
N34053	1,900	18,490	1,350
N34054	2,100	18,490	1,350
N34055	-2,000	18,490	1,350
N34056	-2,100	18,490	1,350
N34057	-1,900	18,490	1,350
N34058	14,100	18,490	1,512
N34059	13,900	18,490	1,512
N34060	10,100	18,490	1,512
N34061	9,900	18,490	1,512
N34062	6,100	18,490	1,512
N34063	5,900	18,490	1,512
N34064	2,100	18,490	1,512
N34065	1,900	18,490	1,512
N34066	-1,900	18,490	1,512
N34067	-2,100	18,490	1,512
N34068	14,000	18,820	1,350
N34069	13,900	18,820	1,350
N34070	14,100	18,820	1,350
N34071	10,000	18,820	1,350
N34072	9,900	18,820	1,350
N34073	10,100	18,820	1,350
N34074	6,000	18,820	1,350
N34075	5,900	18,820	1,350
N34076	6,100	18,820	1,350
N34077	2,000	18,820	1,350
N34078	1,900	18,820	1,350
N34079	2,100	18,820	1,350
N34080	-2,000	18,820	1,350
N34081	-2,100	18,820	1,350
N34082	-1,900	18,820	1,350
N34083	14,100	18,820	1,512
N34084	13,900	18,820	1,512
N34085	10,100	18,820	1,512
N34086	9,900	18,820	1,512
N34087	6,100	18,820	1,512
N34088	5,900	18,820	1,512
N34089	2,100	18,820	1,512
N34090	1,900	18,820	1,512
N34091	-1,900	18,820	1,512
N34092	-2,100	18,820	1,512
N34093	14,000	19,150	1,350
N34094	13,900	19,150	1,350
N34095	14,100	19,150	1,350
N34096	10,000	19,150	1,350
N34097	9,900	19,150	1,350
N34098	10,100	19,150	1,350
N34099	6,000	19,150	1,350
N34100	5,900	19,150	1,350
N34101	6,100	19,150	1,350
N34102	2,000	19,150	1,350
N34103	1,900	19,150	1,350
N34104	2,100	19,150	1,350
N34105	-2,000	19,150	1,350
N34106	-2,100	19,150	1,350
N34107	-1,900	19,150	1,350
N34108	14,100	19,150	1,512
N34109	13,900	19,150	1,512
N34110	10,100	19,150	1,512
N34111	9,900	19,150	1,512
N34112	6,100	19,150	1,512
N34113	5,900	19,150	1,512
N34114	2,100	19,150	1,512
N34115	1,900	19,150	1,512
N34116	-1,900	19,150	1,512
N34117	-2,100	19,150	1,512
N34118	14,000	19,480	1,350
N34119	13,900	19,480	1,350
N34120	14,100	19,480	1,350
N34121	10,000	19,480	1,350
N34122	9,900	19,480	1,350
N34123	10,100	19,480	1,350
N34124	6,000	19,480	1,350
N34125	5,900	19,480	1,350
N34126	6,100	19,480	1,350
N34127	2,000	19,480	1,350
N34128	1,900	19,480	1,350
N34129	2,100	19,480	1,350
N34130	-2,000	19,480	1,350
N34131	-2,100	19,480	1,350
N34132	-1,900	19,480	1,350
N34133	14,100	19,480	1,512
N34134	13,900	19,480	1,512
N34135	10,100	19,480	1,512
N34136	9,900	19,480	1,512
N34137	6,100	19,480	1,512
N34138	5,900	19,480	1,512
N34139	2,100	19,480	1,512
N34140	1,900	19,480	1,512
N34141	-1,900	19,480	1,512
N34142	-2,100	19,480	1,512
N34143	14,000	19,810	1,350
N34144	13,900	19,810	1,350
N34145	14,100	19,810	1,350
N34146	10,000	19,810	1,350
N34147	9,900	19,810	1,350
N34148	10,100	19,810	1,350
N34149	6,000	19,810	1,350
N34150	5,900	19,810	1,350
N34151	6,100	19,810	1,350
N34152	2,000	19,810	1,350
N34153	1,900	19,810	1,350
N34154	2,100	19,810	1,350
N34155	-2,000	19,810	1,350
N34156	-2,100	19,810	1,350
N34157	-1,900	19,810	1,350
N34158	14,100	19,810	1,512
N34159	13,900	19,810	1,512
N34160	10,100	19,810	1,512
N34161	9,900	19,810	1,512
N34162	6,100	19,810	1,512
N34163	5,900	19,810	1,512
N34164	2,100	19,810	1,512
N34165	1,900	19,810	1,512
N34166	-1,900	19,810	1,512
N34167	-2,100	19,810	1,512
N34168	14,000	20,140	1,350
N34169	13,900	20,140	1,350
N34170	14,100	20,140	1,350
N34171	10,000	20,140	1,350
N34172	9,900	20,140	1,350
N34173	10,100	20,140	1,350
N34174	6,000	20,140	1,350
N34175	5,900	20,140	1,350
N34176	6,100	20,140	1,350
N34177	2,000	20,140	1,350
N34178	1,900	20,140	1,350
N34179	2,100	20,140	1,350
N34180	-2,000	20,140	1,350
N34181	-2,100	20,140	1,350
N34182	-1,900	20,140	1,350
N34183	14,100	20,140	1,512
N34184	13,900	20,140	1,512
N34185	10,100	20,140	1,512
N34186	9,900	20,140	1,512
N34187	6,100	20,140	1,512
N34188	5,900	20,140	1,512
N34189	2,100	20,140	1,512
N34190	1,900	20,140	1,512
N34191	-1,900	20,140	1,512
N34192	-2,100	20,140	1,512
N34193	14,000	20,470	1,350
N34194	13,900	20,470	1,350
N34195	14,100	20,470	1,350
N34196	10,000	20,470	1,350
N34197	9,900	20,470	1,350
N34198	10,100	20,470	1,350
N34199	6,000	20,470	1,350
N34200	5,900	20,470	1,350
N34201	6,100	20,470	1,350
N34202	2,000	20,470	1,350
N34203	1,900	20,470	1,350
N34204	2,100	20,470	1,350
N34205	-2,000	20,470	1,350
N34206	-2,100	20,470	1,350
N34207	-1,900	20,470	1,350
N34208	14,100	20,470	1,512
N34209	13,900	20,470	1,512
N34210	10,100	20,470	1,512
N34211	9,900	20,470	1,512
N34212	6,100	20,470	1,512
N34213	5,900	20,470	1,512
N34214	2,100	20,470	1,512
N34215	1,900	20,470	1,512
N34216	-1,900	20,470	1,512
N34217	-2,100	20,470	1,512
N34218	14,000	20,800	1,350
N34219	13,900	20,800	1,350
N34220	14,100	20,800	1,350
N34221	10,000	20,800	1,350

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N34222	9,900	20,800	1,350
N34223	10,100	20,800	1,350
N34224	6,000	20,800	1,350
N34225	5,900	20,800	1,350
N34226	6,100	20,800	1,350
N34227	2,000	20,800	1,350
N34228	1,900	20,800	1,350
N34229	2,100	20,800	1,350
N34230	-2,000	20,800	1,350
N34231	-2,100	20,800	1,350
N34232	-1,900	20,800	1,350
N34233	14,100	20,800	1,512
N34234	-2,100	20,800	1,512
N34235	14,000	21,130	1,350
N34236	13,900	21,130	1,350
N34237	14,100	21,130	1,350
N34238	10,000	21,130	1,350
N34239	9,900	21,130	1,350
N34240	10,100	21,130	1,350
N34241	6,000	21,130	1,350
N34242	5,900	21,130	1,350
N34243	6,100	21,130	1,350
N34244	2,000	21,130	1,350
N34245	1,900	21,130	1,350
N34246	2,100	21,130	1,350
N34247	-2,000	21,130	1,350
N34248	-2,100	21,130	1,350
N34249	-1,900	21,130	1,350
N34250	14,100	21,130	1,512
N34251	13,900	21,130	1,512
N34252	10,100	21,130	1,512
N34253	9,900	21,130	1,512
N34254	6,100	21,130	1,512
N34255	5,900	21,130	1,512
N34256	2,100	21,130	1,512
N34257	1,900	21,130	1,512
N34258	-1,900	21,130	1,512
N34259	-2,100	21,130	1,512
N34260	14,000	21,460	1,350
N34261	13,900	21,460	1,350
N34262	14,100	21,460	1,350
N34263	10,000	21,460	1,350
N34264	9,900	21,460	1,350
N34265	10,100	21,460	1,350
N34266	6,000	21,460	1,350
N34267	5,900	21,460	1,350
N34268	6,100	21,460	1,350
N34269	2,000	21,460	1,350
N34270	1,900	21,460	1,350
N34271	2,100	21,460	1,350
N34272	-2,000	21,460	1,350
N34273	-2,100	21,460	1,350
N34274	-1,900	21,460	1,350
N34275	14,100	21,460	1,512
N34276	13,900	21,460	1,512
N34277	10,100	21,460	1,512
N34278	9,900	21,460	1,512
N34279	6,100	21,460	1,512
N34280	5,900	21,460	1,512
N34281	2,100	21,460	1,512
N34282	1,900	21,460	1,512
N34283	-1,900	21,460	1,512
N34284	-2,100	21,460	1,512
N34285	14,000	21,790	1,350
N34286	13,900	21,790	1,350
N34287	14,100	21,790	1,350
N34288	10,000	21,790	1,350
N34289	9,900	21,790	1,350
N34290	10,100	21,790	1,350

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N34291	6,000	21,790	1,350
N34292	5,900	21,790	1,350
N34293	6,100	21,790	1,350
N34294	2,000	21,790	1,350
N34295	1,900	21,790	1,350
N34296	2,100	21,790	1,350
N34297	-2,000	21,790	1,350
N34298	-2,100	21,790	1,350
N34299	-1,900	21,790	1,350
N34300	14,100	21,790	1,512
N34301	13,900	21,790	1,512
N34302	10,100	21,790	1,512
N34303	9,900	21,790	1,512
N34304	6,100	21,790	1,512
N34305	5,900	21,790	1,512
N34306	2,100	21,790	1,512
N34307	1,900	21,790	1,512
N34308	-1,900	21,790	1,512
N34309	-2,100	21,790	1,512
N34310	14,000	22,120	1,350
N34311	13,900	22,120	1,350
N34312	14,100	22,120	1,350
N34313	10,000	22,120	1,350
N34314	9,900	22,120	1,350
N34315	10,100	22,120	1,350
N34316	6,000	22,120	1,350
N34317	5,900	22,120	1,350
N34318	6,100	22,120	1,350
N34319	2,000	22,120	1,350
N34320	1,900	22,120	1,350
N34321	2,100	22,120	1,350
N34322	-2,000	22,120	1,350
N34323	-2,100	22,120	1,350
N34324	-1,900	22,120	1,350
N34325	14,100	22,120	1,512
N34326	13,900	22,120	1,512
N34327	10,100	22,120	1,512
N34328	9,900	22,120	1,512
N34329	6,100	22,120	1,512
N34330	5,900	22,120	1,512
N34331	2,100	22,120	1,512
N34332	1,900	22,120	1,512
N34333	-1,900	22,120	1,512
N34334	-2,100	22,120	1,512
N34335	14,000	22,450	1,350
N34336	13,900	22,450	1,350
N34337	14,100	22,450	1,350
N34338	10,000	22,450	1,350
N34339	9,900	22,450	1,350
N34340	10,100	22,450	1,350
N34341	6,000	22,450	1,350
N34342	5,900	22,450	1,350
N34343	6,100	22,450	1,350
N34344	2,000	22,450	1,350
N34345	1,900	22,450	1,350
N34346	2,100	22,450	1,350
N34347	-2,000	22,450	1,350
N34348	-2,100	22,450	1,350
N34349	-1,900	22,450	1,350
N34350	14,100	22,450	1,512
N34351	13,900	22,450	1,512
N34352	10,100	22,450	1,512
N34353	9,900	22,450	1,512
N34354	6,100	22,450	1,512
N34355	5,900	22,450	1,512
N34356	2,100	22,450	1,512
N34357	1,900	22,450	1,512
N34358	-1,900	22,450	1,512
N34359	-2,100	22,450	1,512

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N34360	14,000	22,780	1,350
N34361	13,900	22,780	1,350
N34362	14,100	22,780	1,350
N34363	10,000	22,780	1,350
N34364	9,900	22,780	1,350
N34365	10,100	22,780	1,350
N34366	6,000	22,780	1,350
N34367	5,900	22,780	1,350
N34368	6,100	22,780	1,350
N34369	2,000	22,780	1,350
N34370	1,900	22,780	1,350
N34371	2,100	22,780	1,350
N34372	-2,000	22,780	1,350
N34373	-2,100	22,780	1,350
N34374	-1,900	22,780	1,350
N34375	14,100	22,780	1,512
N34376	13,900	22,780	1,512
N34377	10,100	22,780	1,512
N34378	9,900	22,780	1,512
N34379	6,100	22,780	1,512
N34380	5,900	22,780	1,512
N34381	2,100	22,780	1,512
N34382	1,900	22,780	1,512
N34383	-1,900	22,780	1,512
N34384	-2,100	22,780	1,512
N34385	14,000	23,110	1,350
N34386	13,900	23,110	1,350
N34387	14,100	23,110	1,350
N34388	10,000	23,110	1,350
N34389	9,900	23,110	1,350
N34390	10,100	23,110	1,350
N34391	6,000	23,110	1,350
N34392	5,900	23,110	1,350
N34393	6,100	23,110	1,350
N34394	2,000	23,110	1,350
N34395	1,900	23,110	1,350
N34396	2,100	23,110	1,350
N34397	-2,000	23,110	1,350
N34398	-2,100	23,110	1,350
N34399	-1,900	23,110	1,350
N34400	14,100	23,110	1,512
N34401	13,900	23,110	1,512
N34402	10,100	23,110	1,512
N34403	9,900	23,110	1,512
N34404	6,100	23,110	1,512
N34405	5,900	23,110	1,512
N34406	2,100	23,110	1,512
N34407	1,900	23,110	1,512
N34408	-1,900	23,110	1,512
N34409	-2,100	23,110	1,512
N34410	14,000	23,440	1,350
N34411	13,900	23,440	1,350
N34412	14,100	23,440	1,350
N34413	10,000	23,440	1,350
N34414	9,900	23,440	1,350
N34415	10,100	23,440	1,350
N34416	6,000	23,440	1,350
N34417	5,900	23,440	1,350
N34418	6,100	23,440	1,350
N34419	2,000	23,440	1,350
N34420	1,900	23,440	1,350
N34421	2,100	23,440	1,350
N34422	-2,000	23,440	1,350
N34423	-2,100	23,440	1,350
N34424	-1,900	23,440	1,350
N34425	14,100	23,440	1,512
N34426	13,900	23,440	1,512
N34427	10,100	23,440	1,512
N34428	9,900	23,440	1,512

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N34429	6,100	23,440	1,512
N34430	5,900	23,440	1,512
N34431	2,100	23,440	1,512
N34432	1,900	23,440	1,512
N34433	-1,900	23,440	1,512
N34434	-2,100	23,440	1,512
N34435	14,000	23,770	1,350
N34436	13,900	23,770	1,350
N34437	14,100	23,770	1,350
N34438	10,000	23,770	1,350
N34439	9,900	23,770	1,350
N34440	10,100	23,770	1,350
N34441	6,000	23,770	1,350
N34442	5,900	23,770	1,350
N34443	6,100	23,770	1,350
N34444	2,000	23,770	1,350
N34445	1,900	23,770	1,350
N34446	2,100	23,770	1,350
N34447	-2,000	23,770	1,350
N34448	-2,100	23,770	1,350
N34449	-1,900	23,770	1,350
N34450	14,100	23,770	1,512
N34451	13,900	23,770	1,512
N34452	10,100	23,770	1,512
N34453	9,900	23,770	1,512
N34454	6,100	23,770	1,512
N34455	5,900	23,770	1,512
N34456	2,100	23,770	1,512
N34457	1,900	23,770	1,512
N34458	-1,900	23,770	1,512
N34459	-2,100	23,770	1,512
N34460	14,000	24,100	1,350
N34461	13,900	24,100	1,350
N34462	14,100	24,100	1,350
N34463	10,000	24,100	1,350
N34464	9,900	24,100	1,350
N34465	10,100	24,100	1,350
N34466	6,000	24,100	1,350
N34467	5,900	24,100	1,350
N34468	6,100	24,100	1,350
N34469	2,000	24,100	1,350
N34470	1,900	24,100	1,350
N34471	2,100	24,100	1,350
N34472	-2,000	24,100	1,350
N34473	-2,100	24,100	1,350
N34474	-1,900	24,100	1,350
N34475	14,100	24,100	1,512
N34476	13,900	24,100	1,512
N34477	10,100	24,100	1,512
N34478	9,900	24,100	1,512
N34479	6,100	24,100	1,512
N34480	5,900	24,100	1,512
N34481	2,100	24,100	1,512
N34482	1,900	24,100	1,512
N34483	-1,900	24,100	1,512
N34484	-2,100	24,100	1,512
N34485	14,000	24,430	1,350
N34486	13,900	24,430	1,350
N34487	14,100	24,430	1,350
N34488	10,000	24,430	1,350
N34489	9,900	24,430	1,350
N34490	10,100	24,430	1,350
N34491	6,000	24,430	1,350
N34492	5,900	24,430	1,350
N34493	6,100	24,430	1,350
N34494	2,000	24,430	1,350
N34495	1,900	24,430	1,350
N34496	2,100	24,430	1,350
N34497	-2,000	24,430	1,350

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N34498	-2,100	24,430	1,350
N34499	-1,900	24,430	1,350
N34500	14,100	24,430	1,512
N34501	13,900	24,430	1,512
N34502	10,100	24,430	1,512
N34503	9,900	24,430	1,512
N34504	6,100	24,430	1,512
N34505	5,900	24,430	1,512
N34506	2,100	24,430	1,512
N34507	1,900	24,430	1,512
N34508	-1,900	24,430	1,512
N34509	-2,100	24,430	1,512
N34510	14,000	24,760	1,350
N34511	13,900	24,760	1,350
N34512	14,100	24,760	1,350
N34513	10,000	24,760	1,350
N34514	9,900	24,760	1,350
N34515	10,100	24,760	1,350
N34516	6,000	24,760	1,350
N34517	5,900	24,760	1,350
N34518	6,100	24,760	1,350
N34519	2,000	24,760	1,350
N34520	1,900	24,760	1,350
N34521	2,100	24,760	1,350
N34522	-2,000	24,760	1,350
N34523	-2,100	24,760	1,350
N34524	-1,900	24,760	1,350
N34525	14,100	24,760	1,512
N34526	-2,100	24,760	1,512
N34527	14,000	25,090	1,350
N34528	13,900	25,090	1,350
N34529	14,100	25,090	1,350
N34530	10,000	25,090	1,350
N34531	9,900	25,090	1,350
N34532	10,100	25,090	1,350
N34533	6,000	25,090	1,350
N34534	5,900	25,090	1,350
N34535	6,100	25,090	1,350
N34536	2,000	25,090	1,350
N34537	1,900	25,090	1,350
N34538	2,100	25,090	1,350
N34539	-2,000	25,090	1,350
N34540	-2,100	25,090	1,350
N34541	-1,900	25,090	1,350
N34542	14,100	25,090	1,512
N34543	13,900	25,090	1,512
N34544	10,100	25,090	1,512
N34545	9,900	25,090	1,512
N34546	6,100	25,090	1,512
N34547	5,900	25,090	1,512
N34548	2,100	25,090	1,512
N34549	1,900	25,090	1,512
N34550	-1,900	25,090	1,512
N34551	-2,100	25,090	1,512
N34552	14,000	25,420	1,350
N34553	13,900	25,420	1,350
N34554	14,100	25,420	1,350
N34555	10,000	25,420	1,350
N34556	9,900	25,420	1,350
N34557	10,100	25,420	1,350
N34558	6,000	25,420	1,350
N34559	5,900	25,420	1,350
N34560	6,100	25,420	1,350
N34561	2,000	25,420	1,350
N34562	1,900	25,420	1,350
N34563	2,100	25,420	1,350
N34564	-2,000	25,420	1,350
N34565	-2,100	25,420	1,350
N34566	-1,900	25,420	1,350

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N34567	14,100	25,420	1,512
N34568	13,900	25,420	1,512
N34569	10,100	25,420	1,512
N34570	9,900	25,420	1,512
N34571	6,100	25,420	1,512
N34572	5,900	25,420	1,512
N34573	2,100	25,420	1,512
N34574	1,900	25,420	1,512
N34575	-1,900	25,420	1,512
N34576	-2,100	25,420	1,512
N34577	14,000	25,750	1,350
N34578	13,900	25,750	1,350
N34579	14,100	25,750	1,350
N34580	10,000	25,750	1,350
N34581	9,900	25,750	1,350
N34582	10,100	25,750	1,350
N34583	6,000	25,750	1,350
N34584	5,900	25,750	1,350
N34585	6,100	25,750	1,350
N34586	2,000	25,750	1,350
N34587	1,900	25,750	1,350
N34588	2,100	25,750	1,350
N34589	-2,000	25,750	1,350
N34590	-2,100	25,750	1,350
N34591	-1,900	25,750	1,350
N34592	14,100	25,750	1,512
N34593	13,900	25,750	1,512
N34594	10,100	25,750	1,512
N34595	9,900	25,750	1,512
N34596	6,100	25,750	1,512
N34597	5,900	25,750	1,512
N34598	2,100	25,750	1,512
N34599	1,900	25,750	1,512
N34600	-1,900	25,750	1,512
N34601	-2,100	25,750	1,512
N34602	14,000	26,080	1,350
N34603	13,900	26,080	1,350
N34604	14,100	26,080	1,350
N34605	10,000	26,080	1,350
N34606	9,900	26,080	1,350
N34607	10,100	26,080	1,350
N34608	6,000	26,080	1,350
N34609	5,900	26,080	1,350
N34610	6,100	26,080	1,350
N34611	2,000	26,080	1,350
N34612	1,900	26,080	1,350
N34613	2,100	26,080	1,350
N34614	-2,000	26,080	1,350
N34615	-2,100	26,080	1,350
N34616	-1,900	26,080	1,350
N34617	14,100	26,080	1,512
N34618	13,900	26,080	1,512
N34619	10,100	26,080	1,512
N34620	9,900	26,080	1,512
N34621	6,100	26,080	1,512
N34622	5,900	26,080	1,512
N34623	2,100	26,080	1,512
N34624	1,900	26,080	1,512
N34625	-1,900	26,080	1,512
N34626	-2,100	26,080	1,512
N34627	14,000	26,410	1,350
N34628	13,900	26,410	1,350
N34629	14,100	26,410	1,350
N34630	10,000	26,410	1,350
N34631	9,900	26,410	1,350
N34632	10,100	26,410	1,350
N34633	6,000	26,410	1,350
N34634	5,900	26,410	1,350
N34635	6,100	26,410	1,350

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N34636	2,000	26,410	1,350
N34637	1,900	26,410	1,350
N34638	2,100	26,410	1,350
N34639	-2,000	26,410	1,350
N34640	-2,100	26,410	1,350
N34641	-1,900	26,410	1,350
N34642	14,100	26,410	1,512
N34643	13,900	26,410	1,512
N34644	10,100	26,410	1,512
N34645	9,900	26,410	1,512
N34646	6,100	26,410	1,512
N34647	5,900	26,410	1,512
N34648	2,100	26,410	1,512
N34649	1,900	26,410	1,512
N34650	-1,900	26,410	1,512
N34651	-2,100	26,410	1,512
N34652	14,000	26,740	1,350
N34653	13,900	26,740	1,350
N34654	14,100	26,740	1,350
N34655	10,000	26,740	1,350
N34656	9,900	26,740	1,350
N34657	10,100	26,740	1,350
N34658	6,000	26,740	1,350
N34659	5,900	26,740	1,350
N34660	6,100	26,740	1,350
N34661	2,000	26,740	1,350
N34662	1,900	26,740	1,350
N34663	2,100	26,740	1,350
N34664	-2,000	26,740	1,350
N34665	-2,100	26,740	1,350
N34666	-1,900	26,740	1,350
N34667	14,100	26,740	1,512
N34668	13,900	26,740	1,512
N34669	10,100	26,740	1,512
N34670	9,900	26,740	1,512
N34671	6,100	26,740	1,512
N34672	5,900	26,740	1,512
N34673	2,100	26,740	1,512
N34674	1,900	26,740	1,512
N34675	-1,900	26,740	1,512
N34676	-2,100	26,740	1,512
N34677	14,000	27,070	1,350
N34678	13,900	27,070	1,350
N34679	14,100	27,070	1,350
N34680	10,000	27,070	1,350
N34681	9,900	27,070	1,350
N34682	10,100	27,070	1,350
N34683	6,000	27,070	1,350
N34684	5,900	27,070	1,350
N34685	6,100	27,070	1,350
N34686	2,000	27,070	1,350
N34687	1,900	27,070	1,350
N34688	2,100	27,070	1,350
N34689	-2,000	27,070	1,350
N34690	-2,100	27,070	1,350
N34691	-1,900	27,070	1,350
N34692	14,100	27,070	1,512
N34693	13,900	27,070	1,512
N34694	10,100	27,070	1,512
N34695	9,900	27,070	1,512
N34696	6,100	27,070	1,512
N34697	5,900	27,070	1,512
N34698	2,100	27,070	1,512
N34699	1,900	27,070	1,512
N34700	-1,900	27,070	1,512
N34701	-2,100	27,070	1,512
N34702	14,000	27,400	1,350
N34703	13,900	27,400	1,350
N34704	14,100	27,400	1,350

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N34705	10,000	27,400	1,350
N34706	9,900	27,400	1,350
N34707	10,100	27,400	1,350
N34708	6,000	27,400	1,350
N34709	5,900	27,400	1,350
N34710	6,100	27,400	1,350
N34711	2,000	27,400	1,350
N34712	1,900	27,400	1,350
N34713	2,100	27,400	1,350
N34714	-2,000	27,400	1,350
N34715	-2,100	27,400	1,350
N34716	-1,900	27,400	1,350
N34717	14,100	27,400	1,512
N34718	13,900	27,400	1,512
N34719	10,100	27,400	1,512
N34720	9,900	27,400	1,512
N34721	6,100	27,400	1,512
N34722	5,900	27,400	1,512
N34723	2,100	27,400	1,512
N34724	1,900	27,400	1,512
N34725	-1,900	27,400	1,512
N34726	-2,100	27,400	1,512
N34727	14,000	27,730	1,350
N34728	13,900	27,730	1,350
N34729	14,100	27,730	1,350
N34730	10,000	27,730	1,350
N34731	9,900	27,730	1,350
N34732	10,100	27,730	1,350
N34733	6,000	27,730	1,350
N34734	5,900	27,730	1,350
N34735	6,100	27,730	1,350
N34736	2,000	27,730	1,350
N34737	1,900	27,730	1,350
N34738	2,100	27,730	1,350
N34739	-2,000	27,730	1,350
N34740	-2,100	27,730	1,350
N34741	-1,900	27,730	1,350
N34742	14,100	27,730	1,512
N34743	13,900	27,730	1,512
N34744	10,100	27,730	1,512
N34745	9,900	27,730	1,512
N34746	6,100	27,730	1,512
N34747	5,900	27,730	1,512
N34748	2,100	27,730	1,512
N34749	1,900	27,730	1,512
N34750	-1,900	27,730	1,512
N34751	-2,100	27,730	1,512
N34752	14,000	28,060	1,350
N34753	13,900	28,060	1,350
N34754	14,100	28,060	1,350
N34755	10,000	28,060	1,350
N34756	9,900	28,060	1,350
N34757	10,100	28,060	1,350
N34758	6,000	28,060	1,350
N34759	5,900	28,060	1,350
N34760	6,100	28,060	1,350
N34761	2,000	28,060	1,350
N34762	1,900	28,060	1,350
N34763	2,100	28,060	1,350
N34764	-2,000	28,060	1,350
N34765	-2,100	28,060	1,350
N34766	-1,900	28,060	1,350
N34767	14,100	28,060	1,512
N34768	13,900	28,060	1,512
N34769	10,100	28,060	1,512
N34770	9,900	28,060	1,512
N34771	6,100	28,060	1,512
N34772	5,900	28,060	1,512
N34773	2,100	28,060	1,512

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N34774	1,900	28,060	1,512
N34775	-1,900	28,060	1,512
N34776	-2,100	28,060	1,512
N34777	14,000	28,390	1,350
N34778	13,900	28,390	1,350
N34779	14,100	28,390	1,350
N34780	10,000	28,390	1,350
N34781	9,900	28,390	1,350
N34782	10,100	28,390	1,350
N34783	6,000	28,390	1,350
N34784	5,900	28,390	1,350
N34785	6,100	28,390	1,350
N34786	2,000	28,390	1,350
N34787	1,900	28,390	1,350
N34788	2,100	28,390	1,350
N34789	-2,000	28,390	1,350
N34790	-2,100	28,390	1,350
N34791	-1,900	28,390	1,350
N34792	14,100	28,390	1,512
N34793	13,900	28,390	1,512
N34794	10,100	28,390	1,512
N34795	9,900	28,390	1,512
N34796	6,100	28,390	1,512
N34797	5,900	28,390	1,512
N34798	2,100	28,390	1,512
N34799	1,900	28,390	1,512
N34800	-1,900	28,390	1,512
N34801	-2,100	28,390	1,512
N34802	14,000	28,720	1,350
N34803	13,900	28,720	1,350
N34804	14,100	28,720	1,350
N34805	10,000	28,720	1,350
N34806	9,900	28,720	1,350
N34807	10,100	28,720	1,350
N34808	6,000	28,720	1,350
N34809	5,900	28,720	1,350
N34810	6,100	28,720	1,350
N34811	2,000	28,720	1,350
N34812	1,900	28,720	1,350
N34813	2,100	28,720	1,350
N34814	-2,000	28,720	1,350
N34815	-2,100	28,720	1,350
N34816	-1,900	28,720	1,350
N34817	14,100	28,720	1,512
N34818	-2,100	28,720	1,512
N34819	14,000	29,050	1,350
N34820	13,900	29,050	1,350
N34821	14,100	29,050	1,350
N34822	10,000	29,050	1,350
N34823	9,900	29,050	1,350
N34824	10,100	29,050	1,350
N34825	6,000	29,050	1,350
N34826	5,900	29,050	1,350
N34827	6,100	29,050	1,350
N34828	2,000	29,050	1,350
N34829	1,900	29,050	1,350
N34830	2,100	29,050	1,350
N34831	-2,000	29,050	1,350
N34832	-2,100	29,050	1,350
N34833	-1,900	29,050	1,350
N34834	14,100	29,050	1,512
N34835	13,900	29,050	1,512
N34836	10,100	29,050	1,512
N34837	9,900	29,050	1,512
N34838	6,100	29,050	1,512
N34839	5,900	29,050	1,512
N34840	2,100	29,050	1,512
N34841	1,900	29,050	1,512
N34842	-1,900	29,050	1,512

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N34843	-2,100	29,050	1,512
N34844	14,000	29,380	1,350
N34845	13,900	29,380	1,350
N34846	14,100	29,380	1,350
N34847	10,000	29,380	1,350
N34848	9,900	29,380	1,350
N34849	10,100	29,380	1,350
N34850	6,000	29,380	1,350
N34851	5,900	29,380	1,350
N34852	6,100	29,380	1,350
N34853	2,000	29,380	1,350
N34854	1,900	29,380	1,350
N34855	2,100	29,380	1,350
N34856	-2,000	29,380	1,350
N34857	-2,100	29,380	1,350
N34858	-1,900	29,380	1,350
N34859	14,100	29,380	1,512
N34860	13,900	29,380	1,512
N34861	10,100	29,380	1,512
N34862	9,900	29,380	1,512
N34863	6,100	29,380	1,512
N34864	5,900	29,380	1,512
N34865	2,100	29,380	1,512
N34866	1,900	29,380	1,512
N34867	-1,900	29,380	1,512
N34868	-2,100	29,380	1,512
N34869	14,000	29,710	1,350
N34870	13,900	29,710	1,350
N34871	14,100	29,710	1,350
N34872	10,000	29,710	1,350
N34873	9,900	29,710	1,350
N34874	10,100	29,710	1,350
N34875	6,000	29,710	1,350
N34876	5,900	29,710	1,350
N34877	6,100	29,710	1,350
N34878	2,000	29,710	1,350
N34879	1,900	29,710	1,350
N34880	2,100	29,710	1,350
N34881	-2,000	29,710	1,350
N34882	-2,100	29,710	1,350
N34883	-1,900	29,710	1,350
N34884	14,100	29,710	1,512
N34885	13,900	29,710	1,512
N34886	10,100	29,710	1,512
N34887	9,900	29,710	1,512
N34888	6,100	29,710	1,512
N34889	5,900	29,710	1,512
N34890	2,100	29,710	1,512
N34891	1,900	29,710	1,512
N34892	-1,900	29,710	1,512
N34893	-2,100	29,710	1,512
N34894	14,000	30,040	1,350
N34895	13,900	30,040	1,350
N34896	14,100	30,040	1,350
N34897	10,000	30,040	1,350
N34898	9,900	30,040	1,350
N34899	10,100	30,040	1,350
N34900	6,000	30,040	1,350
N34901	5,900	30,040	1,350
N34902	6,100	30,040	1,350
N34903	2,000	30,040	1,350
N34904	1,900	30,040	1,350
N34905	2,100	30,040	1,350
N34906	-2,000	30,040	1,350
N34907	-2,100	30,040	1,350
N34908	-1,900	30,040	1,350
N34909	14,100	30,040	1,512
N34910	13,900	30,040	1,512
N34911	10,100	30,040	1,512

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N34912	9,900	30,040	1,512
N34913	6,100	30,040	1,512
N34914	5,900	30,040	1,512
N34915	2,100	30,040	1,512
N34916	1,900	30,040	1,512
N34917	-1,900	30,040	1,512
N34918	-2,100	30,040	1,512
N34919	14,000	30,370	1,350
N34920	13,900	30,370	1,350
N34921	14,100	30,370	1,350
N34922	10,000	30,370	1,350
N34923	9,900	30,370	1,350
N34924	10,100	30,370	1,350
N34925	6,000	30,370	1,350
N34926	5,900	30,370	1,350
N34927	6,100	30,370	1,350
N34928	2,000	30,370	1,350
N34929	1,900	30,370	1,350
N34930	2,100	30,370	1,350
N34931	-2,000	30,370	1,350
N34932	-2,100	30,370	1,350
N34933	-1,900	30,370	1,350
N34934	14,100	30,370	1,512
N34935	13,900	30,370	1,512
N34936	10,100	30,370	1,512
N34937	9,900	30,370	1,512
N34938	6,100	30,370	1,512
N34939	5,900	30,370	1,512
N34940	2,100	30,370	1,512
N34941	1,900	30,370	1,512
N34942	-1,900	30,370	1,512
N34943	-2,100	30,370	1,512
N34944	14,000	30,700	1,350
N34945	13,900	30,700	1,350
N34946	14,100	30,700	1,350
N34947	10,000	30,700	1,350
N34948	9,900	30,700	1,350
N34949	10,100	30,700	1,350
N34950	6,000	30,700	1,350
N34951	5,900	30,700	1,350
N34952	6,100	30,700	1,350
N34953	2,000	30,700	1,350
N34954	1,900	30,700	1,350
N34955	2,100	30,700	1,350
N34956	-2,000	30,700	1,350
N34957	-2,100	30,700	1,350
N34958	-1,900	30,700	1,350
N34959	14,100	30,700	1,512
N34960	-2,100	30,700	1,512
N34961	14,000	1,330	1,350
N34962	13,900	1,330	1,350
N34963	14,100	1,330	1,350
N34964	10,000	1,330	1,350
N34965	9,900	1,330	1,350
N34966	10,100	1,330	1,350
N34967	6,000	1,330	1,350
N34968	5,900	1,330	1,350
N34969	6,100	1,330	1,350
N34970	2,000	1,330	1,350
N34971	1,900	1,330	1,350
N34972	2,100	1,330	1,350
N34973	-2,000	1,330	1,350
N34974	-2,100	1,330	1,350
N34975	-1,900	1,330	1,350
N34976	14,100	1,330	1,512
N34977	-2,100	1,330	1,512
N34993	14,000	0,240	0,000
N34995	13,900	0,240	1,512
N34996	10,000	0,240	0,000

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N34997	10,100	0,240	1,512
N34998	9,900	0,240	1,512
N34999	6,000	0,240	0,000
N35000	6,100	0,240	1,512
N35001	5,900	0,240	1,512
N35002	2,000	0,240	0,000
N35003	2,100	0,240	1,512
N35004	1,900	0,240	1,512
N35005	-2,000	0,240	0,000
N35006	-1,900	0,240	1,512
N35023	14,000	0,360	0,000
N35025	13,900	0,360	1,512
N35026	10,000	0,360	0,000
N35027	10,100	0,360	1,512
N35028	9,900	0,360	1,512
N35029	6,000	0,360	0,000
N35030	6,100	0,360	1,512
N35031	5,900	0,360	1,512
N35032	2,000	0,360	0,000
N35033	2,100	0,360	1,512
N35034	1,900	0,360	1,512
N35035	-2,000	0,360	0,000
N35036	-1,900	0,360	1,512
N35053	14,000	0,480	0,000
N35055	10,000	0,480	0,000
N35056	6,000	0,480	0,000
N35057	2,000	0,480	0,000
N35058	-2,000	0,480	0,000
N35075	14,000	0,600	0,000
N35078	10,000	0,600	0,000
N35081	6,000	0,600	0,000
N35084	2,000	0,600	0,000
N35087	-2,000	0,600	0,000
N35105	14,000	0,720	0,000
N35107	10,000	0,720	0,000
N35108	6,000	0,720	0,000
N35109	2,000	0,720	0,000
N35110	-2,000	0,720	0,000
N35127	14,000	0,840	0,000
N35129	10,000	0,840	0,000
N35130	6,000	0,840	0,000
N35131	2,000	0,840	0,000
N35132	-2,000	0,840	0,000
N35149	14,000	0,960	0,000
N35151	13,900	0,960	1,512
N35152	10,000	0,960	0,000
N35153	10,100	0,960	1,512
N35154	9,900	0,960	1,512
N35155	6,000	0,960	0,000
N35156	6,100	0,960	1,512
N35157	5,900	0,960	1,512
N35158	2,000	0,960	0,000
N35159	2,100	0,960	1,512
N35160	1,900	0,960	1,512
N35161	-2,000	0,960	0,000
N35162	-1,900	0,960	1,512
N35164	14,000	31,060	0,000
N35168	10,000	31,060	0,000
N35169	6,000	31,060	0,000
N35170	2,000	31,060	0,000
N35171	-2,000	31,060	0,000
N35199	14,000	31,180	0,000
N35200	10,000	31,180	0,000
N35201	6,000	31,180	0,000
N35202	2,000	31,180	0,000
N35203	-2,000	31,180	0,000
N35219	14,000	31,300	0,000
N35220	10,000	31,300	0,000
N35221	6,000	31,300	0,000

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N35222	2,000	31,300	0,000
N35223	-2,000	31,300	0,000
N35239	14,000	31,420	0,000
N35240	10,000	31,420	0,000
N35241	6,000	31,420	0,000
N35242	2,000	31,420	0,000
N35243	-2,000	31,420	0,000
N35259	14,000	31,540	0,000
N35260	10,000	31,540	0,000
N35261	6,000	31,540	0,000
N35262	2,000	31,540	0,000
N35263	-2,000	31,540	0,000
N35279	14,000	31,660	0,000
N35280	10,000	31,660	0,000
N35281	6,000	31,660	0,000
N35282	2,000	31,660	0,000
N35283	-2,000	31,660	0,000
N35299	14,000	31,780	0,000
N35300	10,000	31,780	0,000
N35301	6,000	31,780	0,000
N35302	2,000	31,780	0,000
N35303	-2,000	31,780	0,000
N35304	14,000	31,900	1,350
N35305	13,900	31,900	1,350
N35306	14,100	31,900	1,350
N35307	10,000	31,900	1,350
N35308	9,900	31,900	1,350
N35309	10,100	31,900	1,350
N35310	6,000	31,900	1,350
N35311	5,900	31,900	1,350
N35312	6,100	31,900	1,350
N35313	2,000	31,900	1,350
N35314	1,900	31,900	1,350
N35315	2,100	31,900	1,350
N35316	-2,000	31,900	1,350
N35317	-2,100	31,900	1,350
N35318	-1,900	31,900	1,350
N35319	14,000	31,900	0,000
N35320	10,000	31,900	0,000
N35321	6,000	31,900	0,000
N35322	2,000	31,900	0,000
N35323	-2,000	31,900	0,000
N35386	14,100	31,900	1,512
N35395	-2,100	31,900	1,512
N35396	14,000	0,000	0,000
N35397	14,000	8,000	0,000
N1	14,000	16,000	0,000
N35398	14,000	24,000	0,000
N35399	14,000	32,000	0,000
N35400	10,000	0,000	0,000
N35401	10,000	8,000	0,000
N35402	10,000	24,000	0,000
N35403	10,000	32,000	0,000
N35404	10,000	16,000	0,000
N35405	6,000	0,000	0,000
N35406	6,000	8,000	0,000
N35407	6,000	24,000	0,000
N35408	6,000	32,000	0,000
N35409	6,000	16,000	0,000
N35410	2,000	0,000	0,000
N35411	2,000	8,000	0,000
N35412	2,000	24,000	0,000
N35413	2,000	32,000	0,000
N35414	2,000	16,000	0,000
N35415	-2,000	0,000	0,000
N35416	-2,000	8,000	0,000
N35417	-2,000	24,000	0,000
N35418	-2,000	32,000	0,000
N35419	-2,000	16,000	0,000

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N35420	14,000	0,230	1,350
N35421	13,900	0,230	1,350
N35422	14,100	0,230	1,350
N35423	10,000	0,230	1,350
N35424	9,900	0,230	1,350
N35425	10,100	0,230	1,350
N35426	6,000	0,230	1,350
N35427	5,900	0,230	1,350
N35428	6,100	0,230	1,350
N35429	2,000	0,230	1,350
N35430	1,900	0,230	1,350
N35431	2,100	0,230	1,350
N35432	-2,000	0,230	1,350
N35433	-2,100	0,230	1,350
N35434	-1,900	0,230	1,350
N35435	14,000	0,230	0,000
N35436	14,100	0,230	1,512
N35437	13,900	0,230	1,512
N35438	10,000	0,230	0,000
N35439	10,100	0,230	1,512
N35440	9,900	0,230	1,512
N35441	6,000	0,230	0,000
N35442	6,100	0,230	1,512
N35443	5,900	0,230	1,512
N35444	2,000	0,230	0,000
N35445	2,100	0,230	1,512
N35446	1,900	0,230	1,512
N35447	-2,000	0,230	0,000
N35448	-1,900	0,230	1,512
N35449	-2,100	0,230	1,512
N35450	14,000	0,360	1,350
N35451	13,900	0,360	1,350
N35452	14,100	0,360	1,350
N35453	10,000	0,360	1,350
N35454	9,900	0,360	1,350
N35455	10,100	0,360	1,350
N35456	6,000	0,360	1,350
N35457	5,900	0,360	1,350
N35458	6,100	0,360	1,350
N35459	2,000	0,360	1,350
N35460	1,900	0,360	1,350
N35461	2,100	0,360	1,350
N35462	-2,000	0,360	1,350
N35463	-2,100	0,360	1,350
N35464	-1,900	0,360	1,350
N35466	14,100	0,360	1,512
N35479	-2,100	0,360	1,512
N35480	14,000	0,490	1,350
N35481	13,900	0,490	1,350
N35482	14,100	0,490	1,350
N35483	10,000	0,490	1,350
N35484	9,900	0,490	1,350
N35485	10,100	0,490	1,350
N35486	6,000	0,490	1,350
N35487	5,900	0,490	1,350
N35488	6,100	0,490	1,350
N35489	2,000	0,490	1,350
N35490	1,900	0,490	1,350
N35491	2,100	0,490	1,350
N35492	-2,000	0,490	1,350
N35493	-2,100	0,490	1,350
N35494	-1,900	0,490	1,350
N35495	14,000	0,490	0,000
N35496	14,100	0,490	1,512
N35497	13,900	0,490	1,512
N35498	10,000	0,490	0,000
N35499	10,100	0,490	1,512
N35500	9,900	0,490	1,512
N35501	6,000	0,490	0,000

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N35502	6,100	0,490	1,512
N35503	5,900	0,490	1,512
N35504	2,000	0,490	0,000
N35505	2,100	0,490	1,512
N35506	1,900	0,490	1,512
N35507	-2,000	0,490	0,000
N35508	-1,900	0,490	1,512
N35509	-2,100	0,490	1,512
N35510	14,000	0,620	1,350
N35511	13,900	0,620	1,350
N35512	14,100	0,620	1,350
N35513	10,000	0,620	1,350
N35514	9,900	0,620	1,350
N35515	10,100	0,620	1,350
N35516	6,000	0,620	1,350
N35517	5,900	0,620	1,350
N35518	6,100	0,620	1,350
N35519	2,000	0,620	1,350
N35520	1,900	0,620	1,350
N35521	2,100	0,620	1,350
N35522	-2,000	0,620	1,350
N35523	-2,100	0,620	1,350
N35524	-1,900	0,620	1,350
N35525	14,000	0,620	0,000
N35526	14,100	0,620	1,512
N35527	10,000	0,620	0,000
N35528	6,000	0,620	0,000
N35529	2,000	0,620	0,000
N35530	-2,000	0,620	0,000
N35531	-2,100	0,620	1,512
N35532	14,000	0,750	1,350
N35533	13,900	0,750	1,350
N35534	14,100	0,750	1,350
N35535	10,000	0,750	1,350
N35536	9,900	0,750	1,350
N35537	10,100	0,750	1,350
N35538	6,000	0,750	1,350
N35539	5,900	0,750	1,350
N35540	6,100	0,750	1,350
N35541	2,000	0,750	1,350
N35542	1,900	0,750	1,350
N35543	2,100	0,750	1,350
N35544	-2,000	0,750	1,350
N35545	-2,100	0,750	1,350
N35546	-1,900	0,750	1,350
N35547	14,000	0,750	0,000
N35548	14,100	0,750	1,512
N35549	13,900	0,750	1,512
N35550	10,000	0,750	0,000
N35551	10,100	0,750	1,512
N35552	9,900	0,750	1,512
N35553	6,000	0,750	0,000
N35554	6,100	0,750	1,512
N35555	5,900	0,750	1,512
N35556	2,000	0,750	0,000
N35557	2,100	0,750	1,512
N35558	1,900	0,750	1,512
N35559	-2,000	0,750	0,000
N35560	-1,900	0,750	1,512
N35561	-2,100	0,750	1,512
N35562	14,000	0,880	1,350
N35563	13,900	0,880	1,350
N35564	14,100	0,880	1,350
N35565	10,000	0,880	1,350
N35566	9,900	0,880	1,350
N35567	10,100	0,880	1,350
N35568	6,000	0,880	1,350
N35569	5,900	0,880	1,350
N35570	6,100	0,880	1,350

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N35571	2,000	0,880	1,350
N35572	1,900	0,880	1,350
N35573	2,100	0,880	1,350
N35574	-2,000	0,880	1,350
N35575	-2,100	0,880	1,350
N35576	-1,900	0,880	1,350
N35577	14,000	0,880	0,000
N35578	14,100	0,880	1,512
N35579	10,000	0,880	0,000
N35580	6,000	0,880	0,000
N35581	2,000	0,880	0,000
N35582	-2,000	0,880	0,000
N35583	-2,100	0,880	1,512
N35584	14,000	31,770	1,350
N35585	13,900	31,770	1,350
N35586	14,100	31,770	1,350
N35587	10,000	31,770	1,350
N35588	9,900	31,770	1,350
N35589	10,100	31,770	1,350
N35590	6,000	31,770	1,350
N35591	5,900	31,770	1,350
N35592	6,100	31,770	1,350
N35593	2,000	31,770	1,350
N35594	1,900	31,770	1,350
N35595	2,100	31,770	1,350
N35596	-2,000	31,770	1,350
N35597	-2,100	31,770	1,350
N35598	-1,900	31,770	1,350
N35599	14,000	31,770	0,000
N35600	14,100	31,770	1,512
N35601	13,900	31,770	1,512
N35602	10,000	31,770	0,000
N35603	10,100	31,770	1,512
N35604	9,900	31,770	1,512
N35605	6,000	31,770	0,000
N35606	6,100	31,770	1,512
N35607	5,900	31,770	1,512
N35608	2,000	31,770	0,000
N35609	2,100	31,770	1,512
N35610	1,900	31,770	1,512
N35611	-2,000	31,770	0,000
N35612	-1,900	31,770	1,512
N35613	-2,100	31,770	1,512
N35614	14,000	31,640	1,350
N35615	13,900	31,640	1,350
N35616	14,100	31,640	1,350
N35617	10,000	31,640	1,350
N35618	9,900	31,640	1,350
N35619	10,100	31,640	1,350
N35620	6,000	31,640	1,350
N35621	5,900	31,640	1,350
N35622	6,100	31,640	1,350
N35623	2,000	31,640	1,350
N35624	1,900	31,640	1,350
N35625	2,100	31,640	1,350
N35626	-2,000	31,640	1,350
N35627	-2,100	31,640	1,350
N35628	-1,900	31,640	1,350
N35629	14,000	31,640	0,000
N35630	14,100	31,640	1,512
N35631	13,900	31,640	1,512
N35632	10,000	31,640	0,000
N35633	10,100	31,640	1,512
N35634	9,900	31,640	1,512
N35635	6,000	31,640	0,000
N35636	6,100	31,640	1,512

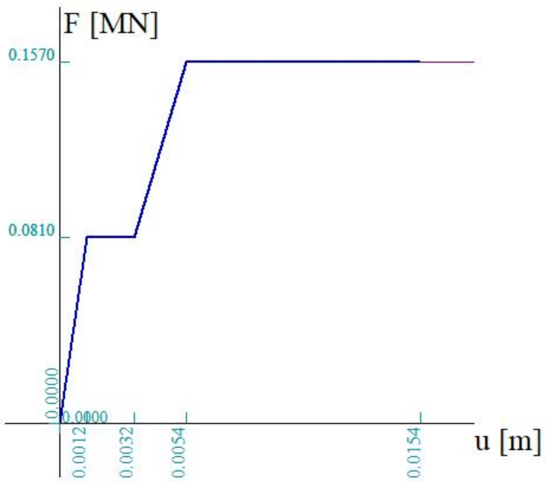
Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N35637	5,900	31,640	1,512
N35638	2,000	31,640	0,000
N35639	2,100	31,640	1,512
N35640	1,900	31,640	1,512
N35641	-2,000	31,640	0,000
N35642	-1,900	31,640	1,512
N35643	-2,100	31,640	1,512
N35644	14,000	31,510	1,350
N35645	13,900	31,510	1,350
N35646	14,100	31,510	1,350
N35647	10,000	31,510	1,350
N35648	9,900	31,510	1,350
N35649	10,100	31,510	1,350
N35650	6,000	31,510	1,350
N35651	5,900	31,510	1,350
N35652	6,100	31,510	1,350
N35653	2,000	31,510	1,350
N35654	1,900	31,510	1,350
N35655	2,100	31,510	1,350
N35656	-2,000	31,510	1,350
N35657	-2,100	31,510	1,350
N35658	-1,900	31,510	1,350
N35659	14,000	31,510	0,000
N35660	14,100	31,510	1,512
N35661	13,900	31,510	1,512
N35662	10,000	31,510	0,000
N35663	10,100	31,510	1,512
N35664	9,900	31,510	1,512
N35665	6,000	31,510	0,000
N35666	6,100	31,510	1,512
N35667	5,900	31,510	1,512
N35668	2,000	31,510	0,000
N35669	2,100	31,510	1,512
N35670	1,900	31,510	1,512
N35671	-2,000	31,510	0,000
N35672	-1,900	31,510	1,512
N35673	-2,100	31,510	1,512
N35674	14,000	31,380	1,350
N35675	13,900	31,380	1,350
N35676	14,100	31,380	1,350
N35677	10,000	31,380	1,350
N35678	9,900	31,380	1,350
N35679	10,100	31,380	1,350
N35680	6,000	31,380	1,350
N35681	5,900	31,380	1,350
N35682	6,100	31,380	1,350
N35683	2,000	31,380	1,350
N35684	1,900	31,380	1,350
N35685	2,100	31,380	1,350
N35686	-2,000	31,380	1,350
N35687	-2,100	31,380	1,350
N35688	-1,900	31,380	1,350
N35689	14,000	31,380	0,000
N35690	14,100	31,380	1,512
N35691	13,900	31,380	1,512
N35692	10,000	31,380	0,000
N35693	10,100	31,380	1,512
N35694	9,900	31,380	1,512
N35695	6,000	31,380	0,000
N35696	6,100	31,380	1,512
N35697	5,900	31,380	1,512
N35698	2,000	31,380	0,000
N35699	2,100	31,380	1,512
N35700	1,900	31,380	1,512
N35701	-2,000	31,380	0,000
N35702	-1,900	31,380	1,512

Name	Coord X [m]	Coord Y [m]	Coord Z [m]
N35703	-2,100	31,380	1,512
N35704	14,000	31,250	1,350
N35705	13,900	31,250	1,350
N35706	14,100	31,250	1,350
N35707	10,000	31,250	1,350
N35708	9,900	31,250	1,350
N35709	10,100	31,250	1,350
N35710	6,000	31,250	1,350
N35711	5,900	31,250	1,350
N35712	6,100	31,250	1,350
N35713	2,000	31,250	1,350
N35714	1,900	31,250	1,350
N35715	2,100	31,250	1,350
N35716	-2,000	31,250	1,350
N35717	-2,100	31,250	1,350
N35718	-1,900	31,250	1,350
N35719	14,000	31,250	0,000
N35720	14,100	31,250	1,512
N35721	13,900	31,250	1,512
N35722	10,000	31,250	0,000
N35723	10,100	31,250	1,512
N35724	9,900	31,250	1,512
N35725	6,000	31,250	0,000
N35726	6,100	31,250	1,512
N35727	5,900	31,250	1,512
N35728	2,000	31,250	0,000
N35729	2,100	31,250	1,512
N35730	1,900	31,250	1,512
N35731	-2,000	31,250	0,000
N35732	-1,900	31,250	1,512
N35733	-2,100	31,250	1,512
N35734	14,000	31,120	1,350
N35735	13,900	31,120	1,350
N35736	14,100	31,120	1,350
N35737	10,000	31,120	1,350
N35738	9,900	31,120	1,350
N35739	10,100	31,120	1,350
N35740	6,000	31,120	1,350
N35741	5,900	31,120	1,350
N35742	6,100	31,120	1,350
N35743	2,000	31,120	1,350
N35744	1,900	31,120	1,350
N35745	2,100	31,120	1,350
N35746	-2,000	31,120	1,350
N35747	-2,100	31,120	1,350
N35748	-1,900	31,120	1,350
N35749	14,000	31,120	0,000
N35750	14,100	31,120	1,512
N35751	13,900	31,120	1,512
N35752	10,000	31,120	0,000
N35753	10,100	31,120	1,512
N35754	9,900	31,120	1,512
N35755	6,000	31,120	0,000
N35756	6,100	31,120	1,512
N35757	5,900	31,120	1,512
N35758	2,000	31,120	0,000
N35759	2,100	31,120	1,512
N35760	1,900	31,120	1,512
N35761	-2,000	31,120	0,000
N35762	-1,900	31,120	1,512
N35763	-2,100	31,120	1,512
N35764	14,000	0,100	0,000
N35765	10,000	0,100	0,000
N35766	6,000	0,100	0,000
N35767	2,000	0,100	0,000
N35768	-2,000	0,100	0,000

2.4. Nonlinear functions

Name	Type	u / F	Positive end	Negative end
ECD no resin	Translation	0.000000 / 0.000000	Free	Flexible
		0.001160 / 81000.000000		
		0.003160 / 81000.000000		
		0.005390 / 157000.000000		
		0.015400 / 157000.000000		

Drawing



2.5. Nodal supports

Name	Node	System	Type	X	Y	Z	Rx	Ry	Rz
Sn1	N35396	GCS	Standard	Rigid	Rigid	Rigid	Free	Free	Free
Sn2	N35400	GCS	Standard	Rigid	Rigid	Rigid	Free	Free	Free
Sn3	N35405	GCS	Standard	Rigid	Rigid	Rigid	Free	Free	Free
Sn4	N35410	GCS	Standard	Rigid	Rigid	Rigid	Free	Free	Free
Sn5	N35415	GCS	Standard	Rigid	Rigid	Rigid	Free	Free	Free
Sn6	N35399	GCS	Standard	Rigid	Free	Rigid	Free	Free	Free
Sn7	N35403	GCS	Standard	Rigid	Free	Rigid	Free	Free	Free
Sn8	N35408	GCS	Standard	Rigid	Free	Rigid	Free	Free	Free
Sn9	N35413	GCS	Standard	Rigid	Free	Rigid	Free	Free	Free
Sn10	N35418	GCS	Standard	Rigid	Free	Rigid	Free	Free	Free

3. Loads

3.1. Free point load

Name	Load case	System	Type	Coord X [m]	Coord Y [m]	Coord Z [m]	Value - F [kN]
TS1	BG2 - Verkeerslast Midspan	GCS	Force	4,359	16,000	1,508	-152,43
TS2	BG2 - Verkeerslast Midspan	GCS	Force	6,359	16,000	1,508	-152,43
TS3	BG2 - Verkeerslast Midspan	GCS	Force	4,359	17,200	1,508	-152,43
TS4	BG2 - Verkeerslast Midspan	GCS	Force	6,359	17,200	1,508	-152,43
TS5	BG3 - FLS-Verkeerslast	GCS	Force	5,000	7,600	1,508	-35,57
TS6	BG3 - FLS-Verkeerslast	GCS	Force	5,000	16,000	1,508	-45,73
TS7	BG3 - FLS-Verkeerslast	GCS	Force	5,000	10,800	1,508	-76,22
TS8	BG3 - FLS-Verkeerslast	GCS	Force	5,000	17,300	1,508	-45,73
TS9	BG3 - FLS-Verkeerslast	GCS	Force	5,000	18,600	1,508	-45,73
TS10	BG3 - FLS-Verkeerslast	GCS	Force	7,000	7,600	1,508	-35,57
TS11	BG3 - FLS-Verkeerslast	GCS	Force	7,000	10,800	1,508	-76,22
TS12	BG3 - FLS-Verkeerslast	GCS	Force	7,000	16,000	1,508	-45,73
TS13	BG3 - FLS-Verkeerslast	GCS	Force	7,000	17,300	1,508	-45,73
TS14	BG3 - FLS-Verkeerslast	GCS	Force	7,000	18,600	1,508	-45,73
TS15	BG2 - Verkeerslast Midspan	GCS	Force	7,359	16,000	1,508	-101,62
TS16	BG2 - Verkeerslast Midspan	GCS	Force	7,359	17,200	1,508	-101,62
TS17	BG2 - Verkeerslast Midspan	GCS	Force	9,359	16,000	1,508	-101,62
TS18	BG2 - Verkeerslast Midspan	GCS	Force	9,359	17,200	1,508	-101,62
TS19	BG2 - Verkeerslast Midspan	GCS	Force	10,359	16,000	1,508	-50,81
TS20	BG2 - Verkeerslast Midspan	GCS	Force	10,359	17,200	1,508	-50,81
TS21	BG2 - Verkeerslast Midspan	GCS	Force	12,359	17,200	1,508	-50,81

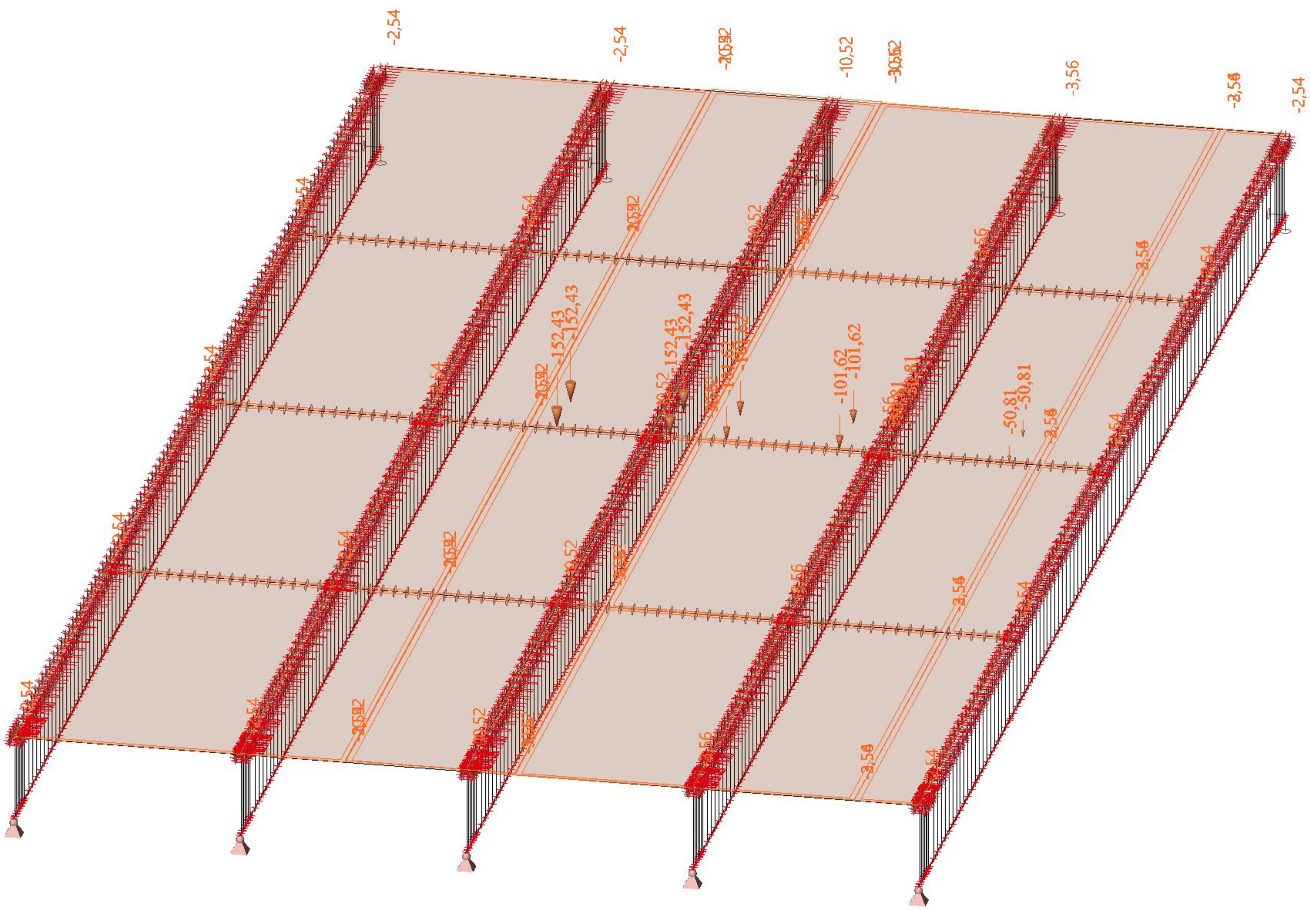
Name	Load case	System	Type	Coord X [m]	Coord Y [m]	Coord Z [m]	Value - F [kN]
TS22	BG2 - Verkeerslast Midspan	GCS	Force	12,359	16,000	1,508	-50,81
TS23	BG8 - Verkeerslast Shear Force	GCS	Force	4,359	5,250	1,508	-152,43
TS24	BG8 - Verkeerslast Shear Force	GCS	Force	6,359	5,250	1,508	-152,43
TS25	BG8 - Verkeerslast Shear Force	GCS	Force	4,359	6,450	1,508	-152,43
TS26	BG8 - Verkeerslast Shear Force	GCS	Force	6,359	6,450	1,508	-152,43
TS27	BG8 - Verkeerslast Shear Force	GCS	Force	7,359	5,250	1,508	-101,62
TS28	BG8 - Verkeerslast Shear Force	GCS	Force	7,359	6,450	1,508	-101,62
TS29	BG8 - Verkeerslast Shear Force	GCS	Force	9,359	5,250	1,508	-101,62
TS30	BG8 - Verkeerslast Shear Force	GCS	Force	9,359	6,450	1,508	-101,62
TS31	BG8 - Verkeerslast Shear Force	GCS	Force	10,359	5,250	1,508	-50,81
TS32	BG8 - Verkeerslast Shear Force	GCS	Force	10,359	6,450	1,508	-50,81
TS33	BG8 - Verkeerslast Shear Force	GCS	Force	12,359	6,450	1,508	-50,81
TS34	BG8 - Verkeerslast Shear Force	GCS	Force	12,359	5,250	1,508	-50,81

Explanations of symbols	
Load case	Verkeerslast Midspan

3.2. Load cases

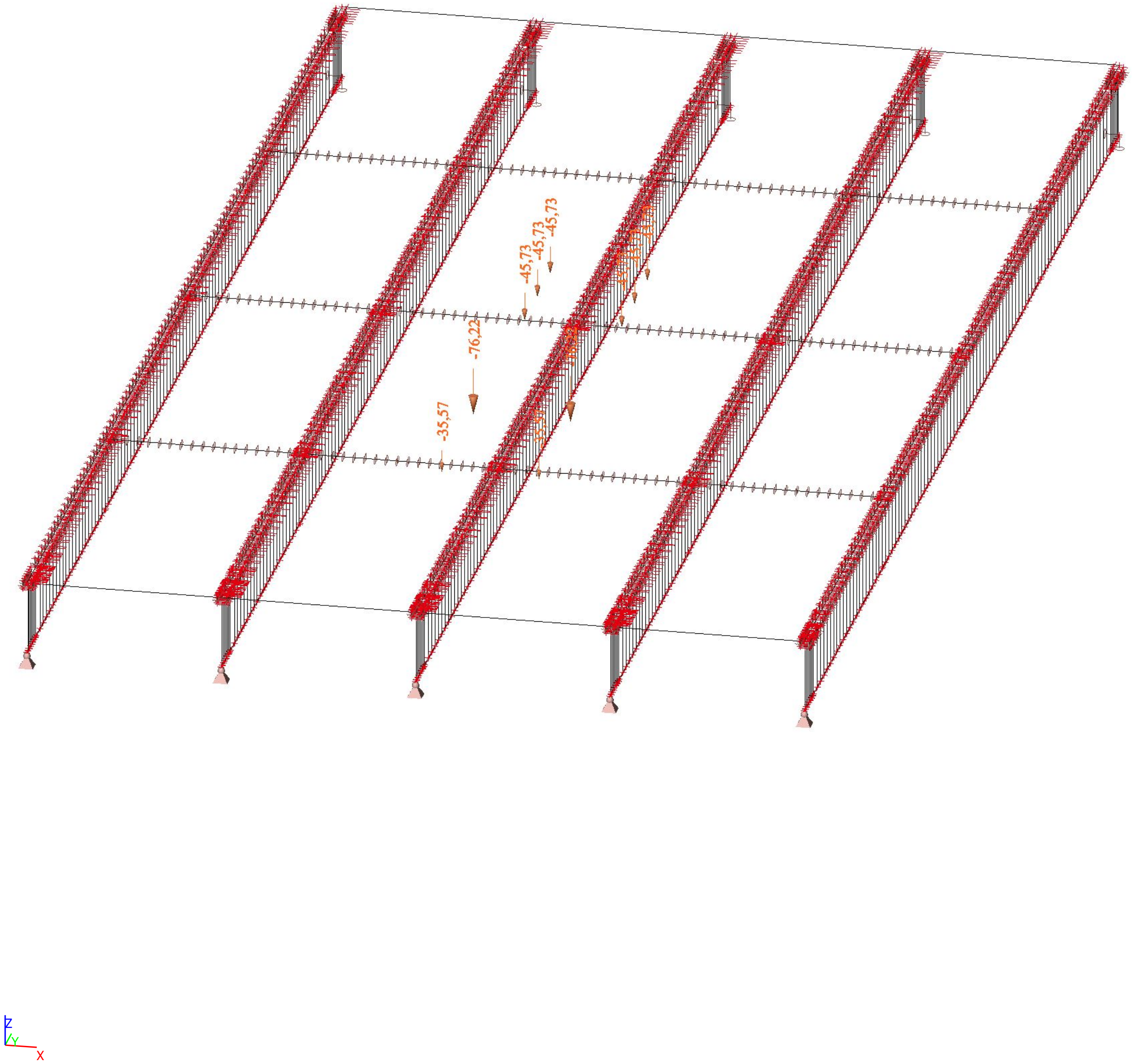
3.2.1. Load cases - BG2

Name	Description	Action type	Load group	Duration	Master load case
	Spec	Load type			
BG2	Verkeerslast Midspan	Variable	Vehicle loads	Short	None
	Standard	Static			



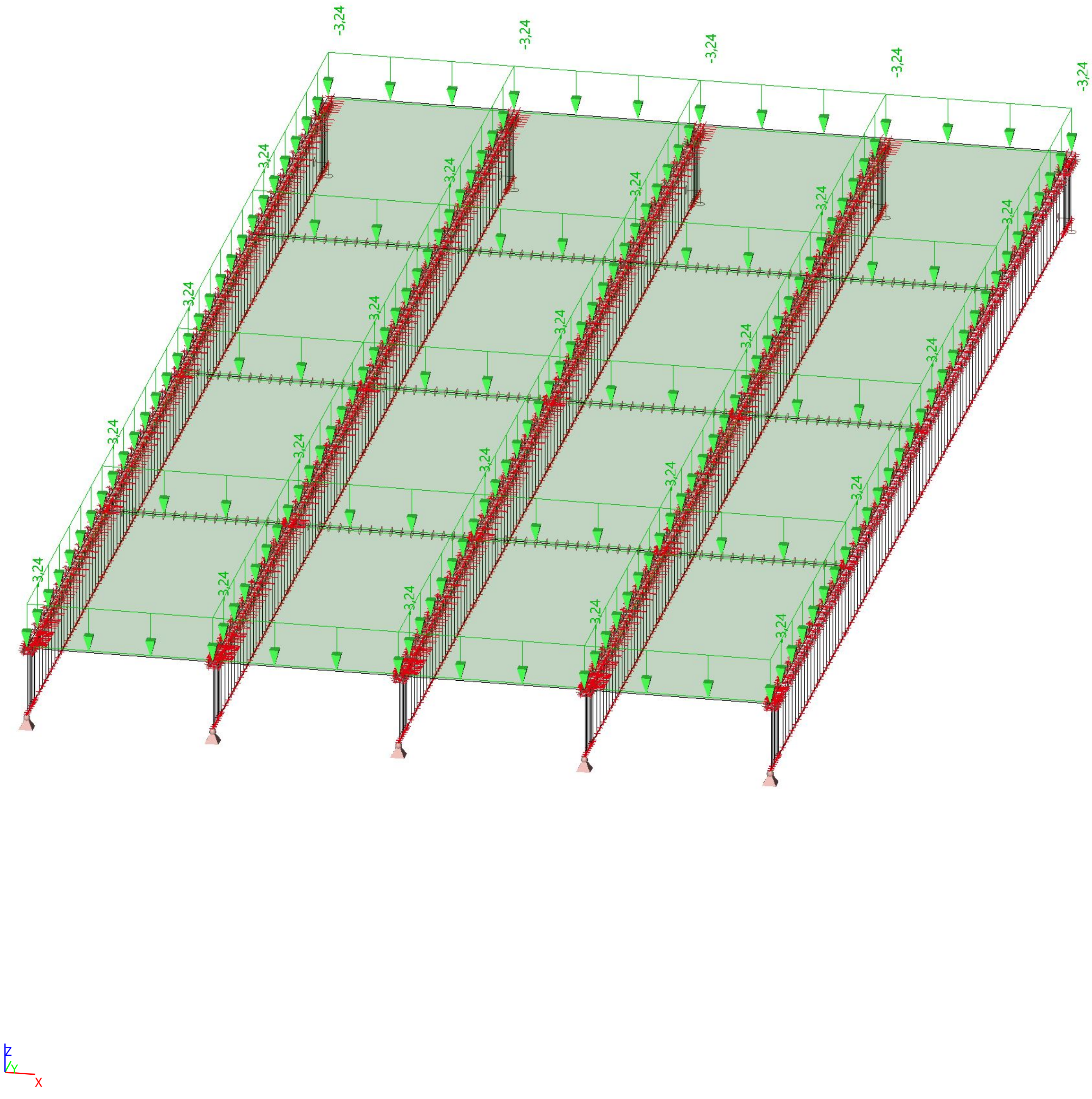
3.2.2. Load cases - BG3

Name	Description	Action type	Load group	Duration	Master load case
	Spec	Load type			
BG3	FLS-Verkeerslast	Variable	Fatigue	Short	None
	Standard	Static			



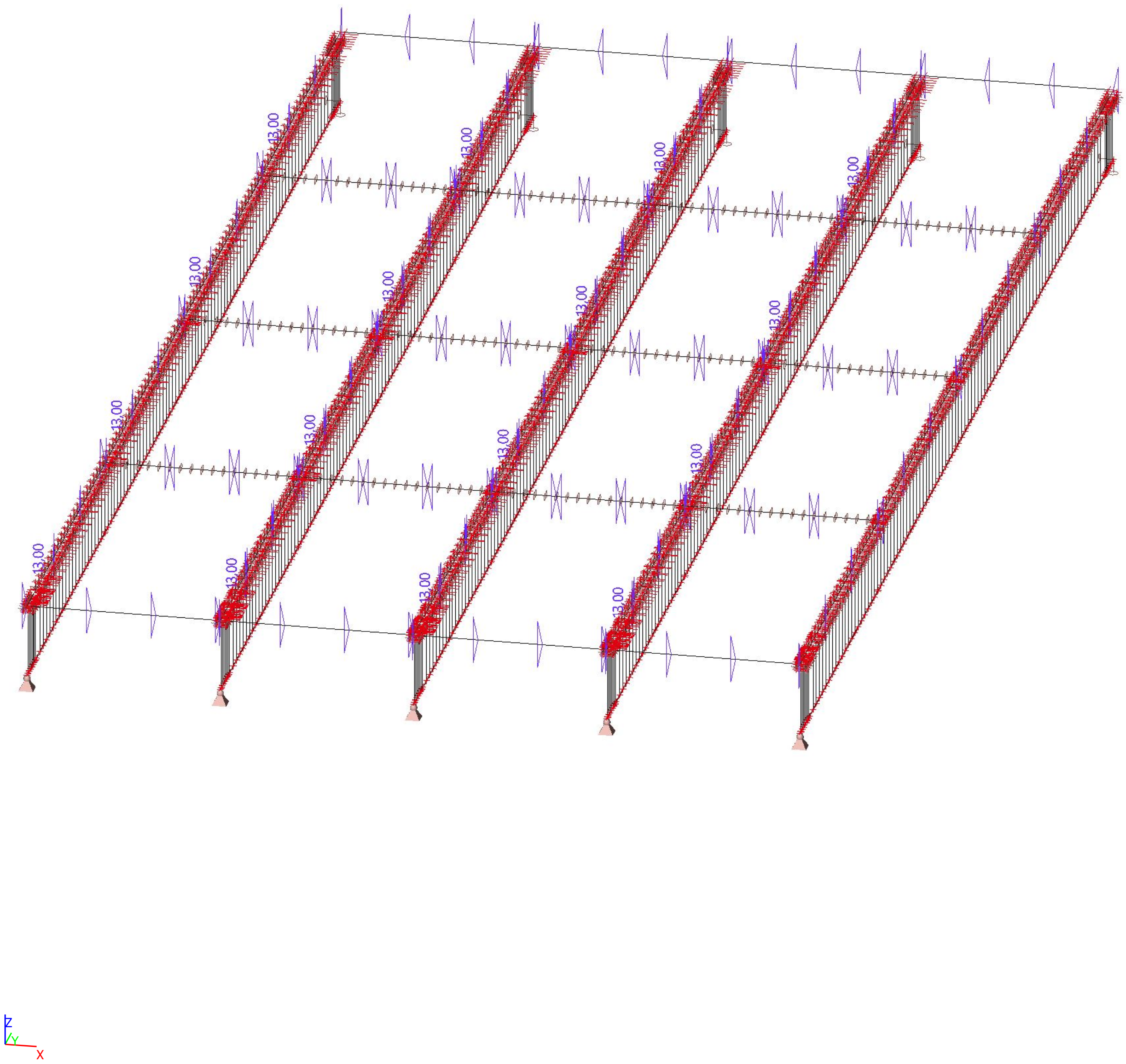
3.2.3. Load cases - BG4

Name	Description	Action type	Load group
	Spec	Load type	
BG4	EG overig	Permanent	Self-weight
		Standard	



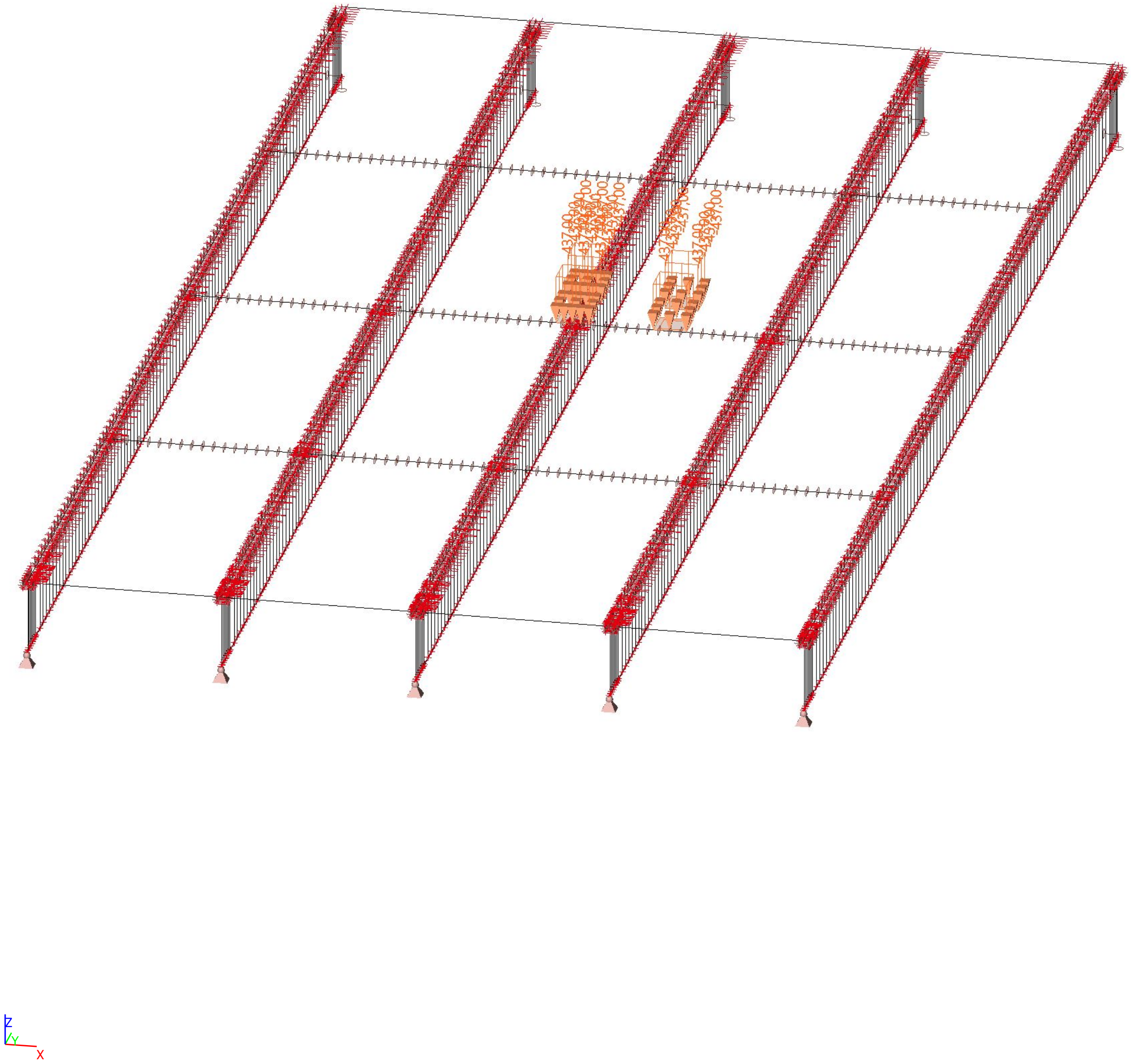
3.2.4. Load cases - BG5

Name	Description	Action type	Load group	Master load case
	Spec	Load type		
BG5	Temperatuur Opwarming	Variable	Temperature loads	None
	Temperature	Static		



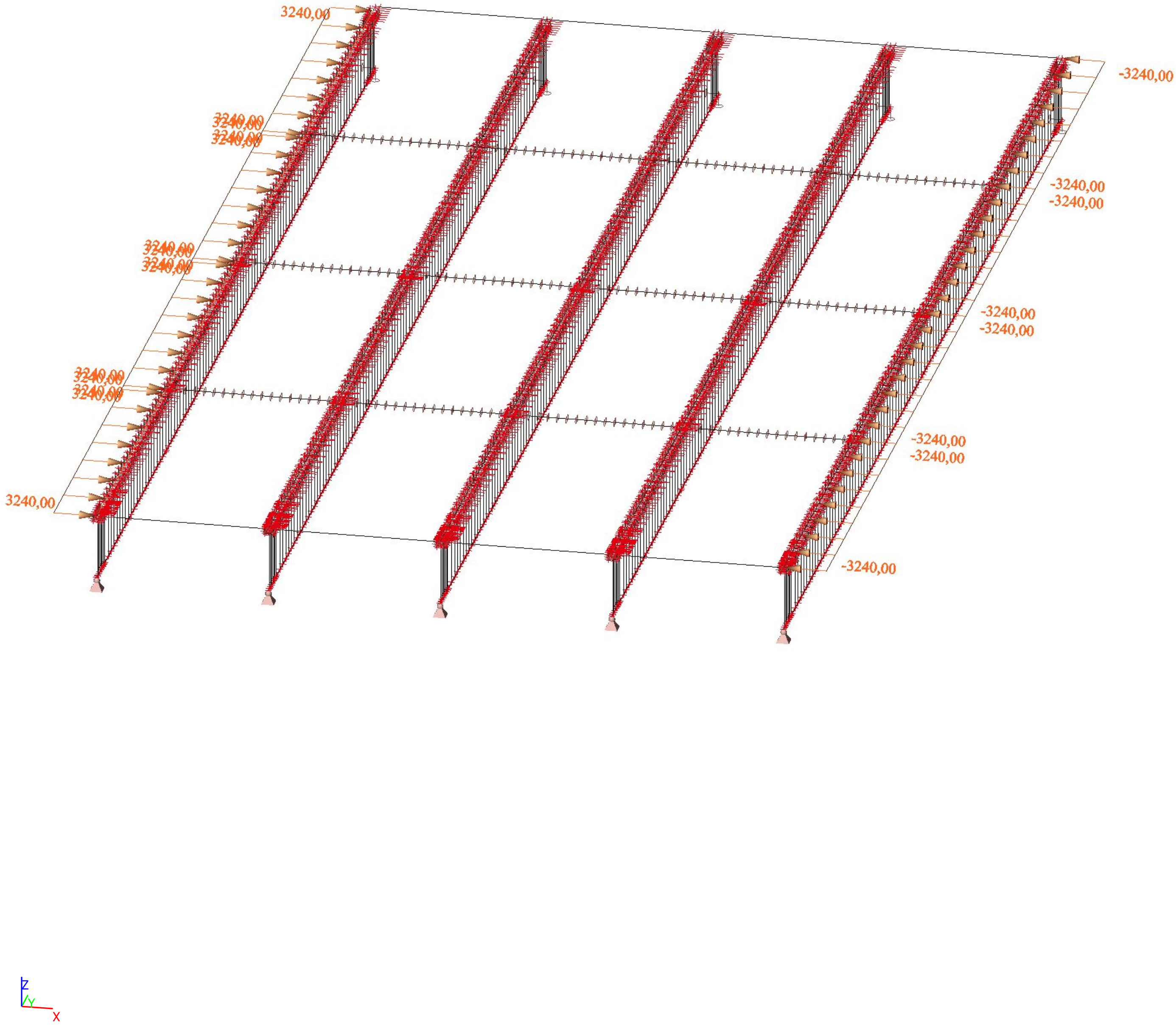
3.2.5. Load cases - BG6

Name	Description	Action type	Load group	Duration	Master load case
	Spec	Load type			
BG6	LM2	Variable	Vehicle loads	Short	None
	Standard	Static			



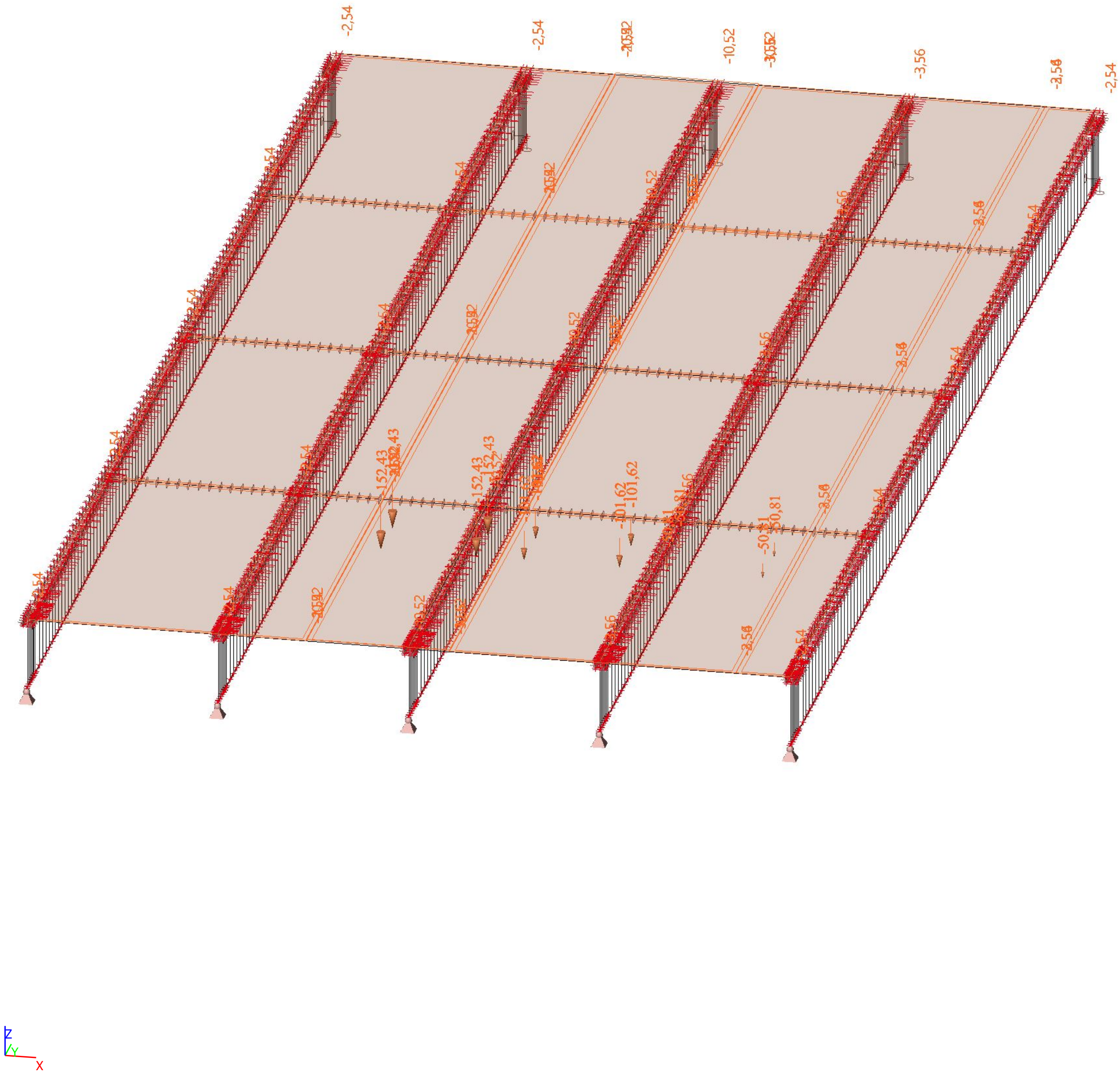
3.2.6. Load cases - BG7

Name	Description	Action type	Load group
	Spec	Load type	
BG7	Prestress	Permanent	Prestress
		Standard	



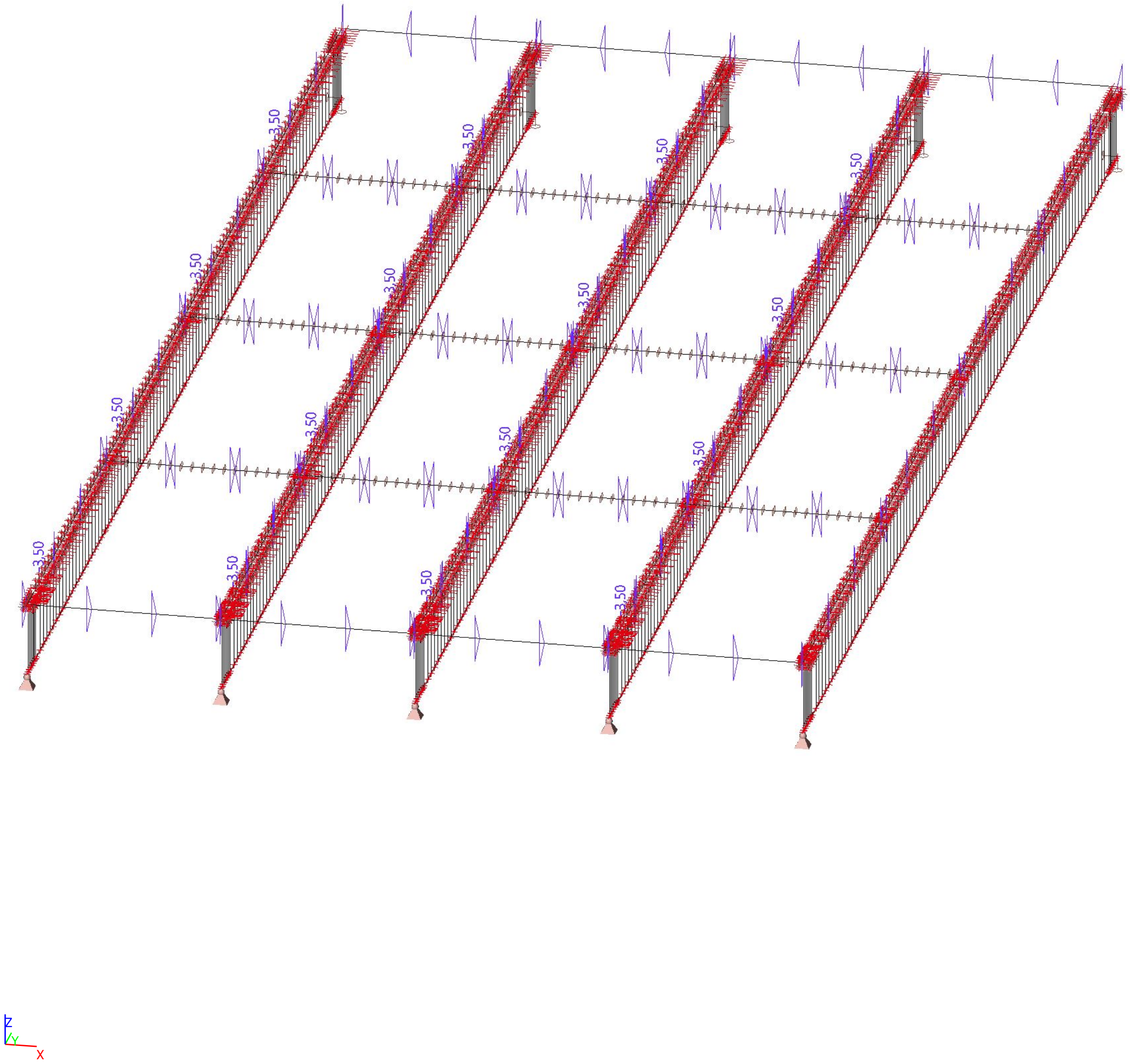
3.2.7. Load cases - BG8

Name	Description	Action type	Load group	Duration	Master load case
	Spec	Load type			
BG8	Verkeerslast Shear Force	Variable	Vehicle loads	Short	None
	Standard	Static			



3.2.8. Load cases - BG9

Name	Description	Action type	Load group	Master load case
	Spec	Load type		
BG9	Temperatuur Afkoeling	Variable	Temperature loads	None
	Temperature	Static		



4. Results

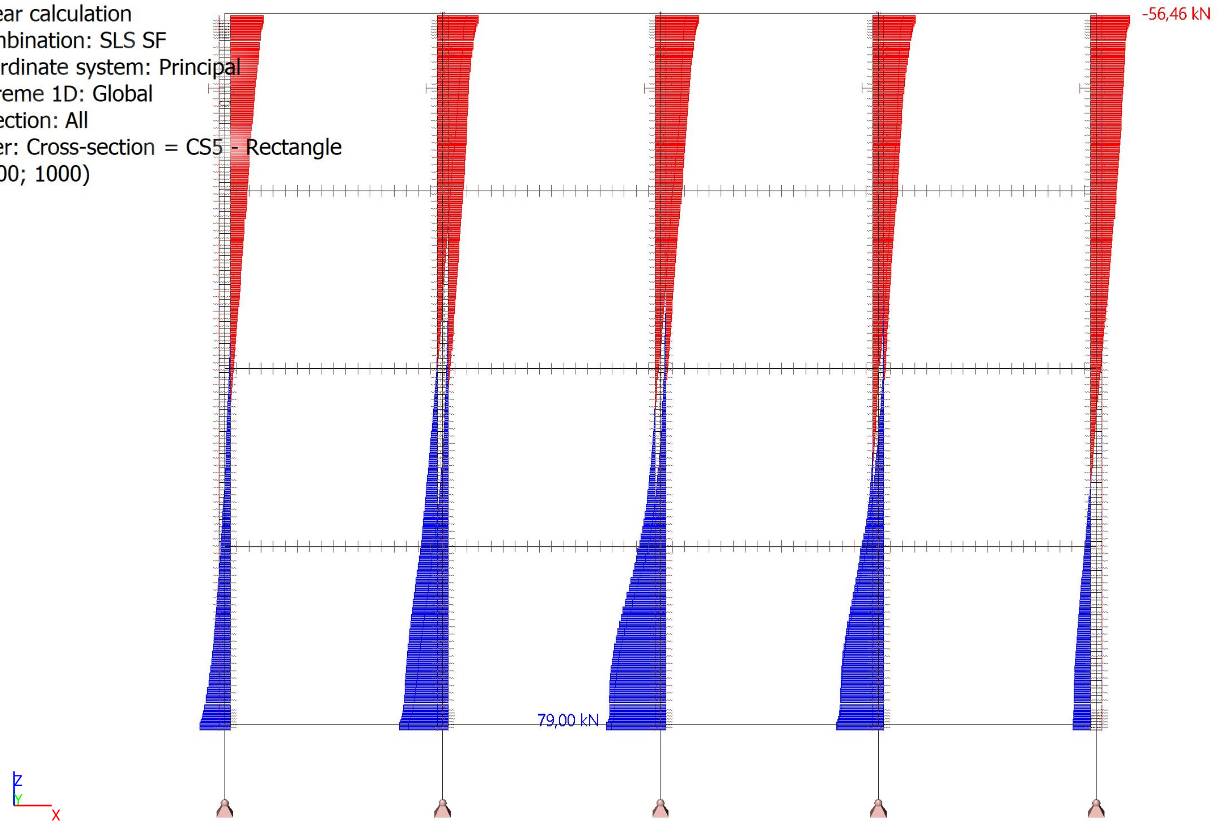
4.1. Shear Connector Forces - SLS

4.1.1. Combinations

Name	Description	Type	Load cases	Coeff. [-]
SLS SF		EN-SLS Characteristic	BG4 - EG overig	1,000
			BG5 - Temperatuur Opwarming	1,000
			BG7 - Prestress	1,000
			BG8 - Verkeerslast Shear Force	1,000

4.1.2. 1D internal forces; V_y

Values: $\mathbf{V_y}$
Linear calculation
Combination: SLS SF
Coordinate system: Principal
Extreme 1D: Global
Selection: All
Filter: Cross-section = CS5 - Rectangle (1000; 1000)



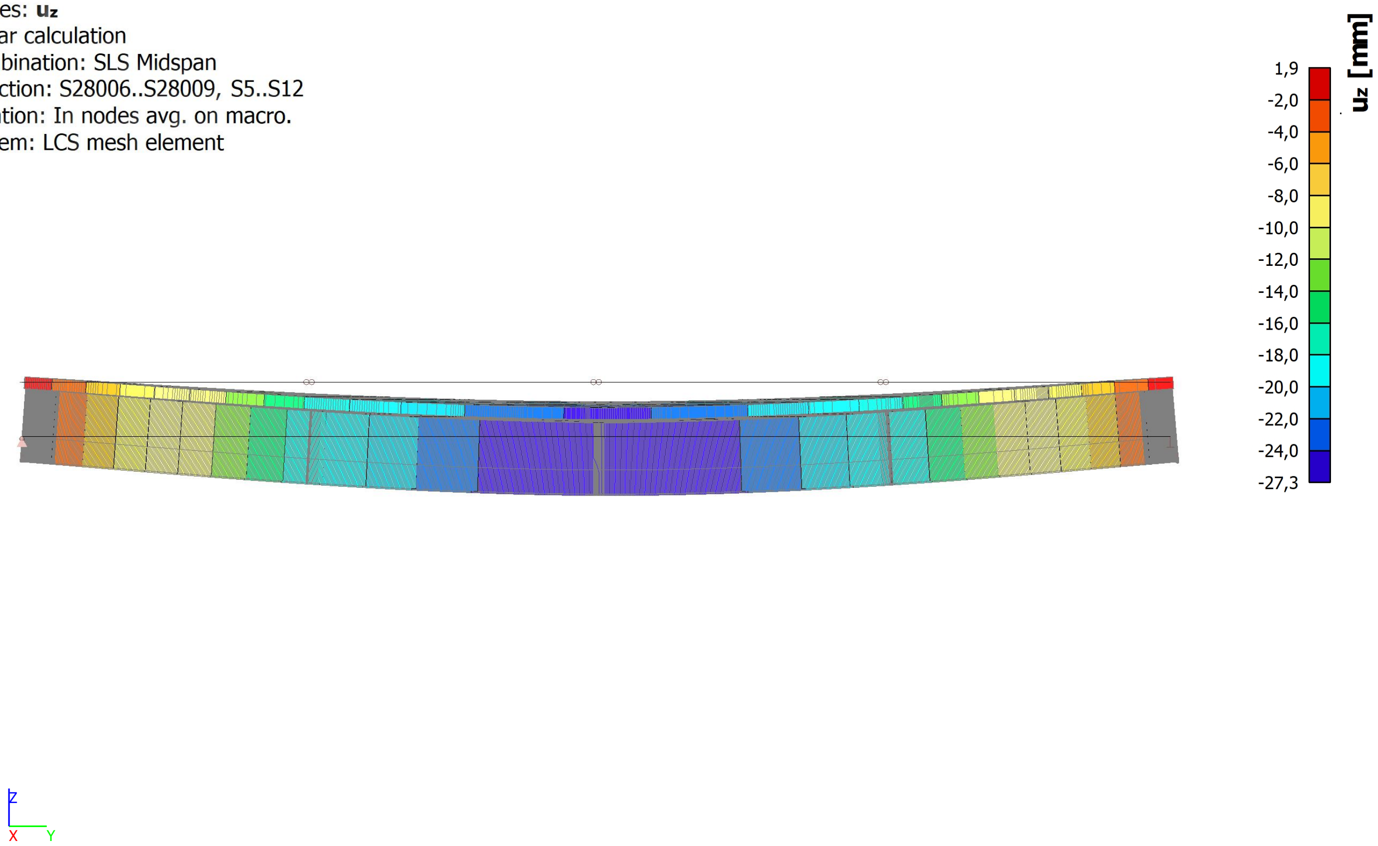
4.2. Deformation - SLS

4.2.1. Combinations

Name	Description	Type	Load cases	Coeff. [-]
SLS Midspan		EN-SLS Characteristic	BG2 - Verkeerslast Midspan	1,000
			BG4 - EG overig	1,000
			BG7 - Prestress	1,000
			BG9 - Temperatuur Afkoeling	1,000

4.2.2. 3D displacement; u_z

Values: u_z
Linear calculation
Combination: SLS Midspan
Selection: S28006..S28009, S5..S12
Location: In nodes avg. on macro.
System: LCS mesh element



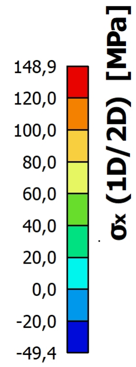
4.3. Steel Stress - ULS

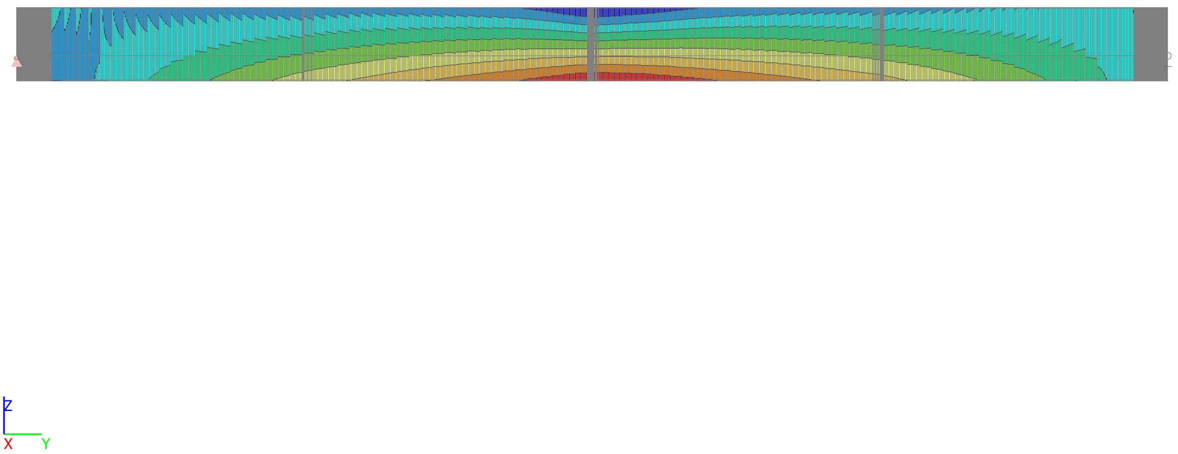
4.3.1. Nonlinear combinations

Name	Type	Load cases	Coeff. [-]
NC Midspan LM1	Ultimate	BG2 - Verkeerslast Midspan	1,500
		BG4 - EG overig	1,250
		BG7 - Prestress	1,200
		BG9 - Temperatuur Afkoeling	0,495

4.3.2. 3D stress; σ_x (1D/2D)

Values: **σ_x (1D/2D)**
Nonlinear calculation
NonLinear Combi: NC Midspan LM1
Selection: All
Filter: Cross-section = CS3 - Iwn
(2058; 14; 300; 20; 660; 38; 2000; 8)
Location: In nodes avg. on macro.
System: LCS mesh element
Basic magnitudes





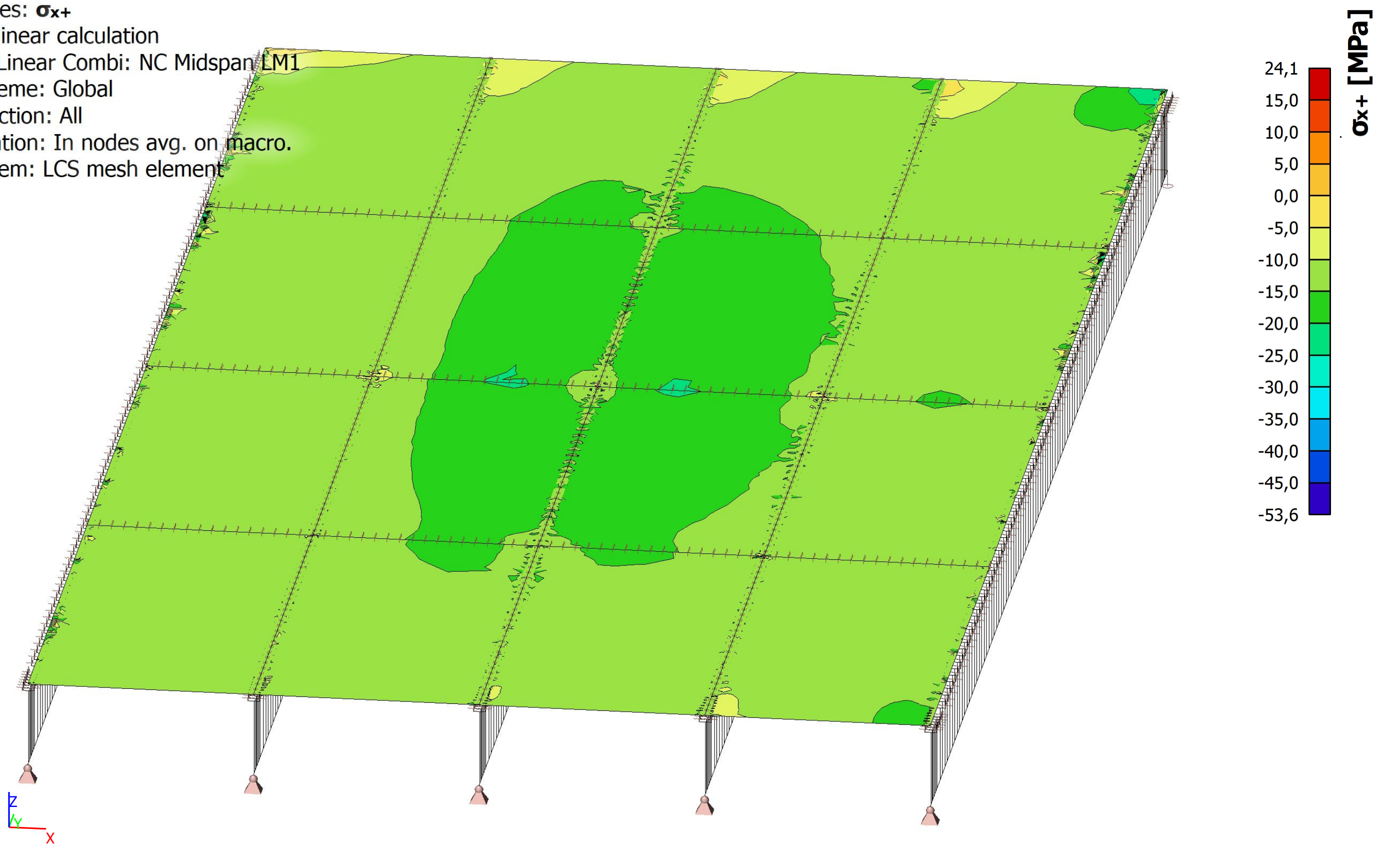
4.4. Concrete Stress - ULS

4.4.1. Nonlinear combinations

Name	Type	Load cases	Coeff. [-]
NC Midspan LM1	Ultimate	BG2 - Verkeerslast Midspan	1,500
		BG4 - EG overig	1,250
		BG7 - Prestress	1,200
		BG9 - Temperatuur Afkoeling	0,495

4.4.2. 2D stress/strain; σ_x+

Values: σ_{x+}
Nonlinear calculation
NonLinear Combi: NC Midspan LM1
Extreme: Global
Selection: All
Location: In nodes avg. on macro.
System: LCS mesh element



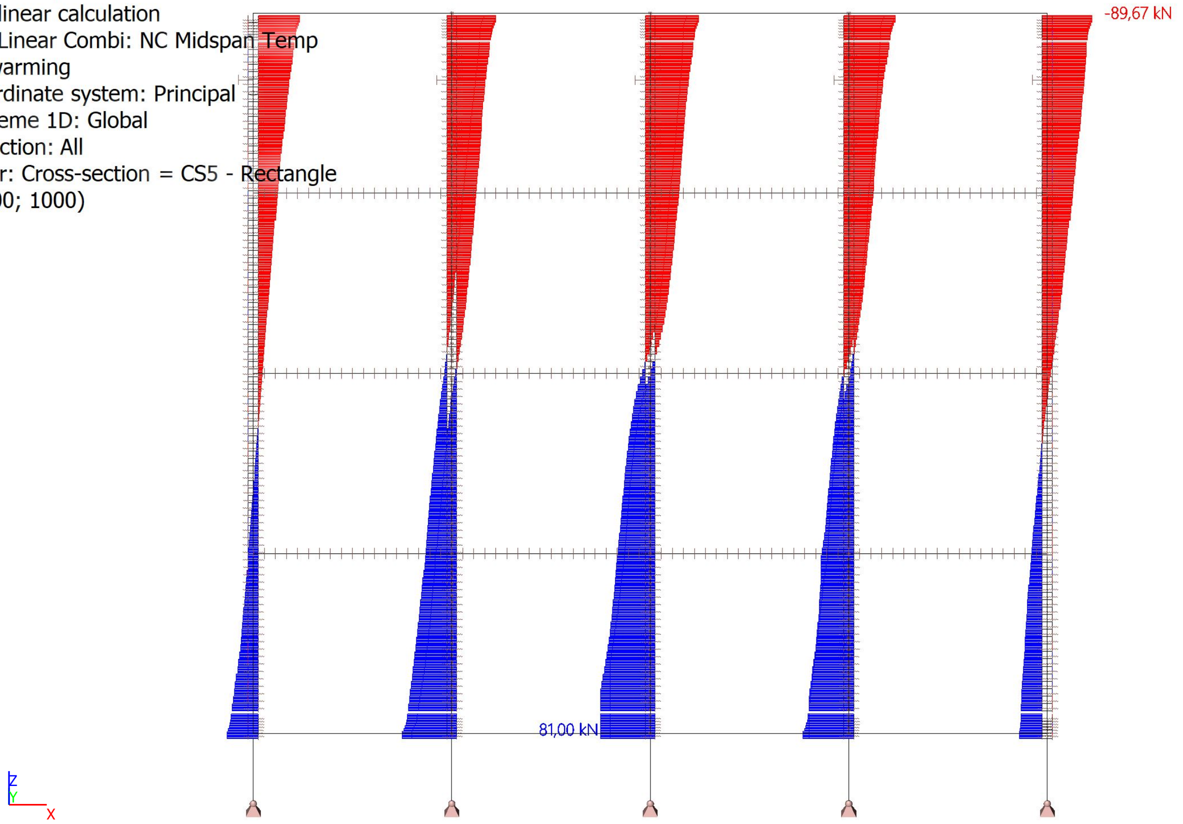
4.5. Shear Connector Forces - ULS

4.5.1. Nonlinear combinations

Name	Type	Load cases	Coeff. [-]
NC Midspan LM1	Ultimate	BG2 - Verkeerslast Midspan	1,500
		BG4 - EG overig	1,250
		BG7 - Prestress	1,200
		BG9 - Temperatuur Afkoeling	0,495

4.5.2. 1D internal forces; V_y

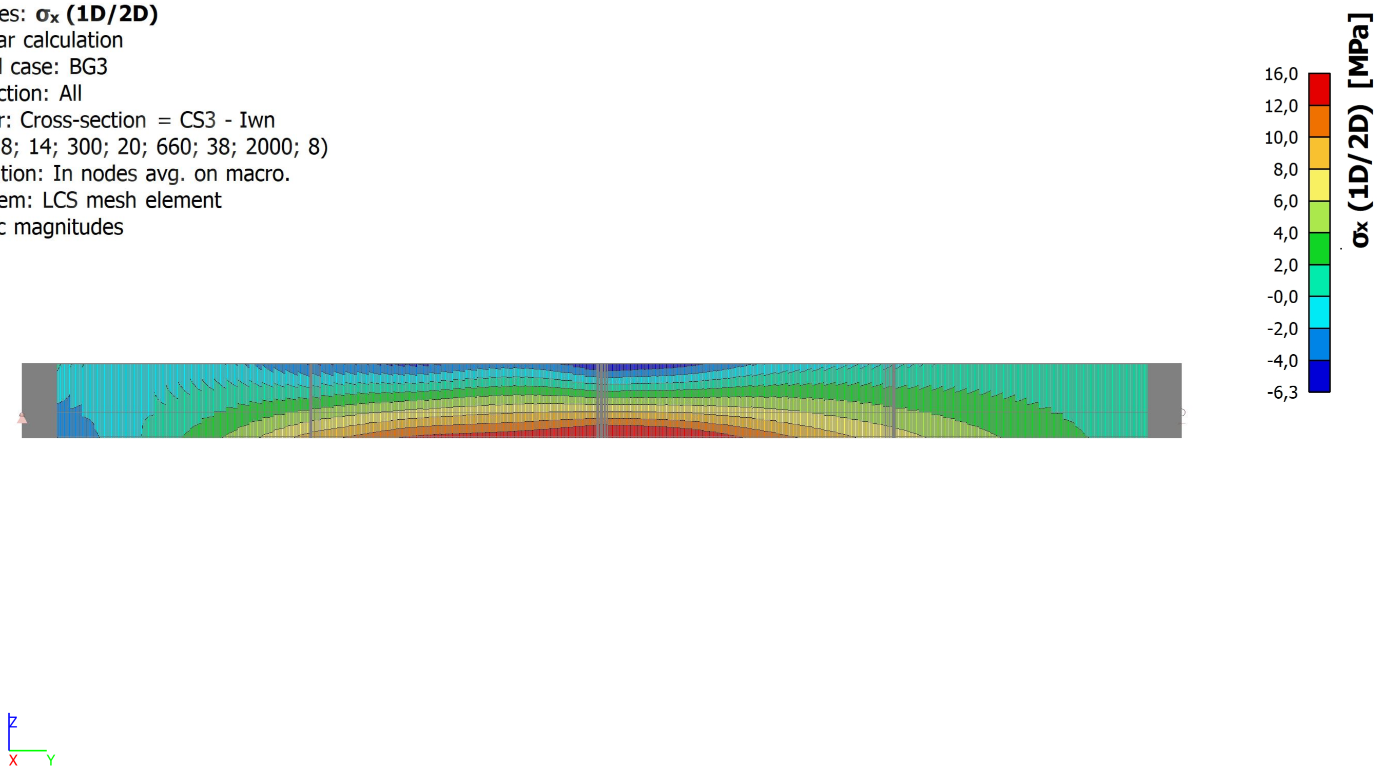
Values: V_y
Nonlinear calculation
NonLinear Combi: NC Midspan Temp
Opwarming
Coordinate system: Principal
Extreme 1D: Global
Selection: All
Filter: Cross-section = CS5 - Rectangle
(1000; 1000)



4.6. Steel Stress - FLS

4.6.1. 3D stress; σ_x (1D/2D)

Values: σ_x (1D/2D)
Linear calculation
Load case: BG3
Selection: All
Filter: Cross-section = CS3 - Iwn
(2058; 14; 300; 20; 660; 38; 2000; 8)
Location: In nodes avg. on macro.
System: LCS mesh element
Basic magnitudes

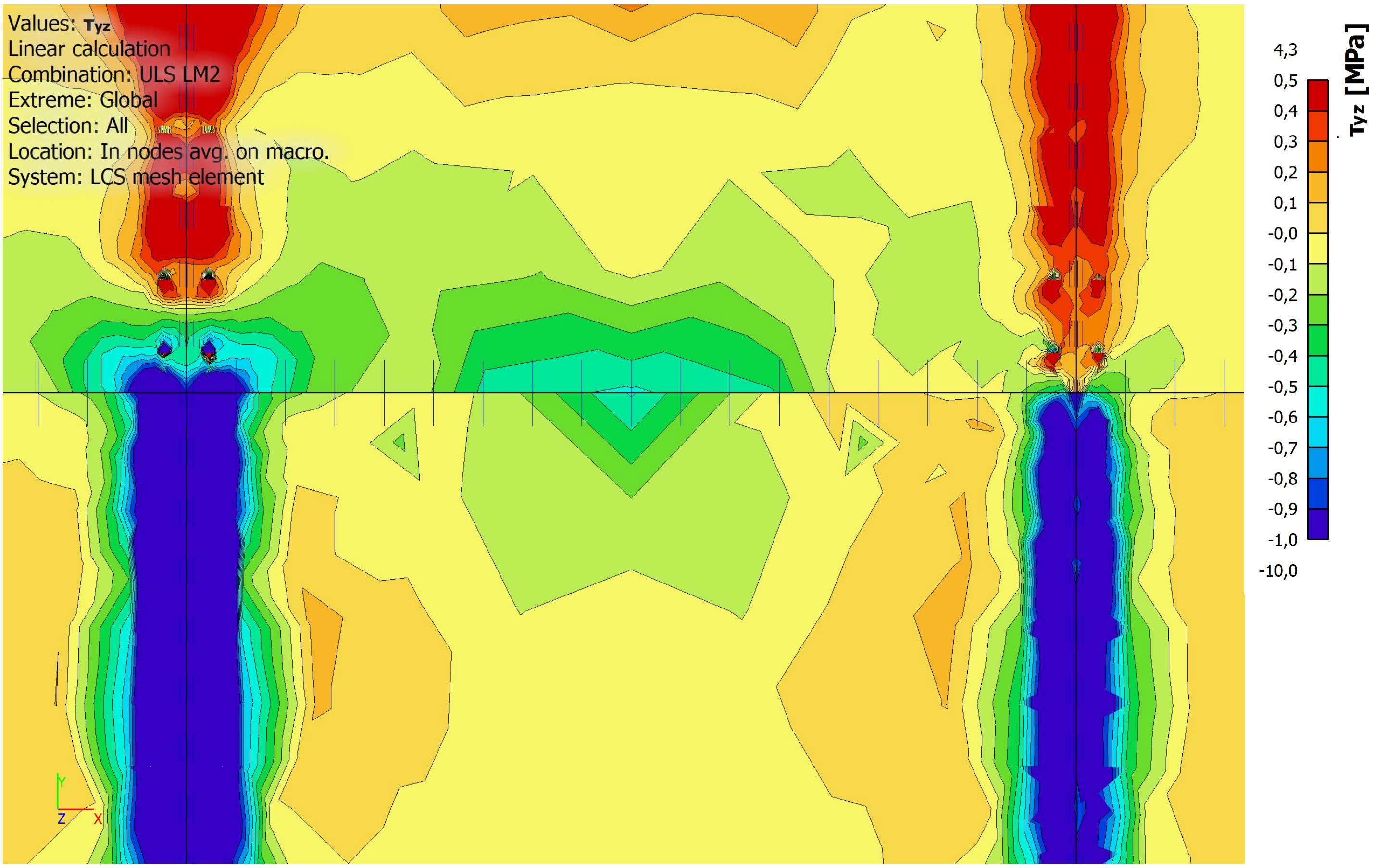


4.7. Shear Keys - ULS

4.7.1. Combinations - ULS LM2

Name	Description	Type	Load cases	Coeff. [-]
ULS LM2		EN-ULS (STR/GEO) Set B	BG4 - EG overig	1,000
			BG5 - Temperatuur Opwarming	1,000
			BG6 - LM2	1,000
			BG7 - Prestress	1,000

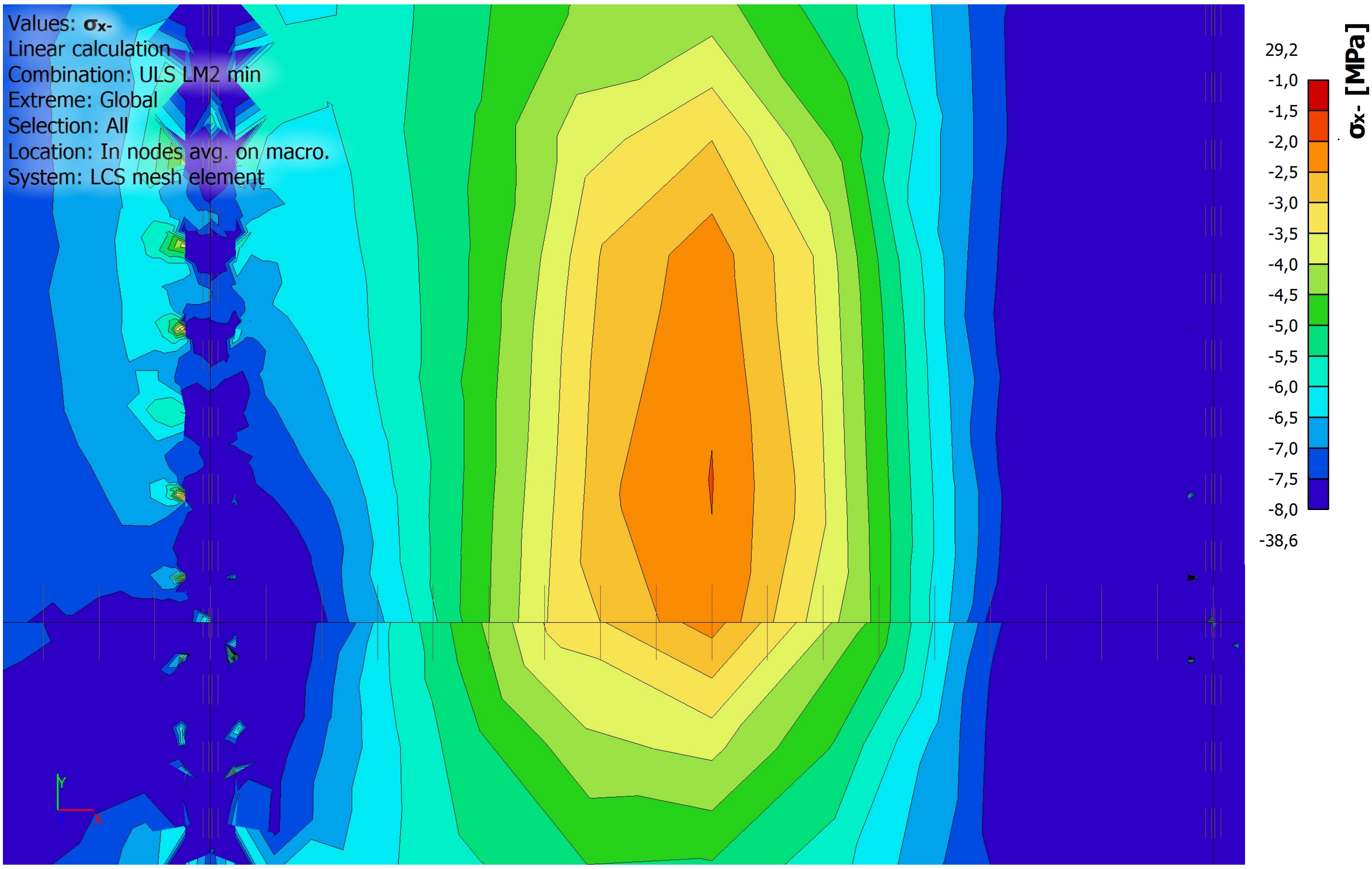
4.7.2. 2D stress/strain; τ_yz



4.7.3. Combinations - ULS LM2 min

Name	Description	Type	Load cases	Coeff. [-]
ULS LM2 min		Linear - ultimate	BG4 - EG overig	0,900
			BG6 - LM2	1,500
			BG7 - Prestress	1,000
			BG9 - Temperatuur Afkoeling	0,495

4.7.4. 2D stress/strain; σ_x-



G

Drawings Report - Steel Girder Connection

Project:
Project no:
Author:

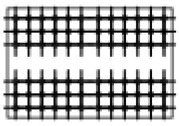
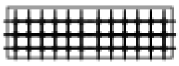
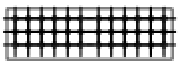
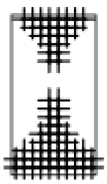
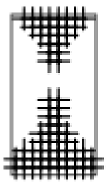
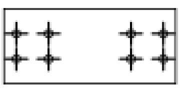
Project item Steel-Steel_Shear plate

Design

Name	Steel-Steel_Shear plate
Description	
Analysis	Stress, strain/ loads in equilibrium

Bill of material

Manufacturing operations

Name	Plates [mm]	Shape	Nr.	Welds [mm]	Length [mm]	Bolts	Nr.
SPL1	P19,0x1000,0-660,0 (S 355)		1			M30 10.9	72
	P19,0x1000,0-307,0 (S 355)		1				
	P19,0x1000,0-307,0 (S 355)		1				
SPL3	P12,0x1000,0-1900,0 (S 355)		1			M30 10.9	68
	P12,0x1000,0-1900,0 (S 355)		1				
SPL4	P6,0x690,0-300,0 (S 355)		1			M30 10.9	8

Welds

Type	Material	Throat thickness [mm]	Leg size [mm]	Length [mm]
Double fillet	S 355	8,0	11,3	12290,0
Not specified	S 355	20,0	28,3	300,0

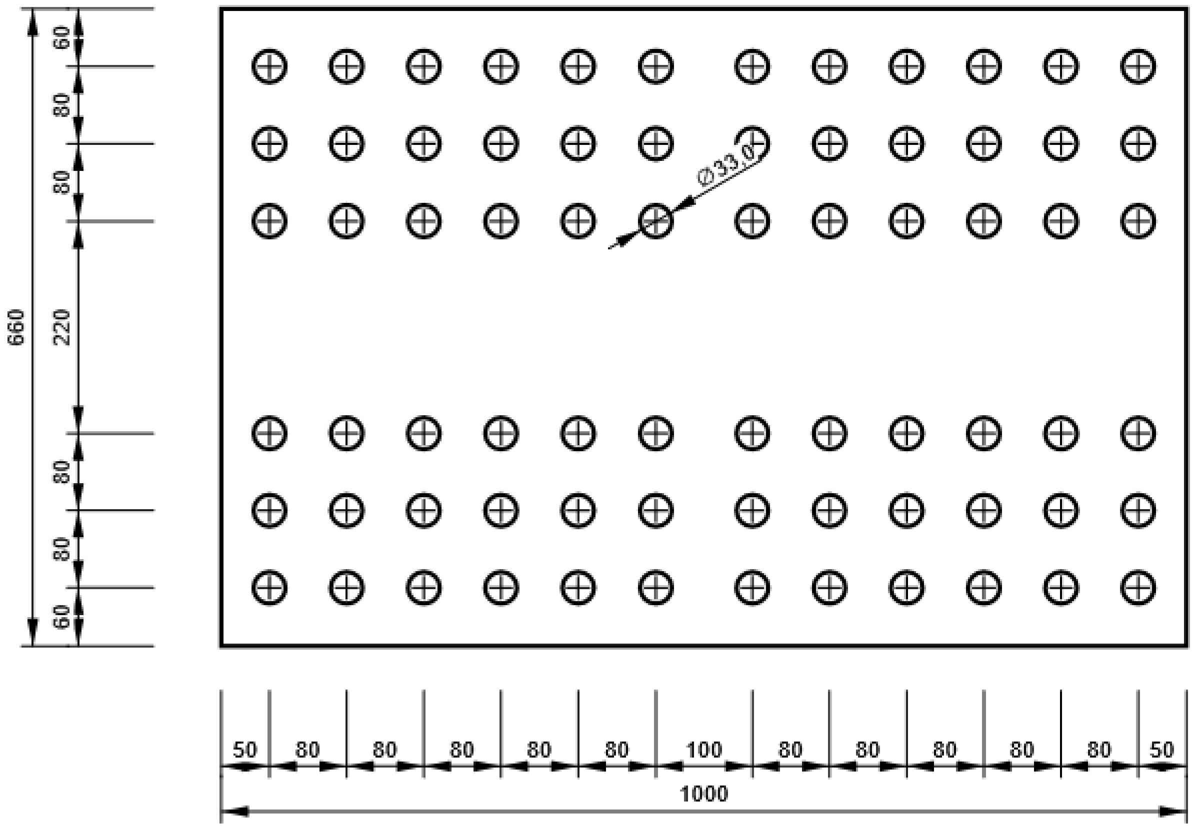
Bolts

Name	Grip length [mm]	Count
M30 10.9	76	72
M30 10.9	38	68
M30 10.9	26	8

Drawing

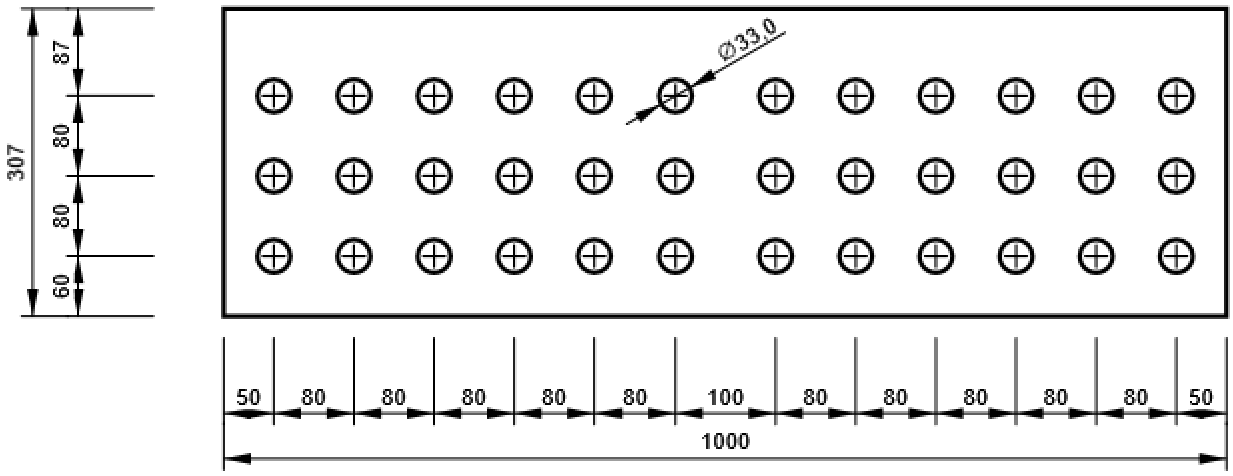
SPL1 - SPL1a

P19,0x660-1000 (S 355)



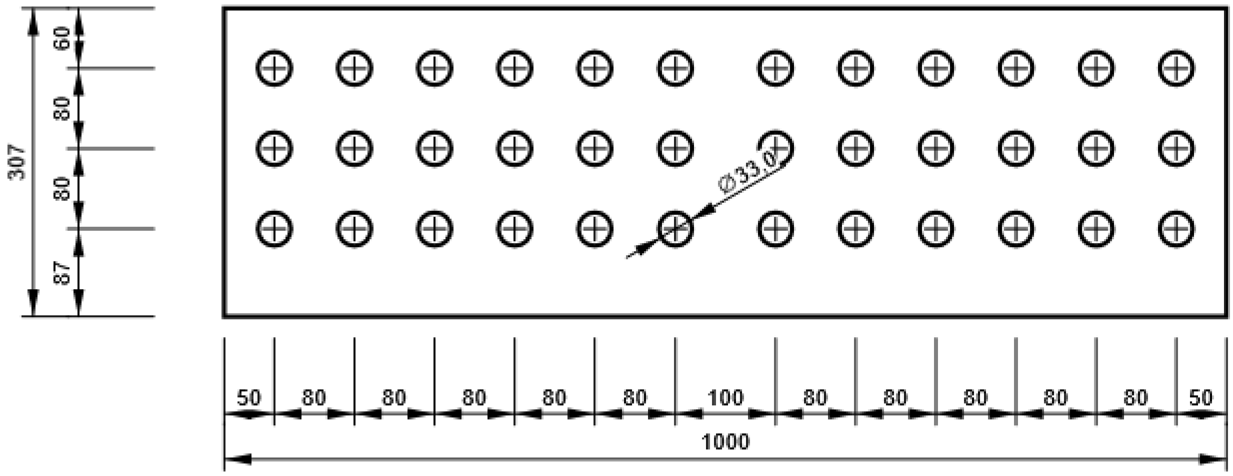
SPL1 - SPL1b

P19,0x307-1000 (S 355)



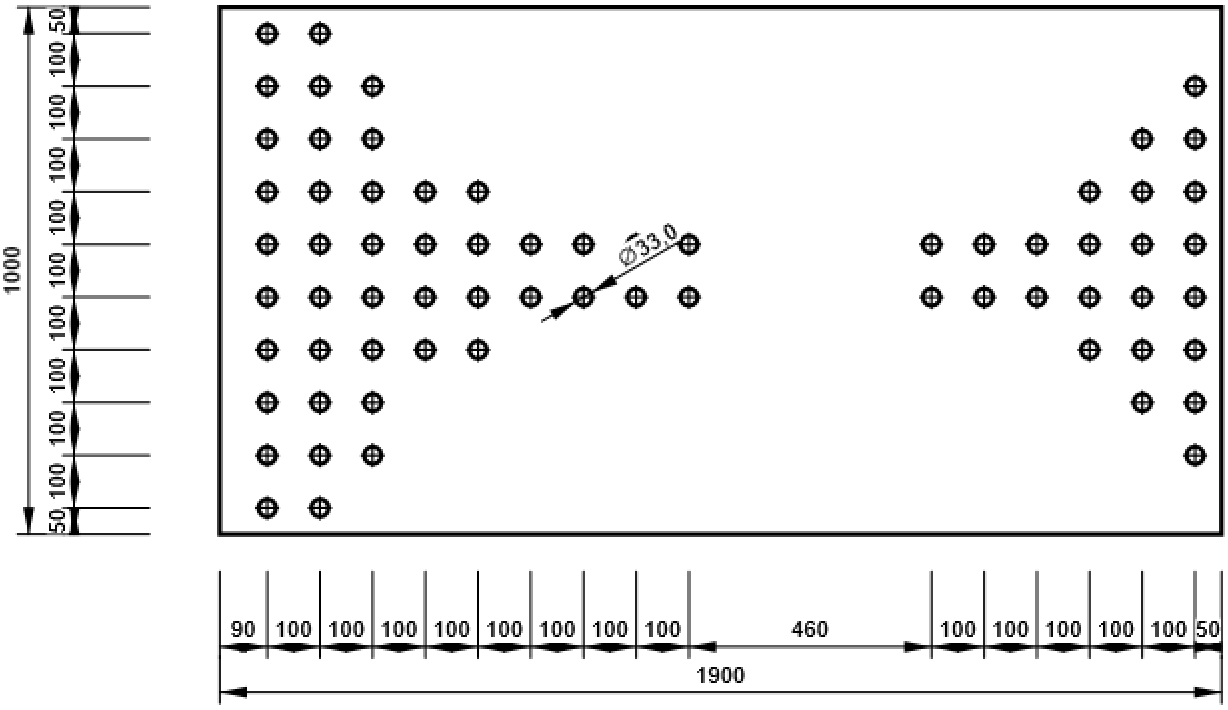
SPL1 - SPL1c

P19,0x307-1000 (S 355)



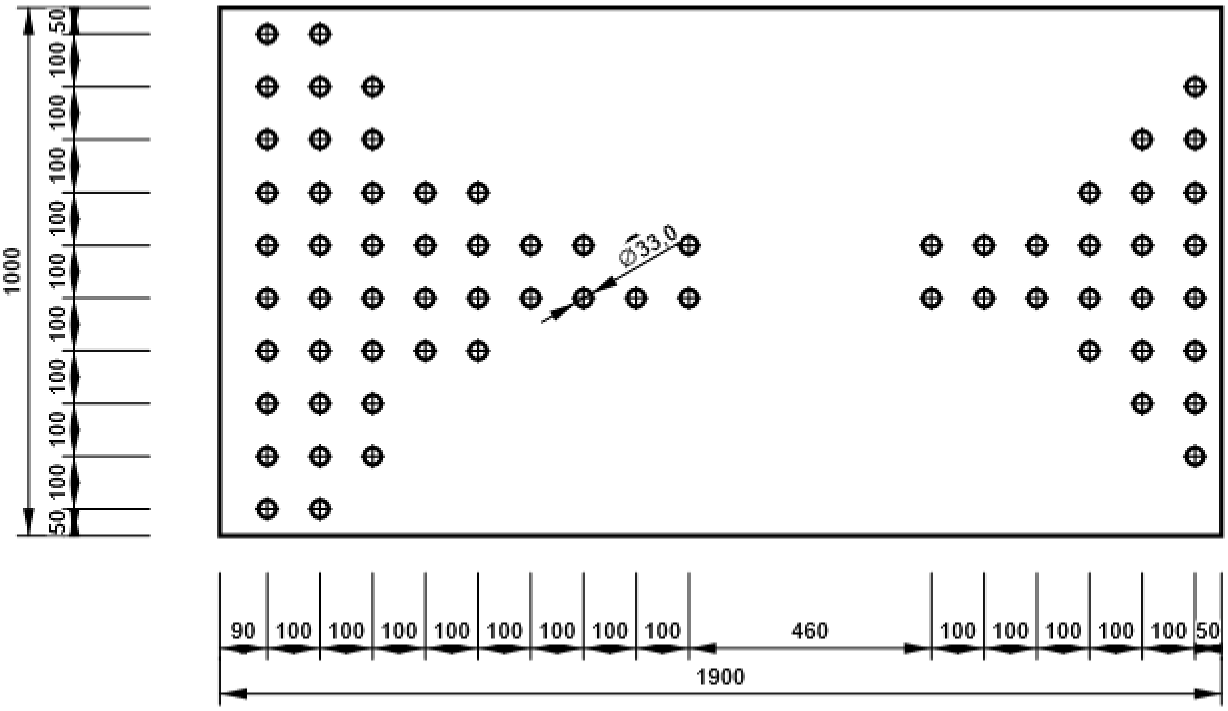
SPL3 - SPL3a

P12,0x1900-1000 (S 355)



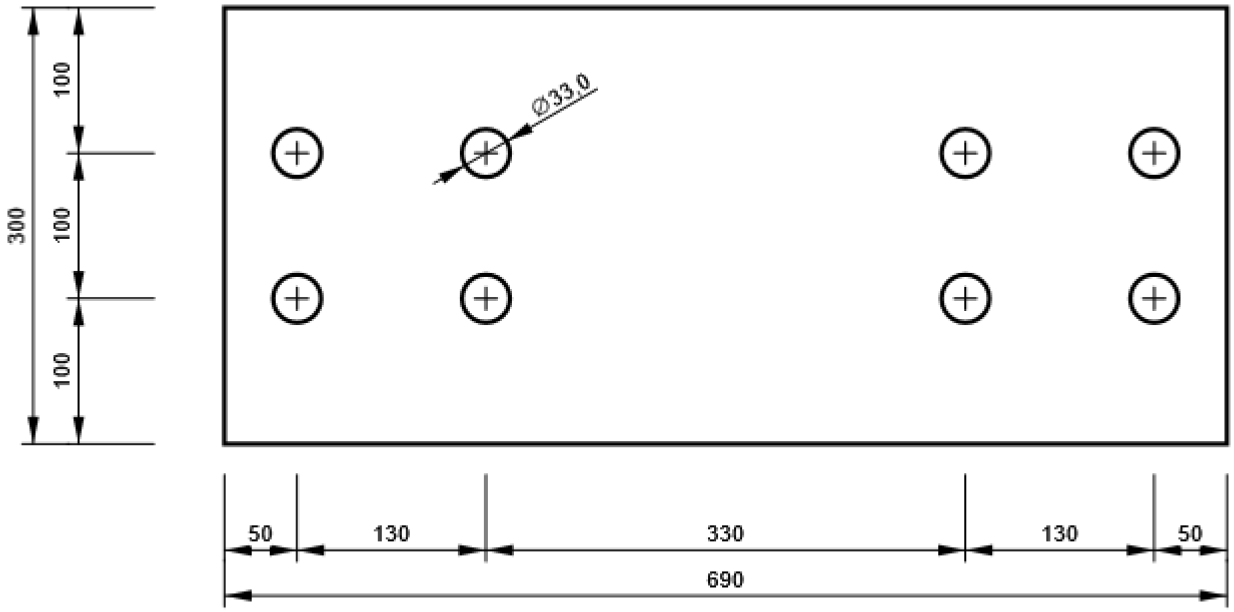
SPL3 - SPL3b

P12,0x1900-1000 (S 355)

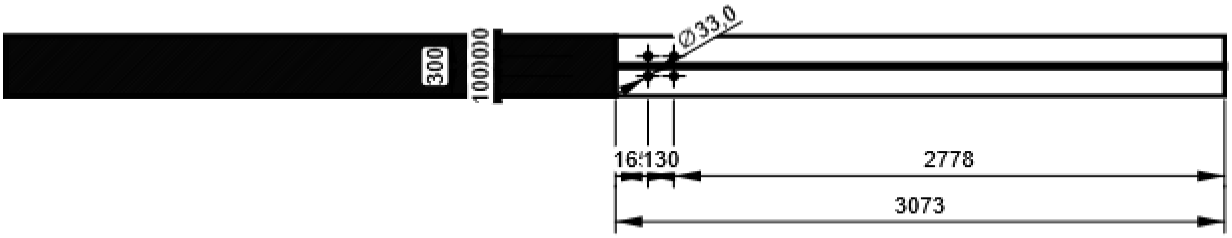


SPL4

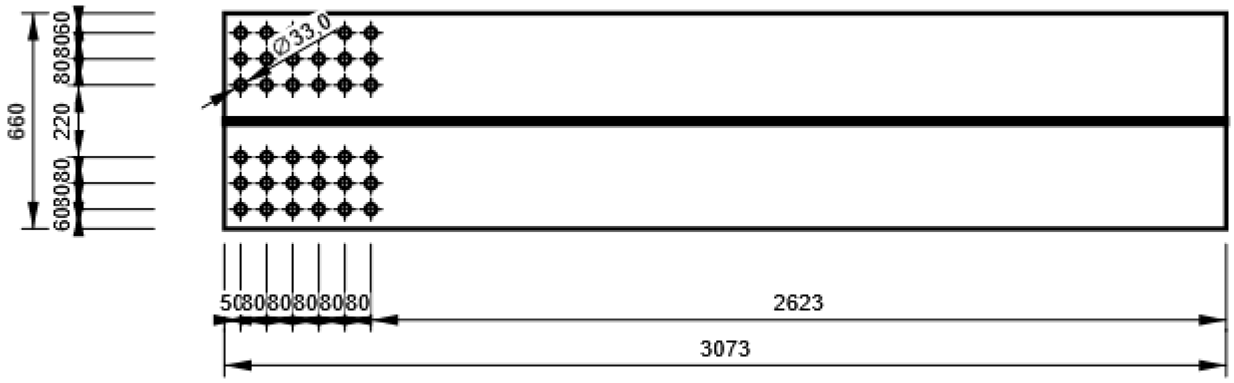
P6,0x300-690 (S 355)



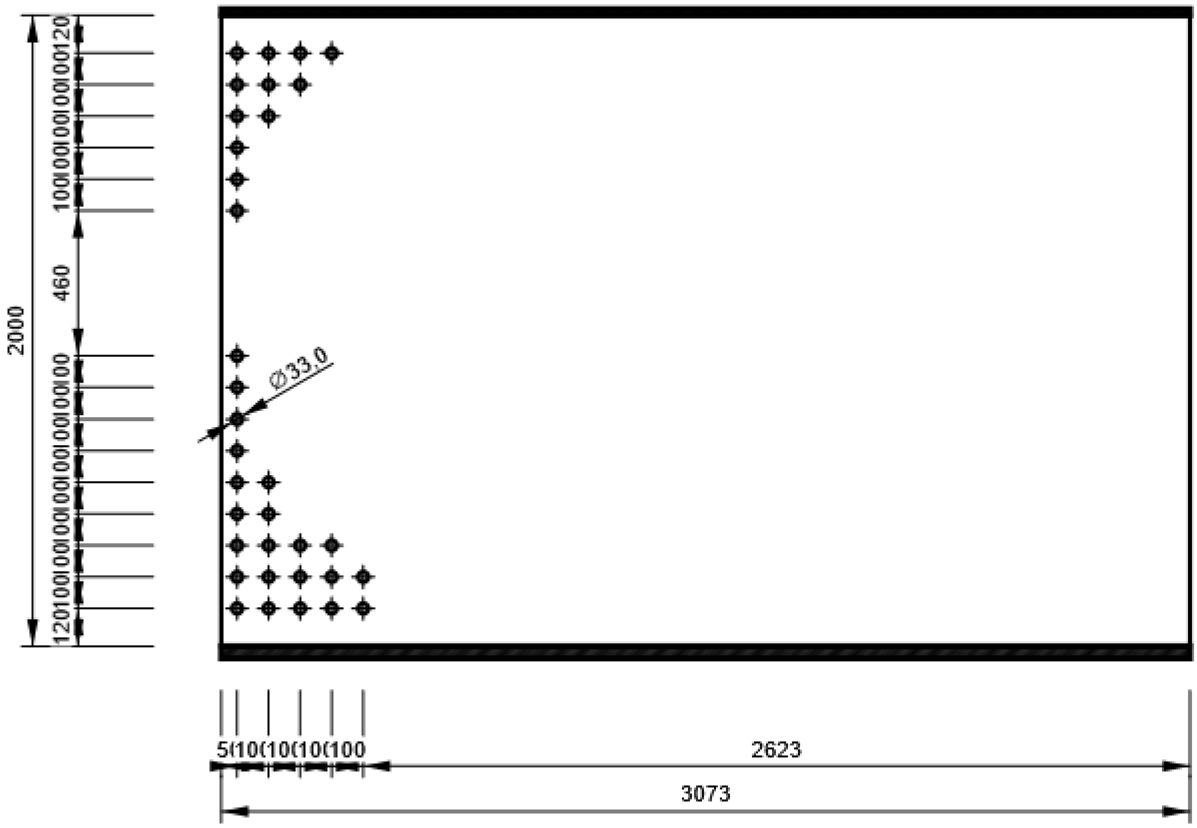
B1, Iwn2058x(300/660) - Top flange 1:



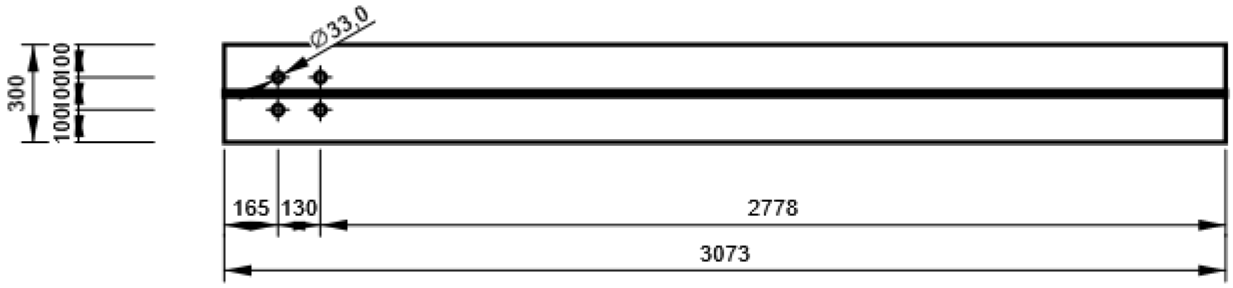
B1, Iwn2058x(300/660) - Bottom flange 1:



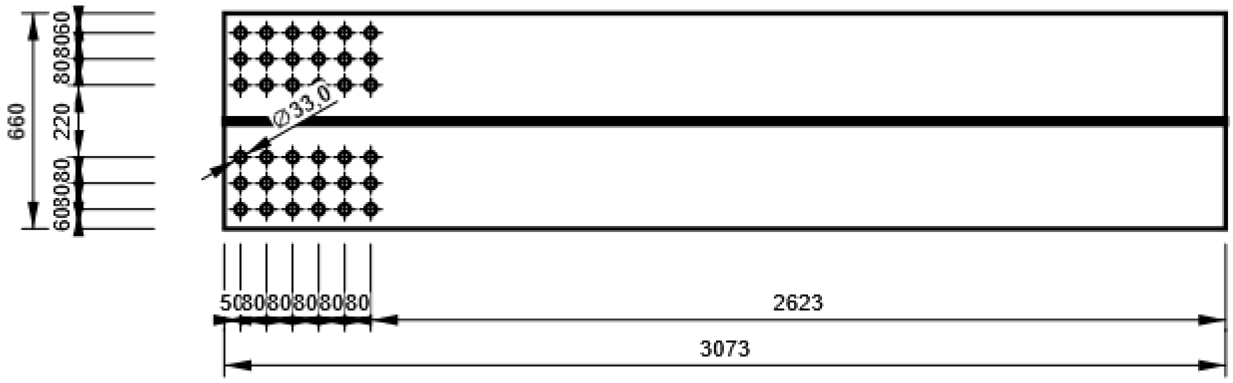
B1, Iwn2058x(300/660) - Web 1:



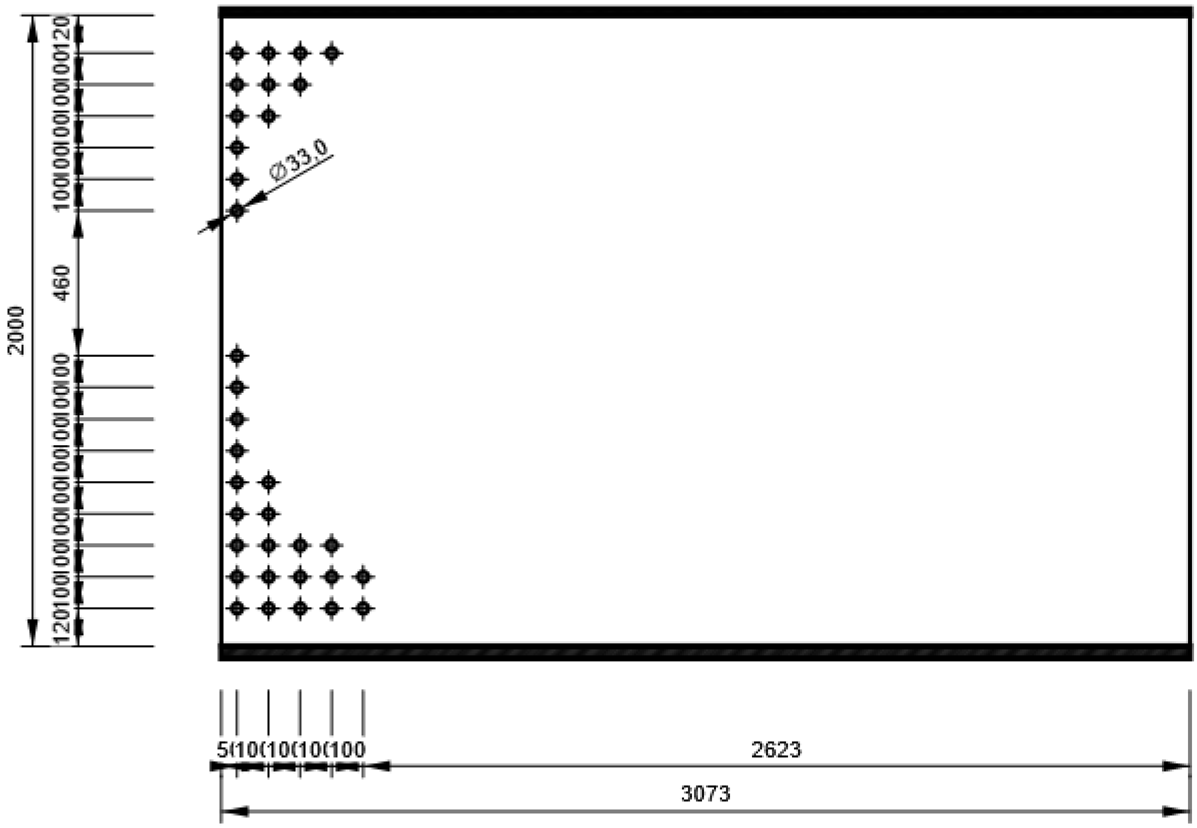
B2, Iwn2058x(300/660) - Top flange 1:



B2, Iwn2058x(300/660) - Bottom flange 1:



B2, Iwn2058x(300/660) - Web 1:



H

Cost Calculations

Table H.1 lists the data used for the calculation of the costs. The costs are estimates made by cost experts from Sweco. Included are the raw material costs, production costs, transportation costs and assembly costs.

Table H.1: Unit prices for materials and processing

Type of costs	Value	Unit
Steel price (t <= 20 mm)	1,45	€/kg
Steel price (t > 20 mm)	1,65	€/kg
Production	2,63	€/kg
Transport	0,37	€/kg
Assembly	0,54	€/kg
Bolt price (M30)	9,50	€/piece
Nut price (M30)	6,25	€/piece
Bolt assembly*	2,50	€/piece

* *Based on assembly of 40 connectors per hour*

I

Tables

Table I.1: Input shear connectors for SLS analysis

Connector type	**Preload**	P_{el}	k_{el}
	[kN]	[kN]	[kN/mm]
HSFGB	240	81	560
Cylinder	240	81	250
ECD (no resin)	240	81	70
ECD (iSRR)	-	77	224

Table I.2: Results on connector layout and deformation (SLS)

Connector	s_{1m}	s_{main}	w_{use}
	[mm]	[mm]	[mm]
HSFGB	60	300	21,9
Cylinder	90	330	22,7
ECD (no resin)	130	330	25,7
ECD (iSRR)	80	330	22,8
LBDSC	*110*	*390*	*24,6*