PROJECT	**Rail Baltica** SBS-Study
PURPOSE	**Study case of typical crossing situations**
FINAL REPORT	**Development of preferred solution - Master Design**
PERFORMANCE PERIOD	05/2019 until 07/2019
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Technical and additional documents

Basis of assignment

[U1] Assignment order (contract) No 8/2017-120-X/X for the provision of expert services, Riga

[U2] Mini competition_SBS-Cases-R0.2

[U3] Bridge Inventory; Rail Baltica; 02.04.2019

Project-specific documents

[U4] Rail Baltica Official Website

[U5] Design guidelines general requirements; Rail Baltica; 25.03.2019

Additional documents

[U6] Gabler, Markus; Fakhouri, Abdalla; Baumann, Katrin: "Zur Gestaltung von Fertigteilbrücken", in: Bautechnik 96 (2019), Heft 2

[U7] U.S. Department of Transpotation, Federal Hghway Administration (2009): "Connection Details for Prefabricated Elements and Systems", Publication No. FHWA-IF-09-010

[U8] CRC-Technology: "High strength joints for precast bridge slabs", Summary report

[U9] Seidl, Günter (SSF Ingenieure AG): "Rahmenbrücken"

[U10] Skanska Norge AS: "Bridge Construction Using Precast Concrete Elements"

[U11] State of Florida, DOT: "Prefabricated Bridge Elements and Systems (PBES) Conceptual Drawings"

[U12] Zement + Beton Handels- und Werbeges.m.b.H: „Brückenbau – Fertigteile auf neuen Wegen", Expertenforum Beton 2005

[U13] Flue-Fluegelausbildung; Bundesanstalt für Straßenwesen bast; 12.2009

[U14] RiL804; DB Netz AG;01.11.2018

[U15] Was-Brückenentwässerung; Bundesanstalt für Straßenwesen bast; 12.2009

[U16] High-Speed 2 BRIDGE DESIGN REQUIREMENTS; Simon Kirby; Sadie Morgan; April 2016

[U17] Dynamic Effects of high-speed trains (Marx, Matsumoto); work in process

[U18] Ril 820.2040 Schienenauszüge, Bauart und Auszugslänge/Einstellmaß; DB; 01.01.2007

[U19] Design guidelines Railway substructure, Part 1 embankments and earthworks; Rail Baltica; 02.11.2018

[U20] Design guidelines Railway substructure, Part 2 hydraulic, drainage and culverts; Rail Baltica; 25.03.2019

[U21] Design guidelines Railway substructure, Part 3 bridges, overpasses, tunnels and similar structures; Rail Baltica; 25.03.2019

[U22] Architecture, Landscape and Visual Identity design Guidelines, Second Interim Report; Rail Baltica; 08.03.2019

[U23] Köörna , Arno Artur/ Tarmisto, Vello Julius/ Stranga , Aivars/ Aruja, Endel/ Smogorzewski, Kazimierz Maciej/ Misiunas, Romuald J., Bater , James H. : "Estonia" at https://www.britannica.com/place/Estonia (last accessed on 15 March 2019)

[U24] Smogorzewski, Kazimierz Maciej/ Roos, Hans/ Dawson, Andrew Hutchinson/ Davies, Norman/ Wandycz, Piotr S./ Jasiewicz, Krzysztof: "Poland" at https://www.britannica.com/place/Poland (last accessed on 15 March 2019)

[U25] Formdynamik an Überführungsbrücken; Michael Kleiser; Beton- und Stahlbetonbau 112, Heft 7; Ernst & Sohn Verlag für Architektur und technische Wissenschaften GmbH & Co. KG, Berlin; 2017

[U26] Leonhardt, F.: Brücken – Ästhetik und Gestaltung. Deutsche Verlags-Anstalt, Stuttgart, 1982, S. 44

[U27] https://www.beboarch.com/

Table of content

1 Introduction

1.1 General

“Rail Baltica is a greenfield rail transport infrastructure project with a goal to integrate the Baltic States in the European rail network. The project includes five European Union countries – Poland, Lithuania, Latvia, Estonia and indirectly also Finland. It will connect Helsinki, Tallinn, Pärnu, Riga, Panevėžys, Kaunas, Vilnius, Warsaw.” [U4]

Integration of a new high-speed railway line in an existing infrastructure network places demands on crossing situations. Therefore, Rail Baltica defined four typical crossing situations (cases) which should be analysed.

1.2 Objective of this document

This document provides guidance and requirements for the design of bridges and associated civil engineering throughout Rail Baltica. It analyses typical crossing situations of the Rail Baltica railway lines and the existing infrastructure network (pedestrian paths; animal paths; roadways; railways; valleys and water lines).

Therefore, this document shows state-of-the-art solutions used in other High-Speed Railway projects in Europe for typical crossing situations. Moreover, it considers the main advantages and disadvantages of the different options and how they meet the Rail Baltica Design Guidelines requirements.

Furthermore, in this report three solutions for each of four typical crossing situations (cases) of the Rail Baltica railway lines with the existing infrastructure network will be shown. It also demonstrates the main advantages and disadvantages of the solutions in a Multi Criteria Analysis of Solution (MCA).

As a result of the MCA one solution for each of the four typical crossing situations (cases) will be presented in detail with focus on:

- drawings to define the structure
- construction methods
- calculation of quantities
- estimation of costs

2 Bridge design

2.1 Introduction

In the majority of the named crossing situations bridges, viaducts, overpasses or underpasses will be necessary to solve the conflict. This represent a high number of repetitive situations that can benefit from the study of standard solutions aimed at being economical, efficient in the use of time and resources for construction and optimized in the use of materials and the existing construction conditions. As representatives of Rail Baltica every bridge shall follow the overarching guidelines previously established within the design principles.

"Bridges are engineering but also architecture. There is a need to be constantly aware of the aesthetic implications of design decisions. A talent for, and understanding of, aesthetics is essential for excellent bridge design." [U16]

Overall the bridge design needs to ensure functionality and durability for the Rail Baltica project.

2.2 Design requirements

2.2.1 High-speed railways

This chapter deals with requirements for High-speed railways and the impact on bridge design.

The main aim in the design of railway bridges for high-speed traffic is the optimisation of the dynamic stability and robustness, while creating a slender and aesthetic structure. The system geometry and stiffness have to be designed for the extreme dynamic forces caused by the different operating high-speed trains so as to avoid resonance during train crossings. [U17]

High-speed rail is a new type of infrastructure in the Baltic states. Experience from established European standards is a key source in consideration of standards for Rail Baltica. Some of the technical requirements have a significant impact upon appearance. For example, requirements of height and construction of highway and footbridge parapets.

2.2.1.1 Track-bridge-interaction

By designing bridges, care has to be taken to ensure that both components bridge superstructure and track system make up a unit and influence each other.

2.2.1.2 Dynamics

Railway bridges are subjected to very high dynamic loads. The dynamic load is, together with track-bridge-interaction, the governing factor for the design of high-speed railway bridges and needs to be taken into account already at the conceptual design stage, when the fundamental system properties are designed. At this stage, the type of structural system, the span-configuration and the stiffness and mass distribution have to be defined. These parameters in particular determine whether a bridge will experience significant vibration or even resonance during train crossings. There are several further parameters that barely affect the static loading of the structure but that have a big impact on its dynamic behaviour due to train crossings, such as the number of spans of continuous beams or the existence of haunches at the bridge girder near the columns. Marx and Matsumoto evaluate the parameters in the study “Dynamic Effects of high-speed trains” [U17] and come to following conclusion:

Span length

- > 40 m no strong resonant vibrations by crossing trains
- < 40 m a high stiffness of the structure is important to avoid dynamic excitations. Stiffness can be achieved by both, cross-section stiffness or a clever structural system.

Number of Spans

- single span girder
  - no neighbouring spans for interaction
  - only effective parameter is beam height → structure looks massive and chunky
  - improve dynamic behaviour by converting the single span girder to a frame
- single span frame
  - much higher first eigenfrequency than single span girder
  - better structural damping than single span girder
  - much better robustness and lower maintenance
- continuous beams
  - greater system stiffness, better robustness than single span
  - neighbouring spans strongly interact during train crossing

Haunches

By adding haunches those eigenfrequencies whose eigenmodes exhibit curvatures at the supports can be significantly increased. Thus, resonance speed for those eigenmodes increases too.

For shorter spans haunches are only improving the behaviour in case of stiff and rigidly connected abutments or piers.

2.2.1.3 Rail tension

- horizontal deformation depends on bridge superstructure, spans and system
- minimise rail tension
- installation of rail expansion joints – depending on amount of longitudinal deformation

2.2.1.4 Systems

- standardized solution
- serial construction
- flexible systems depending on local boundary conditions (span, length, structure types)
- uniform standards → possibility of prefabrication
- robust but slim structures e.g. integral bridges

2.2.1.5 Durability & low maintenance

The aim of bridges in general is a consistent availability of infrastructure. Frequently, weak points of bridges are water drainage systems, sealings, joints (see Figure 2) and bearings (see Figure 1). Due to this defect components, which could be repairable with an increased expense, often the superstructure and substructure are harmed so a replacement construction is necessary.


Picture credit: © SSF Ingenieure

Figure 1: damaged bearing


Picture credit: © SSF Ingenieure

Figure 2: leaking expansion joint

To increase durability:

- avoid joints
- avoid bearings
- use integral structures
- corrosion protection for steel bridges

2.2.1.6 Noise protection

As a high-speed train-line, the Rail Baltica line will generate noise as the trains pass. In some locations, active noise protection is necessary. Noise Barriers provide a solution for noise mitigation where landscaping and planting are not enough. The potential for Noise Barriers to create a harmful visual impact should be acknowledged. Thus, they should be used in a considered manner, only where they are necessary. Influence of noise protection to visual view can be seen in Figure 3.


Picture credit: © DB AG

Figure 3: Gänsebach valley Viaduct during installation of noise protection

2.2.2 Rail Baltica requirements

Rail Baltica requires standard solutions for recurrent crossing situations along the railway track. For all crossing situations the main requirements are **functionality** and **durability**.

Additional to this report and the named requirements the following documents from Rail Baltica have to be taken into account:

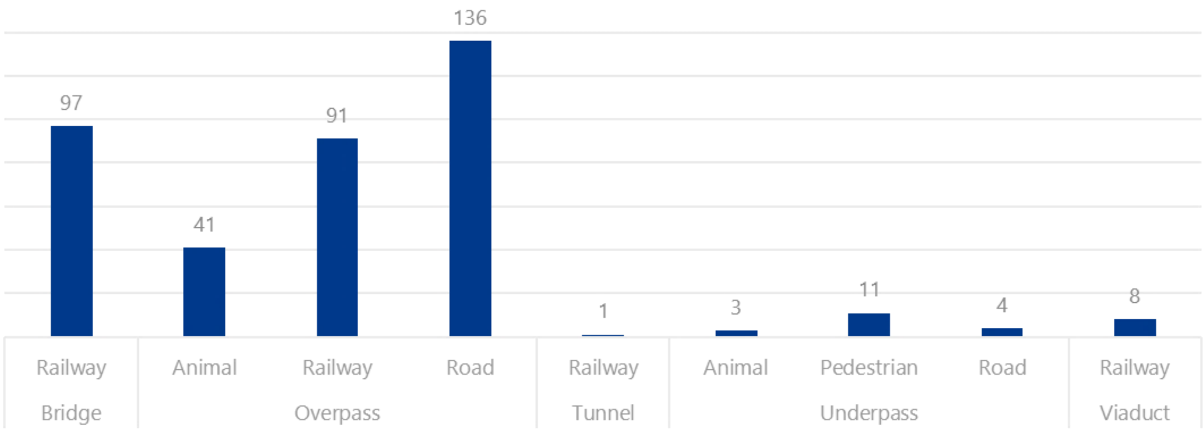
- design guidelines General requirements; 25.03.2019 [U5]
- design guidelines Railway substructure, Part 1 embankments and earthworks; 02.11.2018 [U19]
- design guidelines Railway substructure, Part 2 hydraulic, drainage and culverts; 25.03.2019 [U20]
- design guidelines Railway substructure, Part 3 bridges, overpasses, tunnels and similar structures, 25.03.2019 [U21]
- architecture, Landscaping and Visual Identity design Guidelines08.03.2019 [U22]

2.2.2.1 Occurring crossing situations

According to Bridge Inventory of Rail Baltica project [U3] following types of Structures for crossing situations occur:

TYPE OF STRUCTURE	
Bridge	Structure spanning mainly a body of water (can be road, rail, pedestrian, combined, etc)
Viaduct	Structure spanning mainly over land (can be road, rail, pedestrian, combined, etc)
Overpass	Structure over the railway (can be for road, rail, pedestrian, animals, combined, etc)
Underpass	Structure under the railway (not for water lines)
Tunnel	Structures under the ground level. Can be road or rail.
Culvert	Water passage through embankments (road, rail, etc). *Amount is not identified in this stage of project.*

The main numbers of types of these structure from preliminary design stage* [U3] are shown in following figure:



**Minor structures are not included, as well numbers for RIX section, Central station section, Ulemiste station section*

The Bridge Inventory of Rail Baltica project also shows, that the main spans which have to be realised have to be between 10 m – 30 m. The amount of bridges with a span in that range are 82% in comparison to bigger or smaller spans (not included culverts, wildlife crossings and pedestrian crossings).

To define the Rail Baltica requirements the crossing situations have to be divided into 3 track types:

- open track
- inner-city location
- big river crossings

The following part of this document deals mainly with crossings on open tracks.

2.2.2.2 Crossings on open tracks

<u>Design</u>

– consistent bridge design

<u>Time</u>

– extreme short construction time
– high possibility of prefabrication
– mostly local and partly international prefabrication of structural elements and delivery to site

Prefabrication is one of the key parts to save time. Thus, two documents in Annex 0_2 and Annex 0_3 deal with prefabrication. On the one hand possibilities and limits of prefabrications will be presented (Annex 0_2) and on the other hand a catalogue of different connection types for prefabricated elements (Annex 0_3) is shown in annex.

Topography

- Estonia: The landscape of Estonian is marked by the glacial activity. The main part of Estonia is characterized by small hills and many rivers. The south is shaped by moraine hills [U23].
- Latvia: Latvia also contains a numerous of rivers and lakes. Most of the part of Latvia is plain. In Latvia, they can find an amount of peat which is used in the industry and agriculture.
- Lithuania: Lithuania, as Latvia, also contains a numerous of rivers and lakes. In Lithuania, as in Latvia, they can find an amount of peat which is used in the industry and agriculture.
- Poland: In contrast to the Baltic states Poland is marked by higher hills and great forest. [U24]

Track design

The location and accompanying the shape of topography is the essential reason for decision if an overpass or an underpass is the most economical and environmentally friendly solution.

Crossing situation:

- small hill (embankment) → Underpass or Rail Viaduct (Case 1, 2 or 3)
  minimum clear height: 4.50 m
- small valley (cutting area) → Road overpass (Case 3 or 4)
  minimum clear height: 6.70 m

Conclusion

Extreme short construction time requires a high possibility of prefabrication. Therefore, a high amount of prefabricated bridge elements has to be produced. Local industry is integrated and is going to be upgraded for such a high demand. If necessary structural elements have to be prefabricated international and delivered to site. Still the bridge design concept needs to be constant. Depending on local boundary conditions either an underpass or an overpass is the superior choice.

2.3 Successful design

2.3.1 Proportions

A successful design is directly related to proportions (shown in Figure 4 - Figure 9) of the bridge. Different relationships between bridge parts are therefore important:

The engineer cannot withdraw himself from the process of visually designing. He is inevitably designing due to selecting structural forms with their dimensions and proportions.[U25]

Span to depth ratio:

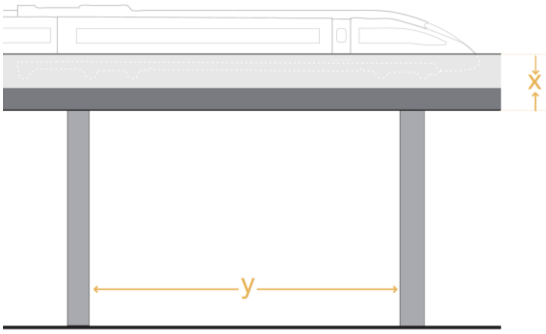


Figure 4: Span to depth ratio [U16]

Clearance to span:

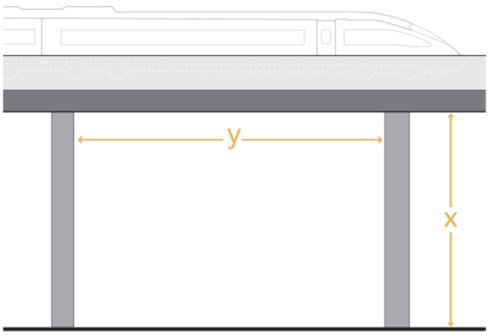


Figure 5: Clearance to span [U16]

Deck depth to clearance ratio:

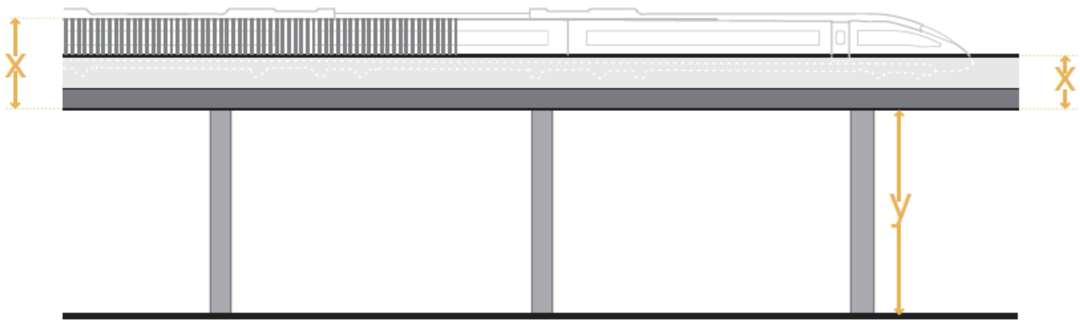


Figure 6: Deck depth to clearance ratio [U16]

Width to clearance:

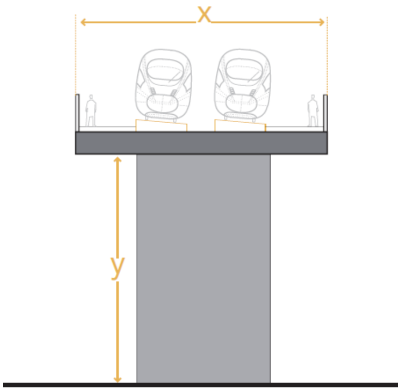


Figure 7: width to clearance [U16]

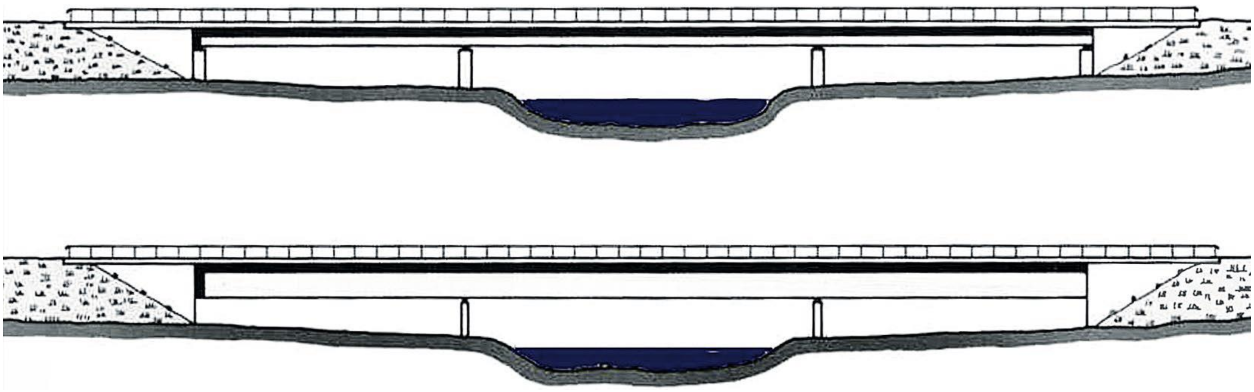


Figure 8: The perceptual forces are balanced (top) and inbalanced (bottom) [U26]

Figure 9: Different perceptions of two similarly dimensioned frame beams [U25]

2.3.2 Location

The outstanding design characteristic is the location. The location defines:

- if an underpass or an overpass is the most efficient solution
- the necessary span → proportions: span to depth ratio + clearance to span
- the pier height → clearance → proportions: clearance to span, deck depth to clearance ratio, width to clearance

2.3.3 What success looks like

The high-speed railway line HS2 **[U16]** defines principles for successful bridge design. Some of them are mentioned below. It is recommended to use these principles or the main aspects of them also for the Rail Baltica high-speed railway line.

- Each bridge shall have a **clear, understandable design concept** with scale, geometry and proportions appropriate to its context.
- Each structure shall be an **elegant aesthetic composition**, with a consistent design language used for all of its components.
- Civil engineering shall be **fully coordinated with the surrounding landscape** design.
- The form and detail of spanning deck and beam structures shall be **simple, continuous profiles, minimising bulk and visual impact.**
- Viaduct, underbridge and overbridge parapets shall have a **consistent** HS2 line-wide **identity** across a range of spans and structural forms.
- Pier design shall be consistent within each structure and in groups of adjacent structures.
- All water run-off shall be fully managed, controlled and collected.
- The **visible extent** of concrete walls and abutments shall be **minimised**.
- In rural locations the landscape form shall be used to conceal vertical concrete faces before considering cladding or screening.
- The design of structures used by pedestrians and cyclists shall recognise the increased level of scrutiny that they will receive.
- Green tunnels and green bridges shall be thoroughly integrated into their surroundings.
- All **materials, components and systems shall be capable of providing a 120-year design life**, subject to appropriate maintenance. **For Rail Baltica it is a 100-year design life.**
- The **need for maintenance shall be minimised**, especially where it requires permanent way access or line possessions.
- Security and safety systems shall be fully coordinated with the civil engineering design.
- All services and rail systems shall be fully coordinated with the civil engineering design.
- Services and rail systems containment and routes shall be concealed from public view.

2.4 Examples


https://commons.wikimedia.org/wiki/Category:CC-BY-SA-3.0,2.5,2.0,1.0

1-MONOTONOUS


Picture credit: © SSF Ingenieure

2-INTERESTING


Picture credit: © DB Netze

3-HEAVY


Picture credit: © DB Netze

4-LIGHT DESIGN


Picture credit: © wikimedia CC-BY-SA-3.0-migratedCC-BY-SA-2.5

5-TOO MUCH


Picture credit: © DB Netze

6-LESS IS BETTER


Picture credit: © wikimedia CC-BY-SA-3.0,2.5,2.0,1.0

7-DECORATION


Picture credit: © DB Netze

8-DESIGN

9-NARROW PASSAGEWAY

10-GENEROUS OPENING

11-MASSIVE PIERS WITH BEARINGS


12-OPEN CONSTRUCTION INTEGRAL

3 Crossing situations

3.1 Presentation of Cases

The following four chapters 3.1.1 - 3.1.4 explain shortly the typical crossing situations (cases) of the Rail Baltica railway lines with the existing infrastructure network. For more information considering structures of this cases in Europe, design options and examples please find a detailed case analyse in annex.

3.1.1 Case 1 Underpass

When the Rail Baltica line crosses over another route the structure that carries it is termed an Underpass. Typical Underpasses as shown in Figure 10 are short (horizontal clearance 10 – 20 m) and often single-span (longer multi-span underpasses are called “rail viaducts” and are covered separately in this report). As for Rail Viaducts (Case 2), the demanded vertical clearance by Rail Baltica is 5.00 m. In Germany the required minimum vertical clearance is 4.50 m. Required minimum thickness of construction by Rail Baltica is 1,50 m. [U2]

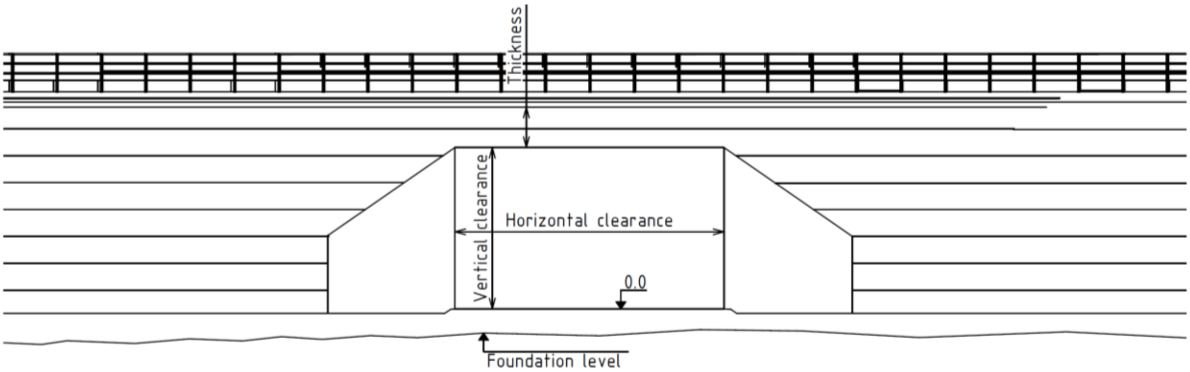


Figure 10: Longitudinal view - Case 1 [U2]

3.1.2 Case 2 Rail Viaduct

Rail Viaducts as shown in Figure 11 should be seen as an important representative of Rail Baltica. The main purpose of these structures is to allow the Rail Baltica line to cross over other infrastructure. A balance between local requirements, therefore needed structure and consistent design along the Rail Baltica line has to be found. Spans around 15 – 30 m and vertical clearance of 7,00 m shall be considered.

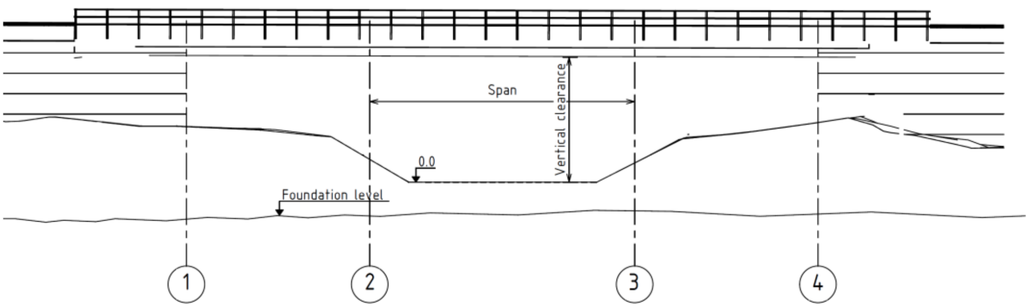


Figure 11: Longitudinal view - Case 2 [U2]

3.1.3 Case 3 Animal Overpass

Animal Overpasses like shown in Figure 12 are structures that allow animals to cross the railway of Rail Baltica. For the high-speed line Rail Baltica Animal Overpasses are designed according to following boundary conditions [U2]:

CASE 3	ANIMAL OVERPASS
HORIZONTAL CLEARANCE [M]	12.50 (CASE 3.1) OR 23 (2 X 5.25+12.50) (CASE 3.2)
FOUNDATION LEVEL [M]	-4.50 OR -20.00
NATURAL GROUND LEVEL [M]	-2.50
VERTICAL CLEARANCE [M]	6.70
SOIL DEPTH [M]	1.50
B MIN [M]	50.00
ALFA [°]	14

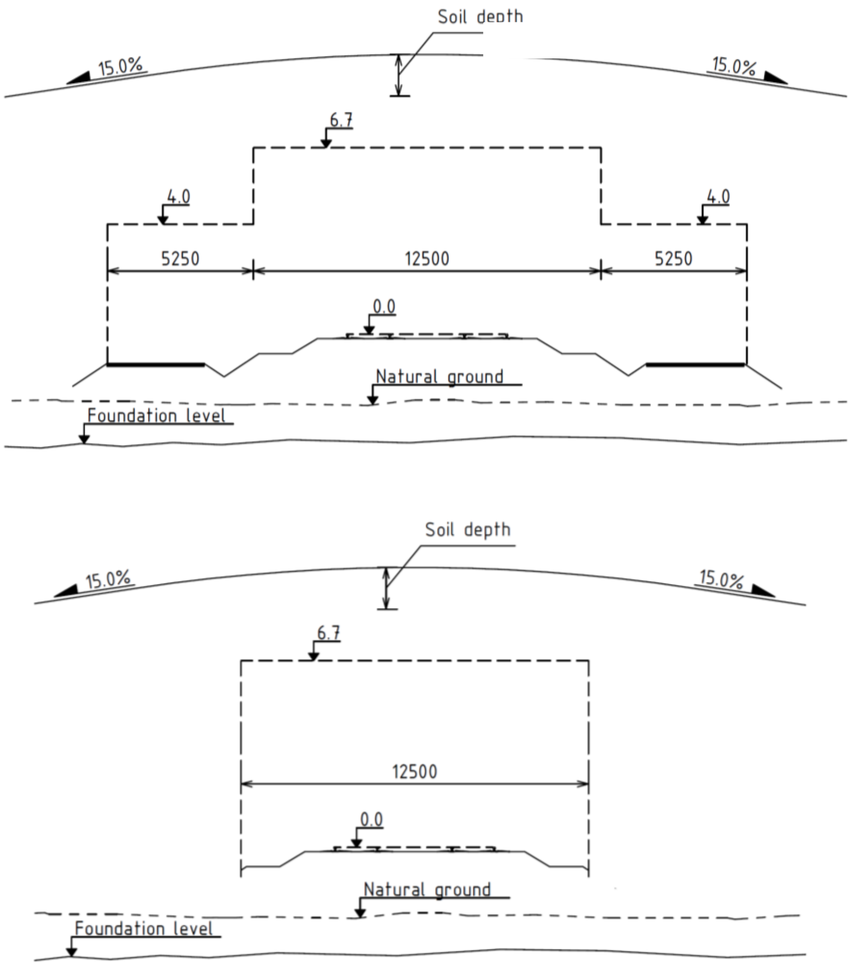


Figure 12: Section A-A - Case 3.1 (top) and Case 3.2 (bottom) [U2]

3.1.4 Case 4 Road Overpass

According to Bridge Inventory of Rail Baltica project [U3] most of the needed bridges are road overpasses like shown in Figure 13. Road overpasses enable motor vehicle, pedestrian and cyclist to cross Rail Baltica. Therefor a width of 12.00 m shall be provided. A vertical clearance of 6.70 m must be provided for high-speed trains. Typical occurring spans for Rail Baltica are between 20 – 30 m. [U2]

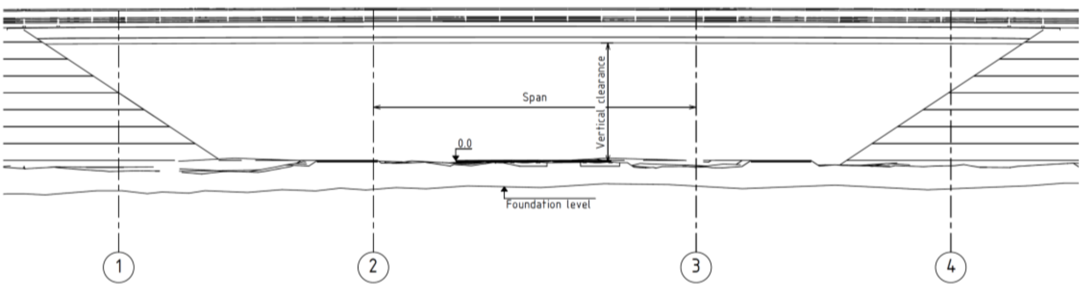


Figure 13: longitudinal view - Case 4 [U2]

3.2 Solution approach

The main idea is to find solutions for each case, which can be seen as one overall design concept. For case 1, 2 and 4 an overall concept is thinkable. Requirements for animal crossings (ecoducs) result in different design. Thus, the design concept for case 3 is not included in an overall design concept.

In a previous step three main overall design concepts were developed:

- straight (A)
- haunched (B)
- v-Form (C)

And three concepts for animal crossings (ecoducts) were:

- arch solutions with plate cross section (A)
- frames with prefabricated T-beams or slabs for cross section (B)
- three hinged arche solution with lengthwise elements as T-beams (C)

Additionally, all bridge variants were designed with an integral concept. Integral bridge design rises durability and decreases maintenance due to avoiding joints and bearings, which are the weak points in bridge construction with lower durability.

Furthermore, the bridge variants A and C for overall concepts and all bridge variants for animal overpasses are designed with as much prefabrication as possible. For advantages and disadvantages of prefabrication (Annex 0_2) as well as connection details of prefabricated elements (Annex 0_3) please find attached documents in annex.

The Multi Criteria Analysis (MCA in Annex 0_5) for Case 1, 2 and 4 shows that overall concept A (straight) gets the highest scoring. Thus, these solutions will be defined up to Master Design phase. These solutions might not be optimal in specific locations. For example, if there are limitations in vertical clearance. As an alternative solution for straight concept (A) could be haunched concept (B).

As an alternative for animal overpasses could be not only design A (Arch), but also design C (Three hinged Arch). Three hinged arch solution (C) is better alternative in bad backfill conditions than arch in concept A.

3.2.1 Preferred solutions

The main overall design concept is a straight and clear language of design. An overview of this concept for different cases is shown in Figure 14.

The idea of the straight concept is to design continuous straight superstructure and straight substructure. This design is a standard design and integral or semi-integral solutions can be applied. In some situations, this concept can be monotonous.

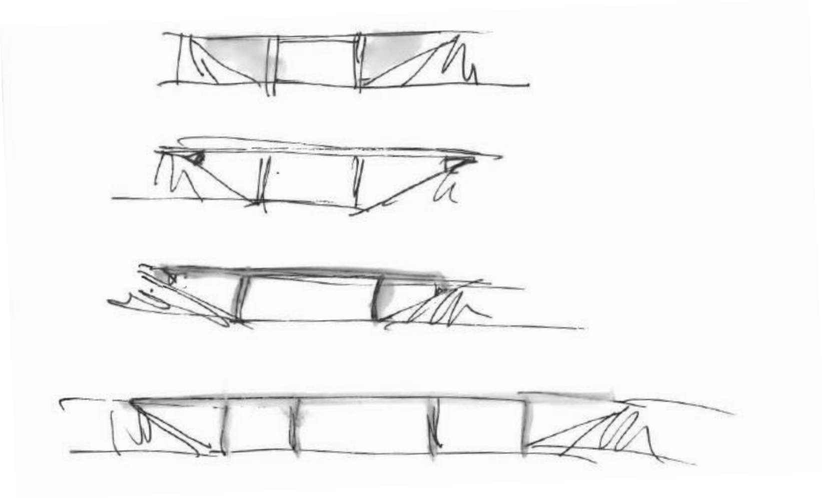


Figure 14: Straight concept overview

Picture credit: © nci

OHIO ROAD BRIDGE

Picture credit: © MKP GmbH

UNDERPASS FRIEDRICHSHAFENER STREET

Picture credit: © MKP GmbH

GÄNSEBACH VALLEY BRIDGEE

Picture credit: © SBP

INTEGRAL BRIDGE BRÜGGE

Requirements for animal crossings lead to arch bridge or tunnel solutions. Therefore, prefabricated concrete plate elements can be used. They can be transported in segments and connected in arch centre without creating a hinge.

INSTALLATION OF C-SERIES BEBO - CANADA

RCH BRIDGE ROADE PROJECT MOORE CONCRETE

ANIMAL OVERCROSSING ARCH BRIDGE

DOBWALLS BYPASS

4 Case 1 – Underpass

4.1 General

The main overall design concept for railway bridges and road overpasses is a straight and clear language of design. Thus, underpass is designed as shown in Figure 15.

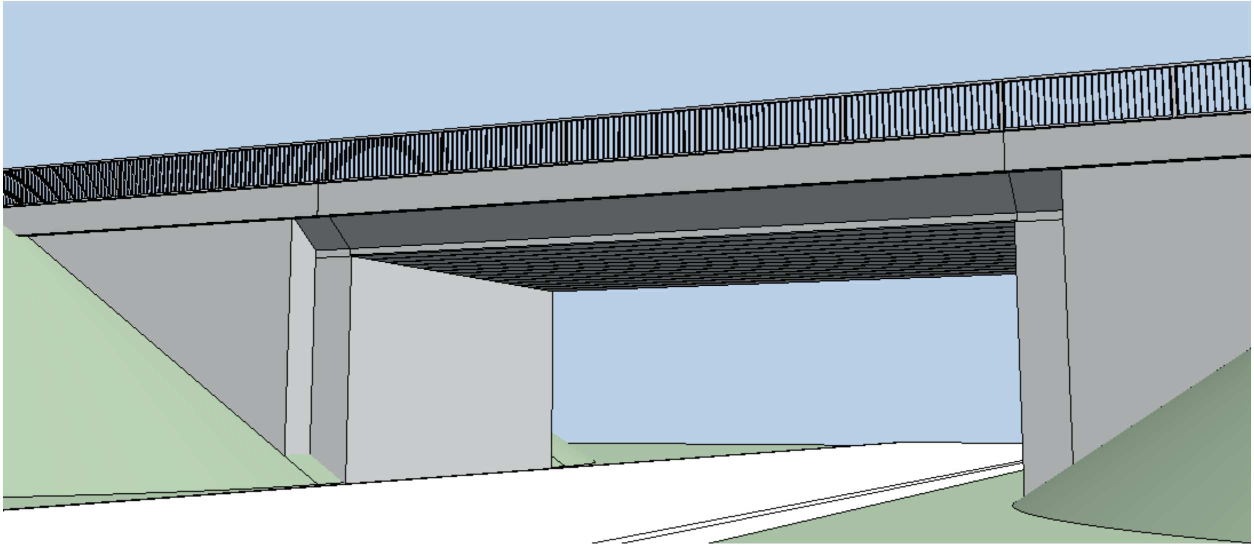


Figure 15: 3D view underpass

Underpass is planned as a frame with a span of 16.00 m (see Figure 16). Straight abutments build the end of the bridge. With put back wing walls the carrying system is presented.

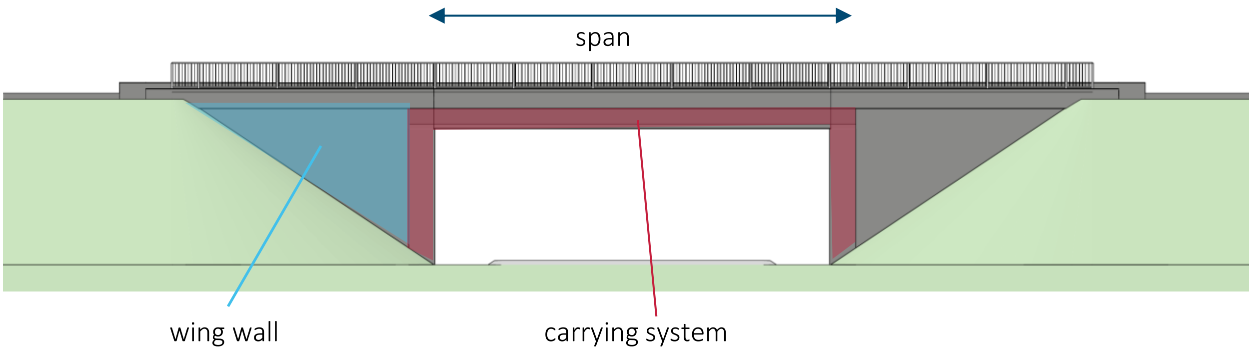


Figure 16: side view Underpass

In this planning phase superstructure is designed with a slenderness of L/H = 16. Due to inclined edge girders visual slenderness is even higher. For detailed geometry, please find drawings in Annex 1_2.

As mentioned in chapter 3.2.1 this underpass solution is a very economical solution (which can also be seen in MCA annex 0_5). A roughly cost estimation was made for the construction with the given geometry in drawings and with good local boundary conditions (Annex 1_1).

Integral bridge design rises durability and decreases maintenance due to avoiding joints and bearings. While necessary bridge inspections crossing partner is interrupted for that small time period. Accessibility for maintenance is good. Accessibility for inspection is possible from below with lifting platform.

4.2 Design influences

4.2.1 Angle of wing walls

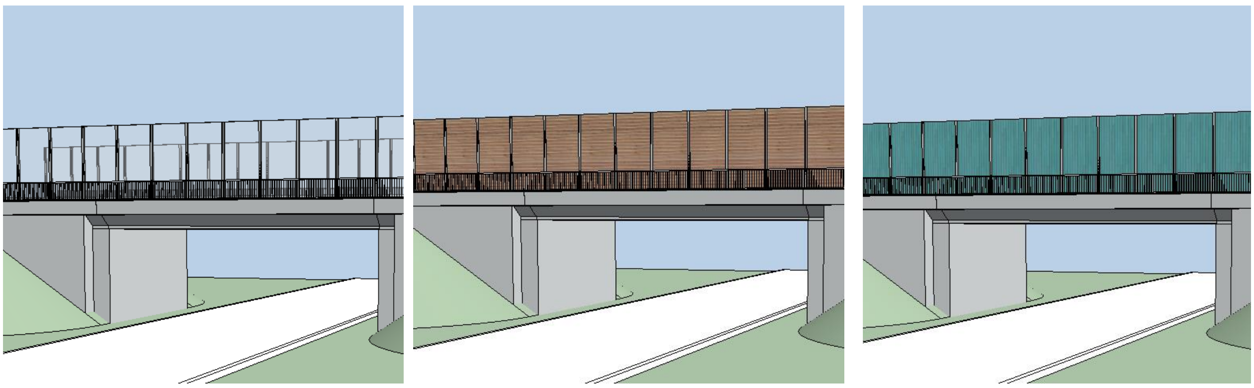
The angle of wing walls can be different depending on landscape situation. Especially for underpasses this angle defines the design and visual impact. Kinds of wing walls are shown in Figure 17.

angled wing walls | parallel wing walls | perpendicular wing walls

Figure 17: Angle of wingwalls

4.2.2 Noise protection walls

If noise protection walls are necessary, they are a big factor in design. The following figure (Figure 18) shows the effect of different material.



transparent material (e.g. perspex) | wood | sheet covering

Figure 18: Influence of noise protection walls

4.3 Construction works

Construction works can be subdivided into eight general steps:

- Preparatory works
- Earthwork
- Founding for abutments
- Substructure
- Superstructure
- Equipment
- Landscaping
- Finalizing work

For detailed information about construction works and their duration please find justification report Annex 1_0.

5 Case 2 – Railway Viaduct

5.1 General

As for Underpass a straight and clear language of design is preferred. Figure 19 shows a first impression of the designed Railway Viaduct.

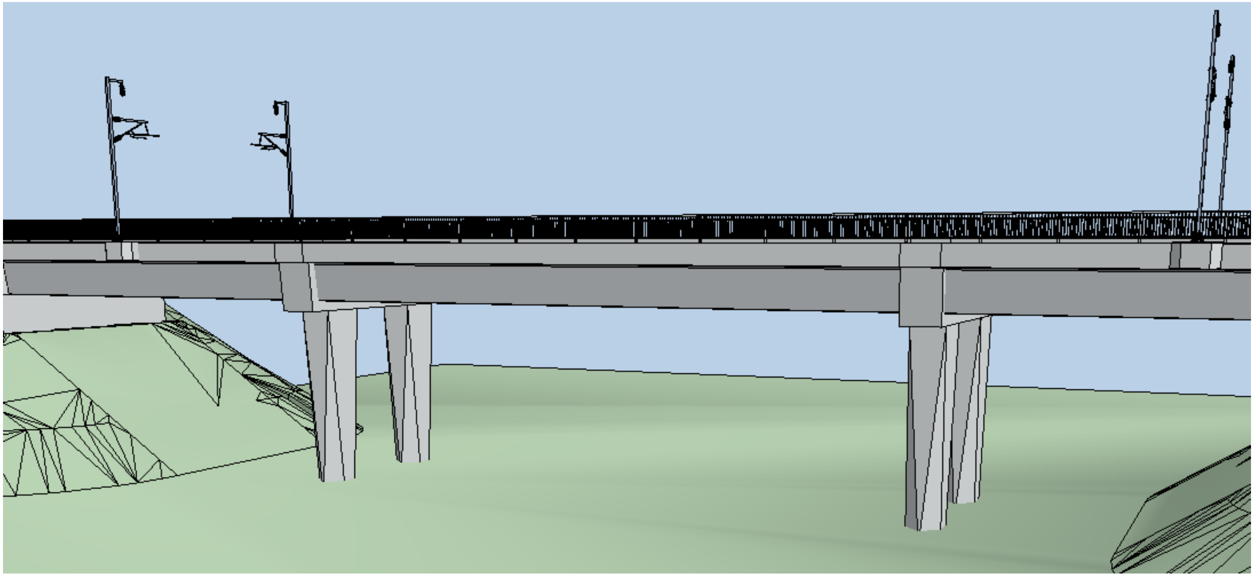


Figure 19: 3D view on Railway Viaduct

It is a three span bridge and straight abutments build the end of the bridge. It's two axis piers are arranged as shown in Figure 20. They are connected to the superstructure via pierheads. For detailed geometry, please find drawings in Annex 2_2.

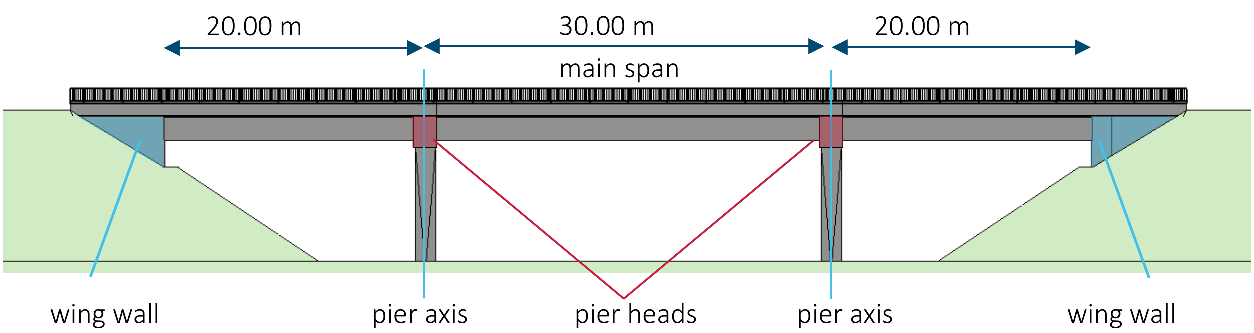


Figure 20: Side view on Railway Viaduct

Aim of this solution is to use as much prefabrication as possible (blue coloured elements in Figure 21). Therefore, requirements in construction phase have to be fulfilled. Please find more detailed information in justification report for Railway Viaduct (Annex 2_0).

As mentioned for case 1, integral bridge design rises durability and decreases maintenance due to avoiding joints and bearings. While necessary bridge inspections crossing partner is interrupted only partly and for that small time period. Accessibility for maintenance is very good. A minimum of 2m between embankment and bottom edge of superstructure ensures an easy access.

standard cross section with prefabricated U-beam elements

Alternativ standard cross section with prefabricated I-beam elements

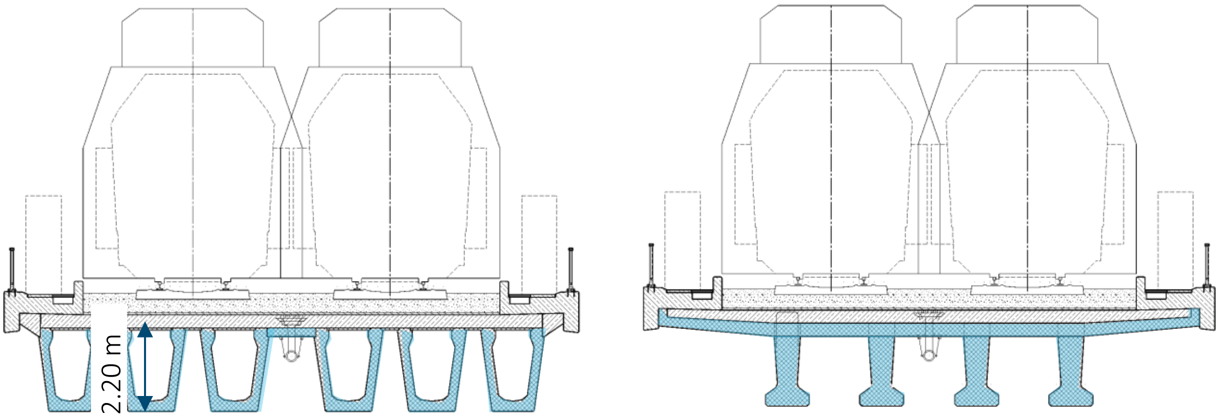


Figure 21: standard cross section with U-profile elements (left) and I-profile elements (right)

A roughly cost estimation was made for the construction with the given geometry in drawings and with good local boundary conditions (Annex 2_1).

5.2 Design influences

5.2.1 Geometry of piers

The geometry of piers influences the design very much. In following figure (Figure 22), the planned piers are shown. The upper cross section of pier differs from the bottom cross section. Thus, diagonal edges occur. With diagonal edges the piers do not seem to be too massive.

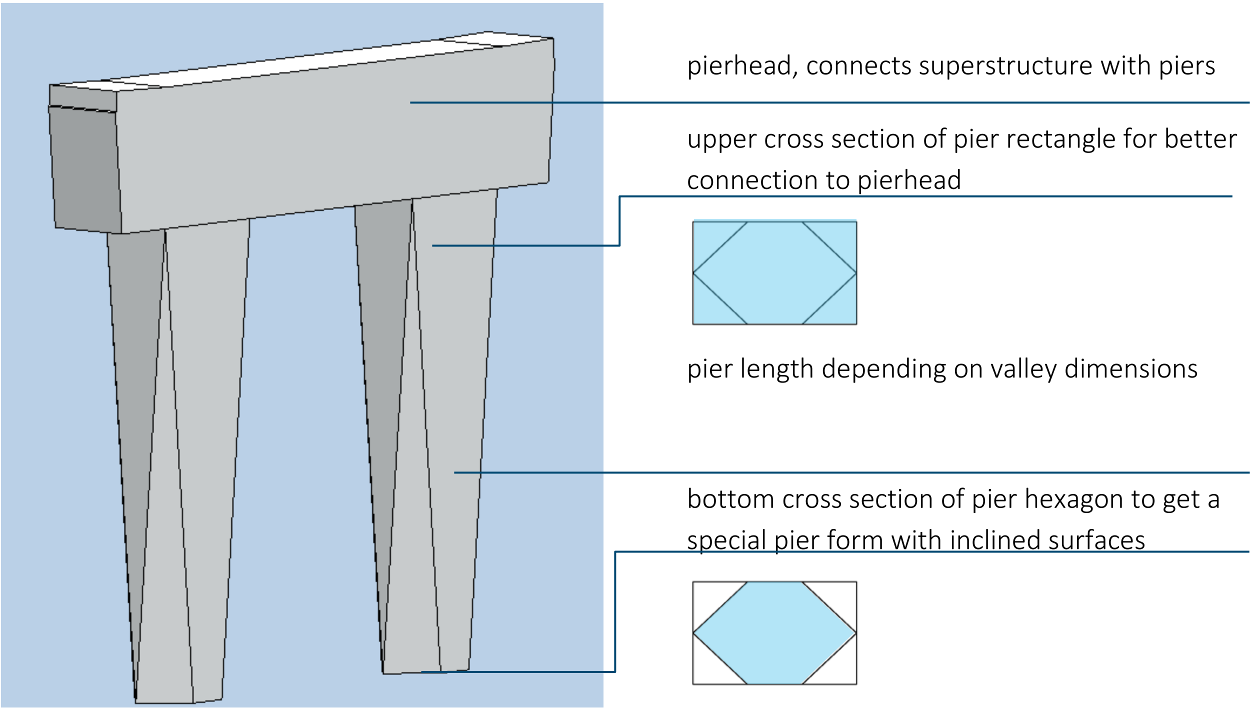


Figure 22: geometry of pier pair

In Figure 23 also piers with round cross section and with constant rectangle cross sections are shown in comparison to chosen piers to show the influence of inclined surfaces to design.

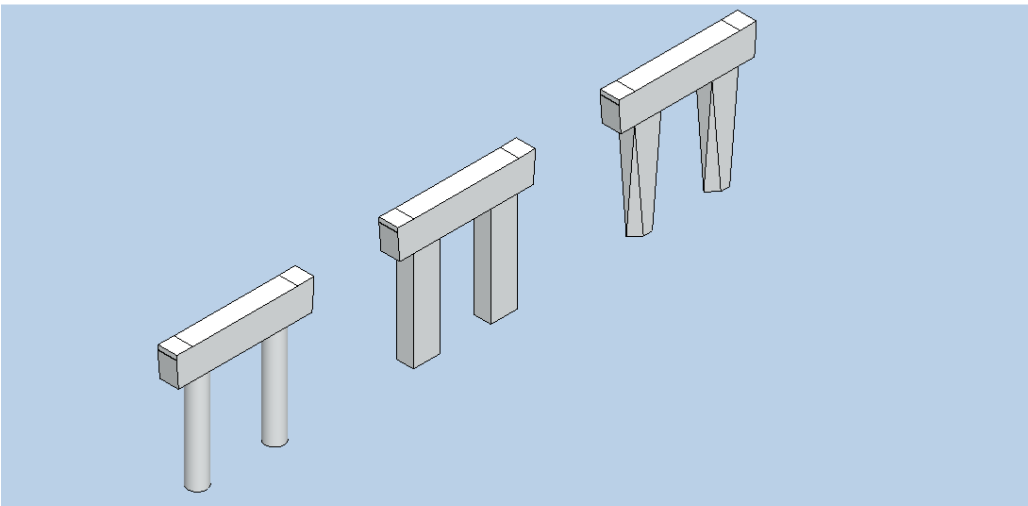


Figure 23: variation of piers

5.3 Construction works

Construction works can be subdivided into eight general steps:

- Preparatory works
- Earthwork
- Founding for abutments and piers
- Substructure
- Superstructure
- Equipment
- Landscaping
- Finalizing work

More detailed information about construction works and their duration is listed in justification report Annex 2_0.

6 Case 3 - Animal overpass

6.1 General

To ensure a safe overcrossing of wild animals over Rail Baltica line animal overpasses are planned. Requirements for animal crossings lead to arch bridge or tunnel solutions. The designed solution is shown in Figure 24 and Figure 25.

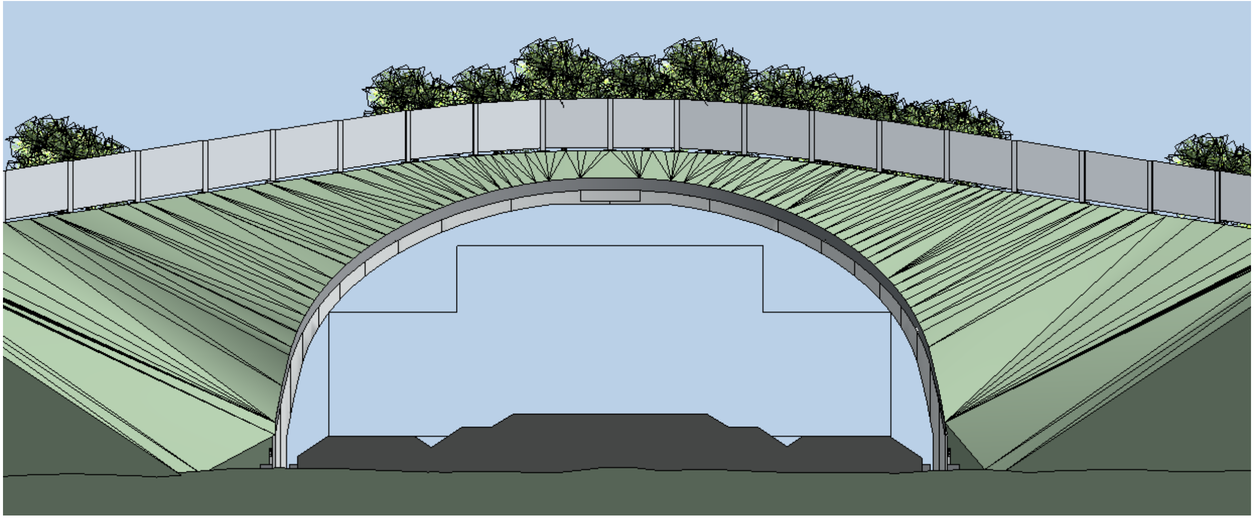


Figure 24: animal overpass, side view

Therefore, prefabricated concrete plate elements can be used. They can be produced and lift in segments and connected in arch centre without creating a hinge. For smaller solutions segments can also be transported from precast factory.

We advise to build the animal overpasses without ways on each side and realize underpasses as small openings as shown in Figure 12 bottom. In our justification report, drawings and estimation of costs are shown for the wide opening solution (Figure 12 top) because it is the more complicated solution. Nevertheless, small openings are the better alternative for animal overpasses.

Integral connections and no use of bearings rise durability and decrease maintenance. Railway infrastructure is interrupted for bridge inspections.

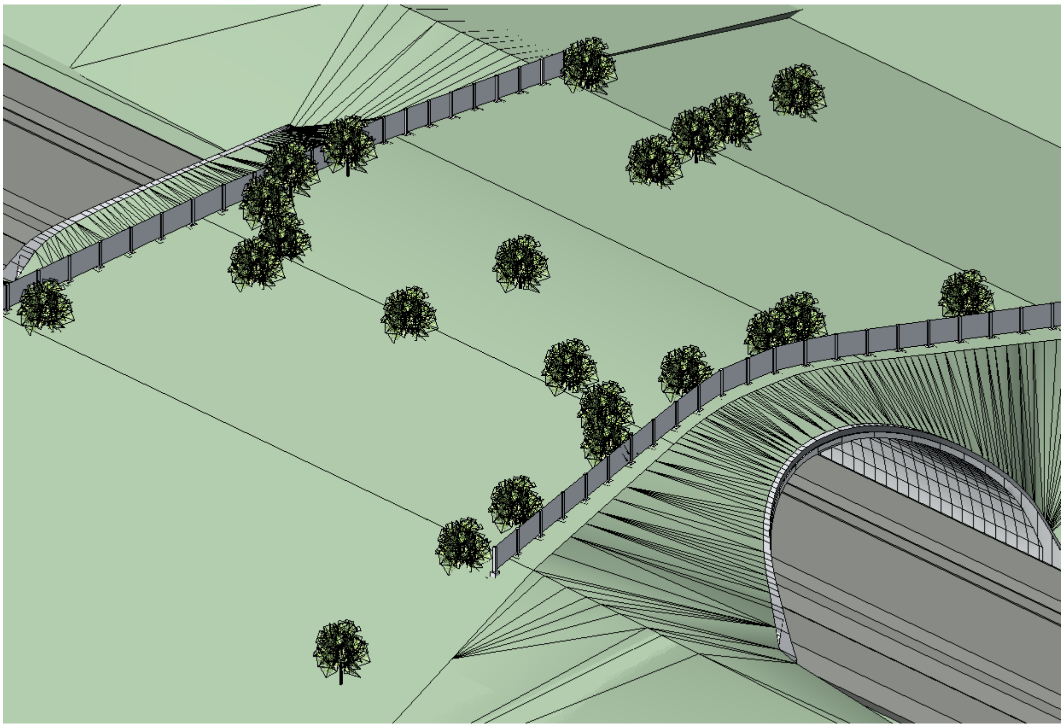


Figure 25: animal overpass, inclined top view, 3D

6.2 Design influences

6.2.1 End treatments

The presented design of animal overpasses shows bevelled ends (Figure 26). Depending on landscape and space requirement other end treatments are thinkable as following figures (Figure 27-Figure 28) present:

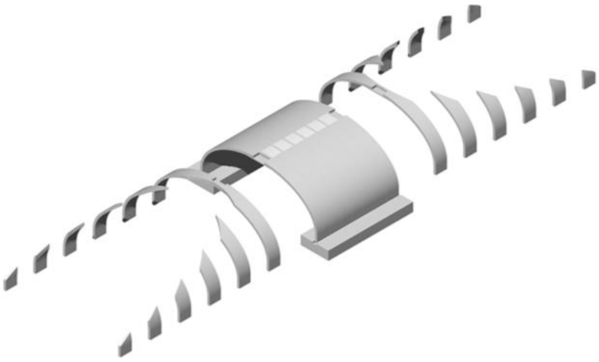


Figure 26: bevelled ends [U27]

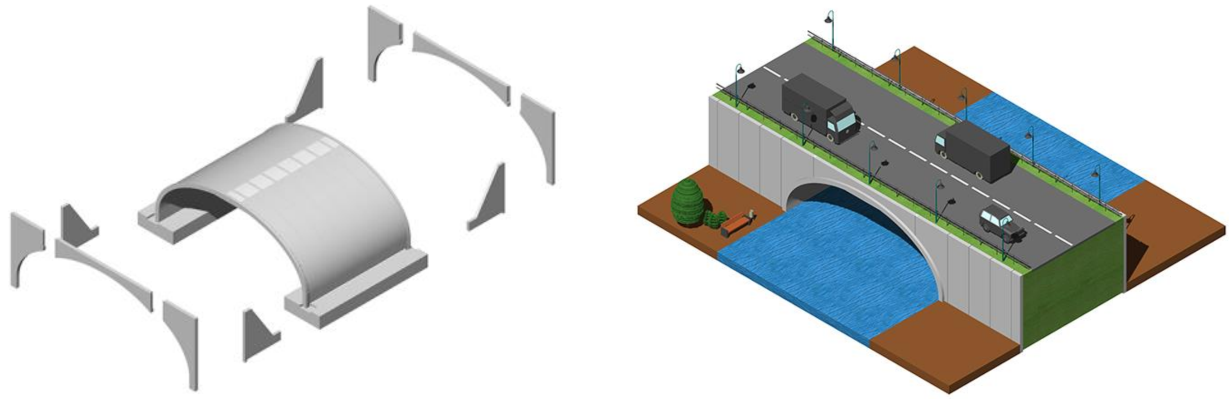


Figure 27: standard spendrel walls [U27]

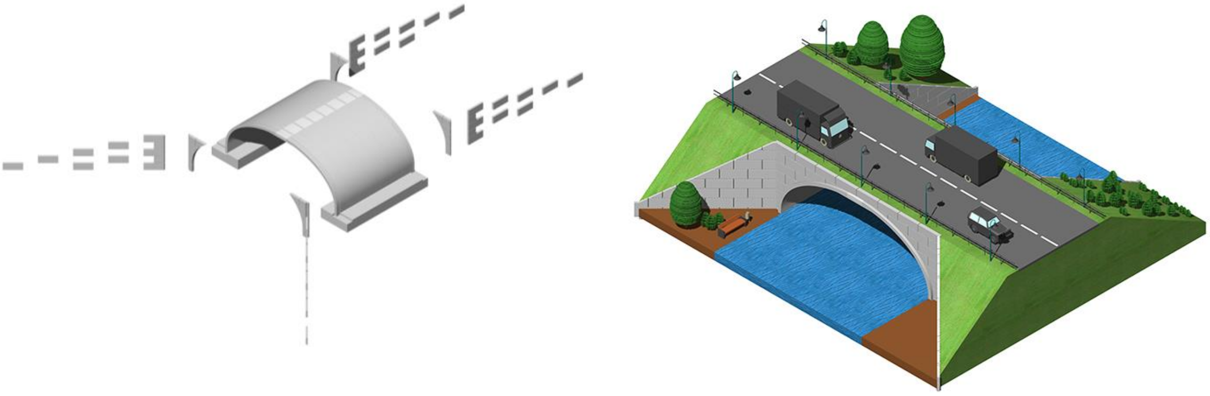


Figure 28: spandrel and wing walls [U27]

But bevelled ends as shown in Figure 26 give the best opportunity to ensure an alpha of 14°. So animals are directed carefully over high-speed railway line.

6.3 Construction works

Construction works can be subdivided into seven general steps:

- Preparatory works
- Earthwork
- Founding
- Superstructure and arch ends (lifting in of prefabricated half arches shown in Figure 29)
- Equipment
- Landscaping
- Finalizing work

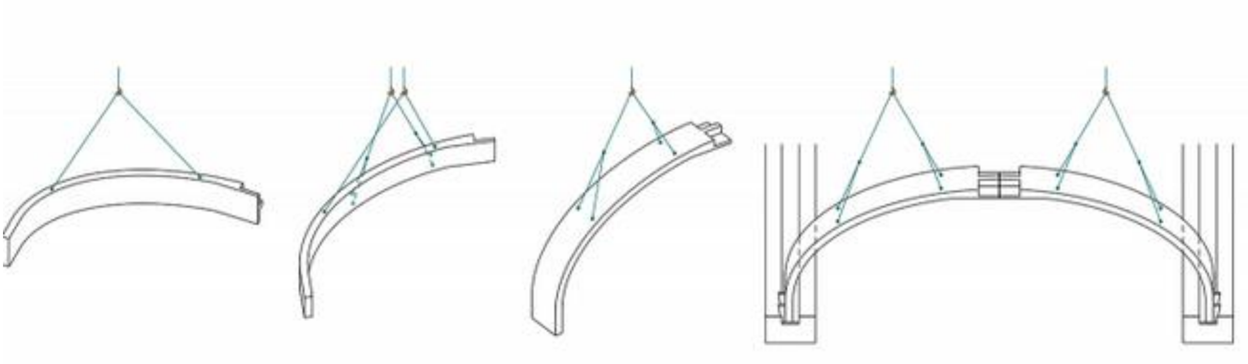


Figure 29: lift prefabricated half arches in founding [U27]

More detailed information about construction works and their duration is listed in justification report Annex 3_0.

7 Case 4 – Road overpass

7.1 General

As mentioned before the main overall design concept for railway bridges and road overpasses is a straight and clear language of design. Figure 29 shows a first impression of the designed Railway Viaduct.

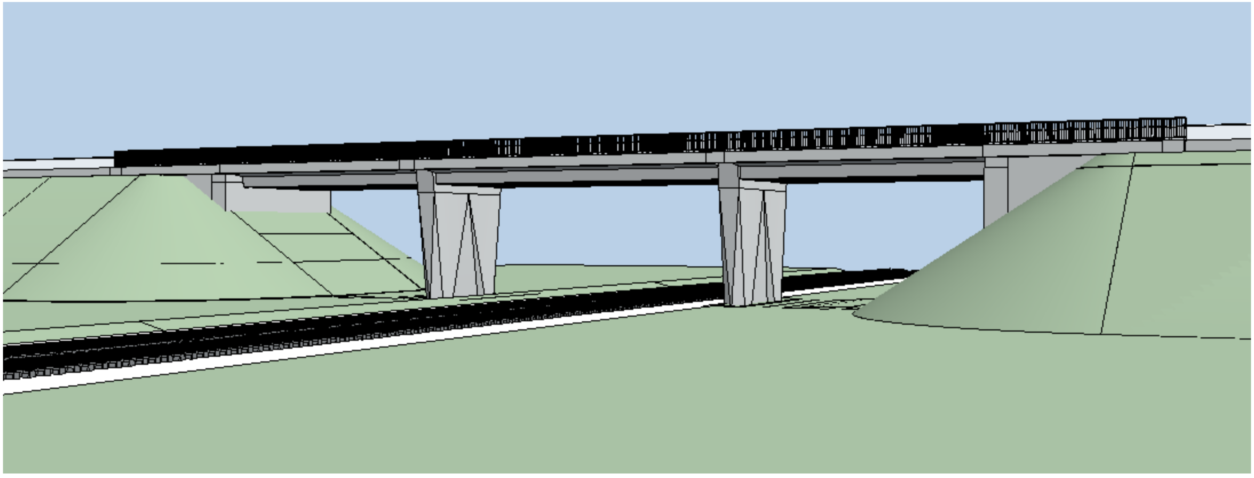


Figure 30: 3D view on Road overpass

Integral bridge design rises durability and decreases maintenance due to avoiding joints and bearings. Railway infrastructure is only partly interrupted for bridge inspections and accessibility for maintenance is very good.

7.2 Design influences

7.2.1 Geometry of pier walls

As for piers in Case 2 – Railway viaduct also the pier walls for road overpasses influence the design very much. In following Figure 31, the planned pierwalls are shown. The upper cross section of pierwalls differs from the bottom cross section. Thus, diagonal edges occur. With diagonal edges the pierwalls do not seem to be too massive.

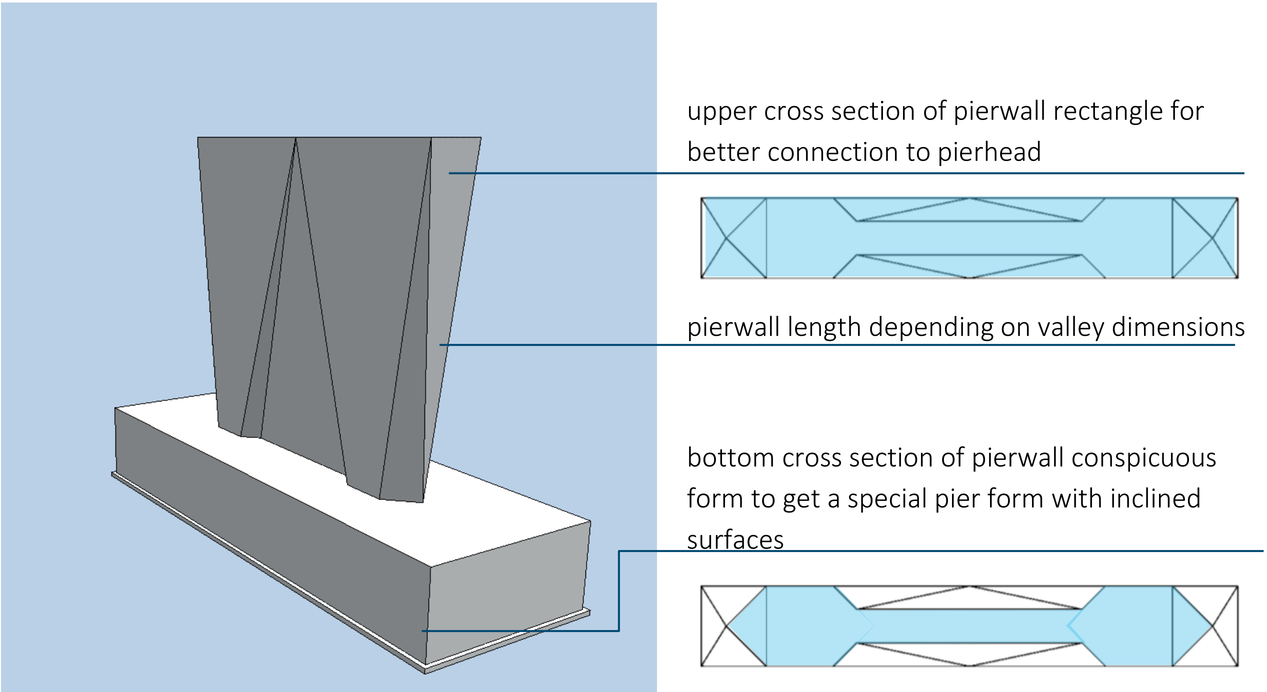


Figure 31: pierwalls

7.2.2 Parapets and protection equipment

For Road overpasses an overhead catenary protection system has to be installed:

- to protect pedestrians from the High Voltage required for Rail Baltica operations
- to provide a high aesthetic quality

There is a significant influence of protection equipment to bridge appearance of road overpasses.

Additionally, the Railway has to be protected from falling objects (e.g. due to accidental offloading of lorries) from the bridge. An Example of overhead catenary protection system is shown in Figure 32.

Figure 32: overhead catenary protection system to protect Railway and pedestrians

7.3 Construction works

Construction works can be subdivided into eight general steps:

- Preparatory works
- Earthwork
- Founding for abutments and pierwalls
- Substructure
- Superstructure
- Equipment
- Landscaping
- Finalizing work

More detailed information about construction works and their duration is listed in justification report Annex 4_0.

Final leaf

editor

Justine Bange, M.Sc.

reviewed

Dipl.-Ing. Ludolf Krontal

Hannover, 27.09.2019

Annex

Annex 0: Information from previous reports

Annex 0_1: Case Analyse; Crossing situations in Europe (Structures, Options and Examples)

Annex 0_2: Prefabrication possibilities and limits

Annex 0_3: Prefabrication connection types

Annex 0_4: Bridge design drawings for value engineering phase

Annex 0_5: Multi Criteria Analysis of Solution (MCA)

Annex 1: Case 1 Underpass

Annex 1_0: Justification report Underpass

Annex 1_1: Estimation of costs Underpass

Annex 1_2: Bridge design drawings master design phase Underpass

- 1_2_001_C1_Underpass_basic plan

Annex 1_3: 3D Model of Underpass

- 1_3_001_C1_Underpass_3D-Model_inkl. landscape
- 1_3_002_C1_Underpass_3D-Model_inkl. landscape + noise protection
- 1_3_003_C1_Underpass_3D-Model_basic model
- 1_3_004_C1_Underpass_3D-Model_alternativ model deep foundation

Annex 2: Case 2 Railway Viaduct

Annex 2_0: Justification report Railway Viaduct

Annex 2_1: Estimation of costs Railway Viaduct

- 2_1_001_C2_Estimation of costs Railway Viaduct_U-cross section
- 2_1_002_C2_Estimation of costs Railway Viaduct_alternative I-cross section

Annex 2_2: Bridge design drawings master design phase Railway Viaduct

- 2_2_001_C2_Railway Viaduct_basic plan
- 2_2_002_C2_Railway Viaduct_additional plan

Annex 2_3: 3D Model of Railway Viaduct

- 2_3_001_C2_Railway Viaduct_u-beam_3D-Model_inkl. landscape
- 2_3_002_C2_Railway Viaduct_u-beam_3D-Model_inkl. landscape + noise protection
- 2_3_003_C2_Railway Viaduct_u-beam_3D-Model_ basic model
- 2_3_004_C2_Railway Viaduct_u-beam_3D-Model_alternativ model deep foundation
- 2_3_005_C2_Railway Viaduct_I-beam_3D-Model_inkl. landscape

- 2_3_006_C2_Railway Viaduct_I-beam_3D-Model_inkl. landscape + noise protection
- 2_3_007_C2_Railway Viaduct_I-beam_3D-Model_ basic model
- 2_3_008_C2_Railway Viaduct_I-beam_3D-Model_alternativ model deep foundation

Annex 3: Case 3 Animal Overpass

Annex 3_0: Justification report Animal Overpass

Annex 3_1: Estimation of costs Animal Overpass

Annex 3_2: Bridge design drawings master design phase Animal Overpass

- 3_2_001_C3_Animal Overpass_basic plan

Annex 3_3: 3D Model of Animal Overpass

- 3_3_001_C3_Animal Overpass_3D-Model_inkl. landscape
- 3_3_002_C3_Animal Overpass_3D-Model_basic model
- 3_3_003_C3_Animal Overpass_3D-Model_alternative model deep foundation

Annex 4: Case 4 Road Overpass

Annex 4_0: Justification report Road Overpass

Annex 4_1: Estimation of costs Road Overpass

Annex 4_2: Bridge design drawings master design phase Road Overpass

- 4_2_001_C4_Road Overpass_basic plan
- 4_2_002_C4_Road Overpass_additional plan

Annex 3_3: 3D Model of Road Overpass

- 4_3_001_C4_Road Overpass_3D-Model_inkl. landscape
- 4_3_002_C4_Road Overpass_3D-Model_basic model
- 4_3_002_C4_Road Overpass_3D-Model_alternative model deep foundation

Annex 5 principles of detail for railway bridges

Annex 5_0: C1+C2_detail plan Railway briges

- 5_0_001_C1+C2_detail plan Railway briges I
- 5_0_002_C1+C2_detail plan Railway briges II