Underpasses for railways

Standardization of the design

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Challenge the future

UNDERPASSES FOR RAILWAYS

STANDARDIZATION OF THE DESIGN

by

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This thesis is confidential and cannot be made public until February 13, 2017.

Abstract

Introduction

There is a need for a standardized design of an underpass at a railway crossing, that can be applied at most of the locations that require such a tunnel, which is very unusual, because for underpasses is common to create a customized design, instead of a standardized design. This gives rise to the following research question: is it feasible to develop such a standardized design or is the influence of the parameters such that customized designs are unavoidable? The objective of this study is to realize a prototype underpass, which has a degree of standardization that is as large as possible.

Literature

A brief literature review is conducted on the two most important concepts of this study: standardization and underpasses. Since this is only a summary no references are used.

Standardization

According to the Cambridge University Dictionary the definition of standardization is to make things of the same type that all have the same basic features. We see that standardization makes its appearance when a large demand arises or if a large supply must be created. Examples can be found from Eli Whitney the first who used the principle of standardization, Henry Ford who became famous for his assembly line or IKEA who standardized the entire process of building furniture. It was also IKEA that stated that decomposition of a product is *the* precondition for standardized production. Further a number of pro's and con's are found regarding standardization. Pros of standardization are: saving of time and cost for design, construction and maintenance, more reliability and less chance of construction errors. Cons are: less flexibility, less optimization due to oversizing and restriction of the knowledge and freedom of the designer.

Underpasses

The definition of an underpass is a road or path that goes under something such as a busy road, allowing vehicles or people to go from one side to the other. The type of underpass is mainly defined by the altitude of the railway track, the type of the crossing road and the soil condition and groundwater level. There are two methods for the construction of underpasses that are most often applied: the method of the inserted deck and the method of the pulled (or pushed) tunnel.

Sensitivity analysis

A sensitivity analysis is performed to get a clear understanding of which design parameters vary and which are often the same. An inventory is made of all the railway crossings at the routes of PHS, see §1.1. The inventory consists of underpasses, overpasses, grade crossings and stations and for all these cases a comparison is made between the different parameters that have influence on the design.

Design parameters

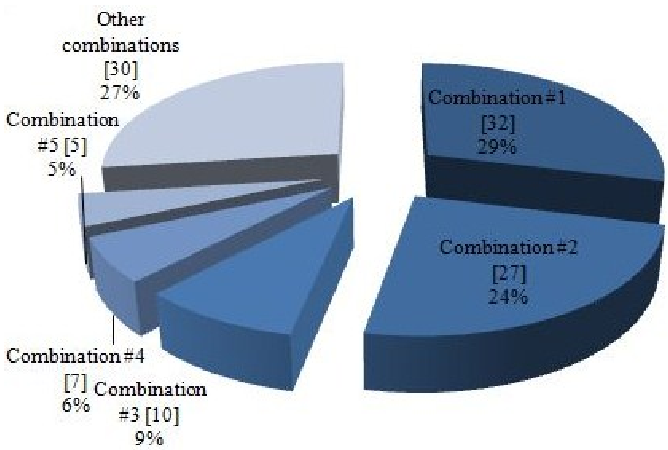
The degree of variation of the following parameters have been investigated:

- crossing type;
- location;
- crossing angle;
- number of tracks;
- road type;
- altitude railway;
- soil condition.

RESULTS

The following results follow from the sensitivity analysis:

1. On the routes of PHS still 28% of all the crossings are grade crossings. This is a total of 111 grade crossings.
2. In 47% of cases the crossings are underpasses.
3. The already constructed underpasses are located mainly in urban areas and are mostly designed for distributor roads.
4. In 29% of the situations with a grade crossings the design parameters are pretty much the same. That situation is a grade crossing in the countryside or in a semi-urban area, with a crossing angle of 90° or that is adaptable to an angle of 90°, where two tracks cross an access road and with the altitude of the railway at ground level position. Another group of grade crossings, 24%, is similar to the first group with to only difference that the altitude of the railway is half in elevation. So two types of underpasses could potentially cover up 54% of all the grade crossings.
5. The group grade crossings that are most eligible to be converted to an underpass is the group that is most difficult to be standardized (urban area; distributor road). Similarly, there is a large group that is quite easy to fit into a standard design, where the demand for adaptation is less (countryside; access road). This raises the question: what degree of standardization is desirable? Combination #1 and #2 (54% of the grade crossings) give rise to a fully standardized design, while combination #3, #4, and #5, and all other combinations which are not shown (together 46% of the grade crossings) to give reason for making a partially standardized design with a certain degree of flexibility, a parametric design (see §4.3 for these combinations).



DECOMPOSITION OF UNDERPASSES

Although there is a set of design parameters that limits the influence of the designer, there still remain a considerable amount of design choices that must be made per project. An inside to these design freedoms is found by decomposing an underpass. A method that is often used for decomposing is systems engineering.

Design choices are made at different levels and in different phases of the design process. Four levels of specification are distinguished. Each level considers a number of components of the underpass. The function of each component and the design choices for each component are described.

- Level 1 – Analyses the total underpass. Design freedoms like the location and the road alignment are considered.
- Level 2 – The underpass is split into three parts: the rail crossing section, the open tunnel section and the pump room. The main dimension of these components are considered, like shape, length, width, etc.

- Level 3 – The three components from level 2 are again split into several parts, as for instance: deck, walls, floors, foundations, etc. Structural dimensions of these sub-elements are considered, like length, hight, thickness, etc.
- Level 4 – This is the most specific level. All the sub-elements from level 3 are further decomposed into for instance: concrete, reinforcement, aesthetic elements, etc. The following design freedoms are considered: materials properties, bar diameters, bar spacing, etc.

To illustrate the decomposition an exploded view of the underpass at level 3 is shown in Figure 1.

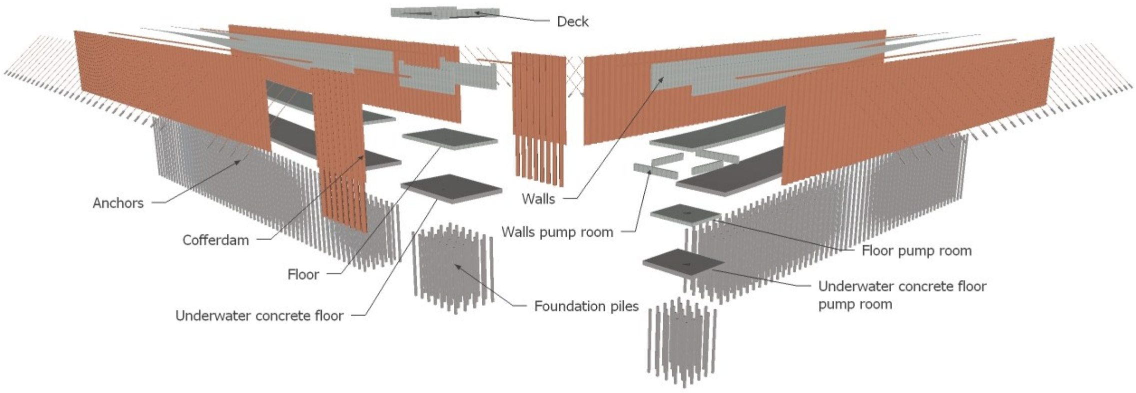


Figure 1: Exploded view of the underpass at decomposition level 3 (SketchUp)

FEASIBILITY OF STANDARDIZATION AND THE DEVELOPMENT OF A PROTOTYPE

TEXT TEXT TEXT

EVALUATION

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CONCLUSIONS

Based on the results of the performed research a set of conclusions can be drawn. The conclusions are listed in order of importance, where the first conclusion is the answer to the research question that was stated in §1.3.

1. It has been proven that it is technically feasible to standardize a major part of the design of an underpass. However, the effects of the variable groundwater level and the variable soil conditions are such that customizing the foundation is unavoidable.
2. A prototype has been developed that can be applied in 29% of the grade crossings on the tracks of PHS. When this prototype is adapted to a half raised railway track, another 24% of these crossing can be covered. This means that we with two prototypes 53% of all the grade crossing can be covered.
3. 53% of 111 grade crossings are 59 potential underpasses. If this is projected on all the 2500 grade crossings in The Netherlands it will be possible the build approximately 1350 underpasses in a similar fashion.
4. A major downside is that the highest demand for new underpasses is found in the urban areas, where the prototype doesn't apply to.

RECOMMENDATIONS

A set recommendations can be given based on the results of this research.

1. Research should be performed on the financial feasibility of standardizing the design. Does the profit due to repetition of construction and the reduction of construction time compensate the extra costs made by over-dimensioning of the design? Is there an optimum to be found?

2. Further detailing of the prototype is necessary for the development of the final standardized underpass.
3. Research should done on the possibility of the application of prefabricated elements for the floor, the walls and the deck of the underpass. A study on this subject is already being performed by Bart van Casteren, which he will publish in his master thesis: "*Feasibility of prefabricated elements for underpasses – watertight connection and structural safety*".
4. A solution must be found for the underpasses that need to be build in urban areas. A possibility might be a design with a lower degree of standardization, which will result in a more parametric design.

Acknowledgments

I would like to take the opportunity to express my gratitude to everyone who contributed in the completion of my thesis. Thanks to my graduation committee, consisting Dick Hordijk, Rolf Dollevoet, Kees Blom and Tom Groeneweg; thanks to Devlin Matagora, who offered me the graduation internship at Movares; thanks to all the colleagues at Movares that helped me find the right direction; thanks to Bart van Casteren and good luck to him on the completion of his thesis on *Feasibility of prefabricated elements for underpasses – watertight connection and structural safety*; thanks to my lovely girlfriend Alexandra Léandre who, together with her grandfather, helped me to produce a report in proper English and finally I would like thank both my parents for supporting me in all possible ways for all these years.

B.C. van Viegen
Delft, February 2015

Preface

In my opinion two things should be avoided when creating a design for a civil structure, namely architects giving a needless identity to the object and the repetition of structural calculations for nearly similar structures. The reason I address these two specific topics is that standardization of civil structures will eliminate both these problems.

During my internship at Movares one of my colleagues said to me that he hoped I would not succeed in creating a standardized design for underpasses, because it would leave him without a job. It made me think about the consequences of my work and whether it would be ethical to proceed with it. I realized that I could justify it, simply because I believe that my colleague's point of view on losing his job was not correct. With the underpasses standardized, Movares can put more energy in other assignments. It will give my colleague the opportunity to do actual engineering and think about new solutions, instead of repeating the same calculations he had made for years.

This brings me to my second topic. I believe that the most beautiful structures are designed by engineers and not by architects. Engineers have the ability create a very simple solution to a very complex problem. A solution that fulfills all requirements with the use of a minimum amount of materials and labor. Architect have a different way of thinking, which is not wrong, but simply doesn't fit the purpose of civil engineering, namely to improve our infrastructure as fast as possible and at the lowest possible cost. Over the years we have seen the influence of architects on the design of civil structures. Weird shapes, prints and colors have resulted in nothing but expensive structures with feigned identity. While I think that the boundary conditions and the state of art solutions should form the identity of the structure. When these boundary conditions are similar for many cases and the structure can be standardized (as I did for the underpass), it doesn't mean it has no identity, it solely means that the essence of its identity is formed by its applicability, and there is nothing wrong with that.

To end this statement I suggest that both civil engineers and architects do what they do best. Let architects focus on the design of their beautiful buildings and let civil engineers deal with the complexity of improving our infrastructure.

B.C. van Viegen
Delft, May 2014

Contents

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INTRODUCTION

This graduation project is carried out by Koen van Viegen as part of course CIE5060-09 MSc Thesis at Delft University of Technology in corporation with Movares.This section describes the problem, the problem statement, the research question and the objective.

1.1. PROBLEM DESCRIPTION

The Dutch government has the plan to change the current train table to a new one, PHS.[1] This means that the train intensity will increase in the coming years. There are, at about 2600 locations[2] in the Netherlands, equal leveled crossings with roads and railways. With the new train table, these crossing will lead to major traffic jams at these locations.

Therefore, tunnels have to be build under the existing railways. ProRail is planning on tendering a set of tunnels for a certain route or area. A tunnel alliance, formed by an engineering company and a contractor, will be responsible for the realization of the complete set of tunnels. In order not having to make a unique design for every single case, Movares would like to find a way to create a standardized and parameterized design, which can be applied at all these locations in the Netherlands, with only the adaption of the parameters, that have influence on the design.

The following routes will be adjusted: Alkmaar – Amsterdam; Amsterdam – Utrecht – Eindhoven; Schiphol – Utrecht – Arnhem/Nijmegen; Den Haag – Rotterdam – Breda; Breda – Eindhoven. All grade crossings[3] on these routes qualify for a tunnel. The goal of ProRail is to finish the PHS and to realize all changes regarding the crossings before the end of the year 2028.

The reason for Movares to invest in a standardization of the design process is that it will save a lot of time in the early engineering phase of the project. A time saving of six months up to one year is considered possible. The standardization may also result in a profit for the construction of the tunnels, because when it is standardized it can be build in a similar way for all different projects, which results in a repetition factor and a reduction of the construction costs. The combination of both types of cost reductions are an interesting prospect.

1.2. PROBLEM STATEMENT

There is a need for a standardized design of an underpass at a railway crossing, that can be applied at most of the locations that require such a tunnel, which is very unusual, because for underpasses is common to create a customized design, instead of a standardized design.

[1] Programma Hoogfrequent Spoorvervoer, Program High frequency Rail transport
[2] The exact amount will be verified in the research
[3] NL: overwegen

1.3. RESEARCH QUESTION

Is it feasible to develop a standardized design as described in §1.2 or is the influence of the parameters such that customized designs are unavoidable?

1.4. OBJECTIVE

It's important to realize that there is in general a direct relation between the degree of standardization and the degree of parameterization of a design. When a design is fully standardized, non of the design parameters will have any influence on the outcome of the design. On the other hand, when all the possible design parameters have influence on the design, then the diversity will be such that nothing is standardized. So there is transition area between a non standardized design and a fully standardized design. The objective is to eliminate as much design parameters as possible, which makes the degree of standardization as large as possible. The degree of standardization, the degree of parametrization and the objective are shown in Figure 1.1.

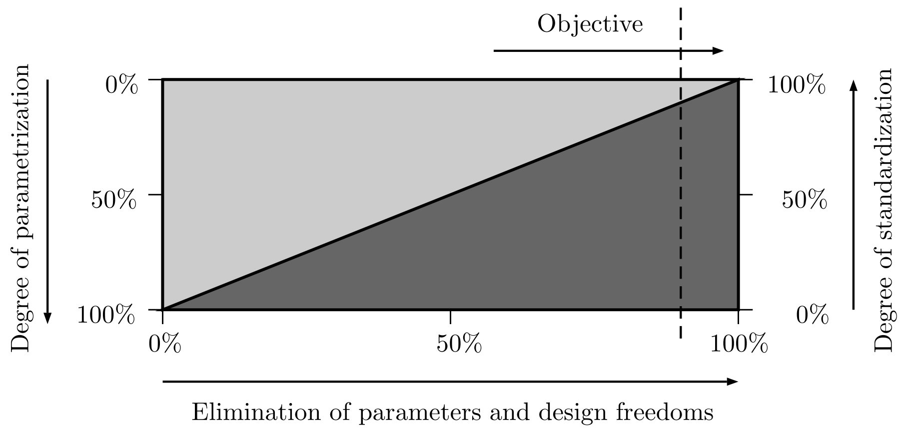


Figure 1.1: Degree of standardization vs degree of parametrization

2

Literature

This chapter provides a brief literature review conducted on the two main concepts of the thesis: standardization and underpasses.

2.1. Standardization

What is standardization in general? What is the history of standardization? Which processes lead to standardization? Where do we see examples of standardization? Is there standardization in civil engineering? What are the profits and what are the downsides? These questions are answered in this section.

Definition

Standardization is derived from the word standardize. What is described by the dictionary as: "*to make things of the same type that all have the same basic features.*"[1] It is a process in which the degree of variation is limited as much as possible.

History of standardization

In the year 1780, Thomas Jefferson asked engineer and inventors Eli Whitney to make 10,000 muskets. Whitney, who was known for the invention of the cotton gin, had never designed a rifle before. In that time guns were made by a blacksmith and were all unique, but Whitney created a musket which consisted of interchangeable parts, that were all identical. He was the first man who showed that mass production was feasible and the first who used the principle of standardization. [2]

Figure 2.1: Eli Whitney, father of standardization [3]

Later in 1913, Henry Ford used the same principle to optimize the production of his cars. Ford's goal was to build as many cars as possible, with the most simplistic design and for the lowest price. He managed to do it by standardizing of the separate parts and by assembling them in a sequence until the car was ready. Though the design was standardized there was still a fair amount of variation in the cars that came off the assembly line, see Figure 2.2. There were different colors, different wheels, different interior, etc., but because all the basic features were similar Ford could construct them in the same manner. The contemporary production of automobiles and other industrial products is done in much the same manner as a hundred years ago, except for the workers who are in many cases replaced by machines and robots. [4]

Figure 2.2: Henry Ford's assembly line [4]

IKEA ®

IKEA, the well known furniture company, might be the best example in how designs can be successfully standardized. They have standardized and optimized hundreds of products and sell them in large numbers all over the world. How do they manage to do that?

"*The design of home furnishing products at IKEA starts with an understanding of people's everyday needs at home, especially the needs of the majority of people, who have limited incomes and limited living spaces.*"[5] When IKEA decides to develop a new product, the first thing they determine is the price for which it ought to be sold. From that point the designers work backwards to come to a design. It leads to products that fit in flat boxes and consist of a set semi-finished products that ought to be assembled at location instead of in the factory. According to IKEA: "*the decomposition of a product is thé precondition of standardized production.*"[6] To ensure an error-free assembly there is a step-by-step instruction for every product. The products are designed in such a way that they fit in almost every living room, so the applicability is close to 100%.[6][7]

One of the oldest and most famous product of IKEA is the BILLY Bookcase, which forms the base for the BILLY System, see Figure 2.3. It's a very basic bookcase, which comes in many forms and colors, but all with the same basic structure with two side panels, two top panels, a back panel and a number of shelves. The connections are standardized as well and work, not only for the BILLY, but also for some similar products.[8]

Figure 2.3: BILLY Bookcase with some optional accessories [8]

STANDARDIZATION IN CIVIL ENGINEERING

Standardization in civil engineering does occur, but rarely at the level that occurs at Ford or IKEA. We see that parts of structures there are standardized. Think of prefabricated girders for bridge decks, sheet piles, foundation piles etc. Plenty of such examples can be found, but it is seldom that a total structure is standardized in a way where it can be applied to multiple locations. So there is no standardization of the final product.

Which gives rises to the question: why is there no standardization of the final product? A few reasons can be found. The first and most important reason is that projects in civil engineering are always very complex, because there are a large number of factors that have influence on the design, for example soil conditions, water levels, the surrounding area etc. The variation in these factors often gives rise to a unique design. A second reason is that the method of tendering is an obstacle for the standardization of designs. Even similar projects are mostly tendered piece by piece.

A good example of standardization regarding railways are the *Waterstaatstations*. Between 1860 and 1875 almost a hundred of such standardized stations were built in the Netherlands. The costs were kept low and the construction time was faster, resulting in five basic designs, see 2.4. The designs were made by engineers and were consistent with the objectives of civil engineering: soberness, efficiency and simplicity.[9][10] In

Figure 2.4: Example: Station Wolvega, 1868, SS 4th class [10]

2011 *Rijkswaterstaat* launched a project which is known as *MultiWaterWerk*. The objective of the project is to replace several waterworks more efficiently. Standardization of design is an important factor for this project to succeed. To achieve this *Rijkswaterstaat* is willing to tender a set of similar projects all together. [11]

PROS AND CONS OF STANDARDIZATION

Standardization may lead to number of pros:

- Savings of time and cost of the design process, construction and maintenance of a project;
- Parts of the structure are replaceable, which might result in more reliability;
- Repetition gives less chance on construction errors.

The cons of standardization may be:

- Less flexibility in the design;
- Because of over sizing the solution for a specific situation might be less optimal;
- It restricts freedom of the designer.[11]

2.2. UNDERPASSES

This section gives an overview of underpasses and all the aspects involved. What's the definition? Which types of underpasses are there? Which aspects play a role in the design process? Which construction methods are available for underpasses? These questions are answered in this section.

DEFINITION

Underpass: “*a road or path that goes under something such as a busy road, allowing vehicles or people to go from one side to the other*” [1] In this case the busy road being the railway track. In Figure 2.5 an impression is shown of a new to build underpass at Wolvega.

Figure 2.5: Impression underpass Wolvega [12]

TYPES OF UNDERPASSES

There is a lot of variety regarding underpasses in The Netherlands, but for all these underpasses the basic principles are quite similar. At the location of the railway crossing section it’s just a concrete box in ground, that allows trains to run over and traffic to pass through. Still there are different types of underpasses. The largest distinctions are made based on the following three factors:

- altitude of the railway track,
- type of road crossing,
- soil condition and groundwater level.[13]

Altitude railway track The altitude of the railway track ranges from fully raised to ground level location. This means that there are an endless amount of options, but there is a distinction made between only three options. The following variations are possible, see also Figure 2.6:

- fully raised track,
- half raised track,
- track at groud level.[13]

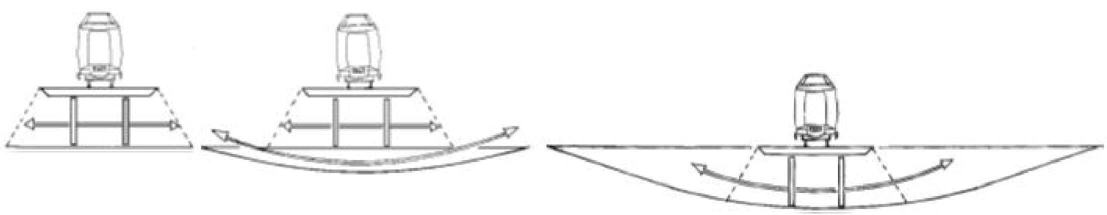


Figure 2.6: Altitude railway: fully raised (left), half raised (center) and ground level (right) [14]

Road type The type of road that crosses the railway track has influence on the type of underpass. Mostly on the gauge, which on itself has an influence on all the other dimensions. A distinction can be made between four road types:

- road for cattle,

- bicycle path and pedestrian walkway,
- access road[1],
- distributor road[2].[13]

Soil condition and groundwater level The last factor of influence is the soil condition in combination with the ground water level. When the soil is soft and the groundwater level is high, underwater concrete is required. Also tunnel walls are needed to retain the ground water and the soil. On the other hand, when the soil is stiff and the ground water level is low there can be a dry excavation of the tunnel and tunnel walls may be replaced by simple slopes.[13]

CONSTRUCTION METHODS

The construction methods are not considered in §2.2. In this section, the two main constructions methods are considered. The method of the inserted deck and the method of the pulled (or pushed) tunnel. This is a pretty basic division, but it gives an idea of how underpasses are usually built.

Inserted deck This is the most common method used in Netherlands. It has its origin in a requirement of ProRail that the track may be decommissioned for a maximum of one hundred hours. Therefore the entire deck is prefabricated next to track so it can be placed in position in one weekend. It varies slightly per contractor and the surrounding area is also of influence, but roughly the underpass is constructed with the following steps:

1. Applying sheet piles both perpendicular and parallel to the railway track (1st decommissioning 50 hours).
2. Wet excavation of the cofferdam and the application of a water-tight seal, usually in the form of underwater concrete.
3. Construction of the concrete floor and walls of the access ramps.
4. Prefabrication of the entire deck.
5. Removing the railway track at the site of the railway crossing section. Insertion of the deck on the sheet piles and restore the deleted track (second decommissioning 50 hours).
6. Wet excavation underneath the deck and the application of a water-tight seal, also in the form of underwater concrete.
7. Finish the tunnel and slightly lift the deck so it rests on the concrete walls instead of on the sheet piles.

Contractors may vary the order of the different steps. Also, in the case of a low groundwater level or fully raised track, it is possible that the access ramps of the tunnel will not be executed as an open concrete tunnel, but just with slopes.

Figure 2.7 shows a photograph of an underpass under construction with the method of the inserted deck. In the photograph the deck is prefabricated and ready to be placed in position.[15]

Figure 2.7: Method of the inserted deck applied at the underpass Fortweg between Utrecht and Houten[15]

[1] NL: erftoegangsweg
[2] NL: gebiedsontsluitingsweg

Pulled tunnel This method is used less often than the method of the inserted deck. Instead of just prefabricating the deck, the entire tunnel is prefabricated and then pulled under the railway track. There is also a similar method is available in which the tunnel is pushed instead of pulled, but because a pulled tunnel is drawn to one point, it is easier to place it in the correct position. Figure 2.8 shows a schematization of this method. The following steps are taken during the construction:

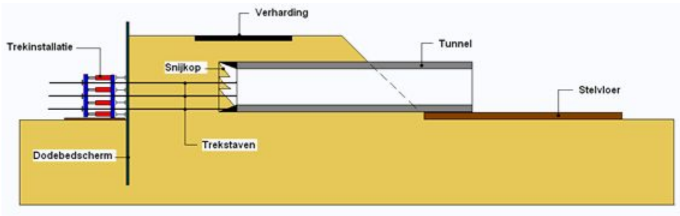


Figure 2.8: Schematic representation of a pulled tunnel [16]

1. Sheet piles are applied parallel to the railway track. The sheet piles will later absorb the forces from the pulling installation.
2. Prefabricating the tunnel by connecting concrete elements with pre-stressing tendons.
3. Drilling pull rods below the tracks and connecting them to the tunnel.
4. Attaching a cutting head to the front of the tunnel.
5. The pulling installation pulls the tunnel under the railway track.
6. Finishing the tunnel.

There are however some limitations to this method. The maximum width of the tunnel is $8.0m$, because the size of the elements are restricted by limitations on the road. This means that it cannot be applied for the larger roads. Other factors are the soil condition and the groundwater level. The soil has to be stiff, because a pile foundation cannot be applied. Also the groundwater level should not be higher than the bottom of the tunnel, otherwise the tunnel will flood. [16]

2.3. CONCLUSIONS

1. Standardization is to make things of the same type that all have the same basic features.[1]
2. In the cases of Eli Whitney and his muskets, Henry Ford and his cars and IKEA ®and there furniture, we see that when a large demand arises or if a large supply must be created, standardization makes its appearance.[2][4][5][6][7][8]
3. In civil engineering standardization of the entire design is uncommon, because there is usually just a request for one product (one bridge, one tunnel, etc.) and the surrounding conditions are often so specific for the project that it is very hard to create a design that's applicable at multiple locations.[11]
4. According to IKEA ®, the decomposition of a product is *the* precondition of standardized production.[6]
5. Pros of standardization: saving of time and cost for design, construction and maintenance, more reliability and less chance of construction errors.[11]
6. Cons of standardization: less flexibility, less optimization due to oversizing and restriction of the knowledge and freedom of the designer.[11]
7. An underpass is a road or path that goes under something such as a busy road, allowing vehicles or people to go from one side to the other. [1]
8. The type of underpass is mainly defined by the altitude of the railway track, the type of the crossing road and the soil condition and groundwater level.[13][14]
9. There are two methods for the construction of underpasses that are most often applied: the method of the inserted deck and the method of the pulled (or pushed) tunnel.[15][16]

3

Process of standardization

Based on the study of literature a method is developed to examine the feasibility of standardizing the design of an underpass and to create a suitable prototype solution. The four steps that ought to be taken for this are explained in this chapter.

3.1. Sensitivity analysis

A sensitivity analysis is executed on the matter of variation of the design parameters. Which parameters vary and which parameters are often the same? Is there a combination of parameters that often occurs? Let this combination be a base for a standardized design.

3.2. Decomposition of underpasses

An underpass is decomposed to find out what of components it is built? What is there function? How do these components vary? The decomposition of the underpass leads to an object tree, like is done in systems engineering.

3.3. Feasibility of standardization and the development of a prototype

Is it feasible to standardize each component of the underpass? That is the main question in this chapter. For each component the technical feasibility of standardizing it is examined and a solution for the prototype is suggested. If it's not possible to standardize a component it's influence on the rest of the underpass will be tested and an alternative suggestion will be given to guarantee applicability.

3.4. Testing and optimizing the prototype

In theory the prototype is applicable in 100% of the cases that followed from the sensitivity analysis. In order to test if this works in practice as well, the prototype is applied in some randomly chosen cases. The prototype will be over-dimensioned for some situations in order to guarantee this 100% applicability. This calls for an optimization. It might be more beneficial to have for instance a standardized underpass for 90% of the cases and customize the remaining 10%. In order to determine the optimum of this ratio, the financial feasibility must be investigated as well. Since financial analysis are out of the scope of this thesis, the actual optimization won't be performed. Instead an evaluation is made where the initial parameters are reconsidered and suggestions for optimization possibilities are given.

3.5. Conclusions and recommendations

Conclusions are drawn regarding the research question and the objective of the thesis. A set of recommendations are given on follow-up studies.

3.6. FLOW CHART OF THE STANDARDIZATION PROCESS

In order to make the standardization process extra clear a flow chart has been created, which is shown in Figure 3.1.

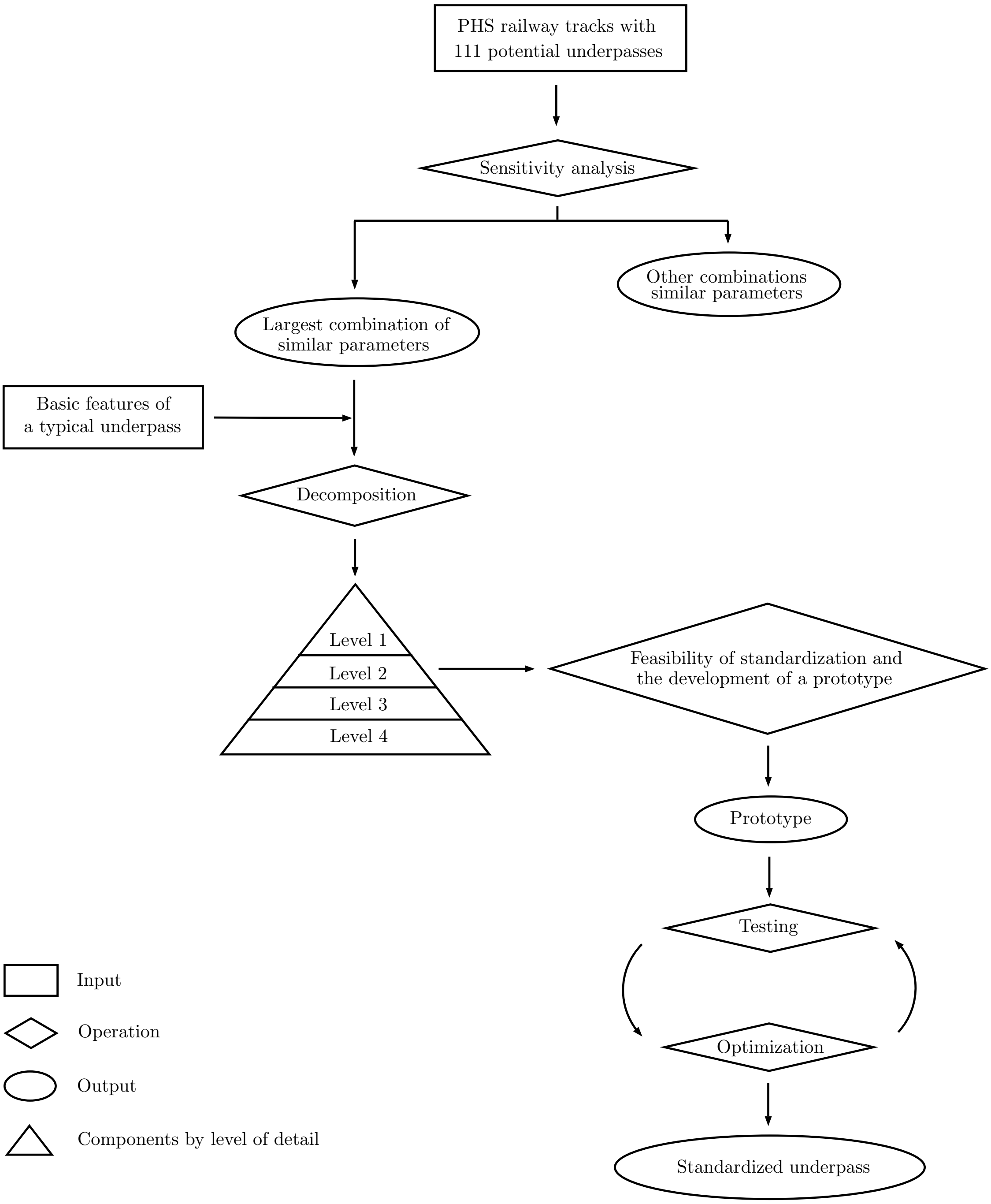


Figure 3.1: Flow chart of the standardization process.

4

SENSITIVITY ANALYSIS

As stated in §1.4, there is a direct relation between the degree of standardization and the degree of parameterization of a design. A sensitivity analysis is performed to get clear which design parameters vary and which are often the same. An inventory is made of all the railway crossings at the routes of PHS, see §1.1. The inventory consists of underpasses, overpasses, grade crossings and stations and for all these cases a comparison is made between the different parameters that have influence on the design.

4.1. GENERAL

PURPOSE

The purpose of this analysis is to determine to what extent the different parameters vary. In addition, it also considers whether and where similarities occur.

METHOD

The inventory of railway crossings is created with the help of Google™ Earth. The location of the crossing is registered so it can be verified if necessary. Both Top View and Street View perspectives are used to determine to what extent the different parameters vary. The data is then processed in an Excel file.

4.2. DESIGN PARAMETERS

In §2.2 three design parameters are already given to define the different types of underpasses, however this is a coarse definition. Even the same types of underpasses may have different dimensions. Other parameters also have influence on the dimensions of the structure. The degree of variation of the following parameters have been investigated:

- crossing type;
- location;
- crossing angle;
- number of tracks;
- road type;
- altitude railway;
- soil condition.

Another important parameter is the groundwater level, but it is almost impossible to determine this for the more than 400 crossings in this research. Therefore, the influence is not investigated. When creating a standardized design an upper limit can be used for structural calculations. Further details follow in Chapter **??**. The remainder of this section provides an explanation of the design parameters listed above. It is also indicated in what way they are processed in the inventory.

Crossing type

Four crossing types are considered. The most interesting type for this project is the grade crossing, because is has the potential to become an underpass. The other three options are an underpass, an overpass and a station. These are considered to give a complete image of the crossings.

Location

A distinction is made between three different locations: urban, semi-urban and countryside. The options urban and countryside are self-explanatory, but semi-urban may be harder to interpret. It refers to an area with buildings, but they are so far from the crossing that it does not complicate the integration. The main effect of the location is the integration of the tunnel in the area. It is much easier to fit a tunnel in the countryside than in an urban area.

Crossing angle

The crossing angle is measured in the Top View perspective of Google™ Earth with an accuracy of 5°. The smallest angle is measured, which means the angle is always between 0° and 90°. 90° is the ideal situation, because in this case the least material is used. If the crossing angle deviates from this ideal situation, it is checked whether there is a possibility to adapt to this situation to a 90° angle. Note that only the possibility of adaptation is considered, not whether it is desirable.

Number of tracks

These are the number of tracks at the location of the crossing road. The number of tracks determine the length of the closed part of the tunnel.

Road type

A distinction is made between five types of roads: distributor road, access road, bicycle- and pedestrians path, road for cattle and a highway. For more information see §2.2.

Road width

The width of the road is somewhat related to the road type, however there is still a lot variation. It is measured by the ruler application in Google™ Earth, with an accuracy of 1.0m.

Altitude railway

The altitude of the railway track cannot be measured in Google™ Earth, and is therefore estimated. A distinction is made between three option: entirely in elevation, half in elevation and ground level position. For more information see §2.2.

Soil condition

There is so much variety in the soil conditions in The Netherlands that only a course distinction can be made. It's either soft soil or sand. The soil condition is determined based on the location that follows from Google™ Earth and the corresponding soil data from BIS Netherlands, see Appendix A.

4.3. RESULTS

The inventory of railway crossings and the recapitulative results are shown in Appendix B. A total of 405 crossings are found on the tracks of PHS. 111 of these crossings are grade crossings, 190 are underpasses, 58 are overpasses and 46 are stations. Figure 4.1 shows a typical Google™ Earth image. It's a grade crossing with two tracks, an access road, in a countryside environment, with a crossing angle to 90° or adaptable to 90° and the altitude of the railway at ground level position.

Figure 4.1: Typical Google™ Earth image[17]

N.B.: Some Google™ Earth images date from 2005 or earlier, which means that the current situation may be changed at several locations.

MOST COMMON COMBINATIONS

In §B the most common option per parameter is shown, but perhaps more interesting are the most common combinations. Opportunities for a standardized design occur, when multiple situations are found with the same combination of design parameters. This could lead to a few types of underpasses that together constitute a catalog that cover most of the situations. The most obvious combinations have been tested. These combinations are shown below and the appearance is shown in Figure 4.2.

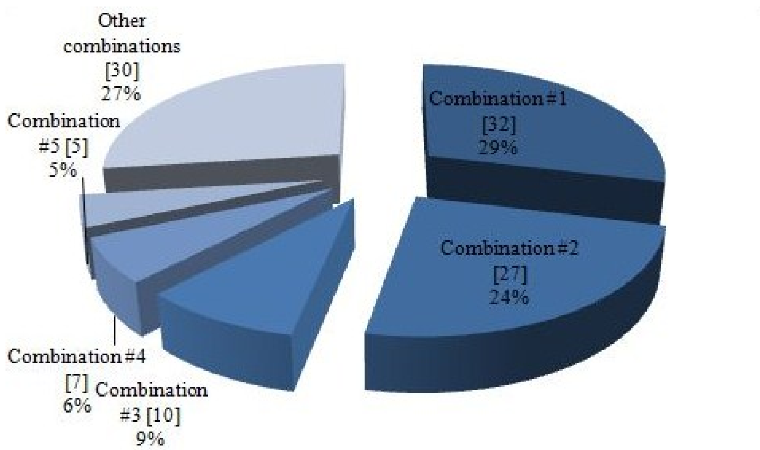


Figure 4.2: Most common combinations for grade crossings

Combination #1

- Crossing type = Grade crossing
- Location = Countryside and semi-urban (two options, because it makes virtually no difference to the integration of the underpass in the area)
- Crossing angle = 90° (or adaptable to 90°)
- Number of tracks = 2 tracks
- Road type = Access road
- Altitude railway = Ground level position
- Soil condition = Sand and soft soil

Combination #2

- Crossing type = Grade crossing
- Location = Countryside and semi-urban (two options, because it makes virtually no difference to the integration of the underpass in the area)
- Crossing angle = 90° (or adaptable to 90°)
- Number of tracks = 2 tracks
- Road type = Access road
- Altitude railway = Half in elevation
- Soil condition = Sand and soft soil

Combination #3

- Crossing type = Grade crossing
- Location = Urban
- Crossing angle = 90° (or adaptable to 90°)
- Number of tracks = 2 tracks
- Road type = Access road
- Altitude railway = Ground level position
- Soil condition = Sand and soft soil

Combination #4

- Crossing type = Grade crossing
- Location = Urban
- Crossing angle = Not 90° and not adaptable to 90°
- Number of tracks = 2 tracks
- Road type = Access road
- Altitude railway = Ground level position
- Soil condition = Sand and soft soil

Combination #5

- Crossing type = Grade crossing
- Location = Countryside and semi-urban (two options, because it makes virtually no difference to the integration of the underpass in the area)
- Crossing angle = 90° (or adaptable to 90°)
- Number of tracks = 2 tracks
- Road type = Distributor road
- Altitude railway = Ground level position
- Soil condition = Sand and soft soil

4.4. CONCLUSIONS

Based on the results in this chapter the following conclusions can be drawn:

1. On the tracks of PHS still 28% of all the crossings are grade crossings. This is a total of 111 grade crossings.
2. In 47% of cases the crossings are underpasses.
3. The already constructed underpasses are located mainly in urban areas and are mostly designed for distributor roads.
4. In 29% of the situations with a grade crossings the design parameters are pretty much the same. That situation is a grade crossing in the countryside or in a semi-urban area, with a crossing angle of 90° or that is adaptable to an angle of 90°, where two tracks cross an access road and with the altitude of the railway at ground level position. This situation is, not coincidentally, already been shown in Figure 4.1. Another group of grade crossings, 24%, is similar to the first group with to only difference that the altitude of the railway is half in elevation. So two types of underpasses could potentially cover up 54% of all the grade crossings.
5. The group grade crossings that are most eligible to be converted to an underpass is the group that is most difficult to be standardized (urban area; distributor road). Similarly, there is a large group that is quite easy to fit into a standard design, where the demand for adaptation is less (countryside; access road). This raises the question: what degree of standardization is desirable? Combination #1 and #2 (54% of the grade crossings) give rise to a fully standardized design, while combination #3, #4, and #5, and all other combinations which are not shown (together 46% of the grade crossings) to give reason for making a partially standardized design with a certain degree of flexibility, a parametric design.

The results presented in this chapter give rise for an initial feedback on the research question, see §1.3. The fact that combination #1 and #2 potentially cover 54% of all the grade crossings, see §4.3, shows that a standardized design might be feasible for a substantial part of the new to built underpasses. The other 46% can be partly standardized, but the influence of the design parameters cannot be neglected completely. A parametric design can in many cases be a solution, but in some situation, mainly in urban areas, a custom design will be unavoidable.

5

Decomposition of underpasses

Although there is a set of design parameters (see §4.2) that limits the influence of the designer, there still remain a considerable amount of design choices that must be made per project. This chapter provides an inside to these design freedoms by decomposing an underpass. A method that is often used for decomposing is systems engineering.

5.1. General

Problem

The design of an underpass is not only determined by the design parameters, see Chapter 4, but also by a set of design choices that have to be made by the designer. In order to create a standardized design, these design freedoms will have to be taken away.

Question

Which design freedoms play a role in the design of an underpass and what considerations are made during the design process?

Purpose

The purpose of this chapter is to gather a clear understanding of the design freedoms that play a role in the design of an underpass, so these freedoms can be eliminated leaving a standardized design.

Method

The structure of the underpass will be decomposed, so that the design choices are clearly displayed. For each structural element the function and the design freedoms are examined. Think of shape, dimensions, construction methods and material properties. The parts are further decomposed into sub elements. This leads to an object tree.

5.2. Levels of decomposing

Design choices are made at different levels and in different phases of the design process. Four levels of specification are distinguished. Each level considers a number of components of the underpass. The function of each component and the design choices for each component are described.

- Level 1 – Analyses the total underpass. Design freedoms like the location and the road alignment are considered.
- Level 2 – The underpass is split into three parts: the rail crossing section, the open tunnel section and the pump room. The main dimension of these components are considered, like shape, length, width, etc.
- Level 3 – The three components from level 2 are again split into several parts, as for instance: deck, walls, floors, foundations, etc. Structural dimensions of these sub-elements are considered, like length, hight, thickness, etc.

- Level 4 – This is the most specific level. All the sub-elements from level 3 are further decomposed into for instance: concrete, reinforcement, aesthetic elements, etc. The following design freedoms are considered: materials properties, bar diameters, bar spacing, etc.

These four levels make it possible to decompose the underpass in a clear way, without forgetting any essential aspects and neither falling in to too much detail. Reference is made to Appendix C for the entire decomposition by levels.

5.3. LEVEL 1

JUSTIFICATION OF THE MANNER OF DECOMPOSING

In level 1 the entire underpass is considered. This can be justified because there are a few functions that are applicable to the entire underpass. Echoing thereon, there are also a number of design choices that have to be made, that apply to the entire tunnel. See Figure 5.1 for an exploded view of the underpass decomposition level 1. The cofferdam on the front side had been left out for visual purposes.

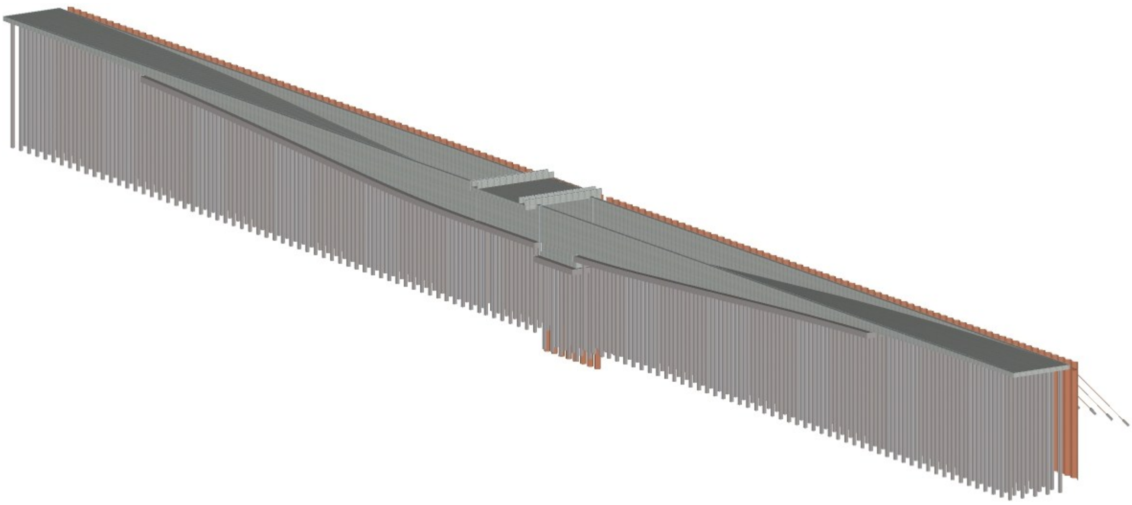


Figure 5.1: Decomposition underpass at level 1 (SketchUp)

TOTAL UNDERPASS

Function Creating the possibility for two traffic flows, namely that of the railway track en the road, to cross at different altitude levels.

Design choice(s) On this level the following needs to be determined:

- the location of the underpass;
- the horizontal alignment of the road and thereby the crossing angle;
- the vertical alignment of the road;
- the structure gauge and
- the construction method.

For the construction method it's considered to be likely that the most common option of the inserted deck will be used, see §2.2. This assumption is necessary for the further decomposition of the underpass.

5.4. LEVEL 2

JUSTIFICATION OF THE MANNER OF DECOMPOSING

In level 2 the underpass is divided into three parts: the rail crossing section, the open tunnels section and the pump room. This can be justified because each of these elements has is own separate function. Also the design choices that ought to be made hold for these separate elements, although some sub-elements, as the walls and floors, might have the same dimensions for the different components. See Figure 5.2 for an exploded view of the underpass decomposition level 2. The cofferdam on the front side had been left out for visual purposes.

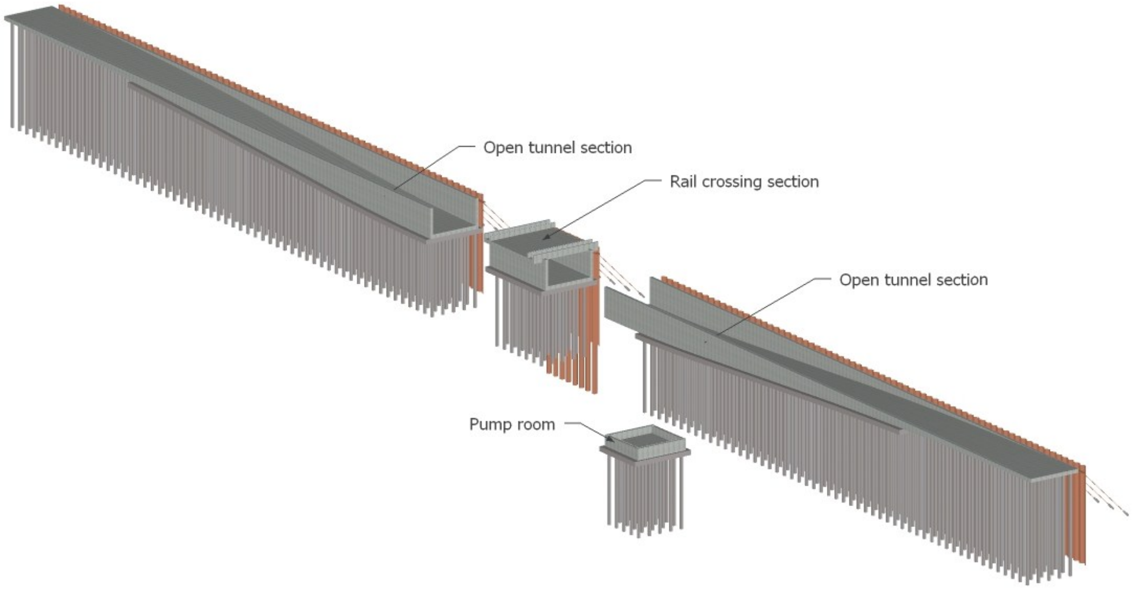


Figure 5.2: Decomposition underpass at level 2 (SketchUp)

RAIL CROSSING SECTION

Function Providing the possibility for the traffic to pass under the railway track and for the train to pass over the road.

Design choice(s) The following needs to be determined:

- the shape of the closed part, which follows from the road alignments;
- the length of the closed part, which follows from the dimensions of the deck;
- the hight of the closed part, which follows from the structure gauge and
- the width of the closed part of the underpass.

OPEN TUNNEL SECTION

Function The function of the open tunnel part is to provide the possibility for the vertical movement of the traffic over a certain distance so that it will fit under the railway track.

Design choice(s) The shape of the open tunnel section needs to be determined. This is based on the horizontal and vertical alignment of the road.

PUMP ROOM

Function Storing rainwater that falls down into the tunnel.

Design choice(s) Based on the area of the open tunnel section the required volume of the pump room can be calculated. Further design choices that need to be made are:

- the location of the pump room;
- the width of the pump room;
- the length of the pump room;
- the depth of the pump room and
- the location of the partition wall, which divides the pump room in separate compartments with a part for the storing of the rainwater, a part to filter sand and other dirt and a part for the installation of the actual pump.

5.5. LEVEL 3

JUSTIFICATION OF THE MANNER OF DECOMPOSING

Level 3 divides the element described in level 2 up into sub-elements. All these sub-elements, as the deck, the walls, the floor, etc. have again their own functions. The deck supports the train, the walls retain the horizontal forces from the soil, and so on. See Figure 5.3 for an exploded view of the underpass decomposition level 3. One of the open tunnel sections is turned 90° for visual purposes.

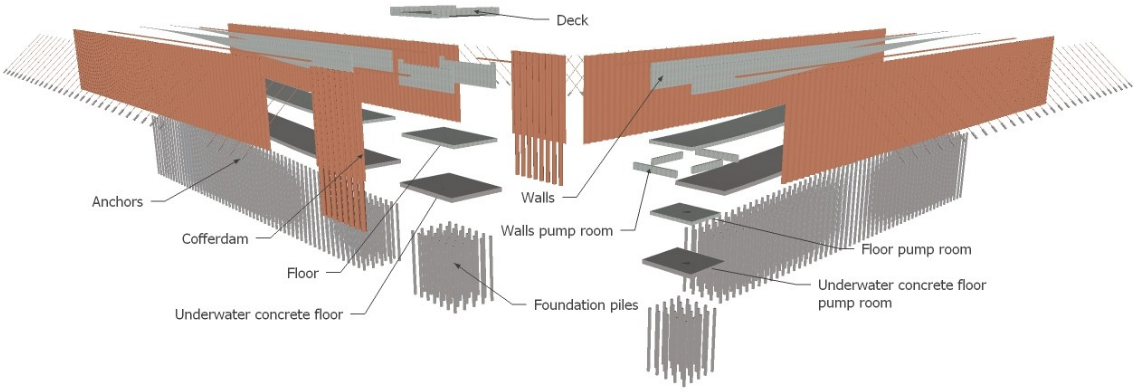


Figure 5.3: Exploded view of the underpass at decomposition level 3 (SketchUp)

DECK (RAIL CROSSING SECTION)

Function The main function of the deck is to offer structural support to the train when it runs over. It also provides space for cables and pipes and for rainwater drainage. On the edges there is room for the support of the skid plates. Finally, it offers mounting options for the overhead line.

Design choice(s) The following needs to be determined:

- the thickness of the deck;
- the width of the deck, including space for the railway track, cables and pipes, rainwater drainage and a safety area in case of an accident;
- the length of the deck;
- degree of chamfer at the longitudinal sides of the deck;
- recesses for the skid plates on the ends of the deck;
- mounting options for the fences, aesthetic elements (architect) and the overhead line and
- interface with the supporting walls, both temporary and permanent.

WALLS (RAIL CROSSING SECTION)

Function Provides structural support to the deck, retaining the horizontal forces from the soil and to create a watertight seal (in corporation with the floor). Further the walls have an aesthetic function. The shape, color and print of the walls can provided a certain identity and social security. Finally, it provides a safety barrier in case of an collision in the tunnel.

Design choice(s) A design choice that has a major influence on the entire underpass is weather or not an intermediate supporting wall is applied. This wall reduces the thickness of the deck and thereby the length of the entire underpass. If a partition wall is chosen the location of this wall should also be determined. Further, the following needs to be determined regarding the walls:

- the thickness of the walls;
- weather or not the walls will be build under a slope and if so under what angle;
- the hight and
- the length and thereby the location of the expansion joints.

WALLS CYCLISTS- AND PEDESTRIANS PATH (RAIL CROSSING SECTION)

Function The structure gauge for a cyclists- and pedestrians path is smaller than for the rest of the road. Therefore, this path is less steep. These walls function as a partition wall between the two traffics. It retains a filling of sand underneath the cyclists- and pedestrians path.

Design choice(s) The following needs to be determined:

- hight of the wall, which follows from the vertical alignment of the bicycle- and pedestrians path;
- shape of the wall;
- thickness of the wall and
- the location of the wall.

FLOOR (RAIL CROSSING SECTION)

Function Providing structural stability to the walls, creating a flat surface for the road structure, providing space for cables and pipes and for rainwater drainage. Also distributing forces equally over the foundation and creating a watertight seal (in corporation with the floor).

Design choice(s) The following need to be determined:

- thickness of the floor;
- width of the floor and
- distance between the expansion joints and thereby the length of the modes.

FOUNDATION (RAIL CROSSING SECTION)

Function Providing structural stability and controlling settlements in permanent phase. In some cases to prevent the tunnel from floating. During the construction phase, providing a dry building pit (in corporation with the cofferdam).

Design choice(s) The type of the foundation needs to be determined. Is a shallow foundation sufficient or should there be a pile foundation? And is there a layer of underwater concrete required? These choices have major consequences for the rest of the choices that ought to be made for the rest of the foundation. Therefor other design choices can't be distinguished at this stage.

TEMPORARY COFFERDAM (RAIL CROSSING SECTION)

Function To provide support to the deck during the construction phase and retaining the soil- and water pressure, also during the construction phase. It also has a guidance function, when the deck is slided into place during construction.

Design choice(s) The following needs to be determined:

- the distance between the permanent and temporary walls;
- the dimensions of the combi wall or sheet piles;
- the type of sliding rail on top of the cofferdam to be able to slide the deck into place;
- the sheet pile tip level;
- the structural dimensions of the girder and
- the structural dimensions and length of the anchors.

SKID PLATES (RAIL CROSSING SECTION)

Function Providing a smooth transition for the train between the relatively soft soil under the railway track and the relatively stiff concrete underpass.

Design choice(s) Skid plates are prefabricated concrete elements. They're standardized and produced in a factory. Which means that only the following needs to be determined:

- the type of skid plate (depending on the supplier);
- the dimension (also depending on the supplier) and
- the number of skid plates.

WALLS (OPEN TUNNEL SECTION)

Function The major difference between these walls and the walls described in §5.5 is that these walls don't need to support the deck. So the only functions are retaining the horizontal forces from the soil and to create a watertight seal. The aesthetic function and the function of the safety barrier are similar to that of the walls of the rail crossing section.

Design choice(s) Partition walls are not relevant for the open tunnel section. The following needs to be determined regarding the walls:

- the thickness of the walls;
- weather or not the walls will be build under a slope and if so, under what angle (this will be the same choice as for the rail crossing section and visa versa);
- the hight;
- the length and thereby the location of the expansion joints and
- the bearing system for the deck.

WALLS CYCLISTS- AND PEDESTRIANS PATH(OPEN TUNNEL SECTION)

The walls for the cyclists- and pedestrians path for the open tunnel section is similar the walls described in §5.5. The only diffence is that the hight in the open tunnel section differs over the length of the underpass.

TEMPORARY COFFERDAM (OPEN TUNNEL SECTION)

Function Retaining the soil- and water pressure during the construction phase and creating a watertight seal in corporation with the underwater concrete layer.

Design choice(s) The following needs to be determined:

- weather or not the cofferdam will be removed after construction;
- the distance between the permanent and temporary walls;
- the dimensions of the sheet piles;
- the sheet pile tip level;
- the structural dimensions of the girder and
- the structural dimensions and length of the anchors.

FLOOR (OPEN TUNNEL SECTION)

The floor for the open tunnel section may differ from the foundation of the rail crossing section. But it has the same functions and the same design choices are made as in §5.5.

FOUNDATION (OPEN TUNNEL SECTION)

The foundation for the open tunnel section may differ from the foundation of the rail crossing section. But it has the same functions and the same design choices are made as in §5.5.

SKID PLATES (OPEN TUNNEL SECTION)

Function Providing a smooth transition for the traffic between the relatively soft soil under the road and the relatively stiff concrete underpass.

Design choice(s) Skid plates are prefabricated concrete elements. They're standardized and produced in a factory. Which means that only the following needs to be determined:

- the type of skid plate (depending on the supplier);
- the dimension (also depending on the supplier) and
- the number of skid plates.

DECK (PUMP ROOM)

Function To support the traffic that runs over the pump room and to give stability to the walls of the pump room.

Design choice(s) The following need to be determined:

- the thickness of the deck (similar to the thickness of the floor of the tunnel) and
- location of openings for rainwater and possibilities for inspection.

WALLS (PUMP ROOM)

Function Retaining soil- and water pressure on the outside of the pump room and retaining rainwater on the inside of the pump room and creating a watertight seal.

Design choice(s) The only thing that needs to be determined is the thickness of the walls, which is usually the same as that of walls of tunnel.

PARTITION WALLS (PUMP ROOM)

Function Separate the different compartments inside the pump room, so sand and other dirt can be filtered and there is a dry area for the pump installation.

Design choice(s) The following needs to be determined:

- the location of these walls (follow from required volumes) and
- the thickness of the partition walls.

TEMPORARY COFFERDAM (PUMP ROOM)

Function Retaining the soil- and water pressure during the construction phase and creating a watertight seal in corporation with the underwater concrete layer.

Design choice(s) The following needs to be determined:

- weather or not the cofferdam will be removed after construction;
- the distance between the permanent and temporary walls;
- the dimensions of the sheet piles;
- the sheet pile tip level;
- the structural dimensions of the girder and
- the structural dimensions and length of the anchors.

FLOOR (PUMP ROOM)

Function To give structural stability to the walls of the pump room, to retain the water pressure on the bottom of the floor and to create a watertight seal (in corporation with the walls of the pump room).

Design choice(s) The only thing that needs to be determined is the thickness of the floor.

FOUNDATION (PUMP ROOM)

The foundation for the pump room may differ from the foundation of the rail crossing section. But it has the same functions and the same design choices are made as in §5.5.

PUMP INSTALLATION (PUMP ROOM)

Function Pumping the rainwater out of the underpass.

Design choice(s) The pump will be prefabricated in a factory. The only design choice that needs to be made is what the capacity of pump must be.

5.6. LEVEL 4

JUSTIFICATION OF THE MANNER OF DECOMPOSING

For Level 4 the sub-elements of Level 3 are again decomposed. This level contains the highest level of detail. It contains detailing of the reinforcement, the concrete mixture and concrete strength class, aesthetic elements, fences, piles, anchors, underwater concrete and so on. To keep the report readable descriptions thereof are contained in Appendix D.

5.7. CONCLUSIONS

For every component of the underpass design choices have to be made. To be able to come to a standardized design research should be done to find out weather it's feasible to eliminate these design freedoms. This will be tested in Chapter 6.

6

Feasibility of standardization and the development of a prototype

In this chapter a feasibility study is performed on the standardization of an underpass. For each design level described in Chapter 5 research is done on how to eliminate the design freedoms. By doing this structurally a prototype is developed. Finally conclusions are drawn and recommendations are given.

6.1. General

Definition

Feasibility: "*the possibility that can be made, done, achieved, or is reasonable*" [1]. A distinction must be made between technical feasibility and financial feasibility. It is technically feasible to standardize a component when it fulfills the demands of all the different situations without changing any of its technical characteristics. Financial feasibility is reached when the profit, which is made by reducing the engineering costs and by the repetition of the construction process, compensates the extra costs, that are caused by over-dimensioning some components.

Only the technical feasibility will be investigated. The financial feasibility is out of the scope of this thesis, but further research should be done on this part.

Problem/Purpose

The problem and the purpose are similar to those described in §5.1.

Question

Is it technically feasible to standardize the different components of an underpass as described in Chapter 5 and is it thereby possible to create a standardized prototype of the entire underpass? If so, how would this prototype look like? If a component cannot be standardized what's the influence of changing it dimension on the rest of the structure?

Method

The following steps are taken to answer the sub-question set in this section:

1. A component is taken from Chapter 5.
2. The functions of the component and different situations form a spectrum of demands.
3. Alternatives are created for this component.
4. Based on the criteria (see 6.2) the best alternative is chosen.
5. Conclusions are drawn on weather or not it's feasible to standardize this component.
6. If it is not feasible to standardize the influence of this component on the rest of the structure is analyzed.
7. This will be done for each individual component, after which they combined to one prototype (if possible).
8. Conclusions are drawn on the feasibility of standardizing of the underpass.

6.2. CRITERIA

Criteria are used to select the most suitable alternative for each and every element. A list of more than a dozen criteria could be selected, after which they are used in a multi criteria analysis, but this might be to complex. Therefore, only the two most important criteria are used: the applicability and the cost.

APPLICABILITY

Applicability is defined as the matter of application of an individual component on the different situation that occur due to the different locations. To make the chances on success for the standardized design as large as possible it is important that it can be applied at as many locations as possible.

COSTS

Costs are defined of the total costs of a component: design- and engineering costs, construction costs, maintenance costs, overhead costs, etc. Next to the applicability, costs are the most important criteria. After all it is the intension to create a standardized design that is a cheaper alternative. However, costs analysis are out of the scope of this thesis. Therefor, the costs are only considered qualitatively.

6.3. LEVEL 1

ENTIRE UNDERPASS

LOCATION

Standardizing the location of the underpass is by definition not possible. The different locations and the variety of the surrounding area is the essence of the problem. However, when the exact location of an underpass has to be determined and multiple options are considered, having a standardized tunnel might help in selecting the optimum location.

ALIGNMENT AND CROSS SECTION

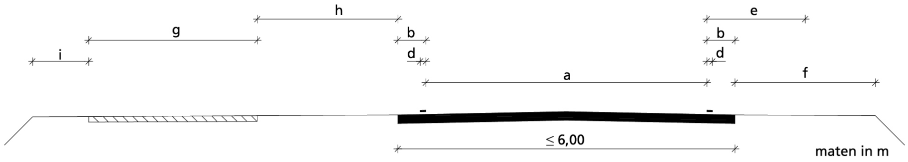
The horizontal- and vertical alignment and the cross section the road that crosses the tunnel is one of the most important features in the process of designing a standardized underpass. Because, when this feature can be standardized the shape is of the tunnel is also pretty much standardized. There are however some difficulties that affect the feasibility of standardizing this part. These problems are listed below and possible solutions are explored in the paragraphs that follow.

1. Variable road width.
2. Variable speed on the road, $60km/h$ and $30km/h$.
3. Variable altitudes of the road and railway.
4. The possibility of roads parallel to the railway track.

Variable road width The inventory set up in Chapter 4 shows that there is a lot of variety in the width of the different access roads, which a minimum width of $4.0m$ in the countryside and a maximum width around $20.0m$ in some urban areas. Now are widths of $20,0m$ exceptions, but there should be a certain margin should be taken into account. The idea is to determine the width based upon the recommendations of the CROW[1] for an access road type 1. It's important to make sure the width is as small as possible, because the influence on the rest of the tunnel is significant. A larger road width leads to obviously to a tunnel with a larger width, but also to a thicker deck. This leads to a deeper and a longer tunnel, where the forces due to water and soil increase, so the thickness of the walls and floor increase as well. Based on Figure 6.1 a suggestion is given for a cross section.

Clearance The clearance is based on the recommendations of the CROW. Although exceptions are possible, the clearance is mostly determined in the following manner:
For cyclists and pedestrians another clearance applies.
In Figure 6.2 the clearance in both the vertical as the horizontal direction are shown graphically.

[1] Dutch knowledge platform for infrastructure and public space



	ideaal	gebruikelijk	minimaal
a rijloper	4,50	3,50	3,50
b kant- of uitwijkstrook	0,50	0,50	0,35
d markering	0,10	0,10	0,10
e obstakelvrije zone	3)	1,50	1,50
f buitenberm	3)	2,50	1,50
g fietspad, eenzijdig in twee richtingen bereden	4,00	2,50	1,50 2)
h tussenberm	3)	2,50	1,50
i buitenberm/obstakelvrije zone	3)	1,00	0,50

minimum wijkt af van ontwerpwijzer fietsverkeer
geen grenswaarde aan ideaal, wel groter dan 'gebruikelijk'

Figure 6.1: Cross section according to CROW (in Dutch) [18]

Driving strip	$4.50m$
Edge strip	$2 \times 0.50m$
Bicycle path	$2.50m$
Sidewalk (not specified by CROW)	$1.50m$
Partition wall (estimation)	$0.50m$
Total width w_{tunnel}	$10.00m$

Design height vehicle	$4.00m$
Vertical movements	$0.25m$
Vertical object distance	$0.25m$
Asphalt layer	$0.10m$
Reservation (future asphalt layer)	$0.10m$
Total clearance	$4.70m$

Design height cyclist	$1.75m$
Margin	$0.75m$
Asphalt layer	$0.10m$
Reservation (future asphalt layer)	$0.10m$
Total clearance	$2.70m$

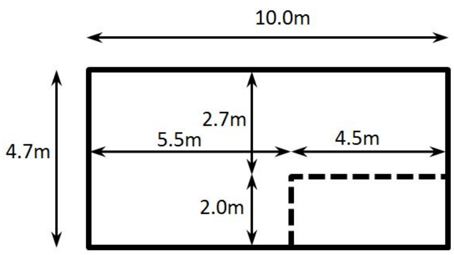


Figure 6.2: Clearance in both directions

Variable speed Combination #1, described in §4.3, contains both roads in the countryside as in a semi-urban area. The majority of these roads will have a maximum speed of $60km/h$, but some of them have a maximum speed of $30km/h$. The question is whether is feasible to use the design for a road with a maximum of $60km/h$ on road with a maximum of $30km/h$. Different design rules hold for different speeds. In Tabel 6.1

the rules that apply to the design of the vertical alignment are shown.[18]

	Minimum upward curve	Minimum downward curve	Maximum slope
Access road 60km/h	550m	1250m	6%
Access road 30km/h	35m	185m	7%

Table 6.1: Design rules vertical alignment access roads

The principles of the vertical alignment of the open tunnel section are shown in Figure 6.3. In Appendix E the minimum length for a tunnel of road of 30km/h is compared with a that of a road of 60km/h. Minimum curvatures and maximum slope are used, because this results in the shortest tunnel, which give maximum applicability. A transitional height of 6.0m is assumed to be reasonable. The result is that required length of the open tunnel section for a 60km/h road is 65% higher than for a 30km/h road. This is such a difference that the conclusion can be drawn that it is not feasible to use the alignment of the 60km/h road on a 30km/h road.

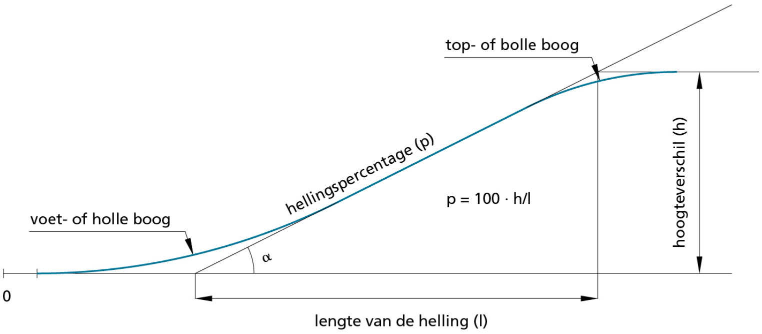


Figure 6.3: Vertical alignment according to CROW (in Dutch) [18]

Variable altitudes In an ideal situation the level of the top of the rail in relation to the level of the road on both sides of the track would always be the same. However, this will never be the case. So a solution must be found to guarantee the applicability of the underpass. In Figure 6.4 the problem and the possible solutions are shown. There are two ideas to create maximum applicability with minimum adjustments on the standard design. The first idea is to raise the walls on top of the deck, so variations in the altitude of the track can be compensated by thickening the gravel layer or applying an extra layer of lightweight concrete. Another solution is to adjust level of the connecting road, but this might cause problems in the surrounding area.

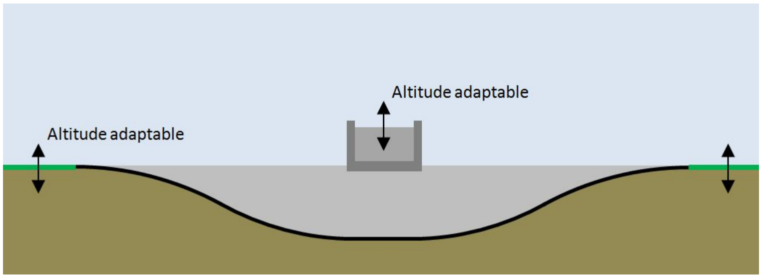


Figure 6.4: Adaptable altitudes

Parallel roads To increase the applicability of the underpass it will be profitable the include the option of adding a bridge for a road parallel to the tunnel. For instance in the situation show in Figure 4.1 it is desirable to create a bridge for the parallel road so a situation is obtained as shown in Figure 6.5.

Horizontal alignment Since one of the assumptions regarding the alignment is that there are no horizontal curves, the horizontal alignment will consist of a simple straight line, which crosses the railway track at an angle of 90°.

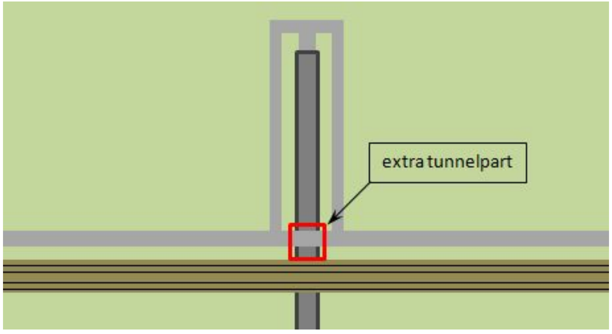


Figure 6.5: Situation with continues parallel road (schematic)

Standardization by parts A solution to overcome the problems of a variable speed and the parallel roads can be a standardization by parts. Which means that not the entire underpass is standardized, but just parts of it. Parts that can be linked together, creating a set of combinations that raises the applicability of the standardized underpass. In Figure 6.6 a graphical impression is given of the separate parts. It contains a rail crossing section, two open tunnel parts ($60 km/h$ and $30 km/h$) and an optional tunnel part for a parallel road, which can be placed on both sides of the rail crossing section. The dimension of the walls, the floors and the decks are not determined in this image, they're just based on reasonable assumptions to create a credible sketch.

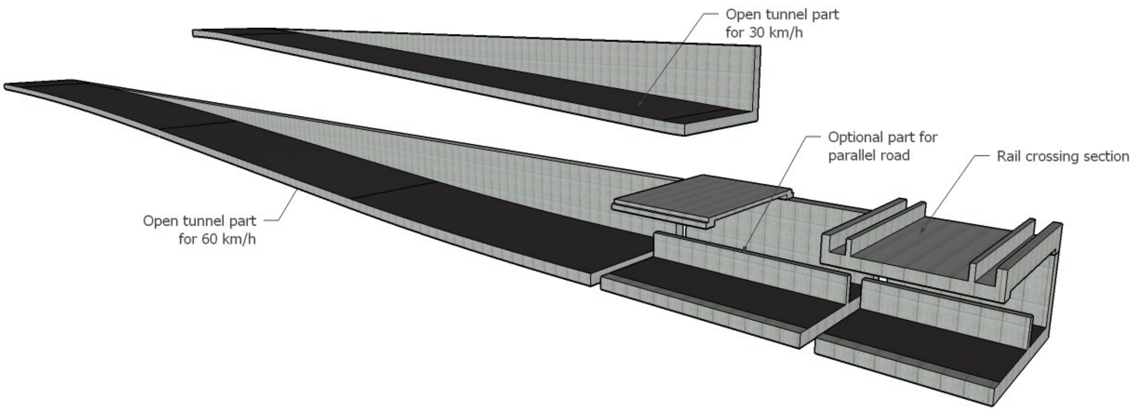


Figure 6.6: Impression of standardization by parts (SketchUp)

6.4. LEVEL 2

RAIL CROSSING SECTION

According to §5.4 the following design choices should be made for the rail crossing section: the shape, the length, the width and the height. The shape and the width have been standardized in §6.3. The height will follow from the hight of the deck, which is not standardized at this point and the length will follow from the width of the deck, which is also not standardized jet.

OPEN TUNNEL SECTION

The same holds for the open tunnel section as does for the rail crossing section, namely that the conclusions can only be drawn after it's clear whether or not the components in level 3 and 4 can be standardized.

OPTIONAL PART FOR PARALLEL ROADS

Standardization of this particular part is not further examined, but it is assumed that when standardization of the rail crossing section and the open tunnel part is feasible, standardization of this part will also be feasible.

PUMP ROOM

MAIN DIMENSIONS (LENGTH, WIDTH AND DEPTH)

The main dimensions of the pump room are depending on three factors:

1. The rainfall in a certain period of time.
2. The total surface area of the underpass.
3. The capacity of the pump.

All the factors are variable and have thereby influence on the standardization process.

Rainfall According the KNMI[2] the are regional differences regarding the amount of rain that can fall in a certain period of time, see Figure 6.7. With probability of ones in a hundred years holds: $73mm/m^2/24h$ for area L and $90mm/m^2/24h$ for area H+. The are no regional differences for periods shorter than $24h$. The rainfall for these periods is shown in Table 6.2.[19]

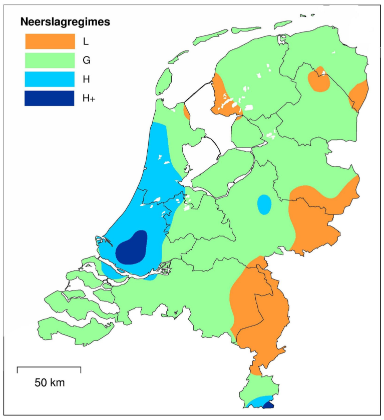


Figure 6.7: Rainfall regimes in The Netherlands (L = low; H+ = high)[19]

Rainfall $[mm/m^2]$	Period of time [var.]
17	$5min$
29	$15min$
37	$30min$
43	$1h$
48	$2h$
55	$4h$
59	$6h$
62	$8h$
68	$12h$

Table 6.2: Rainfall in The Netherlands for periods shorter than $24h$

Surface area of the underpass The surface area of the underpass is defined by the width of the underpass times the total length. The width is standardized, see §6.3. The only variable is the length of the underpass, which varies when the maximum speed on the crossing road varies and/or when the an extra bridge for a parallel road is integrated in the underpass.

Pump capacity The pump capacity can vary. However, this variation is controlled by the designers. In theory, if the capacity of the pump would be large enough, a buffer space to store rainwater wouldn't be necessary at all. On the other hand, when the smallest pump possible is installed, the buffer space will be absurdly large.

[2] EN: Royal Netherlands Meteorological Institute

Suggested solutions Two solutions are given to deal with the variation in rainfall, surface area and pump capacity.

1. The volume of the pomp room will be standardized for every situation, the capacity of the pump is adjusted to the amount rainfall and the surface area underpass.

2. The maximum amount of rainfall is held as normative, the same pump is used for every underpass and the volume of the pump is adjusted based on the surface area of the tunnel.

LOCATION

Since water flows downwards, the pump room must be situated at the lowest part of the underpass. This means that it will be either coupled to the rail crossing section or to the lowest point of the open tunnel section. It's seams convenient to attach the pump room to the open tunnel section for two reasons:

1. The dimensions of the pump room depend on the total area of the tunnel. The variation in this surface area is mostly due to the change of the open tunnel section ($30km/h$ or $60km/h$). Therefor, it makes sense to connect the pump room to the open tunnel section. So there is a standardized pump room for each open tunnel part option.

2. Building the pump room under the rail crossing section gives extra difficulties during construction, because one has to dig deeper in an area where it is desirable to have as little activities as possible. This is another reason why is better to place the pump room under the open tunnel section.

In Figure 6.8 an impression is given of how the pump room situated under the open tunnel section might look like.

N.B.: It was found out later that the installation room is often on the outside of the underpass, so it's easier to replace the pumps.

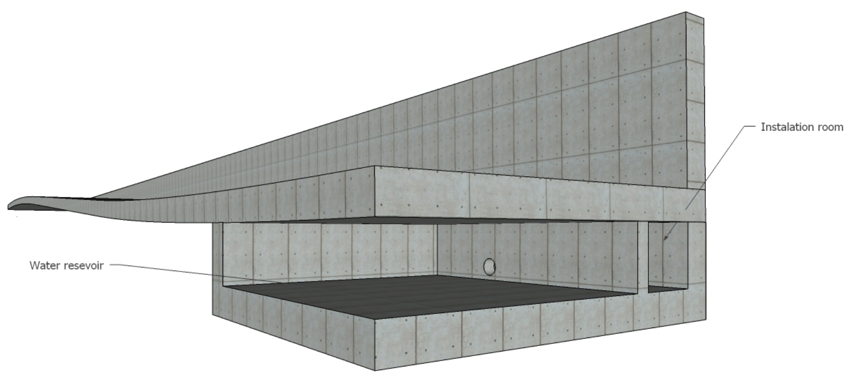


Figure 6.8: Impression of pump room (SketchUp)

Another option can be to decouple the pump room from the tunnel and build it next to it. In that way a universal pump room can be designed, which fulfill the requirements of all the possible situations. In that way it might even be possible to prefabricate it.

6.5. LEVEL 3

Level 3 consists of components with a relatively high degree of detail, which results into a large set components. To reduce the amount of work, only the components of the rail crossing section are considered in the feasibility analysis. Except for the deck, the open tunnel section consists of the same features as the rail crossing section. The dimensions of for instance the walls and the floor may differ for the different sections, but the conclusions regarding technical feasibility are considered to be similar for both situations.

DECK (RAIL CROSSING SECTION)

LENGTH DECK

The length of the deck depends on three factors.

1. The width of the crossing road, which is standardized, see §6.3 at page 26.
2. The slope of the walls of the underpass, which is standardized at an angle of 90°, see §6.5 at page 35.
3. The thickness of the walls is standardized at 0.60m, see §6.5 at page 36.
4. The distance between the permanent walls and the temporary walls, which is estimated at this point.
5. The thickness of the cofferdam, which is estimated at this point.

Suggested solution Based on the dimensions referred to in the enumeration above the following length of the deck is suggested as the solution for the prototype:

Horizontal clearance	10.00m
Thickness of the walls	$2 \times 0.60m$
Spacing between permanent and temporary walls	$2 \times 1.00m$
Thickness of the cofferdam	$2 \times 1.00m$
Total length of the deck (l_{deck})	13.20m

WIDTH DECK

The horizontal clearance of the railway track is the main factor of influence on the width of the deck and this clearance may change under different circumstances. Further needs to be dealt with space for cables and pipes.

Clearance railway track The clearance of the railway track is based on the requirements of OVS[3], see Figure 6.9. It implicates a minimum clearance of 11.00m in case there is no curvature in the horizontal alignment of the railway track.

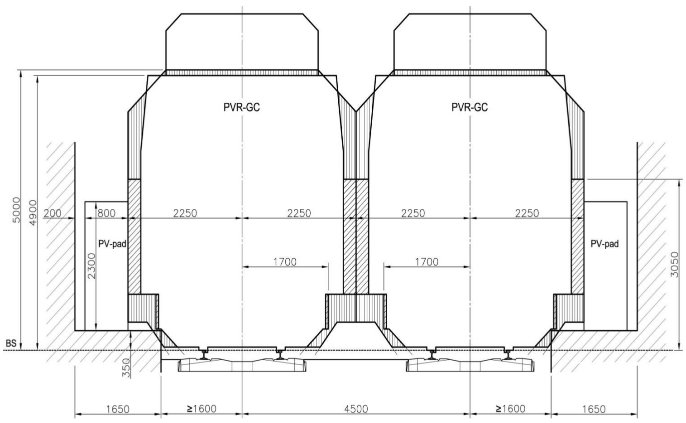


Figure 6.9: Clearance railway track[20]

However, if there is curvature in the horizontal alignment, the clearance increases. According to the OVS the extra clearance for a radius of 100m is 1.10m. On top of that there is the extra clearance due to the deck that will be straight and the alignment if it's curved. This is illustrated in Figure 6.10.
This gives a total clearance of 12.42m for the railway track, which should be applicable to most of the crossings with two tracks.

Cables and pipes Cables and pipes are parallel to the railway track. The deck provides space on both sides of the track for these cables and pipes. It's not always clear what cables and pipes exactly in ground. To

[3] NL: Ontwerpvoorschift spoorwegen; EN: Design rules railways

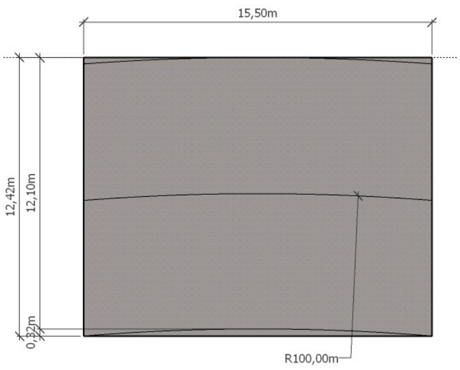


Figure 6.10: Extra clearance due to curvature of the horizontal alignment (SketchUp)

guarantee applicability the cable duct should be kept reasonably spacious. The influence on the rest of the underpass is nil. Based on the designs that are already made by Movares a spacing of $1.50m$ on each side will do.[21]

Walls on the deck For the walls on top of the deck the same existing design are used. Resulting in an outer wall with a thickness of $0.45m$ and an inner wall thickness of $0.30m$. The loads on these walls are similar for all the different situation, which makes it possible to standardize them.[21]

Suggested solution Based on the previous paragraphs a solutions as shown in Figure 6.11 is suggested for the prototype.

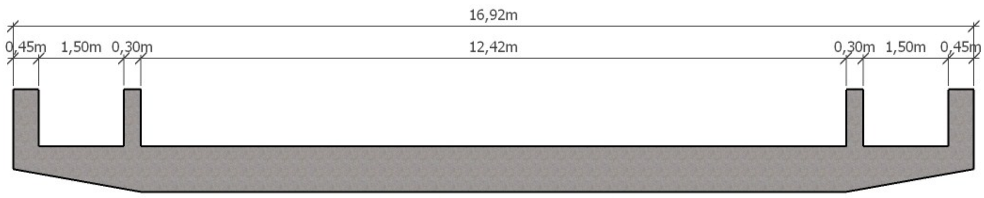


Figure 6.11: Layout and width of the deck (SketchUp)

THICKNESS DECK

The thickness of the deck depends on a number of influence factors that follow from the rest of the structure and a number of freedoms that need to be determined by the designer.

1. The length of the deck, which is standardized, see §6.5 at page 32.
2. The load on the deck.
3. Reinforced or prestressed concrete.
4. Concrete strength class.

Load on the deck The loads follow from the requirements set out in the NEN-EN and the OVS. The normative loads are standardized by definition and thereby the same for every underpass.

Reinforced or prestressed concrete To use prestressing in the deck is a designers choice. In 2006 an article was published in the German magazine *Beton- und Stahlbetonbau* about a research on the slenderness of reinforced and prestressed structures. The results showed that for railway bridges the slenderness of the reinforced deck is similar to the prestressed deck, both between 20 and 25. On highway bridges there is a difference between the two, but that aside.[22]

Concrete strength class (Level 4) The options for the concrete strength class reach from C12/15 to C50/60 for conventional concrete and even up to C90/105 for high strength concrete or even higher for ultra high strength concrete. A higher strength class might reduce the thickness of the deck and thereby the depth and length of the tunnel, but it's still hard to apply high strength concrete for a structure that's casted in situ. The benefits regarding the construction height by using a higher strength class are quite little for a deck with a small span. This is show in Figure 6.12, where the construction height is plotted as a function of the concrete strength class.

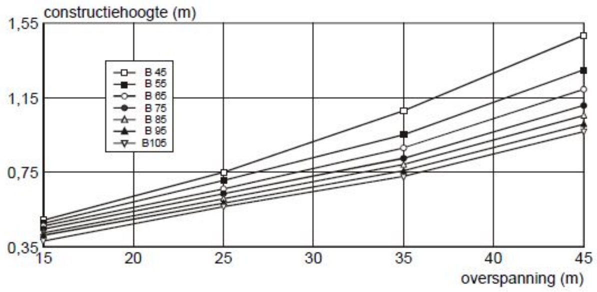


Figure 6.12: Structural height as function of the concrete strenght class for prestressed plate bridges (NL) [23]

Suggested solution Without making any structural calculation the thickness of the deck can be determined. The upper boundary of the rule of thumb published in in the article in the magazine *Beton- und Stahlbeton-bau* will be used, which lead the following dimensions of the thickness of the deck. Thickness of the deck will be approximately $t_{deck} \approx \frac{1}{20} \times 13.2 \approx 0.75m$. A concrete strength of C35/45 is suggested because the span of the structure is relatively small and the benefits of a higher strength class would probably not compensate the extra costs, see Figure 6.12. Because the length of the deck standardized, see §6.5, it's feasible to standardize the thickness and the concrete strength class of the deck.

DEGREE OF CHAMFER AT LONGITUDINAL SIDES DECK

It's common to chamfer the longitudinal sides of the deck, because it makes the structure look more slender and it saves a bit material. What's often seen is that the deck under the duct for cables and pipes is being chamfered. The thickness is reduced to 50% of the original thickness of the deck over a constant slope. An impression is given in Figure 6.11.

CONSOLES SKID PLATES

Because the width and the thickness of the deck are standardized, see §6.5 and §6.5, and the skid plates themselves can be standardized, see §**??**, the consoles for the skid plates can be standardized as well. Without giving any dimensions, the principle of the console is shown Figure 6.13.

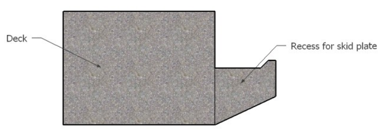


Figure 6.13: Impression console for skid plates (SketchUp)

MOUNTING OPTIONS: FENCES, AESTHETIC ELEMENTS AND OVERHEAD LINE

Since the length and the width of deck are standardized, see §6.5 at page 32 and 32, the mounting options for fences, aesthetic elements and the overhead line can be standardized as well.

Fences and aesthetic elements (Level 4) Up until now, the role of the architect was ignored in the process of standardization. In order to allow the architect to give a certain identity to the underpass, fences and aesthetic elements can be designed by the architect. However, this must still be done within the boundaries of the standardized design. This means that the fences and aesthetic elements may differ in appearance, but they all must be able to be mounted in a similar way. One could compare it with adding an optional spoiler to a car. A suggestion for such an element and the fence is shown in Figure 6.14.

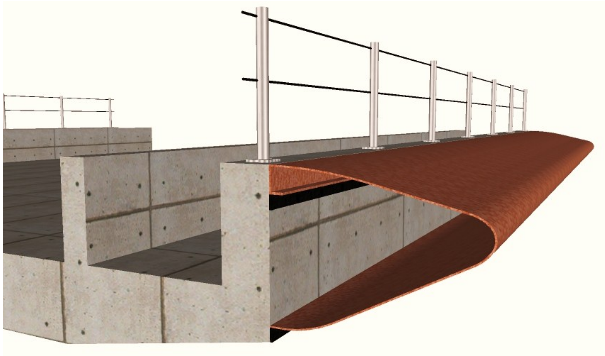


Figure 6.14: Impression fences and aesthetic elements (SketchUp)

INTERFACE SUPPORTING WALLS (TEMPORARY AND PERMANENT)

The deck can either be monolithic connected or freely connected to the supporting walls. In this case, where the underpass is also a tunnel, it's common to use a monolithic connection. The advantages are that this connection insures a water- and soil tight seal and the deck can absorb the horizontal forces. Another reason why a monolithic connection is used is that the deck is places in position before the walls are constructed. When the walls are cast it's easiest to connect them directly to the deck.

WALLS (RAIL CROSSING SECTION)

SLOPE OF THE WALLS

Building the walls under a slope or not is designers choice and doesn't depend on any variables. The are two reasons for a designer chose a slope.

1. Increasing social security.
2. Create better vision when the road bends.

In Figure 6.15 the difference between straight walls and walls under a slope is visualized.

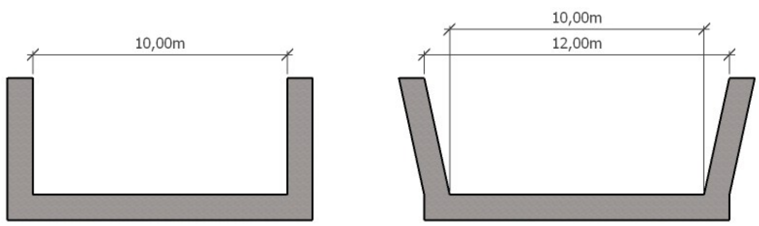


Figure 6.15: Cross-section tunnel straight walls(left) and walls under a slope(right) (SketchUp)

Social security There has been a lot of discussion on whether or not the social security increases when the walls are build under a slope. The idea is that sloped walls let more light into the tunnel and also create the illusion of a possible escape route. But still it's the illusion of safety, rather than safety itself. The solution costs more, because the it's more difficult to construct and it is more difficult to integrate the underpass into the surrounding area, simply because it uses a larger area. The are engineers who say that if a larger area is used, the walls might as well be straight, because that increases the width of the tunnel and thereby the security.

Better vision Since the horizontal alignment of the prototype solution consists of only a straight line (see §6.3) the argument of better vision does no longer hold.

Suggested solution Based on the criteria set in §6.2 a solution is suggested with straight walls and the original width. In that way the highest applicability and the lowest costs are found.

HEIGHT WALLS

The height of the walls directly follow from the vertical alignment and the clearance, see §6.3, and can thereby be standardized. The height of the walls $h_{wall} = 4.70m$.

THICKNESS WALLS

The thickness of the walls is based on the shear resistance at the lowest part of the wall. Knowing the this, there are three important factors that play a role in the determination of the thickness of the walls.

1. Groundwater level.
2. Concrete strength class.
3. Application of shear reinforcement.

Structural calculation In order to find the effect of the horizontal forces and the concrete strength class on the thickness of the walls, structural calculations are made. The document with these calculations can be found in Appendix F. A schematization as shown in Figure 6.16 with a as a parameter for the groundwater level is used the calculate the horizontal forces.

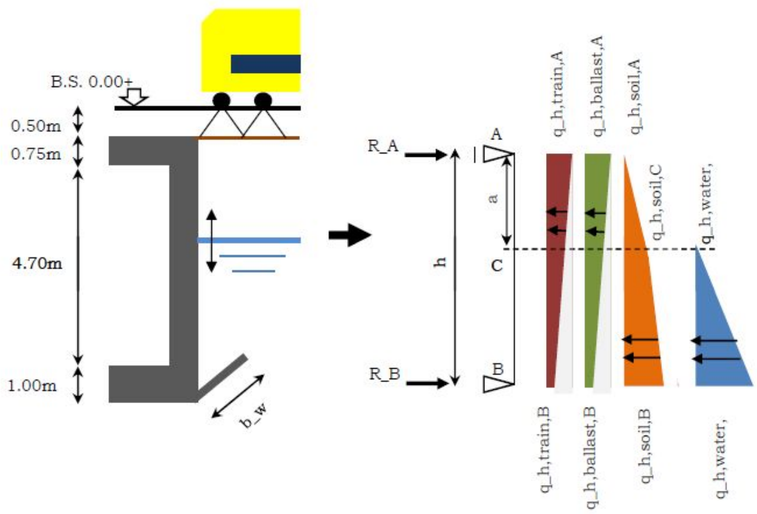


Figure 6.16: Schamatization of loads on the wall with a as a parameter (MS Excel).

N.B.: Forces due to breaking and acceleration have not been taken into account.

The results of the calculation are shown in Figure 6.17, with the groundwater level a on the horizontal axes and the minimum required thickness of the wall t_{wall} on the vertical axes. The functions are plotted for a set of concrete strength classes.

Variable groundwater level *The* biggest challenge in the standardization process of the underpass is dealing with variable groundwater level. The results plotted in Figure 6.17 prove this. The required thickness increases with 36% (for all concrete strength classes) as the groundwater level rises from the bottom to top of the wall. Technical feasibility can be fulfilled, simply by using the upper bound value for the thickness of the wall. Research should be done to the financial feasibility of using this upper bound value. The thickness of the wall won't have influence on the dimensions of other parts of the underpass.

Concrete strength class (Level 4) A higher concrete class leads to a more slender structure, see Figure 6.17. In the previous paragraph was stated the thickness of wall has no influence on the dimension of the rest of the underpass, but the concrete strength class for the walls will be the same as for the floor.

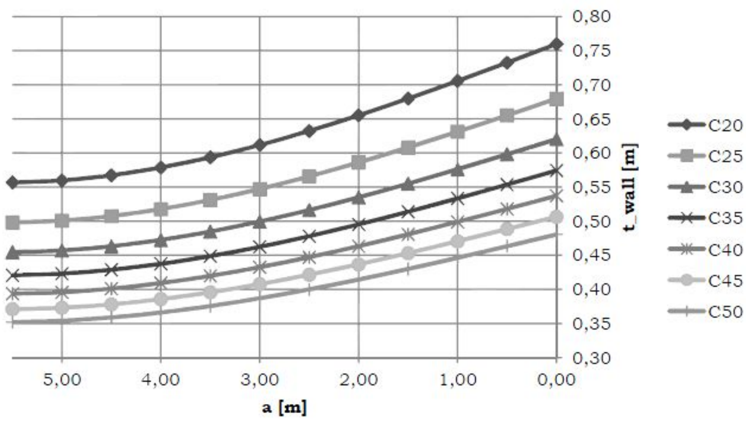


Figure 6.17: Thickness of the walls in relation to the groundwater level a and the concrete strength class f_{ck}

Shear reinforcement (Level 4) The application of shear reinforcement will reduce the thickness of the walls. However, the application of shear reinforcement costs a lot of labor and time. Another problem with shear reinforcement in walls is the risk on leakage. Water may flow parallel to the shear reinforcement and with 6.00m of water pressure on the wall, the smallest crack in the cover layer could to lead to a fountain in the tunnel wall.

Suggested solution A concrete strength class of C35/45 is suggested, because it's common to use that strength class for in situ casted concrete. A wall thickness of 0.60m is suggested for this strength class. This leads to a wall that is applicable in every situation, but that might be over dimensioned in some situations.

LENGTH WALLS AND LOCATION EXPANSION JOINTS

Because of imposed deformations expansion joints must be applied. It's common to apply such a joint every 20m to 25m. The concept of standardization by parts (see §6.3) makes is logical to apply expansion joint at the beginning and end of the rail crossing sections. With a width of the deck of 16.92m and an extra meter on each side, a length of 19m seems logical.

WALL CYCLISTS- AND PEDESTRIANS PATH (RAIL CROSSING SECTION)

HEIGHT WALL

The height of the walls follow from Figure 6.2, see §6.3. It depends only on the clearance and since the clearance is standardized, the height of the wall for the cyclists- and pedestrians path, might as well be standardized.

Suggested solution The suggested height for this wall $h_{wall,cycl} = 2.00m$.

THICKNESS WALL

The thickness of the wall depends on the horizontal loading. Since the vertical load on the cyclists- and pedestrians path will be the same for every situation and a variable groundwater level won't be of influence on the internal wall, the only variable left is the height of the wall, which was standardized in §6.5 at page 37. Also in case of a collision the load on the wall will be similar for all situations.

Suggested solution Without making any calculation the thickness of this wall $t_{wall,cylc}$ is determined at 0.50m. This is based on previous build underpasses.[13]

LOCATION WALL

The location of the wall follows, just like the height of the wall, from Figure 6.2, see §6.3. The location of this wall can be standardized for the same reasoning. This being said, there is also the options of placing the internal wall on the other side, mirroring the entire underpass.

Suggested solution The space between the outer tunnel wall and the wall for the cyclists- and pedestrians path must be 5.50m.

FOUNDATION (RAIL CROSSING SECTION)

FOUNDATION TYPE

The determination of the foundation type depends, next to the load/weight that follows from the structure, on two critical variables.

1. Groundwater level.
2. Soil condition.

Groundwater level When the groundwater level is high and the upward force under the underpass is larger than the downward force from the structure the tunnel will start to float. An underwater concrete floor in combination with piles or anchors can be applied in order to prevent this. However, both the costs and risks are high for the construction of such a floor. This means that it cannot be stated that the underwater concrete floor must be applied for all the underpasses, just to fulfill the applicability criterion. A contractor will always adjust the design if it's not absolutely necessary to apply underwater concrete. Therefor the critical groundwater level $a_{critical}$ is examined, see Appendix G and Figure 6.18. Calculations show that when $a_{critical} < 4.43m$ an underwater concrete floor is required. This number may change when the thickness of the floor and the deck are optimized.

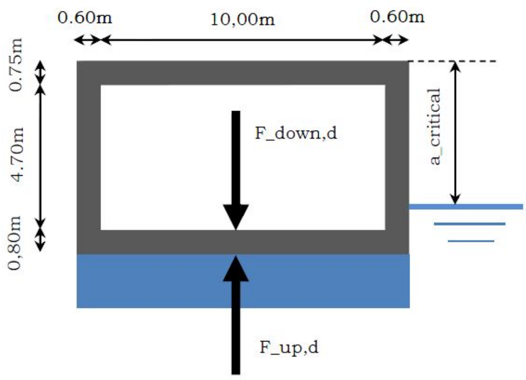


Figure 6.18: Critical groundwater level $a_{critical}$

But there are more situations in which an underwater concrete floor is unavoidable. Whenever the groundwater level is above the lowest part of the tunnel and dewatering is not allowed, an underwater concrete floor must be applied in order to create a dry building pit. Regulations for dewatering vary by location.

Soil condition Next to the variable groundwater level, the variable soil condition is the biggest problem in the standardization process of the underpass. In Chapter 4, an attempt was made to distinguish sand and soft soil for each underpass, but even then it is hard to say if the soil will be stiff enough for a shallow foundation or to determine what the pile tip level should be.

Suggested solutions Based on the previous two paragraph the conclusion can be drawn that is *not* feasible to standardize the foundation of the underpass in a way that the applicability criterion can be met. It's nonsense to apply an underwater concrete floor if that ain't required. Even so, a pile foundation is to be avoided when a shallow foundation suffices. And if a pile foundation is required, the pile tip level will be different for each and every underpass (if not, it will be just a coincidence). Therefor, an alternative solution must be found, that ensure applicability without influencing the rest of the structure. In Figure 6.25 a set of four solutions is presented. The solutions follow from the problem sketched in the previous two paragraph and coop with the variable groundwater level and soil condition. The itemization below shows for each solution the conditions that apply to them and the part that needs to be customized for every location.

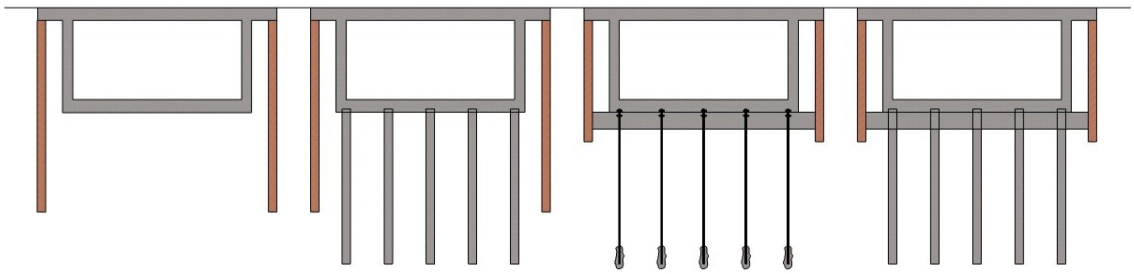


Figure 6.19: From left to right: shallow foundation; pile foundation; underwater concrete + anchors; underwater concrete + piles. (SketchUp)

1. Shallow foundation
   Low groundwater level ($a \geq a_{critical}$)
   Stiff or stiffened soil
2. Pile foundation
   Low groundwater level ($a \geq a_{critical}$)
   Soft soil
   Pile tip level custom to each situation
3. Underwater concrete + anchors
   High groundwater level ($a < a_{critical}$)
   Soft soil
   Only upward forces
   Layer for anchor is very is deep in the soil
   Anchor tip level and thickness underwater concrete floor custom to each situation
4. Underwater concrete + piles
   High groundwater level ($a < a_{critical}$)
   Soft soil
   Both upward and downward forces
   Pile tip level and thickness underwater concrete floor custom to each situation

N.B.: An essential remark is that the center-to-center distance of the piles and anchors must be the same in both directions in order to make it possible create a floor that can be standardized. Further will these different solutions all lead to different forces on the floor of the underpass. Whether or not the floor can be designed in such a way that is applicable for all the different foundations will be examined in the section that addresses the floor of the rail crossing section.

Temporary cofferdam (Rail crossing section)

Dimensions cofferdam

The dimensions of the cofferdam for the rail crossing section depend on four factors of influence.

1. Foundation type.
2. Vertical load from the deck.
3. Soil condition and groundwater level.

Foundation type In the previous section four solutions were determined for the foundation. The different foundation types will have their effect on the dimensions of the cofferdam. The use of an underwater concrete floor

Vertical load During construction the deck is supported by the temporary cofferdam. Since the deck has been standardized, see §6.5 on page 33, the vertical load will be identical for every situation.

Soil condition and groundwater level The soil condition and the groundwater level are variable. The remarks that are made in §6.5 at page 38 hold here as well.

Suggested solution It's not technically feasible to standardize the temporary cofferdam. Both the depth of the sheet pile tip level as the structural dimension vary to much to suggested a standardized solution. Therefor, a parametric solution is required. The input and output parameters for the design of the temporary cofferdam are shown in Table 6.3.

Input parameters	Output results
Foundation type (static schematization)	Cofferdam type (combi wall or sheet piles)
Soil condition	Structural dimensions
Groundwater level	Sheet pile tip level

Table 6.3: Input and output parameters for the design of the temporary cofferdam

FLOOR (RAIL CROSSING SECTION)

The feasibility of standardizing the floor will be essential for the feasibility of standardizing the entire underpass. It is *the* link between the standardized tunnel and the customized foundation. Therefor, detailed analyses are made to determine the influence of the different foundation types on thickness of the floor. The variable groundwater level and the variable stiffness of the soil and the piles are included in these analysis. Later on in this chapter at level 4 of feasibility analysis the possibility of standardizing the reinforcement will be investigated as well, see §6.6.

WIDTH FLOOR

The width of the floor w_{floor} follows directly from the width of the tunnel and the thickness of the walls, which are both standardized, see §6.3 at Page 27 and §6.5 at Page 38.

$$w_{floor} = w_{tunnel} + 2 \times t_{wall} = 10.00 + 2 \times 0.60 = 11.20m \tag{6.1}$$

THICKNESS FLOOR

As stated, the floor is the essential component is the standardization of the under the underpass and therefor the thickness of the floor depends on a large set of variables, which are listed below.

1. Foundation type.
   - Groundwater level.
   - Soil condition including soil stiffness.
   - Pile type, pile plan and pile stiffness.
2. Width of the floor (standardized, see §6.5 at page 40
3. Concrete strength class (similar to the concrete strength class applied for the walls, see §6.5 at page 36.
4. Structural dimensions of the deck and walls (standardized, see respectively §6.5 at page 33 and §6.5 at page 36).
5. Mobile load by the train (similar to the load on the deck, see §6.5 at page 33).

Structural calculations In order to find the effect of the foundation on the thickness of the floor, structural calculations are made. The thickness of the floor will be based on shear resistance and in the case of the application of piles or anchors, punching shear resistance. As was done for the thickness of the wall, (punching) shear reinforcement is considered to be not desirable. The safety factors, load cases, load combinations and all the calculations can found in Appendix H.

Foundation type The influence of the different foundation types, see §6.5 at page 38, on the thickness of the floor has been tested. Two models were created in MatrixFrame and they are both shown in Figure 6.20. The left model represents the shallow foundation and the right model the pile foundation and the underwater concrete plus the piles or anchors. The shallow foundation is modeled with a number of 21 springs that represent a soil stiffness of $0.10N/mm^3$. The pile foundation is modeled with a number of five springs that represent a pile stiffness of $100kN/m$. Assumption regarding the stiffness of the soil and the stiffness of the piles and anchors are based on the book *Stabiliteit voor ontwerpers*, by D. Dicke.[24]. Since this are just assumptions and the real situation will most definitely vary from these assumptions, the influence of the variation of the stiffness of the soil and the stiffness of the piles has been tested.

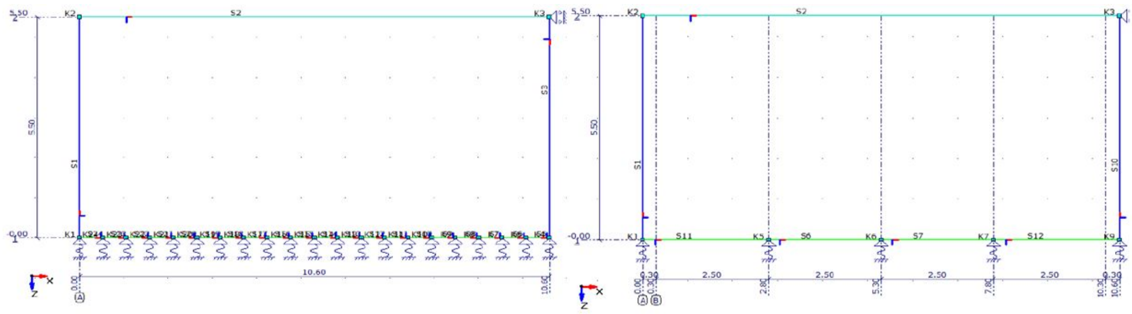


Figure 6.20: Static schematisation rail crossing section. Left: shallow foundation. Right: pile foundation and underwater concrete + piles or anchors.

In Figure 6.21, Figure 6.22 and Figure 6.23 the shear force development over the width of the floor is plotted for the different foundation types. What can be seen is that both a lower soil stiffness as a lower pile stiffness give slightly higher shear forces. This is to be expected, since a softer foundation leads to larger deformations and thereby to higher occurring forces.

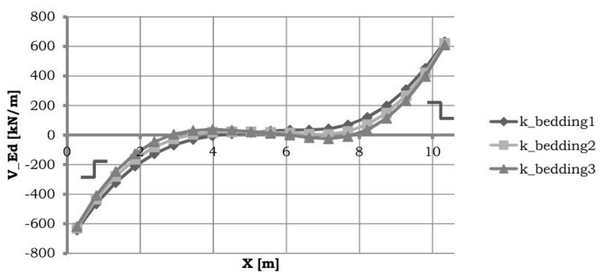


Figure 6.21: Shear force in floor for a shallow foundation with variable soil stiffnesses (MS Excel).

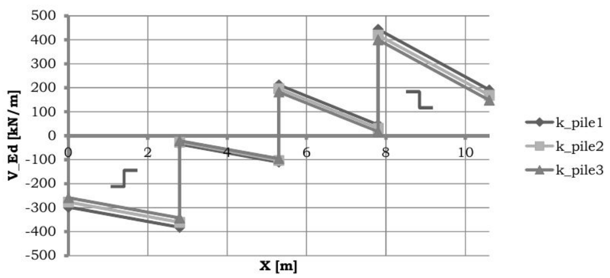


Figure 6.22: Shear force in floor for a pile foundation with variable pile stiffnesses (MS Excel).

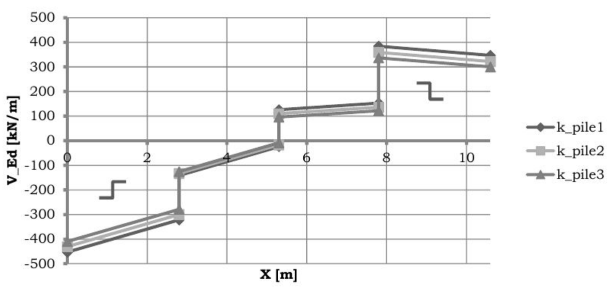


Figure 6.23: Shear force in floor for an underwater concrete + pile foundation with variable pile stiffnesses (MS Excel).

The enveloping shear forces of the different foundation types are shown in Figure 6.24. The maximum shear forces for each foundation type are plotted in bold. The largest shear force, with a maximum of $642kN/m$, is found with the shallow foundation. Shear forces for the pile foundation and the underwater concrete + pile foundations are, with respectively $444kN/m$ and $453kN/m$, way lower. Table 6.4 shows the relation between the thickness of the floor and the shear force resistance. According to the table shallow foundation requires a thickness of $1200m$ (Unity check = 1.02), where the pile foundation and the underwater concrete + pile foundation only require a floor thickness of $900mm$.

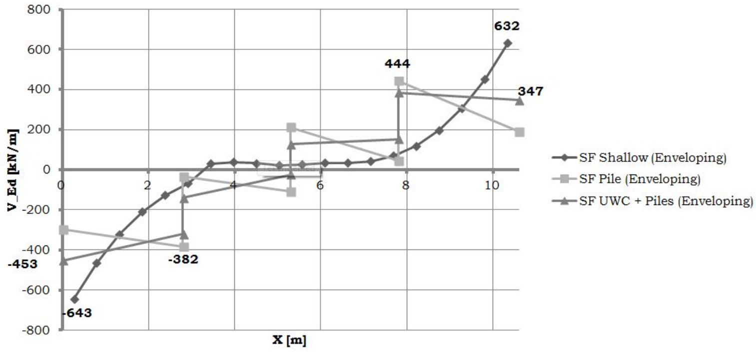


Figure 6.24: Enveloping shear forces for a shallow, a pile and an underwater concrete + pile foundation (MS Excel).

t_{floor} [mm]	$V_{Ed,c}$ [kN/m]
600	316
700	369
800	422
900	474
1000	527
1100	580
1200	633
1300	685

Table 6.4: Shear resistance by floor thickness for concrete strength class C35/45

N.B.1: The floor for the pile foundation and the underwater concrete + pile foundation has been checked for punching shear resistance, but this didn't prove to be decisive.

N.B.2: The initial thickness of the floor that was used to determine the shear forces was estimated at $800mm$. Therefor, there will be a minor difference in the occurring shear forces when the thickness of $900mm$ or $1200mm$ is applied. Since this is only a feasibility study, no additional calculations are made.

Suggested solution The suggested solution is mainly founded on the criterion of applicability. To be able to apply the same floor thickness for each and every underpass a thickness $t_{floor} = 1200$ is required. A cross-section of this floor is shown in Figure 6.25. The solution leads to a floor that is 33% over-dimensioned in some cases. In Chapter **??** the possibilities for optimization will be investigated.

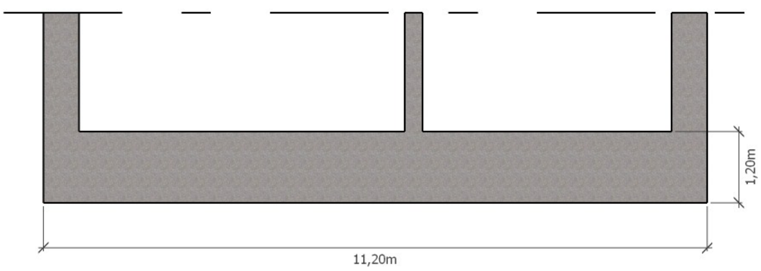


Figure 6.25: Dimensions floor – rail crossing section (SketchUp)

LENGTH OF THE MODES

The length of the modes of the floor correspond with the length of the modes of the wall, because after all the floor and the walls form one structure. The length of the mode for the rail crossing section L_{mode} is thereby determined at $19m$, see §6.5 at Page 37.

6.6. LEVEL 4

For Level 4 holds the same as for level 3, namely that there is such a high degree of detail, that it won't be essential to check the feasibility of standardizing each and every component to drawn conclusion on the feasibility of standardization of the entire underpass. In section §6.5 conclusion were drawn on the concrete strength class, leaving the reinforcement as the most interesting component in Level 4. The feasibility of standardization of the reinforce

REINFORCEMENT

Standardization of the reinforcement leads to a few major advantages. No more structural calculations need to be executed, which will save a lot of engineering costs. Another advantage is that it gives the possibility of prefabrication of the reinforcement, which will reduce the construction time.

LATITUDINAL REINFORCEMENT WALLS (RAIL CROSSING SECTION)

The latitudinal reinforcement in the walls depends on three influence factors.

1. Bending moments (ULS).
   - Traffic load.
   - Groundwater level.
   - Foundation type.
2. Concrete strength class.
3. Thickness of of the wall.

The concrete strength class and the cross-section of the walls are standardized, see §6.5 at page 36. Structural calculation are made to find the effects of the traffic load, the groundwater level and the foundation type on the occurring bending moments and the associated reinforcement. Calculation can be found in Appendix H.

Bending moments (ULS) The results in Table 6.5 show that the foundation type and groundwater level have a negligible effect on the occurring maximum bending moments in the wall. The major contribution comes from the traffic load on the deck.

Situation	M_{Ed} [kNm/m]	$A_{s,req}$ [mm^2]
Shallow / $k_{bedding3}$ / low water / traffic	661	3024
Piles / k_{pile1} / low water / traffic	711	3553
UWC + piles / k_{pile3} / high water / no traffic	194	702
UWC + piles / k_{pile1} / high water / traffic	717	3726

Table 6.5: Bending moments (ULS) in the walls and required reinforcement for different situations

Suggested solution With a wall thickness of $600mm$ and a concrete strength class C35/45 a reinforcement of $\phi 25 - 125$ fulfills all requirements.

LONGITUDINAL REINFORCEMENT WALLS (RAIL CROSSING SECTION)

Longitudinal reinforcement in walls has the purpose to control the crack width. This is essential to create a watertight seal. Because the walls are monolithically connected to the floor and the deck, the walls suffer from prevented imposed deformation both at the bottom and the top. At the bottom it's only shrinkage thats causes the imposed deformation; at the top both shrinkage and a temperature differential due to heating of the deck causes the imposed deformations. This is illustrated in Figure 6.26.
The amount of reinforcement depends on the following factors:

1. Temperature differential.

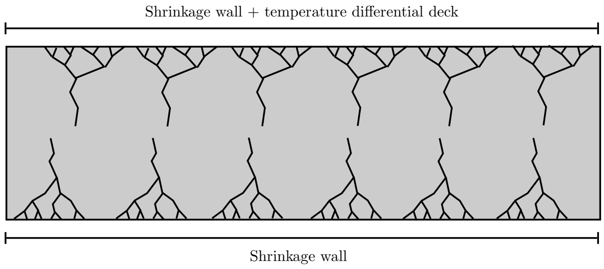


Figure 6.26: Cracking pattern in the wall due to prevented imposed deformations.

2. Maximum crack width (Lohmeyer).
3. Groundwater level.
4. Concrete strength class.
5. Cross-section of the wall.

The concrete strength class and the cross-section of the walls are standardized, see §6.5 at page 36.

Temperature differential The temperature load imposed by deformations of the deck will be similar for every situation. The thickness of the deck has been standardized and the temperature differences in the Netherlands are the same at every location.

Maximum crack width (Lohmeyer) The maximum crack width is determined according to Lohmeyers curve, which is shown in Figure 6.27. According to this figure, both the groundwater level as the wall thickness have their influence on the allowable crack width.

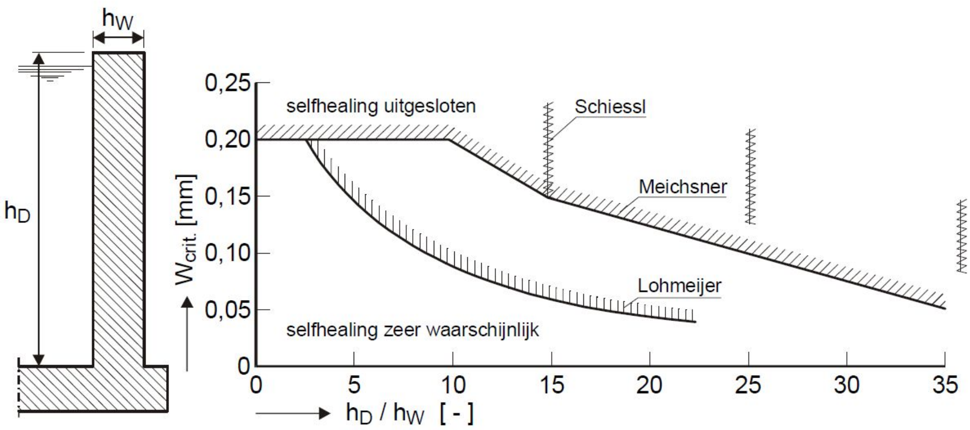


Figure 6.27: Maximum crack width for watertightness according to Lohmeyers curve [25]

Groundwater level The effect of the groundwater level on the required reinforcement in the wall is graphically shown in Figure 6.28. Calculations behind the diagram can be found in Appendix I. There is a difference between the required reinforcement for the lowest groundwater level and the highest groundwater level of 35%.

Suggested solution The suggested solution is to over-dimension the reinforcement in some of the cases and apply a reinforcement of 2 $\phi 20 - 90$ on each side of the wall.

LATITUDINAL REINFORCEMENT FLOOR (RAIL CROSSING SECTION)

For the floor, only the reinforcement in the latitudinal direction is being examined. The latitudinal reinforcement in the floor depends on three influence factors.

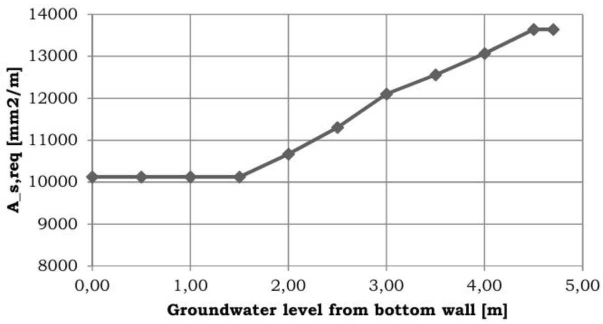


Figure 6.28: Required reinforcement in the wall in relation to groundwater level.

1. Bending moments (ULS).
   Traffic load.
   Groundwater level.
   Foundation type.
   Soil and pile stiffness.
2. Concrete strength class.
3. Thickness of of the floor.

The concrete strength class and the thickness of the floor are standardized, see §6.5 at page 40. Structural calculation are made to find the effects of the traffic load, the groundwater level, the foundation type and the stiffness of the soil and the piles on the occurring bending moments and the associated reinforcement. Calculation can be found in Appendix H.

Soil stiffness The results in Figure 6.29 show that a lower stiffness of the soil lead to higher bending moments in the floor. The holds for a lower stiffness in the piles. To guarantee maximum applicability the results for the lower stiffnesses are used to determine the reinforcement.

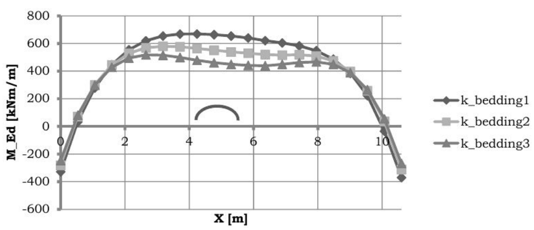


Figure 6.29: Bending moments (ULS) in floor for shallow foundation

Bending moments (ULS) The results in Table 6.6 show the bending moments and the required reinforcement for different situations. The over-dimensioned thickness of the floor results in low reinforcement ratios. For the shallow foundation only a minimum reinforcement ratio is required at both the top and the bottom. The required reinforcement for the pile foundation and the underwater concrete + piles foundation is approximately 46% higher than that for shallow foundation.

Situation	M_{Ed} [kNm/m]	$A_{s,req}$ [mm^2]
Shallow / top	669	1404
Shallow / bottom	370	1404
Piles / top	901	2052
Piles / bottom	368	1404
UWC + piles / top	936	2068
UWC + piles / bottom	478	1404

Table 6.6: Bending moments (ULS) in the floor and required reinforcement for different situations

Suggested solution With a floor thickness of $1200mm$ and a concrete strength class C35/45 a reinforcement of $\phi 20 - 150$ at the top and $\phi 16 - 125$ at the bottom fulfill all requirements.

PREFABRICATION OF THE REINFORCEMENT

As stated in the beginning of this section, standardization of the reinforcement give the possibility of prefabrication of the reinforcement. Prefabrication is out of the scope of this thesis so only an impression some possibilities are given. Extensive research on the application prefabricated elements is performed by Bart van Casteren, which he will publish in his master thesis: "*Feasibility of prefabricated elements for underpasses – watertight connection and structural safety*".

Figure 6.30 shows a possible reinforcement cage for the floor. The idea is that the reinforcement bars on the top extend to the one side and on the bottom to the other side. In Figure 6.31 can be seen that when the reinforcement cages are installed, the bars in the longitudinal direction of the underpass overlap. In order for this to work the bars in the longitudinal direction of the underpass have to be on the very top and very bottom of the reinforcement case. Leaving a slightly smaller internal lever arm, which will result in a larger reinforcement ratio in the other direction. The elements for the walls are designed in a similar fashion, see Figure 6.32.

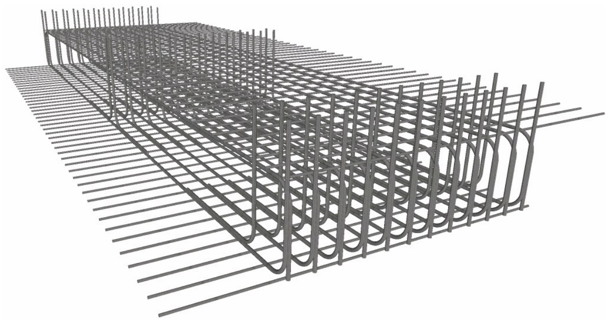


Figure 6.30: Prefabricated reinforcement cage for the floor (SketchUp).

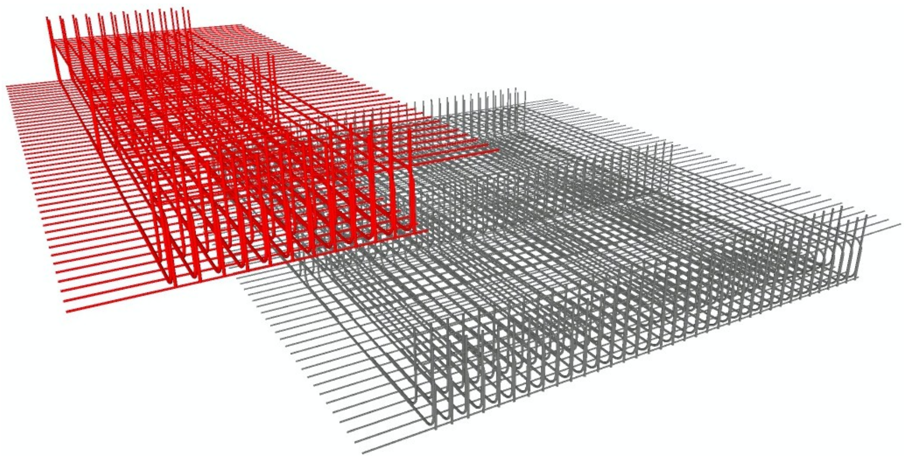


Figure 6.31: Installation of prefabricated reinforcement cages for the floor (SketchUp).

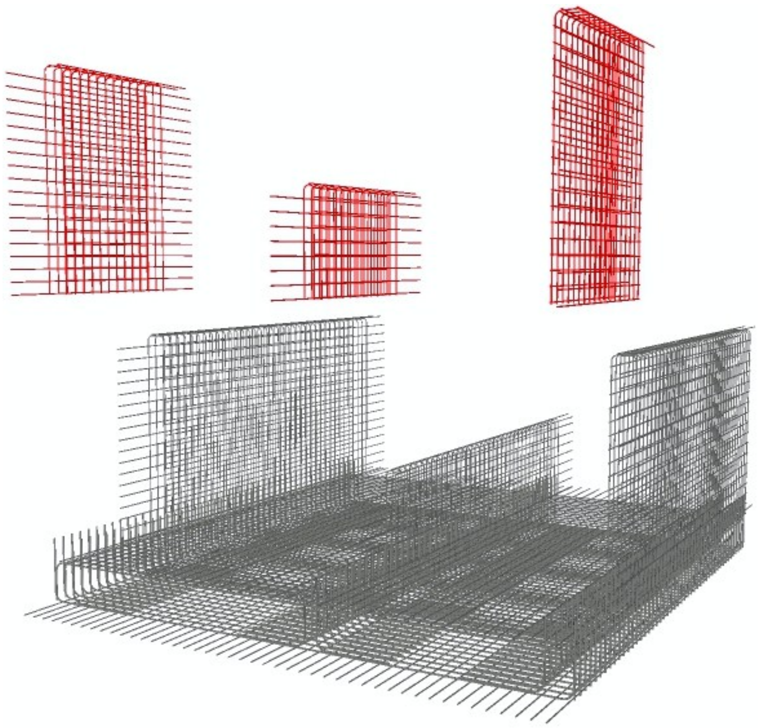


Figure 6.32: Installation of prefabricated reinforcement cages for the walls (SketchUp).

6.7. AN OVERVIEW OF THE PROTOTYPE'S PROPERTIES

In the previous sections of this chapter the properties of several components of the prototype have been determined. The give a clearer image of these results an overview is made in this section. This overview gives the essence of the prototype, visual impressions and the properties by component.

THE ESSENCE OF THE PROTOTYPE

The essence of the prototype can be found in the adaptability of the foundation to groundwater level and soil conditions, creating an environment where the rest of the underpass can be standardized. One of the most critical features is the floor of the underpass. The floor and the walls are designed in such a way that they fulfill all the structural requirements and can be applied for the shallow foundation, the pile foundation and the foundation that consists of an underwater concrete floor combined with concrete piles. The final feature follows from the standardization by parts, which makes it possible compose the underpass from standardized parts. This enables the designer to adapt the underpass in case of speed variation or presence of parallel road(s).

MATERIALS

Some of the materials have been defined, but for others it might be more difficult to find what their properties are. Therefore, a the materials applied in the prototype are listed in Table 6.7.

Material	Component(s) applied to
Concrete C35/45	Deck, walls, floor
Concrete C50/60	Foundation piles
Underwater concrete	Underwater concrete floor
Reinforcement 500B	All reinforcements
Steel S355	Cofferdam, girders, anchors
Asphalt	Crossing road, bicycle path

Table 6.7: Applied materials in prototype.

VISUAL IMPRESSIONS

This section provided a number of visual impressions of the prototype. Figure 6.33 shows a three-dimensional overview of the entire underpass, including the optional part for a parallel road and both the part for $60 km/h$ and $30 km/h$. Figure 6.34 shows the prototype integrated at in an Google™ Earth environment at one of the potential locations for a new to build underpass. Figure 6.35 shows the topview and sideview of the prototype, including dimensions. In Figure 6.36 the structural dimensions of the rail crossing section can be found. And finally, Figure 6.37 shows how the prototype handle the variations of the groundwater level and the soil conditions.

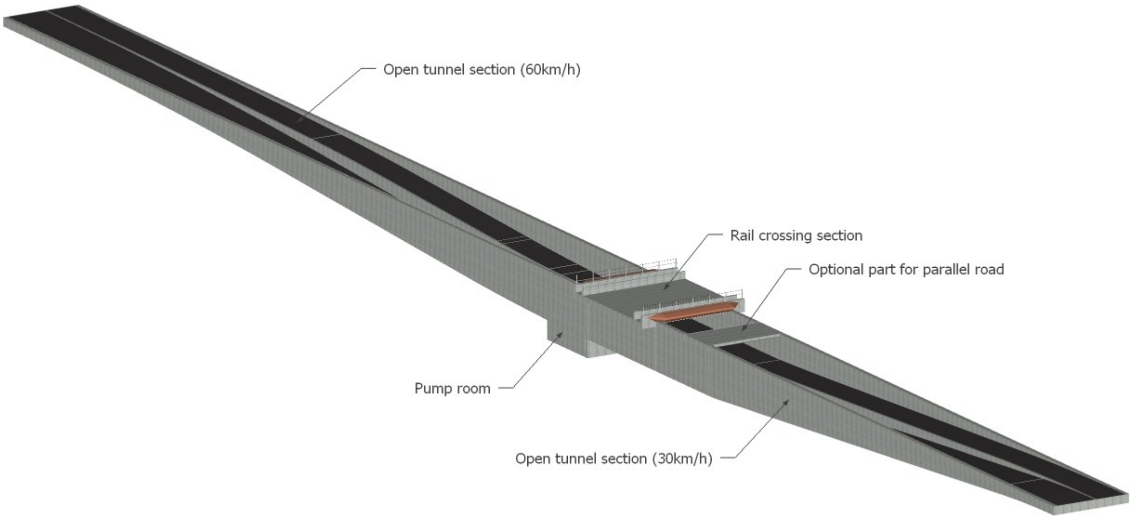


Figure 6.33: 3D overview prototype, including the optional part for a parallel road and both the parts for $60 km/h$ and $30 km/h$ (SketchUp).

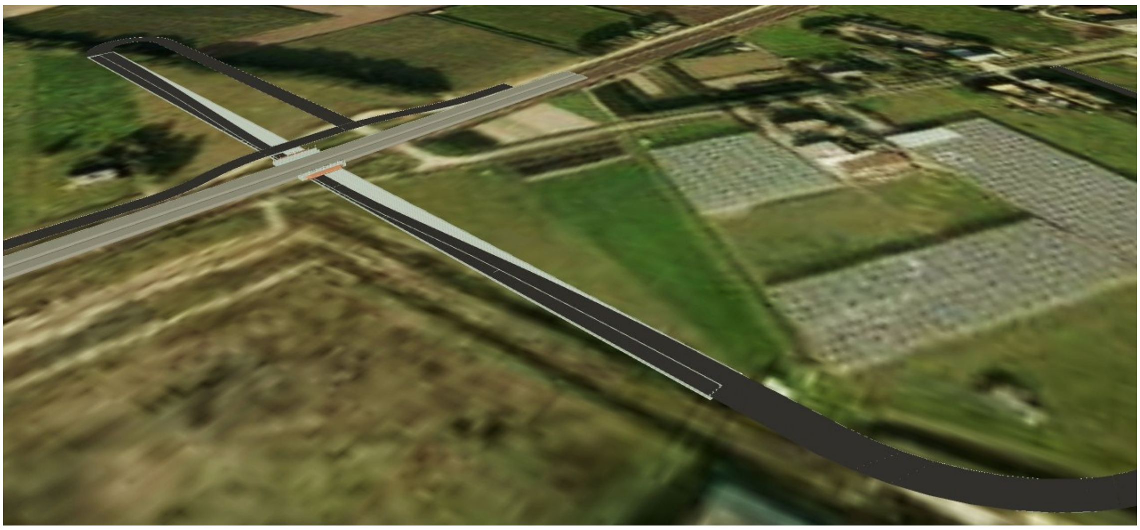


Figure 6.34: Prototype integrated at in an Google™ Earth environment (SketchUp).

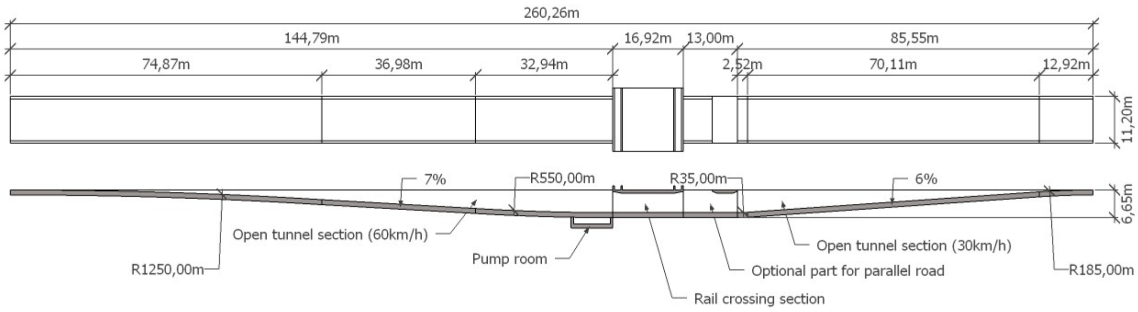


Figure 6.35: Topview (top) and sideview (bottom) of the prototype including the different options (SketchUp).

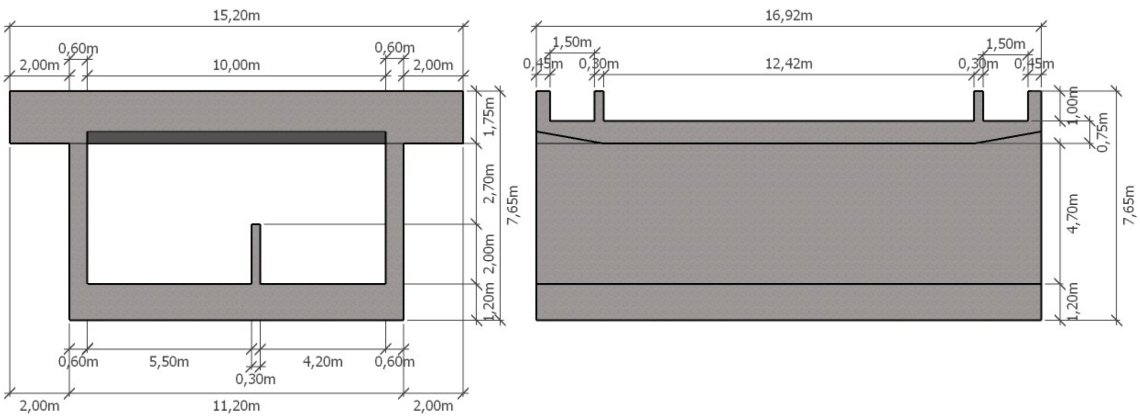


Figure 6.36: Structural dimensions rail crossing section (SketchUp).

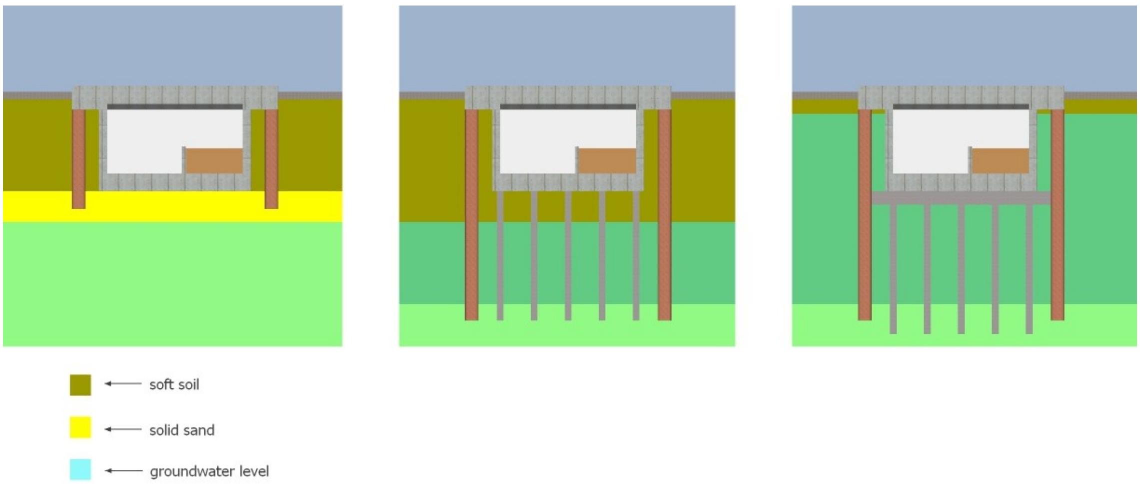


Figure 6.37: Three foundation types that together are suitable four all soil conditions and groundwater levels (SketchUp).

6.8. CONCLUSIONS

Based on the analysis made in the this chapter the following conclusions can be drawn regarding the feasibility of standardization of an underpass.

1. It is not feasible to fully standardize an underpass. The effects of the groundwater level and soil condition are such that the foundation of the underpass needs to be customized to the situation.
2. By over-dimensioning the walls and the floor it is found to be feasible to standardize all the other (non foundation) components at all four levels of decomposing.
3. The feasibility of standardizing the rail crossing section of the tunnel is projected on the open tunnel section and the pump room. Therefor, it is considered that it is feasible to standardize the open tunnel section and the pump room as well.
4. The foundation provides an environment, where the rest of the underpass doesn't experience the influence of the soil condition.
5. Standardization of the walls, the floor and the deck give the possibility of prefabrication of the reinforcement.

7
Evaluation

In Chapter 6 a prototype of the standardized underpass has been developed. Some of the features of the prototype have been over-dimensioned in order to fulfill the applicability criterion. To make sure the standardized underpass is as economically beneficial as possible the prototype must be tested and the options for optimization must be investigated. A comprehensive examination on this optimization, including economic analyses, is out of the scope of this thesis. Further in this chapter a critical reflection is given on curtain assumptions regarding the design parameters and on some the design choices that resulted in over-dimensioned elements.

7.1. General

Problems
The problem is twofold.

1. Some of the features of the prototype have been over-dimensioned in order to fulfill the applicability criterion, but this might not be as economically beneficial as possible.
2. The distribution of the values of the parameters, those that gave rise to the over-dimensioning, is unknown.

Questions
The question is therefore also twofold.

1. What's the distribution of the values of the parameters that gave rise to the over-dimensioning of some components?
2. How can the prototype be optimized so the standardized underpass is as economically beneficial as possible?

Objective
The objective of this chapter is not so much to give an answer to the questions in the previous section, but more to give an example on how the optimization can be achieved.

Method
As stated earlier, financial analysis are out of the scope of this thesis. Therefore, only the concept of the optimization is described. Further a reflection is made on both the design parameters and some of the design choices.

7.2. Optimization
In Figure 7.1 an impression is given of the costs in relation to both the degree of standardization and the applicability of the prototype for the underpass. One can see that when the degree of standardization and the applicability are both 100% costs will be very high. Almost all the components will be over-dimensioned in such a way that standardization will not be beneficial. When the degree of standardization is high and the applicability is very low costs will also be high, because the prototype won't be applied enough to benefit

from repetition. When the degree standardization is very low and the applicability is high the costs will also be high, because the designs will be customized and there will be no benefit from standardization. Behavior on planes of 0% standardization and 0% applicability can be considered irrelevant, since both situations can never exist. Finally it can be stated that the optimum (can be more than one) will be somewhere in the middle.

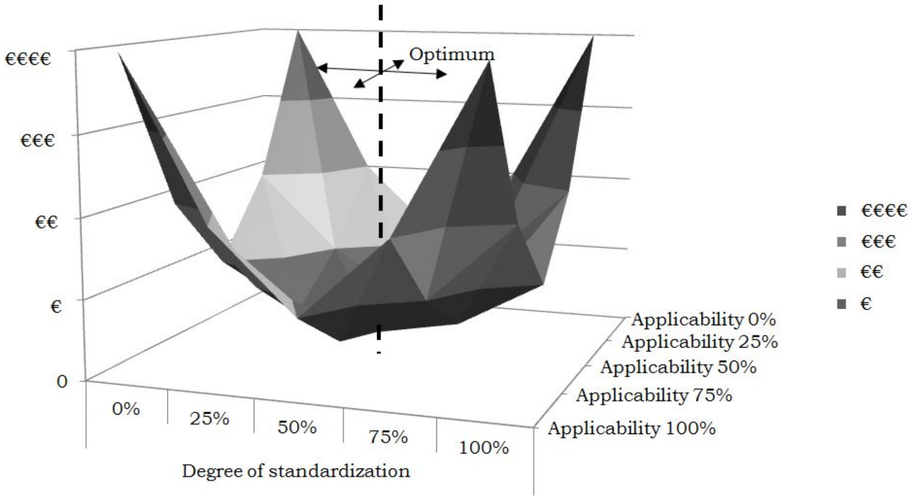


Figure 7.1: Impressions of the costs of the prototype in relation to the degree of standardization and the applicability.

Example The previous paragraph was quite abstract so lets clarify this by giving an example on how to come closer to this optimum. Imagine for instance the longitudinal reinforcement in the wall, see §6.6 at page 43. The consequence of standardizing the reinforcement is that in some cases, when groundwater level is low, 35% more reinforcement is applied then required. The question is whether this is the most beneficial solution. Maybe it's the reinforcement should be calculated for each individual underpass. The applicability will remain the same, but the degree of standardization will go down. Or maybe it's more efficient to standardize it for let's say 80% of underpasses and customize the reinforcement for the other 20%. In that case the degree of standardization will remain the same, while the applicability goes down.

This exercise should be performed for all the components that have been over-dimensioned. Financial analysis must be made to give an inside on the consequences of the standardization process. The following aspects will be essential to calculate this optimum:

- degree of variation of the parameters that causes the over-dimensioning;
- total number of potential underpasses that are eligible for the standardized prototype;
- unit prices of steel, concrete, etc.;
- unit prices of labor and
- potential bonuses for a faster construction process.

All these aspects have a certain uncertainty. The two parameters that have caused most of the problems are the groundwater level and the soil condition. Research should be done on the degree of variation at the location of the potential underpasses. The actual number of potential underpasses won't change, but the willingness of the government give the order for construction might change after elections or economical developments. Also the unit prices of both material and labor can change over time. All these uncertainties make the determination of the optimum prototype a real challenge.

7.3. REFLECTION ON DESIGN PARAMETERS

In Chapter 4 a sensitivity analysis was performed on the variation of the design parameters. The largest group of parameters with identical values formed the base of the prototype. Are there other groups that are also eligible for a prototype? And what happens to the conclusions when it turns out that some of the assumptions and/or measurements are incorrect? These questions will be answered in the remainder of this section.

Altitude railway

In Figure 4.2 at page 13 can be seen that the only difference between combination #1 and combination #2 is the altitude of the railway track. With some adjustments a second prototype can easily be developed in a similar way as the first one. In Figure 7.2 an impression is given of this second prototype. Without making any calculations it can be stated that the total length of the underpass will be shorter and that certain components as the walls, the floor and the reinforcements will have smaller dimensions. Combination #2 covers 24% of the underpasses. Together with the first group this gives a total applicability of 53%, which are a potential of 60 underpasses. When this is projected on all 2500 grade crossing in The Netherlands, a total of 1350 potential standardized underpasses is obtained.

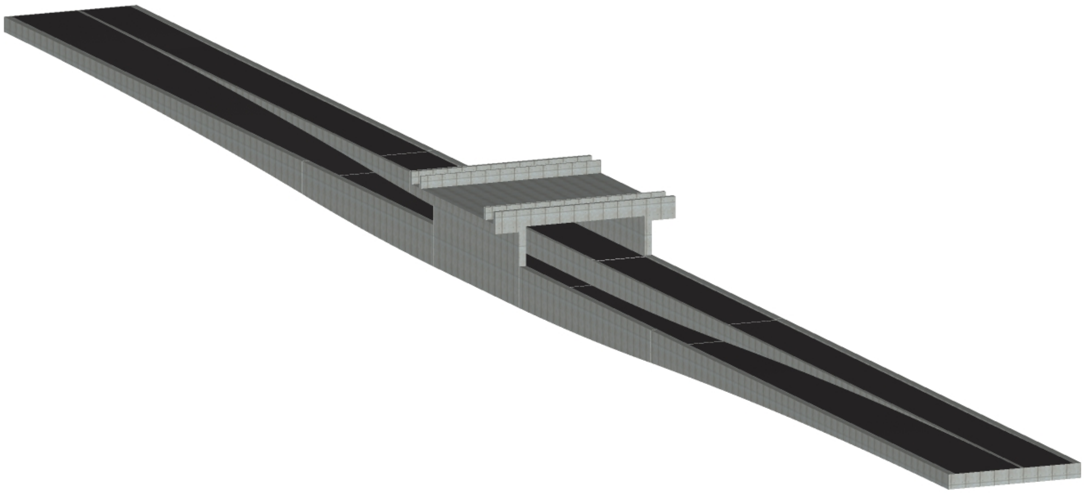


Figure 7.2: Impression of the prototype for the railway half in elevation (SketchUp).

There are some risks regarding this altitude. The data for the sensitivity analyses was obtained in Google™ Earth. For the determination of the altitude of the railway the Street View-function was also applied. The altitude was estimated and divided in three levels: entirely in elevation, half in elevation and ground level position. Since this was estimated instead of measured the risk is that actual spectrum is slightly different. The consequences of this risk small, there are prototypes for both the half in elevation and ground level position category. Another possibility is that is altitude might categorized correctly, but that is still some variation is in the altitude within the category. A solution to deal with this problem was already presented in §6.3 at page 28, where it was suggested to create some margin in the altitude by varying with the thickness of the gravel layer.

Groundwater level and soil condition

As stated in §7.2 the groundwater level and the soil condition for the potential locations must be investigated. It's known that the groundwater level will be lower in areas that are higher below the sea level than other and it's also known which areas have in general better soil conditions than others, but local variation can be caught in such assumptions. These spectra are essential to be able to make a decent optimization.

Urban area vs countryside

Errors in the determination on whether a crossing in a urban area or in the countryside is not to be expected. With the help of Google™ Earth this can easily be determined.

There is however a remark that must be made regarding grade crossings in urban areas. Although a potential of 53% of all the new to build underpasses might be standardized, none of those can be applied in urban areas, while these crossings are most eligible for an underpass. Therefore, more research should be done on smart ways to integrate underpasses in urban areas. Possibly with designs that have a smaller degree of standardization.

CROSSING ANGLE

The crossing angle was measured in Google™ Earth, but the problem with the Google™ Earth is that the pictures that are taken are not all that clear, are not all up to date and are not all made from a straight angle. This might mean that some of the crossings that where considered to be at a 90° angle are actually another angle. The question is, is this a problem? For the urban areas it will be a problem, because buildings close the crossing cannot be removed that easily. In the countryside a little variation in the crossing angle won't be such a problem. Often there is enough space to place the underpass. In some cases it might be necessary to demolish a house or two. This will lead to extra costs, which also have to be taken into account when determining the optimum.

NUMBER OF TRACKS

Almost all the grade crossing that have been examined have two track. The reason for this is that for crossing with four track or more it's obligated to create an underpass or a flyover. There was one grade crossing found with three track. This is at station Driebergen-Zeist, but since this is in an urban area the prototype won't apply to it anyway.

ROAD TYPE AND ROAD WIDTH

The final two design parameters might form a problem. From the sensitivity analysis followed that the prototype should be designed for an access road. A risk is that due to unclarity of the Google™ Earth images at some locations a distributor road is confused for an access road or visa versa. Consequences are the applicability might increase or decrease, depending on the confusion. In the sensitivity analysis was found that even though a lot of the crossing road were access roads, still there was quite some variation regarding the road width. To deal with this problem the width of the prototype underpass was based on the recommendations of CROW. A risk is that the underpass might be over-dimensioned in some cases or that it might to small for others. It's problematic when the tunnel width is too small, because it effects its applicability. Research should be done to make sure the width used for the prototype is the most efficient.

7.4. REFLECTION ON DESIGN CHOICES

In Chapter 6 a partially standardized prototype was obtained by the elimination of design choices. During this elimination some of the components that form the prototype have been over-dimensioned to fulfill the demands of all the different situations. In §7.2 was explained how find a financial optimum between the degree of standardization and the applicability of the prototype and how the over-dimensioned components should be evaluated. In the remainder of this section the components that are eligible for this optimization will be evaluated.

MEASURES THAT HAVE ALREADY BEEN TAKEN

Three measures have already been taken to bring the underpass closer to an optimum:

- the open tunnel section can be adapted to different velocities of the traffic;
- in case of a parallel road an extra tunnel part can be places between the open tunnel section and the rail crossing section and
- there is a possibility to adapt the foundation to the local groundwater level and soil condition.

For these components it was so obvious that fully standardizing them wouldn't be beneficial that these measures have been taken in the first step of developing the prototype. For the other components final analyses must be made to obtain similar results.

WIDTH OF THE DECK

The width of the deck was based on a railway track in the tightest possible bend, because in that situation the widest width is required. At the moment there is no data set available about curvature of railway tracks horizontal alignment at the position of the potential underpasses. Maybe there isn't any curvature at all. This would result in a substantial reduction of the width of the deck. Therefore, research should be done on the horizontal alignment at the position of the potential underpasses and on the financial consequences of over-dimensioning the width.

CONCRETE STRENGTH CLASS

In Chapter 6 the concrete strength class for the deck, the walls and the floor was standardized at C35/45. This was solely based on the fact that this strength class is already often applied for cast in-situ structures. Whether this is the most efficient solution should be investigated, especially because this standardized underpass might be applied in so many situations.

THICKNESS OF THE WALLS

The required thickness of the wall has a direct relation to groundwater level and the concrete strength class, see Figure 6.17 at page 37. To make sure the wall would fulfill all requirements, a upper boundary was used for the determination of the thickness of the wall. As stated in §7.3, it's essential to find out more about the groundwater level to be able find the optimal solution.

Extreme loads due collisions or explosions have been ignored in the development of the prototype. And, as being remarked earlier, also breaking and acceleration forces have not be taken into account. These load cases might result in a thicker wall.

THICKNESS OF THE FLOOR

In §6.5 at page 40 the thickness of the floor was determined. Standardizing the floor was essential for the standardization of the entire prototype. It forms the link between the tunnel part that is standardized and the foundation that has to be customized. A problem is that the floor for the shallow foundation requires a much larger thickness than the floor for the pile foundation and the floor for the underwater concrete + piles foundation, namely 33%. The question is: in how many of a the cases can the shallow foundation be applied and in how many of the cases the other ones. It might be more beneficial the use the floor for the pile foundation and the underwater concrete + piles foundation for the prototype and only apply the floor for the shallow foundation for exceptions. Research should prove this.

LONGITUDINAL REINFORCEMENT IN THE WALLS

The longitudinal reinforcement in the walls was already treaded as an example in §7.2. In Figure 6.28 at page 45 can be seen that the required reinforcement in relation to the groundwater level is approximately bilinear. Research should be done on whether is financially more beneficial to standardize the reinforcement for all the situations or to split it up into two parts.

A WORD ON THE DISTANCE BETWEEN THE PERMANENT AND TEMPORARY WALLS

For rail crossing section, the distance between the permanent concrete wall and the temporary cofferdam was set to $1.00m$. The distance was based on a girder of $0.50m$ leaving a $0.50m$ gap for the placement of the formwork. But with a thickness of the permanent wall of $0.60m$ and thickness of the cofferdam around $1.00m$ the total shift of the support will be $1.80m$. This will lead to a large redistribution of the bending moments in the deck, causing an enormous amount of reinforcement. Therefore, it might be beneficial to optimize this distance. When optimized, the distance can still be standardized, because the optimum will be the same for every single situation.

A WORD ON THE OPEN TUNNEL SECTION

During the development of the prototype the open tunnel section was pretty much ignored. It was assumed that the conclusions regarding the standardization of the components in the rail crossing section could be projected on similar components in the open tunnel section. A remark must be made on this part. Remember the functions of the floor and walls described for the open tunnel section in §5.5. The walls and the floor must retain the soil and the groundwater. What if maximum the groundwater level is not at the top wall, but for instance halfway (see Figure 7.3)? The walls in the rail crossings sections will always be the same height, because they also have the function of supporting the deck, but the walls for the open tunnel section don't have this function. This means that, when there is enough space on both sides of the underpass, the walls can be lowers and the soil can excavated under a slope. This solution is illustrated in Figure 7.4. The enormous reduction of the amount of concrete will almost certainly effect the financial feasibility of standardizing the open tunnel section of the prototype. This is another reason why research much done on the groundwater level at the locations of the new to build underpasses. An inside in the distribution of the groundwater levels will enable the development of an efficient solution for the open tunnel section.

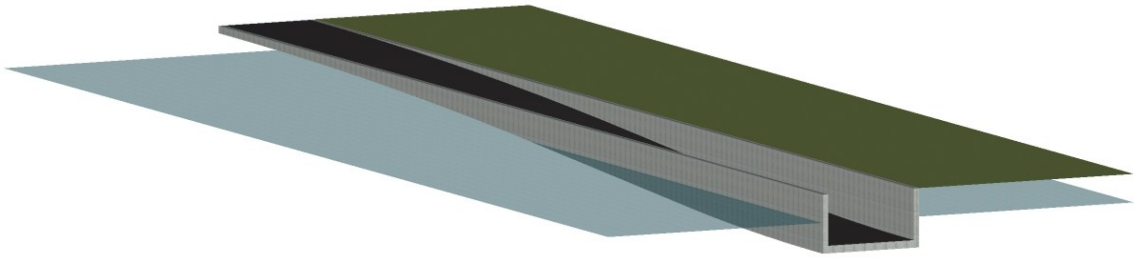


Figure 7.3: Open tunnel section of the prototype (SketchUp).

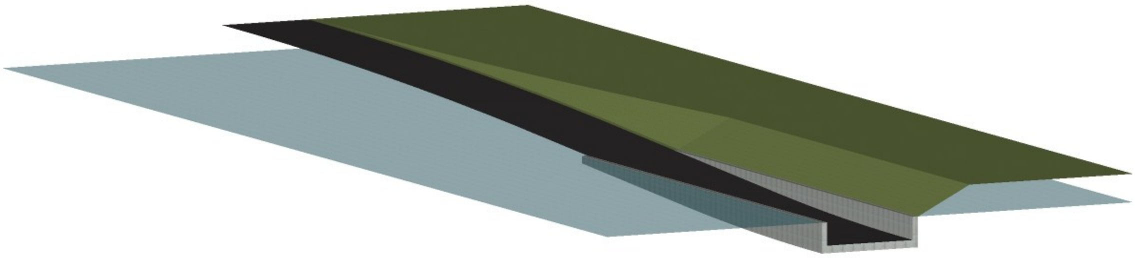


Figure 7.4: Open tunnel section adapted to a lower maximum groundwater level (SketchUp).

7.5. CONCLUSIONS AND RECOMMENDATIONS

Because no actual research is performed in this chapter, the focus of this section will be more on the recommendations than on the conclusions.

CONCLUSIONS

The optimum solution for the standardized prototype is reached when all the over-dimensioned components of the underpass are being tested for their financial feasibility. To do this a trade-off has to made between the degree of standardization the applicability. This is a very complex exercise.

A prototype has been developed that can be applied in 29% of the grade crossings on the tracks of PHS. When this prototype is adapted to a half raised railway track, another 24% of these crossing can be covered. This means that we with two prototypes 53% of all the grade crossing can be covered.

RECOMMENDATIONS

The most important recommendation is the a study must be performed on the financial feasibility of the standardized prototype. It will be essential to find an optimum solution. Other recommendations, that actually sub-recommendations, are listed below.

1. Research should be done on the groundwater level and soil condition at the locations of the new to build underpasses.

2. Solutions should be found for the implementation of underpasses in urban areas.

3. Further research should be done on whether the road width used in the prototype is most efficient.

4. The following components qualify for an optimization, because they where over-dimensioned in the standardization process: the

   width of the crossing road, the

   width of the deck, the

   thickness of the walls, the

   thickness of the floor and the

   longitudinal reinforcement in the walls.

5. The distance between the permanent concrete wall and the temporary wall should be optimized.

6. Further research should be done the find and efficient solution for open tunnel section to deal with the variable groundwater level.

8
Conclusions and recommendations

The most important conclusions and recommendations obtained in the previous chapters have been listed in this chapter. Other conclusions and recommendations can be found in the last sections of each chapter.

8.1. Conclusions

Based on the results of the performed research a set of conclusions can be drawn. The conclusions are listed in order of importance, where the first conclusion is the answer to the research question that was stated in §1.3.

1. It has been proven that it is technically feasible to standardize a major part of the design of an underpass. However, the effects of the variable groundwater level and the variable soil conditions are such that customizing the foundation is unavoidable.
2. A prototype has been developed that can be applied in 29% of the grade crossings on the tracks of PHS. When this prototype is adapted to a half raised railway track, another 24% of these crossing can be covered. This means that we with two prototypes 53% of all the grade crossing can be covered.
3. 53% of 111 grade crossings are 59 potential underpasses. If this is projected on all the 2500 grade crossings in The Netherlands it will be possible the build approximately 1350 underpasses in a similar fashion.
4. A major downside is that the highest demand for new underpasses is found in the urban areas, where the prototype doesn't apply to.

8.2. Recommendations

A set recommendations can be given based on the results of this research.

1. Research should be performed on the financial feasibility of standardizing the design. Does the profit due to repetition of construction and the reduction of construction time compensate the extra costs made by over-dimensioning of the design? Is there an optimum to be found?
2. Further detailing of the prototype is necessary for the development of the final standardized underpass.
3. Research should done on the possibility of the application of prefabricated elements for the floor, the walls and the deck of the underpass. A study on this subject is already being performed by Bart van Casteren, which he will publish in his master thesis: "*Feasibility of prefabricated elements for underpasses – watertight connection and structural safety*".
4. A solution must be found for the underpasses that need to be build in urban areas. A possibility might be a design with a lower degree of standardization, which will result in a more parametric design.

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List of Figures

A

SOIL CONDITIONS IN THE NETHERLANDS

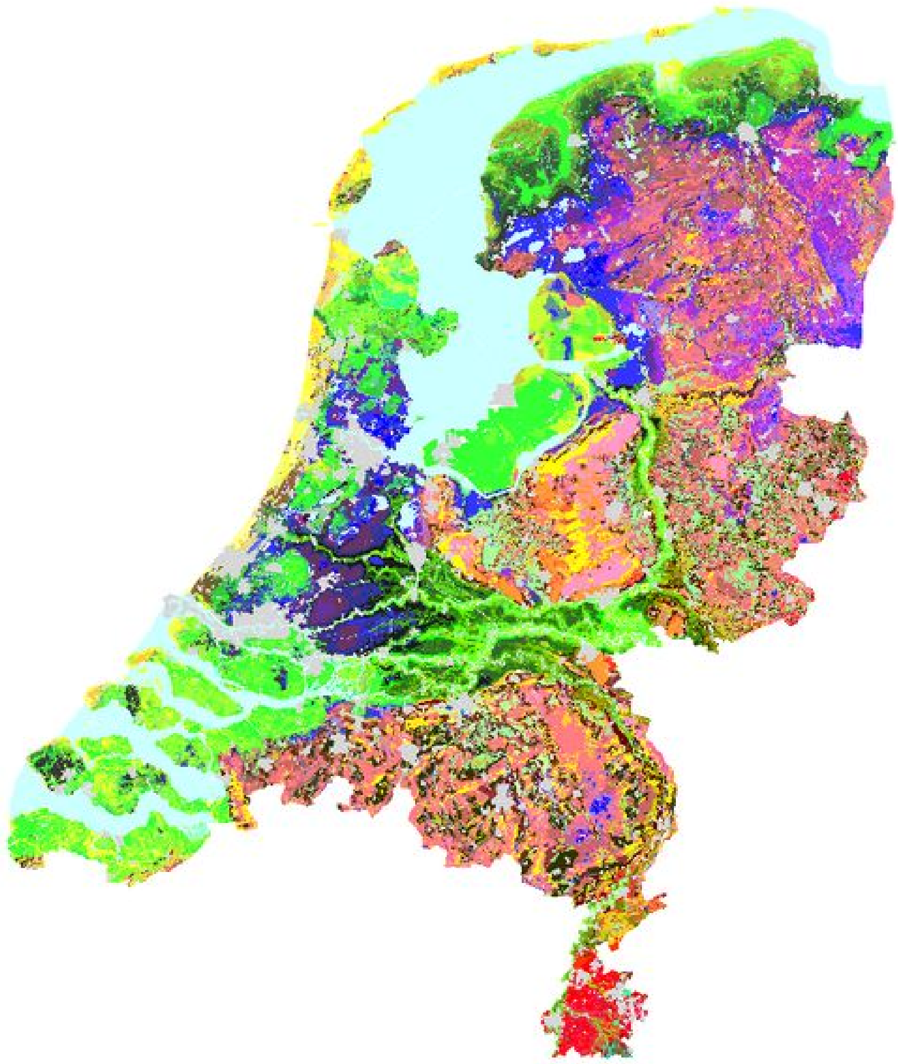


Figure A.1: Soil conditions in The Netherlands (blue = peat; green = clay; pink/yellow = sand) [26]

B

Inventory railway crossings

ALL CROSSINGS

This section gives an overview of all the crossings on the routes of PHS. The results are listed and analyzed for each parameter.

Crossing Of all the crossing the route of PHS, there are 111 (28%) grade crossings. For more than two thirds of those crossings an overpass or underpass solution is found, where most of these solutions are underpasses. Further there are hardly any grade crossings in urban areas, especially in the Randstad. An overview of these results are shown in Figure B.1:

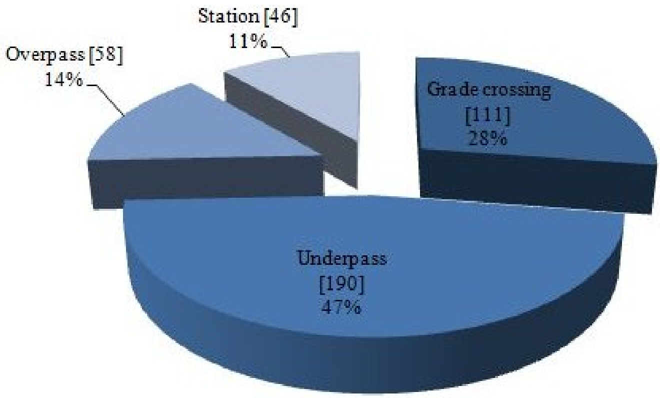


Figure B.1: Crossing types

Location There are two times as much crossings in the urban and semi-urban areas than in the countryside area. This is easily explained on the basis of the volume of traffic in the urban area's compared to the countryside. An overview of these results are shown in Figure B.2:

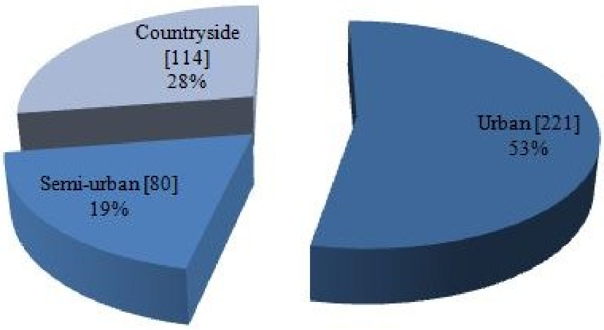


Figure B.2: All crossings: location

Crossing angle Almost half of all the crossings have a crossing angle of 90°. This is promising for creating a standard. An overview of these results are shown in Figure B.3:

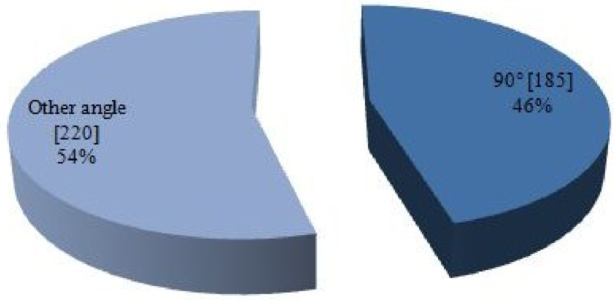


Figure B.3: All crossings: crossing angle

Number of tracks Half of all the crossings consist of two railway tracks. The other half consists is three, four or more tracks. What is striking is that in a situation with four or more tracks no grade crossings appear. Situation with 5 tracks or more often occur in urban areas, close to stations. An overview of these results are shown in Figure B.4:

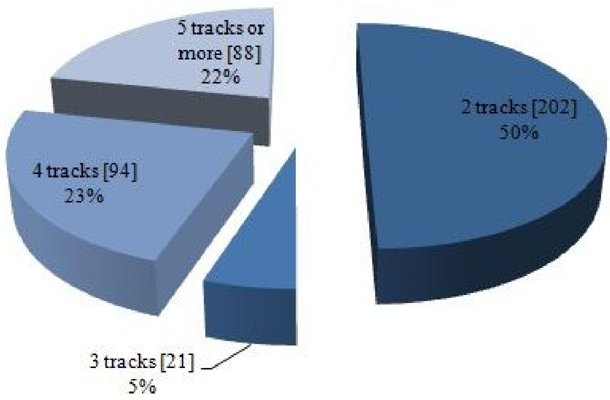


Figure B.4: All crossings: number of tracks

Road type Road type and the width of the road don't correspond necessarily. Especially in urban areas there is a lot of diversity in the road width. In the countryside access roads have often the same width, although there is a margin of a few meters. An overview of these results are shown in Figure B.5:

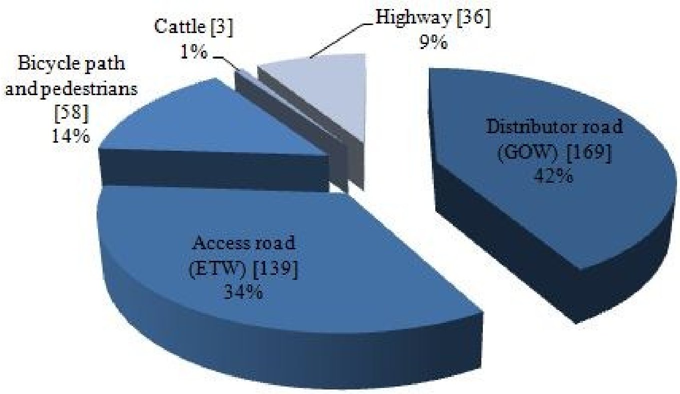


Figure B.5: All crossings: road type

Altitude railway The railway entirely in elevation is mostly seen in urban areas. Railways at ground level position and half in elevation appear more in the countryside. A deepened situation is not often seen. It only appears at the start and end of a train tunnel and at small part of the Veluwe. An overview of these results are shown in Figure B.6:

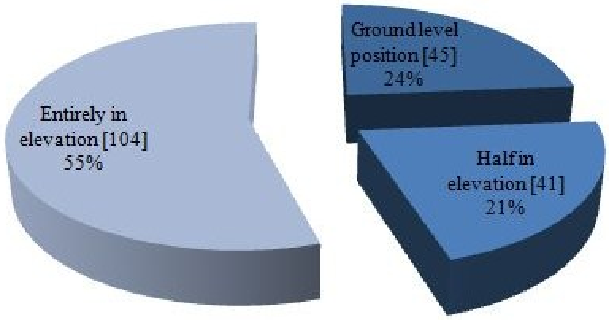


Figure B.6: All crossings: altitude railway

Soil condition At two thirds of all the crossings the condition of the soil is soft. This is easily explained, since the intensity of both roads and railways in the west of the country is higher. An overview of these results are shown in Figure B.7:

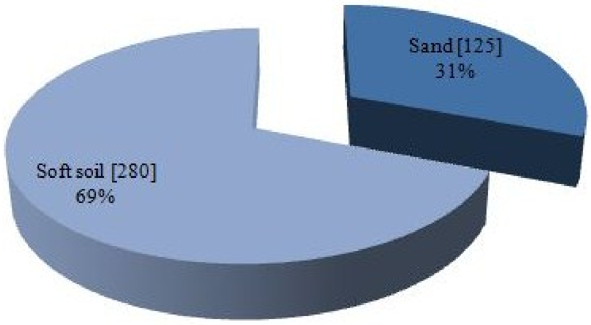


Figure B.7: All crossings: soil conditon

UNDERPASSES

In this section only the results for the underpasses are analyzed.

Location The majority is located in an urban or semi-urban area. This is consistent with the expectations, as grade crossings in cities cause much more discomfort than in a rural area. An overview of these results are shown in Figure B.8:

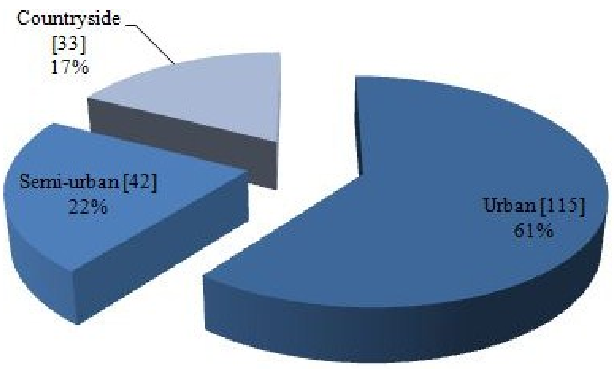


Figure B.8: Underpasses: location

Crossing angle 46% of the underpasses have a crossing angle of 90°, however this doesn't mean that the crossing road is straight. There are situations where the angle is 90° at the point of crossing, but where the approach parts have a curve. An overview of these results are shown in Figure B.9:

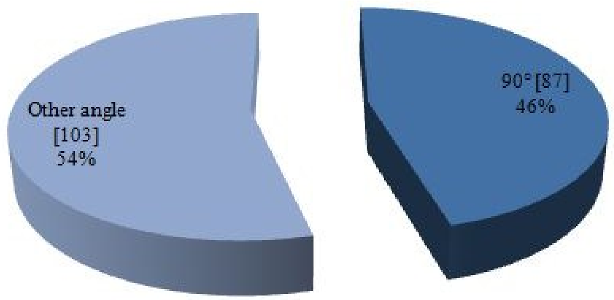


Figure B.9: Underpasses: crossing angle

Number of tracks An overview of these results are shown in Figure B.10:

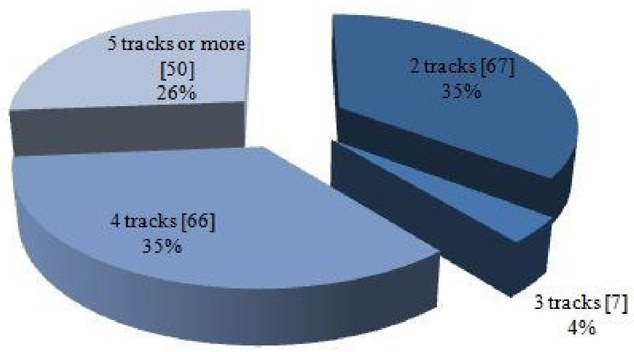


Figure B.10: Underpasses: number of tracks

Road type The majority of the underpasses is designed for a distributor road. Logical, since the hindrance to and distributor road is highest. An overview of these results are shown in Figure B.11:

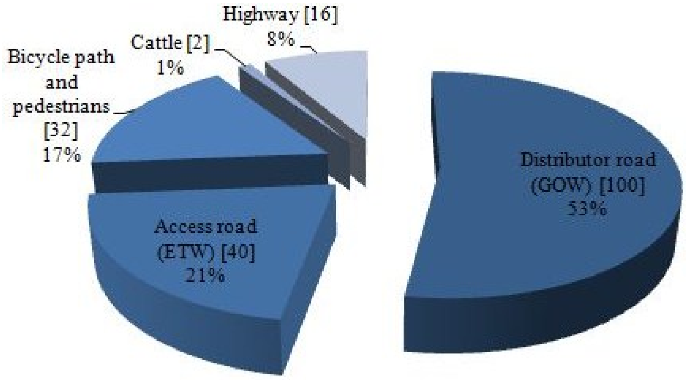


Figure B.11: Underpasses: road type

Altitude railway More than half of the existing underpasses are build under a railway that is entirely in elevation. This is because in urban areas railways are often raised above ground level and in these areas are more underpasses than in the countryside. An overview of these results are shown in Figure B.12:

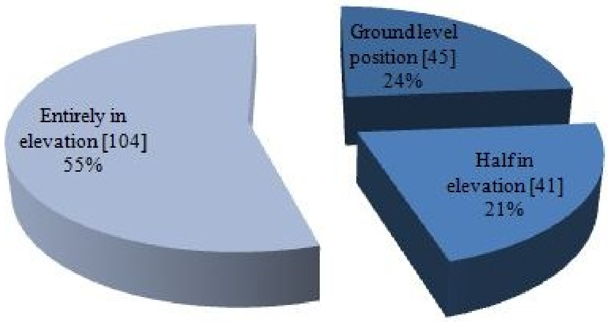


Figure B.12: Underpasses: altitude railway

Soil condition Most of the underpasses are build on a soft soil. This is easy to explain, since most of the underpasses are located in the busy urban area in the western part of The Netherlands. An overview of these results are shown in Figure B.13:

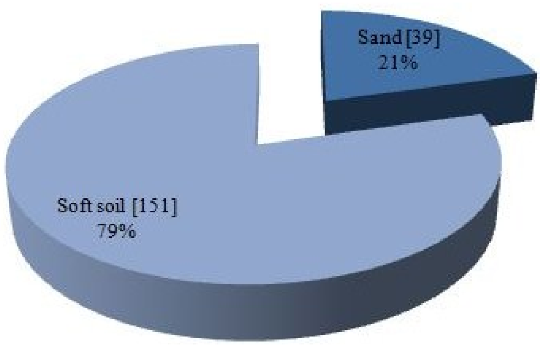


Figure B.13: Underpasses: soil condition

GRADE CROSSINGS

As previously stated grade crossings are the most interesting for this study. In this section the results for grade crossings will be thoroughly analyzed.

Location Almost half of the grade crossings is located in the countryside. Another 21% is located in a semi-urban area. Which means that 69% of the grade crossings are located in an area where it is relatively easy to construct an underpass. Still a third of the grade crossings is in an urban area. It will be hard to find a standardized solution for this group. An overview of these results are shown in Figure B.14:

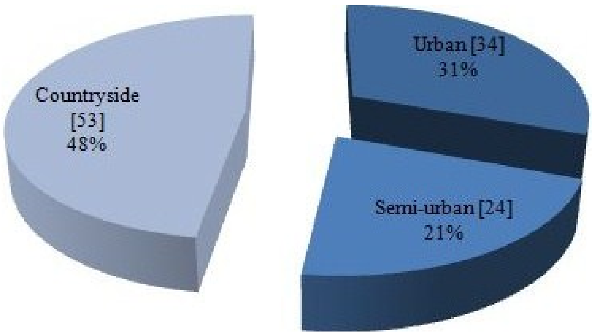


Figure B.14: Grade crossings: location

Crossing angle A crossing angle of 90° is the most favorable situation. Therefore, also the adaptability is studied in a situation in which angle is not 90°. The result is that a total of 81% has a crossing angle of 90° or is adaptable to this angle. A small group of 19% has another angle. The inadaptable angle often appears in an urban area. An overview of these results are shown in Figure B.15:

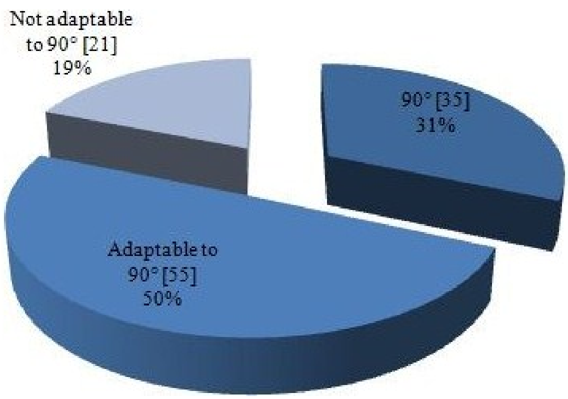


Figure B.15: Grade crossings: crossing angle

Number of tracks Crossings with 4 tracks or more are always underpasses, overpasses or stations. Crossings with 3 tracks are exceptions. 94% of the grade crossings have 2 tracks. Therefore, it can be said that the standard is 2 tracks. An overview of these results are shown in Figure B.16:

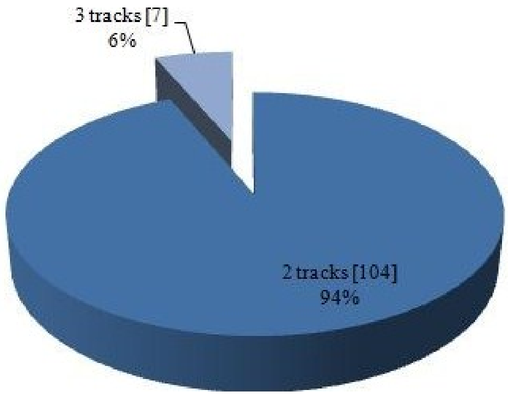


Figure B.16: Grade crossings: number of tracks

Road type The majority of the grade crossings cross with an access road. This is in contrast to the underpasses that have already been built and are designed primarily for distributor roads. The width of these access roads vary between $4m$ and $14m$. An overview of these results are shown in Figure B.17:

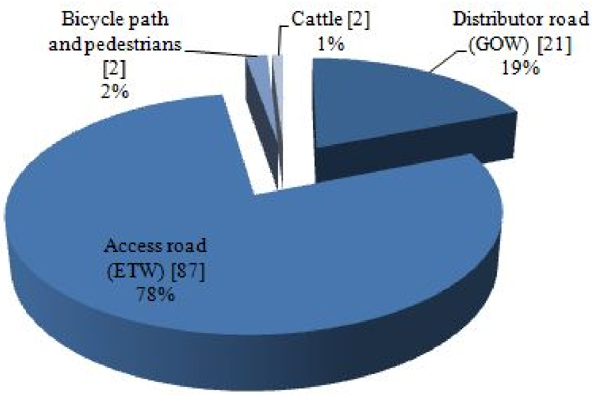


Figure B.17: Grade crossings: road type

Altitude railway Only one percent of the grade crossings is entirely in elevation. This is in contrast to the underpasses that have already been built, where the majority was entirely in elevation. Two thirds of the grade crossings in at ground level position and one third is half in elevation. An overview of these results are shown in Figure B.18:

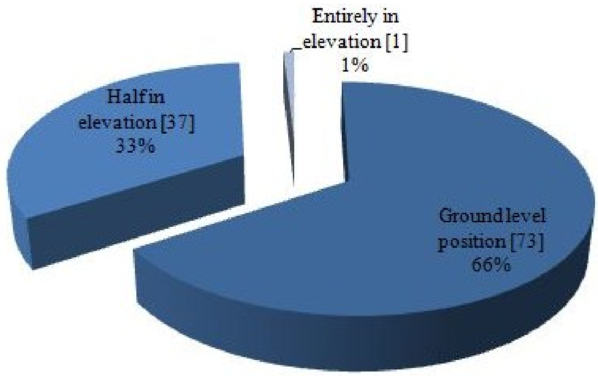


Figure B.18: Grade crossings: altitude railway

Soil condition The division between soft soil and sand is almost equal. This means that neither of the two can be designated as the standard. An overview of the results is shown in Figure B.19:

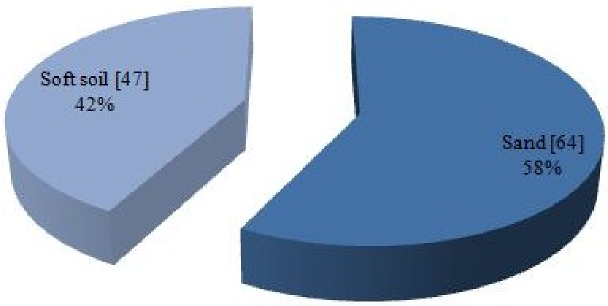


Figure B.19: Grade crossings: soil condition

C

Decomposition by levels

Level 1	**Level 2**	**Level 3**	**Level 4**
Total underpass	Rail crossing section	Deck	Concrete Reinforcement Connection skid plates Fences Overhead lines Railway structure Duct cables and pipes Rainwater drainage Aesthetic elements
		Walls	Concrete Reinforcement Expansion joints Bearing for deck Safety barrier Aesthetic elements
		Walls cyclists- and pedestrians path	Concrete Reinforcement Expansion joints Safety barrier Aesthetic elements
		Temporary cofferdam	Combi wall Girders Anchors
		Floor	Concrete Reinforcement Rainwater drainage Expansion joints Finishing road structure
		Foundation	Piles or anchors Underwater concrete
		Skid plates	Prefab concrete Reinforcement

Level 1	**Level 2**	**Level 3**	**Level 4**
	Open tunnel area	Walls	Concrete Reinforcement Expansion joints Safety barrier Aesthetic elements Fences
		Walls cyclists- and pedestrians path	Concrete Reinforcement Expansion joints Safety barrier Aesthetic elements Fences
		Temporary cofferdam	Sheet piles Girders Anchors or struts
		Floor	Concrete Reinforcement Rainwater drainage Expansion joints Finishing road structure
		Skid plates	Prefab concrete Reinforcement
		Foundation	Piles or anchors Underwater concrete
	Pump room	Deck	Concrete Reinforcement
		Walls	Concrete Reinforcement
		Partition walls	Concrete Reinforcement
		Temporary cofferdam	Sheet piles Girder Anchors or struts
		Floor	Concrete Reinforcement
		Foundation	Piles or anchors Underwater concrete
		Pump installation	

D

Decomposition Level 4

Level 4 – Rail crossing section

Concrete (Deck)

Function Resisting the pressure forces.

Design choice(s) Concrete strength class and the mixture of the concrete.

Reinforcement (Deck)

Function Resisting tension forces and controlling crack width.

Design choice(s) The following needs to be determined:

- the steel strength class;
- the bar diameter;
- the bar spacing and
- further detailing of the reinforcement.

Connection skid plates (Deck)

Function Preventing the skid plates from slipping of the deck.

Design choice(s) Type of connection depends on the supplier of the skid plates.

Fences (Deck)

Function Safety measure to prevent persons from falling of the deck.

Design choice(s) The following needs to be determined:

- the fence type (shape, color, etc. by architect);
- the location of the attachment point on the edge of the deck and
- the structural dimensions of the fence.

Overhead lines (Deck)

Function Provide electricity for the train.

Design choice(s) The system for the overhead lines is standardized. The only thing that needs to be determined is the location of the attachment points.

Railway structure (Deck)

Function Providing a track for the train to run over.

Design choice(s) The railway structure is standardized, but there are some options. There is a choice between a slab track and a ballasted track.

DUCT CABLES AND PIPES (DECK)

Function Providing a space for the cables and pipes, that are parallel to the railway track, to pass through the underpass.

Design choice(s) The following needs to be determined:

- the width of the ducts on each side and
- the depth of the ducts.

RAINWATER DRAINAGE (DECK)

Function Draining the rainwater on the deck.

Design choice(s) The following needs to be determined:

- the number of wells and there location on the deck;
- the location of the drainage pipes and
- the diameters of the drainage pipes.

AESTHETIC ELEMENTS (DECK)

Function To give a certain identity or beauty to underpass and make the deck look more slender.

Design choice(s) The first thing that should be decided is if it's desirable to have such aesthetic elements. If so, the following needs to be determined:

- the shape, color and position of these elements (by architect) and
- the way of connecting them to the edge of the deck.

CONCRETE (WALLS)

Function Resisting the pressure forces.

Design choice(s) Concrete strength class and the mixture of the concrete.

REINFORCEMENT (WALLS)

Function Resisting tension forces and controlling crack width.

Design choice(s) The following needs to be determined:

- the steel strength class;
- the bar diameter;
- the bar spacing and
- further detailing of the reinforcement.

EXPANSION JOINTS (WALLS)

Function Providing the possibility for the concrete walls to expend and to shrink without major cracking of the concrete, while the joint remains a watertight seal.

Design choice(s) The joints are standardized and produced in a factory. The only thing that needs to be determined is the type of joint.

BEARING FOR DECK (WALLS)

Function Creating an interface between the deck and the supporting walls.

Design choice(s) There are many ways to connect the deck to the walls, but most important choice if the deck and the walls are monolith connected or that the deck is free.

Safety barrier (Walls)

Function In case of a collision be a guide structure.

Design choice(s) The shape of the concrete barriers is often the same on the side of the road (front side). On the other side (back side) it depends on the shape of the wall. The safety barrier can be constructed with prefabricated elements, which are placed against the walls. The space between the walls and the elements is than filled with concrete. Or it can be cast in-situ. This is usually done with a slipformpaver.

Aesthetic elements (Walls)

Function To give a certain identity to the underpass, to make it look friendlier for social security or to create a certain beauty.

Design choice(s) The first choice is if it's desirable to place such element. If so, the shape and color should be chosen (by architect). The way that they are connected should also be decided.

Combi wall (Temporary cofferdam)

Function Resisting both vertical and horizontal forces during constructing. Creating a watertight seal during constructing. Providing a rail system so the deck can be slided into place.

Design choice(s) It's stated in the name of this section that is it must be combi wall, but in case of a large resistance in the soil just sheet piles might also be sufficient. Combi wall or sheets piles, the following needs to be determined:

- the steel strength class;
- the profile type and
- the (sheet) pile tip level.

Girders (Temporary cofferdam)

Function Distributing the horizontal forces over the anchors.

Design choice(s) The following needs to be determined:

- the steel strength class;
- the type of girder (HEA, HEB, HEM, one beam or two beams, etc.);
- the dimensions of the girder and
- the location of the girder.

Anchors (Temporary cofferdam)

Function Providing a support at the topside of the cofferdam.

Design choice(s) The following needs to be determined:

- the steel strength class;
- the type of anchors;
- the spacing between the anchors;
- the thickness of the anchors;
- the angle of with they penetrate the soil and
- the length of the anchors.

Concrete (Floor)

Function Resisting the pressure forces.

Design choice(s) Concrete strength class and the mixture of the concrete.

REINFORCEMENT (FLOOR)

Function Resisting tension forces and controlling crack width.

Design choice(s) The following needs to be determined:

- the steel strength class;
- the bar diameter;
- the bar spacing and
- further detailing of the reinforcement.

RAINWATER DRAINAGE (FLOOR)

Function Draining the rainwater in the tunnel.

Design choice(s) The following needs to be determined:

- the number of wells and there location in the floor;
- the location of the drainage pipes and
- the diameters of the drainage pipes.

EXPANSION JOINTS (FLOOR)

Function Providing the possibility for the concrete floor to expend and to shrink without major cracking of the concrete, while the joint remains a watertight seal.

Design choice(s) The joints are standardized and produced in a factory. The only thing that needs to be determined is the type of joint. The joint of the floor and the walls will align.

FINISHING ROAD STRUCTURE (FLOOR)

Function Providing both a smooth as a rough surface for the traffic and giving identity to the road.

Design choice(s) There are regulation for the design choices regarding the road structures (by CROW in the Netherlands). The following needs to be decided:

- the type of asphalt;
- the thickness of the asphalt and
- the lines on the road.

PILES OR ANCHORS (FOUNDATION)

Function Bearing vertical forces, both upwards as downwards.

Design choice(s) The first choice that needs to be made is if piles or anchors will be used, depending on the forces they need to resist. Further the following needs to be determined:

- the material properties;
- the dimensions;
- the grid of spacing between the piles or anchors and
- the pile tip level.

UNDERWATER CONCRETE (FOUNDATION)

Function Creating a watertight seal in combination with the cofferdam. Being a counterweight for the upward pressure of the water.

Design choice(s) The following needs to be decided:

- the mixture of the concrete and
- the thickness of the concrete layer.

Prefab concrete (Skid plates)

Function Resisting the pressure forces.

Design choice(s) Concrete strength class and the mixture of the concrete.

Reinforcement (Skid plates)

Function Resisting tension forces and controlling crack width.

Design choice(s) The following needs to be determined:

- the steel strength class;
- the bar diameter;
- the bar spacing and
- further detailing of the reinforcement.

Level 4 – Open tunnel section

Concrete (Walls)

Function Resisting the pressure forces.

Design choice(s) Concrete strength class and the mixture of the concrete.

Reinforcement (Walls)

Function Resisting tension forces and controlling crack width.

Design choice(s) The following needs to be determined:

- the steel strength class;
- the bar diameter;
- the bar spacing and
- further detailing of the reinforcement.

Expansion joints (Walls)

See §D.

Safety barrier (Walls)

See §D.

Aesthetic elements (Walls)

See §D.

Fences (Walls)

Function Safety measure to prevent persons from falling into the open part of the tunnel.

Design choice(s) The following needs to be determined:

- the fence type (shape, color, etc. by architect);
- the location of the attachment point on the edge of the deck and
- the structural dimensions of the fence.

Concrete (Walls C and P path)

See §D.

Reinforcement (Walls C and P path)

See §D.

Expansion joints (Walls C and P path)
See §D.

Safety barrier (Walls C and P path)
See §D.

Aesthetic elements (Walls C and P path)
See §D.

Fences (Walls)
See §D.

Sheet piles (Temporary cofferdam)
Function Retaining horizontal forces from the soil and creating a watertight seal.

Design choice(s) The following needs to be determined:

- the steel strength class;
- the profile type and
- the (sheet) pile tip level.

Girders (Temporary cofferdam)
See §D.

Anchors or struts (Temporary cofferdam)
See §D.

Concrete (Floor)
Function Resisting the pressure forces.

Design choice(s) Concrete strength class and the mixture of the concrete.

Reinforcement (Floor)
Function Resisting tension forces and controlling crack width.

Design choice(s) The following needs to be determined:

- the steel strength class;
- the bar diameter;
- the bar spacing and
- further detailing of the reinforcement.

Rainwater drainage (Floor)
See §D.

Expansion joints (Floor)
See §D.

Finishing road structure (Floor)
See §D.

Prefab concrete (Skid plates)
Function Resisting the pressure forces.

Design choice(s) Concrete strength class and the mixture of the concrete.

Reinforcement (Skid plates)

Function Resisting tension forces and controlling crack width.

Design choice(s) The following needs to be determined:

- the steel strength class;
- the bar diameter;
- the bar spacing and
- further detailing of the reinforcement.

Piles or anchors (Foundation)

Function Bearing vertical forces, both upwards as downwards.

Design choice(s) The foundation in the open tunnel section may differ from that of the rail crossing section. The first choice that needs to be made is if piles or anchors will be used, depending on the forces they need to resist. Further the following needs to be determined:

- the material properties;
- the dimensions;
- the grid of spacing between the piles or anchors and
- the pile tip level.

Underwater concrete (Foundation)

Function The foundation in the open tunnel section may differ from that of the rail crossing section. Creating a watertight seal in combination with the cofferdam. Being a counterweight for the upward pressure of the water.

Design choice(s) The following needs to be decided:

- the mixture of the concrete and
- the thickness of the concrete layer.

Level 4 – Pump room

Concrete (Deck)

Function Resisting the pressure forces.

Design choice(s) Concrete strength class and the mixture of the concrete.

Reinforcement (Deck)

Function Resisting tension forces and controlling crack width.

Design choice(s) The following needs to be determined:

- the steel strength class;
- the bar diameter;
- the bar spacing and
- further detailing of the reinforcement.

Concrete (Walls)

Function Resisting the pressure forces.

Design choice(s) Concrete strength class and the mixture of the concrete.

REINFORCEMENT (WALLS)

Function Resisting tension forces and controlling crack width.

Design choice(s) The following needs to be determined:

- the steel strength class;
- the bar diameter;
- the bar spacing and
- further detailing of the reinforcement.

SHEET PILES (TEMPORARY COFFERDAM)

Function Retaining horizontal forces from the soil and creating a watertight seal.

Design choice(s) The following needs to be determined:

- the steel strength class;
- the profile type and
- the (sheet) pile tip level.

GIRDERS (TEMPORARY COFFERDAM)

Function Distributing the horizontal forces over the anchors or struts.

Design choice(s) The following needs to be determined:

- the steel strength class;
- the type of girder (HEA, HEB, HEM, one beam of two beams, etc.);
- the dimensions of the girder and
- the location of the girder.

ANCHORS OR STRUTS (TEMPORARY COFFERDAM)

Function Providing a support at the topside of the cofferdam.

Design choice(s) The first choice that needs to be made is if anchors or struts are applied. The following needs to be determined when anchors are chosen:

- the steel strength class;
- the type of anchors;
- the spacing between the anchors;
- the thickness of the anchors;
- the angle of with they penetrate the soil and
- the length of the anchors.

The following needs to be determined when struts are chosen:

- the steel strength class;
- the struts;
- the spacing between the struts;
- the dimensions of the struts and
- the way that they are connected to the girder.

CONCRETE (FLOOR)

Function Resisting the pressure forces.

Design choice(s) Concrete strength class and the mixture of the concrete.

REINFORCEMENT (FLOOR)

Function Resisting tension forces and controlling crack width.

Design choice(s) The following needs to be determined:

- the steel strength class;
- the bar diameter;
- the bar spacing and
- further detailing of the reinforcement.

Piles or anchors (Foundation)

Function Bearing vertical forces, both upwards as downwards.

Design choice(s) The foundation in the open tunnel section may differ from that of the rail crossing section. The first choice that needs to be made is if piles or anchors will be used, depending on the forces they need to resist. Further the following needs to be determined:

- the material properties;
- the dimensions;
- the grid of spacing between the piles or anchors and
- the pile tip level.

Underwater concrete (Foundation)

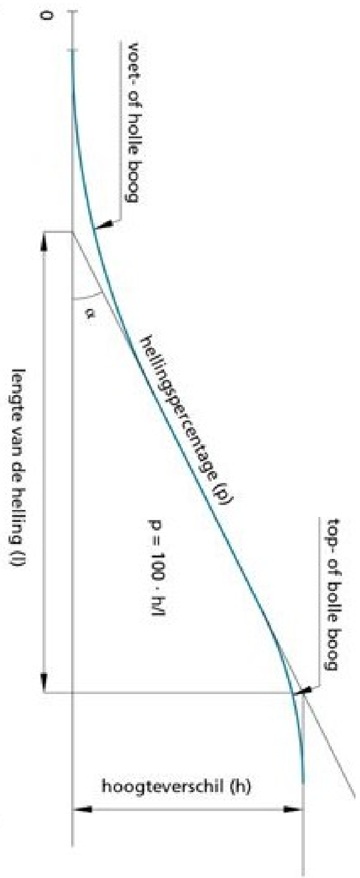
Function The foundation in the open tunnel section may differ from that of the rail crossing section. Creating a watertight seal in combination with the cofferdam. Being a counterweight for the upward pressure of the water.

Design choice(s) The following needs to be decided:

- the mixture of the concrete and
- the thickness of the concrete layer.

E

Tunnel length access roads



Access road 30km/h			
Input			
Height		H_tot	6 m
Minimum upward curve		R_top	185 m
Minimum downward curve		R_bot	35 m
Conditions			
Smooth transition between arcs and slopes			
Maximun slope			7 %
Slope or not (alpha max > alpha = slope needed)			
alpha	0,2341 rad		
alpha max	0,0699 rad	-> slope needed	
Output			
	Length	Height	
Downward curve	2,44 m	0,09 m	
Upward curve	12,92 m	0,45 m	
Slope	78,04 m	5,46 m	
Total	93,40 m	6,00 m	
Overdimensioned	165 %		

Access road 60km/h			
Input			
Height		H_tot	6 m
Minimum upward curve		R_top	1250 m
Minimum downward curve		R_bot	550 m
Conditions			
Smooth transition between arcs and slopes			
Maximun slope			6 %
Slope or not (alpha max > alpha = slope needed)			
alpha	0,0817 rad		
alpha max	0,0599 rad	-> slope needed	
Output			
	Length	Height	
Downward cu	32,94 m	0,99 m	
Upward curve	74,87 m	2,24 m	
Slope	46,15 m	2,77 m	
Total	153,95 m	6,00 m	

F

Thickness walls rail crossing section

Title

Thickness of the walls of the rail crossing section and the relation to:

-groundwater level

-concrete straingth class

Name

Koen van Viegen

Date

30 October 2014

Starting points

Calculations based on:	Eurocode 1 part 2
	Eurocode 2
	OVS00030-6-V004
	ROK 1.2

Safety factors

Factor for permanent loads from soil and water:	γ_per =	1,3
Facter for temporary loads:	γ_tem =	1,65

Material properties

Concrete:

Class	f_ck (MPa)	f_ck,cube (MPa)	E_cm (GPa)
C12/15	12	15	27
C16/20	16	20	29
C20/25	20	25	30
C25/30	25	30	31
C30/37	30	37	33
C35/45	35	45	34
C40/50	40	50	35
C45/55	45	55	36
C50/60	50	60	37

Reinforcement:

Class 500B

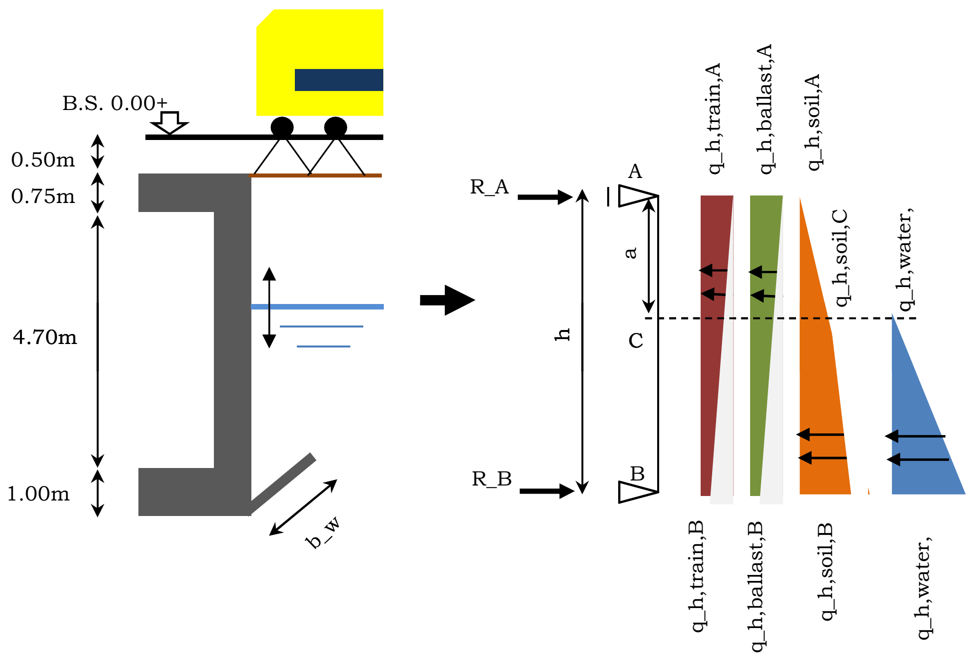
Load properties

Load type	γ [kN/m3]
Soil wet	20
Soil dry	18
Water	10
Gravel railway	18

Load type	Q [kN/m2]
Train*	37,5

*) NEN-EN1991-2 Table 6.1: q_vk =150 kN/m spreads over 4m

Static schematization



h =	5,58	m	
a =	var.	m	
b_w =	1	m	(for calculation)

Loads

Horizontal coficient for soil presure	ψ_h =	0,5
Total width of the track	w_track =	12 m

$q_{h,train,A} = Q_{train} * b_w * \psi_h$
$q_{h,train,B} = (Q_{train} * b_w * w_{track} / (w_{track} + h))\ \psi_h$
$q_{h,ballast,A} = \gamma_{gravel} * 0{,}50 * b_w * \psi_h$
$q_{h,ballast,B} = (\gamma_{gravel} * 0{,}50 * b_w * w_{track} / (w_{track} + h))\ \psi_h$
$q_{h,water,B} = (h - a)\ \gamma_{water} * b_w$
$q_{h,water,C} = 0$
$q_{h,soil,A} = 0$
$q_{h,soil,B} = q_{h,soil,C} + (\gamma_{soil,wet} - \gamma_{water}) * b_w * (h - a) * \psi_h$
$q_{h,soil,C} = \gamma_{soil,dry} * b_w * a * \psi_h$

q_h,train,A =	18,75 kN/m2
q_h,train,B =	12,80 kN/m2
q_h,ballast,A =	4,50 kN/m2
q_h,ballast,B =	3,07 kN/m2
q_h,water,B =	0,00 kN/m2
q_h,soil,A =	0,00 kN/m2

a [m]	q_h,water,B [kN/m2]	q_h,soil,B [kN/m2]	q_h,soil,C [kN/m2]
0,00	55,80	27,90	0,00
0,50	50,80	29,90	4,50
1,00	45,80	31,90	9,00
1,50	40,80	33,90	13,50
2,00	35,80	35,90	18,00
2,50	30,80	37,90	22,50
3,00	25,80	39,90	27,00
3,50	20,80	41,90	31,50
4,00	15,80	43,90	36,00
4,50	10,80	45,90	40,50
5,00	5,80	47,90	45,00
5,50	0,80	49,90	49,50

Shear force

The reaction force R_B will be the critical shear force.

$R_B = R_{B,train} * \gamma_{tem} + (R_{B,ballast} + R_{B,soil} + R_{B,water}) * \gamma_{per}$

$R_{B,train} = q_{h,train,B} * h * 0,5 + (q_{h,train,A} - q_{h,train,B}) * (1 / 12) * h^2$

$R_{B,ballast} = q_{h,ballast,B} * h * 0,5 + (q_{h,ballast,A} - q_{h,ballast,B}) * (1 / 12) * h^2$

$R_{B,soil} = q_{h,soil,C} * h * 0,5 - q_{h,soil,C} * a^2 * 0,5 * (1/3) / h +$

$\quad (q_{h,soil,B} - q_{h,soil}) (h - a) * 0,5 * (h - (1 / 3) * (h - a)) / h$

$R_{B,water} = q_{h,water,B} * (h-a) * 0,5 (h - (1 / 3) (h - a)) / h$

$R_{B,train} =$ 51,1502 kN

$R_{B,ballast} =$ 12,276 kN

a [m]	R_B,soil [kN]	R_B,water [kN]	**R_B,d** **[kN]**
0,00	51,89	103,79	**302,74**
0,50	57,46	89,88	**291,89**
1,00	62,93	76,19	**281,21**
1,50	68,23	62,95	**270,89**
2,00	73,26	50,38	**261,08**
2,50	77,93	38,70	**251,98**
3,00	82,15	28,15	**243,75**
3,50	85,83	18,94	**236,57**
4,00	88,89	11,30	**230,61**
4,50	91,23	5,46	**226,04**
5,00	92,76	1,62	**223,06**
5,50	93,40	0,03	**221,81**

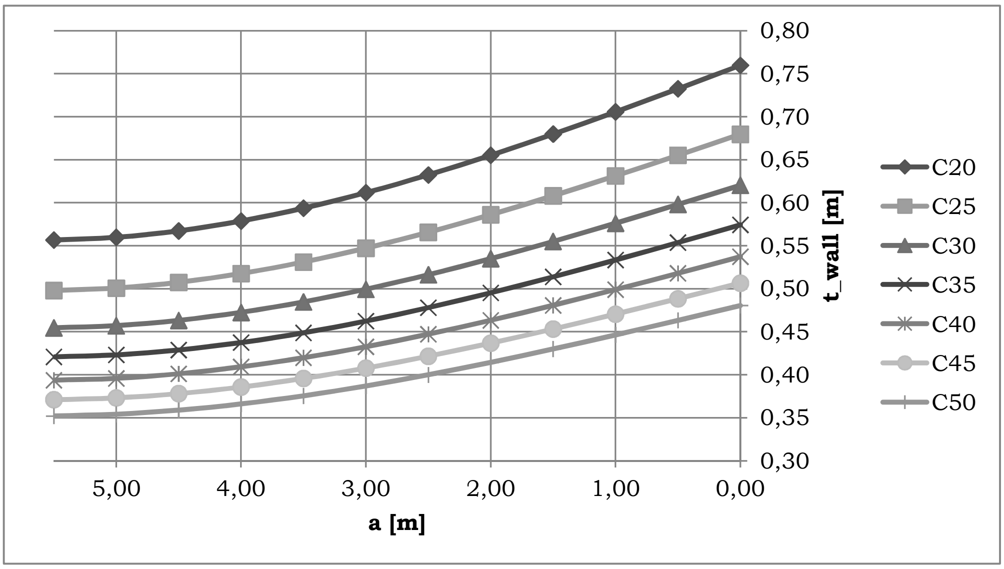
Wall thickness (t_wall)
Eurocode 2 gives the following equation for the shear resistance:

$V_{Rd,c} = v_{min} * b_w * d$

$v_{min} = 0{,}035 * k^{(3/2)} * f_{ck}^{(1/2)}$
$k = 1 + \sqrt{(200/d)} \leq 2{,}0$
$d \approx 0{,}9 * t_{wall}$

$V_{Rd,c} \geq R_{B,d}$
$t_{wall} \geq R_{B,d} / (v_{min} * b_w * 0{,}9)$

t_wall [m]		f_ck [MPa]						
		20	25	30	35	40	45	50
a [m]	0,00	0,76	0,68	0,62	0,57	0,54	0,51	0,48
	0,50	0,73	0,66	0,60	0,55	0,52	0,49	0,46
	1,00	0,71	0,63	0,58	0,53	0,50	0,47	0,45
	1,50	0,68	0,61	0,56	0,51	0,48	0,45	0,43
	2,00	0,66	0,59	0,54	0,50	0,46	0,44	0,41
	2,50	0,63	0,57	0,52	0,48	0,45	0,42	0,40
	3,00	0,61	0,55	0,50	0,46	0,43	0,41	0,39
	3,50	0,59	0,53	0,48	0,45	0,42	0,40	0,38
	4,00	0,58	0,52	0,47	0,44	0,41	0,39	0,37
	4,50	0,57	0,51	0,46	0,43	0,40	0,38	0,36
	5,00	0,56	0,50	0,46	0,42	0,40	0,37	0,35
	5,50	0,56	0,50	0,45	0,42	0,39	0,37	0,35



G

Critical groundwater level

Title
Critical groundwater level for floating of the tunnel

Name
Koen van Viegen

Date
17-nov-14

Starting points

Calculations based on: Eurocode 1 part 2
Eurocode 2

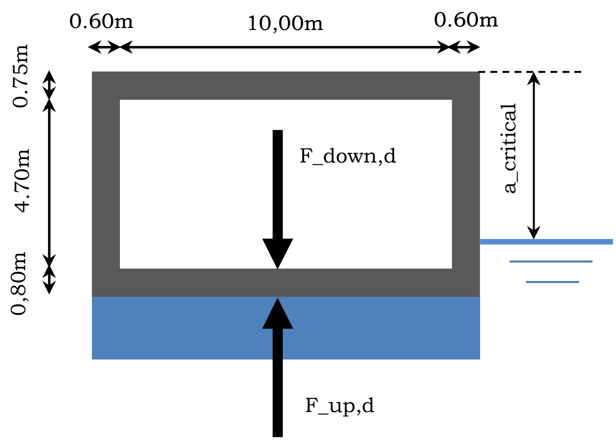
Safety factors

Factor for permanent loads from soil and water:	γ_per =	1,3
Facter for positive permanent loads	γ_per,pos =	0,9

Load properties

Load type	γ [kN/m3]
Water	10
Concrete	25

Static schematication



Assumptions

1 - Groundwater level will never be higher than the top of the deck
2 - Thickness of wall and deck are based of previous calculation, see Thesis
3 - Thickness of the floor is an assumption
4 - The positive effect of the deck and the ballast layer on the deck is neglected

Stability

$F_{up,d} = \gamma_{per} * \gamma_{water} * (h_{wall} + t_{deck} + t_{floor} - a_{critical}) * (2\ t_{wall} + w_{tunnel})$
$F_{down,d} = \gamma_{per,pos} * \gamma_{concrete} * (h_{wall} * t_{wall} + (w_{tunnel} + 2\ t_{wall}) * t_{floor})$

h_wall =	4,70	m
t_wall =	0,60	m
t_deck =	0,75	m
t_floor =	0,80	m
w_tunnel =	10,00	m

Demand:

$$\text{U.C.} \quad \frac{F_{up,d}}{F_{down,d}} \quad \leq \quad 1{,}00$$

Goal seek gives:

F_up,d =	265,05	kN/m
F_down,d =	265,05	kN/m

with:

a_critical =	4,43	m

H

Influence of the foundation on the floor and walls

Title
Influence of diffent foundation types on
-floor thinkness
-reinforcement wall
-reinforcement floor

Name
Koen van Viegen

Date
29-nov-14

Software
MS Excel
MatrixFrame

Starting points

Calculations based on:	Eurocode 1 part 2
	Eurocode 2
	OVS00030-6-V004
	ROK 1.2

Safety factors

Factor for permanent loads from soil and water:	γ_{per1} =	1,3
Factor for permanent loads:	γ_{per2} =	1,5
Facter for temporary loads:	γ_{tem} =	1,65

Material properties
Concrete:

Class	f_ck (MPa)	f_ck,cube (MPa)	f_cd (MPa)	E_cm (GPa)	
C12/15	12	15	8	27	
C16/20	16	20	11	29	
C20/25	20	25	13	30	
C25/30	25	30	17	31	
C30/37	30	37	20	33	
C35/45	35	45	23	34	Used for these calculations
C40/50	40	50	27	35	
C45/55	45	55	30	36	
C50/60	50	60	33	37	

Reinforcement:

Class 500B

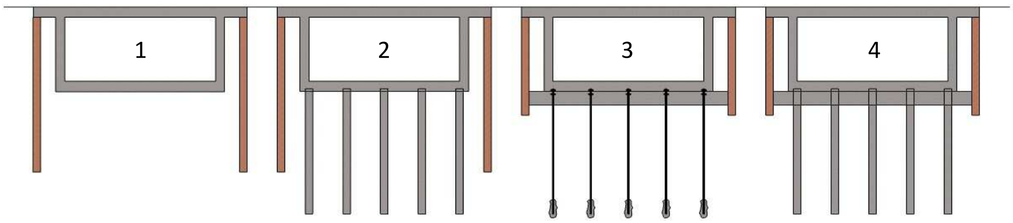
Load proparties

Load type	γ [kN/m3]
Soil wet	20
Soil dry	18
Water	10
Gravel railway	18
Reinfor. Concrete	25

Load type	Q (SW/2) [kN/m2]
Train*	37,5

*) NEN-EN1991-2 Table 6.1: q_vk =150 kN/m spreads over 4m

Foundation types



1 - Shallow foundation
2 - Pile foundation
3 - Underwater concrete floor + tension anchors
4 - Underwater concrete floor + piles

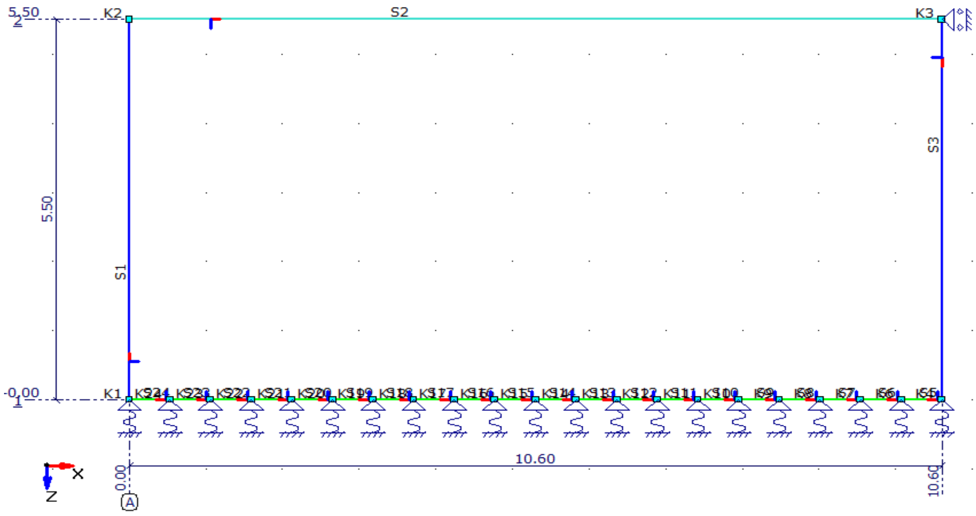
Assumptions
Wall thickness = 0.6 m
Deck thickness = 0.75 m
Floor thickness = 0.80 m
Centre-to-centre distance piles and anchors in both directions = 2.50 m

Because infromation about the soil is missing the stiffness of the soil for the shallow foundation, as the stiffness of the piles and anchors ought to be assumed. A variation of -25% and +25% is included in the calculations. This leads to the following stiffnesses:

Stiffness of the soil for shallow foundation = 0.075; 0.100 and 0.125 N/mm^3
Stiffness of the piles and anchors = 75; 100 and 125 MN/mm

Static schematisation

Shallow foundation

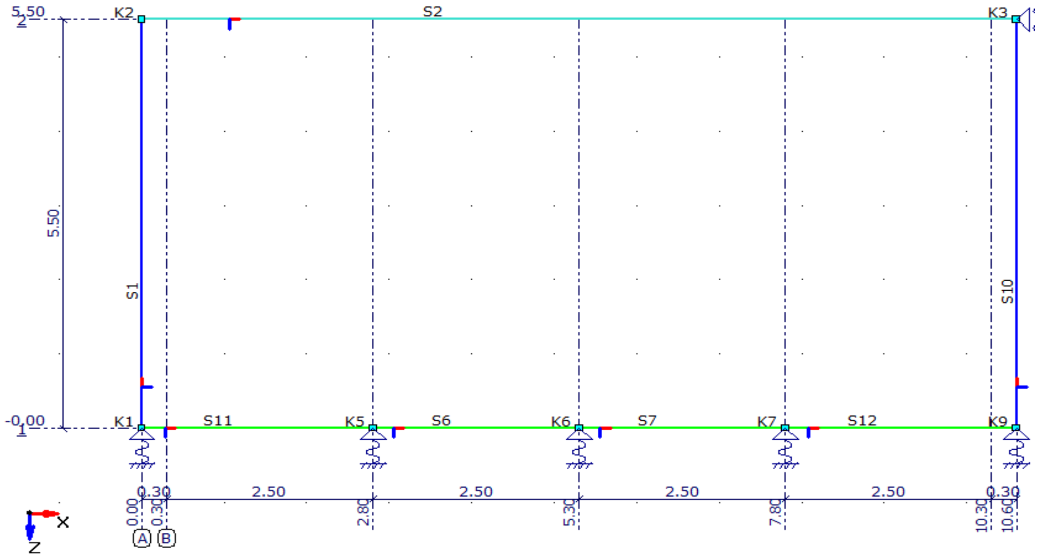


The cross-section has a width of 1.0m in the Y-direction. The bedding is modelled with a set of 21 spings. The stiffness of the springs at the edge is half of the ones in between. The following stiffnesses are used for the springs in the middle:

k_bedding1 = (10.6m / 20) * 1.0m * 0.075N/mm^3 =	39.750 kN/m
k_bedding2 = (10.6m / 20) * 1.0m * 0.100N/mm^3 =	53.000 kN/m
k_bedding3 = (10.6m / 20) * 1.0m * 0.125N/mm^3 =	66.250 kN/m

Pile foundation / Underwater concrete floor + piles and tensions anchors

Because the stiffness of anchors and piles assumed to be the same one calculation for both types will do.

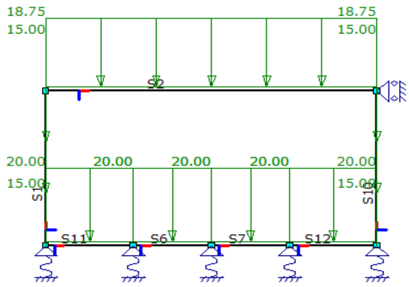


The centre-to-centre distance of the piles and anchors is assumed to be 2.50m. This to prevent the unreinforcend underwater concrete floor from cracking. In the model the outer two piles are placed directly under the wall. This is to prevent MatrixFrame from giving high peak forces that actualy don't occur. Just as with the shallow foundation the width of the cross-section in the Y-direction is 1.0m. This leads to the following stiffnesses of the spings:

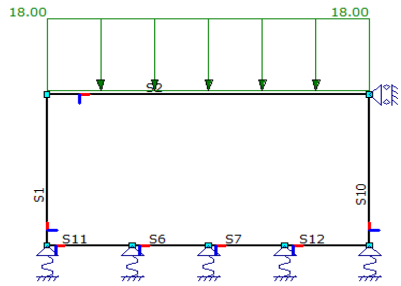
k_pile1 = 75MN/m / 2.5m =	30.000 kN/m
k_pile2 = 100MN/m / 2.5m =	40.000 kN/m
k_pile3 = 125MN/m / 2.5m =	50.000 kN/m

Load cases

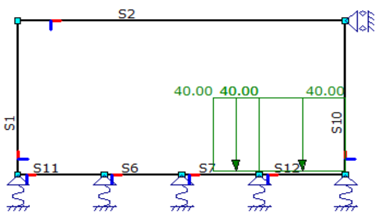
L.C.1 = Self weight



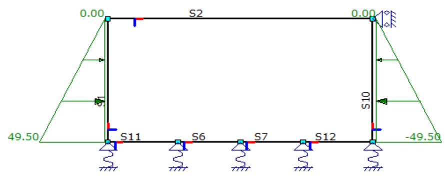
L.C.2 = Ballast



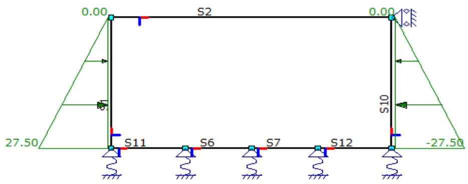
L.C.3 = Bicycle path



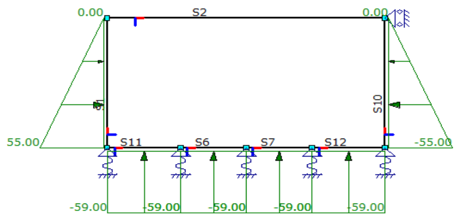
L.C.4 = Horizontal soil pressure dry



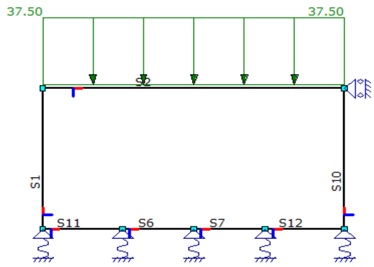
L.C.5 = Horizontal soil pressure wet



L.C.6 = Water pressure high



L.C.7 = Dynamic traffic load train



For symplicity reasons dynamic amplification factors for the traffic load are not taken into account.

Load combinations ULS

Shallow foundation

	L.Com.1	L.Com.2
L.C.1 = Self weight	1,50	1,50
L.C.2 = Ballast	1,50	1,50
L.C.3 = Bicycle path	1,50	1,50
L.C.4 = Horizontal soil pressure dry	1,30	0,90
L.C.5 = Horizontal soil pressure wet		
L.C.6 = Water pressure high		
L.C.7 = Dynamic traffic load train	1,65	1,65

Pile foundation

	L.Com.3	L.Com.4
L.C.1 = Self weight	1,50	1,50
L.C.2 = Ballast	1,50	1,50
L.C.3 = Bicycle path	1,50	1,50
L.C.4 = Horizontal soil pressure dry	1,30	0,90
L.C.5 = Horizontal soil pressure wet		
L.C.6 = Water pressure high		
L.C.7 = Dynamic traffic load train	1,65	1,65

Underwater concrete + piles or anchors

	L.Com.5	L.Com.6	L.Com7	L.Com8
L.C.1 = Self weight	0,90	0,90	1,50	1,50
L.C.2 = Ballast			1,50	1,50
L.C.3 = Bicycle path	0,90	0,90	1,50	1,50
L.C.4 = Horizontal soil pressure dry				
L.C.5 = Horizontal soil pressure wet	1,30	0,90	1,30	0.9
L.C.6 = Water pressure high	1,30	1,30	1,30	1,30
L.C.7 = Dynamic traffic load train			1,65	1,65

Load combinations SLS

Shallow foundation

	L.Com.1	L.Com.2
L.C.1 = Self weight	1,00	1,00
L.C.2 = Ballast	1,00	1,00
L.C.3 = Bicycle path	1,00	1,00
L.C.4 = Horizontal soil pressure dry	1,00	0,90
L.C.5 = Horizontal soil pressure wet		
L.C.6 = Water pressure high		
L.C.7 = Dynamic traffic load train	1,00	1,00

Pile foundation

	L.Com.3	L.Com.4
L.C.1 = Self weight	1,00	1,00
L.C.2 = Ballast	1,00	1,00
L.C.3 = Bicycle path	1,00	1,00
L.C.4 = Horizontal soil pressure dry	1,00	0,90
L.C.5 = Horizontal soil pressure wet		
L.C.6 = Water pressure high		
L.C.7 = Dynamic traffic load train	1,00	1,00

Underwater concrete + piles or anchors

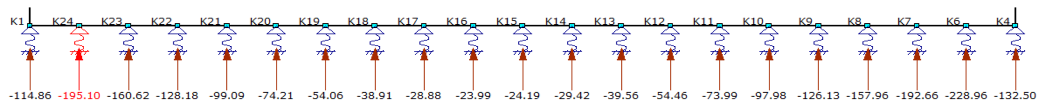
	L.Com.5	L.Com.6	L.Com7	L.Com8
L.C.1 = Self weight	1,00	0,90	1,00	1,00
L.C.2 = Ballast			1,00	1,00
L.C.3 = Bicycle path	1,00	0,90	1,00	1,00
L.C.4 = Horizontal soil pressure dry				
L.C.5 = Horizontal soil pressure wet	1,00	1,00	1,00	0,90
L.C.6 = Water pressure high	1,00	1,00	1,00	1,00
L.C.7 = Dynamic traffic load train			1,00	1,00

Reaction forces

<u>Shallow foundation</u>

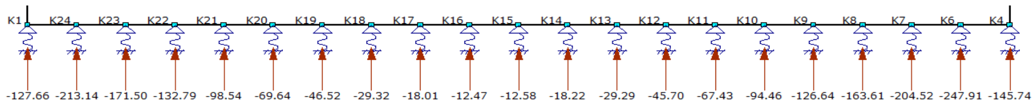
Stiffness = k_bedding1

Sum of vertical forces	2076 kN	→	O.K.
Sum of reaction forces	-2076 kN		



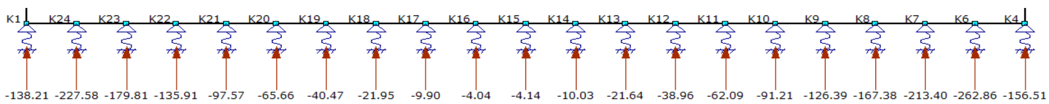
Stiffness = k_bedding2

Sum of vertical forces	2076 kN	→	O.K.
Sum of reaction forces	-2076 kN		



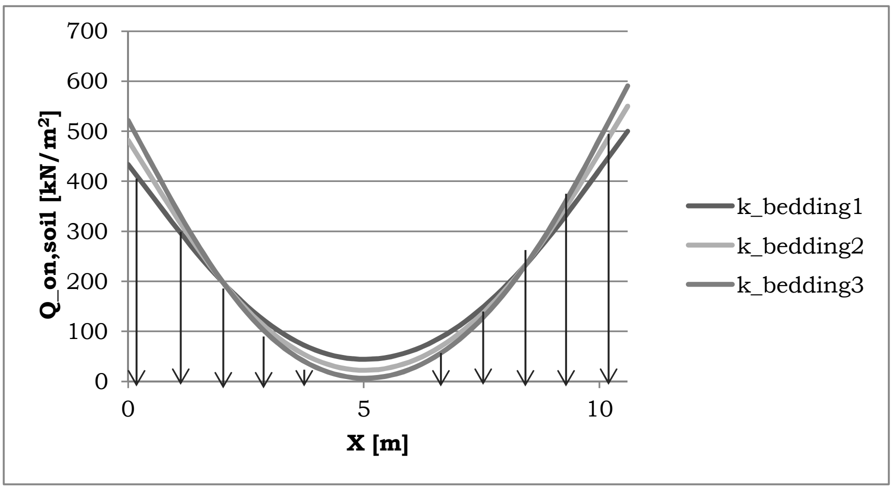
Stiffness = k_bedding3

Sum of vertical forces	2076 kN	→	O.K.
Sum of reaction forces	-2076 kN		



Pressure distribution on the soil

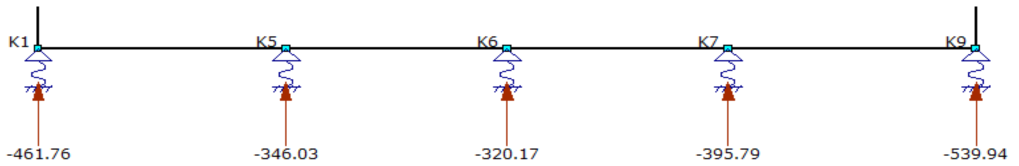
This leads to the following presure distribution on the soil:



<u>Pile foundation</u>

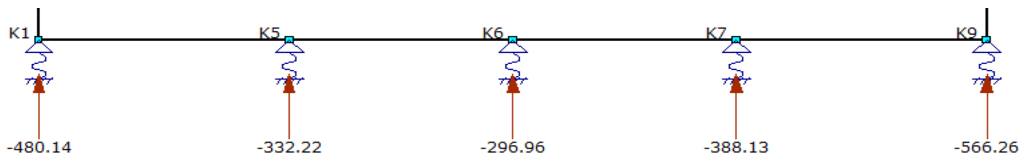
Stiffness = k_pile1

Sum of vertical forces	2064 kN	→	O.K.
Sum of reaction forces	-2064 kN		



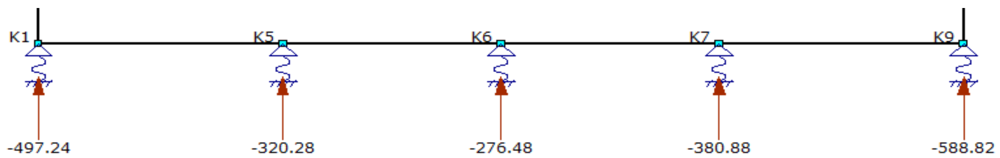
Stiffness = k_pile2

Sum of vertical forces	2064 kN	→	O.K.
Sum of reaction forces	-2064 kN		



Stiffness = k_pile3

Sum of vertical forces	2064 kN	→	O.K.
Sum of reaction forces	-2064 kN		



Resumé

The maximum occuring pressure load on a pile (F_pile,max,down) is:

F_pile,max,down = 589kN * 2,5m = 1473 kN

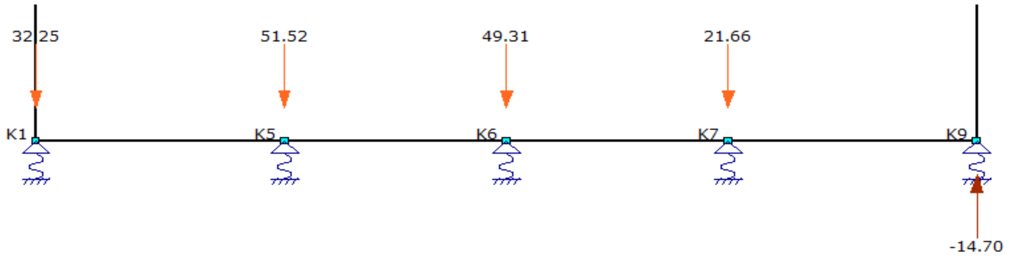
The maximum occuring load on a pile (F_pile,max,punch) that has to be checked for punching shear resistance:

F_pile,max = 395kN * 2,5m = 988 kN

Underwater concrete + piles or anchors

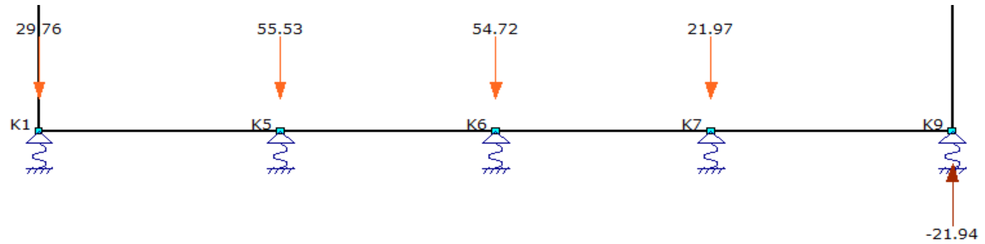
Stiffness = k_pile1

Sum of vertical forces	-140 kN	→	O.K.
Sum of reaction forces	140 kN		



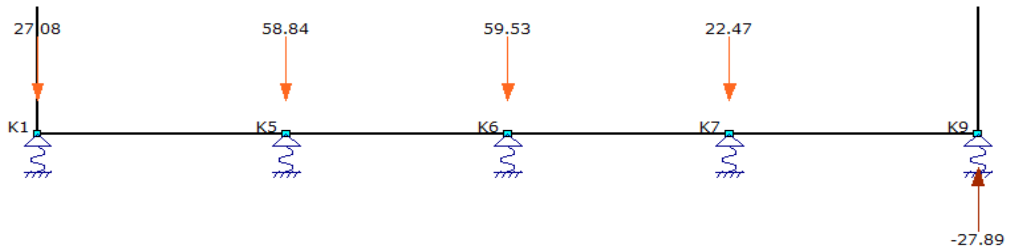
Stiffness = k_pile2

Sum of vertical forces	-140 kN	→	O.K.
Sum of reaction forces	140 kN		



Stiffness = k_pile3

Sum of vertical forces	-140 kN	→	O.K.
Sum of reaction forces	140 kN		



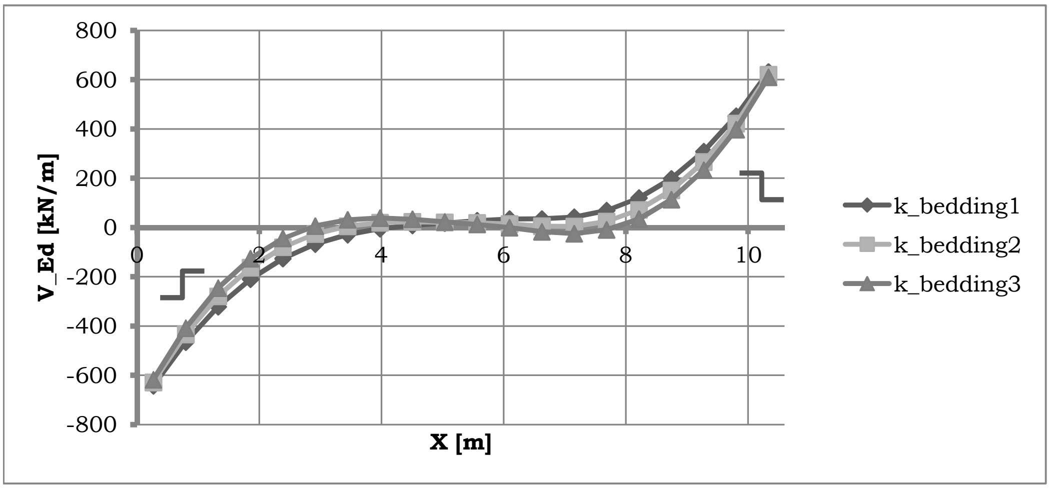
Resumé

The maximum occuring tension load is not a design value for the calculations of foundation piles. This value will occur during the construction face of the structure. Further can be seen that in the final face also a pressure force occurs, which means it won't be possible to use tension anchors.

Shear forces ULS

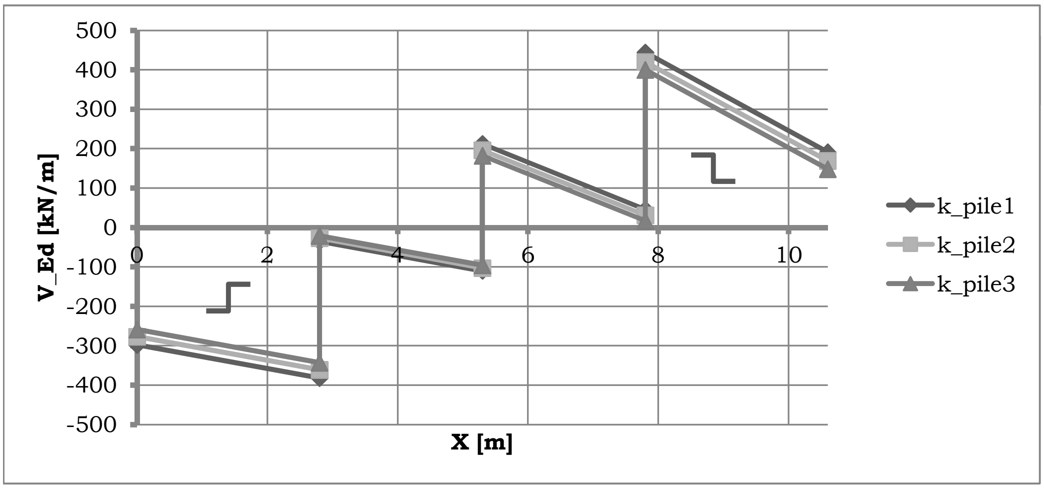
Shallow foundation

The occuring shear forces for the shallow foundation are shown in the figure below. The figure show the shear forces for the different stiffnesses of the soil.



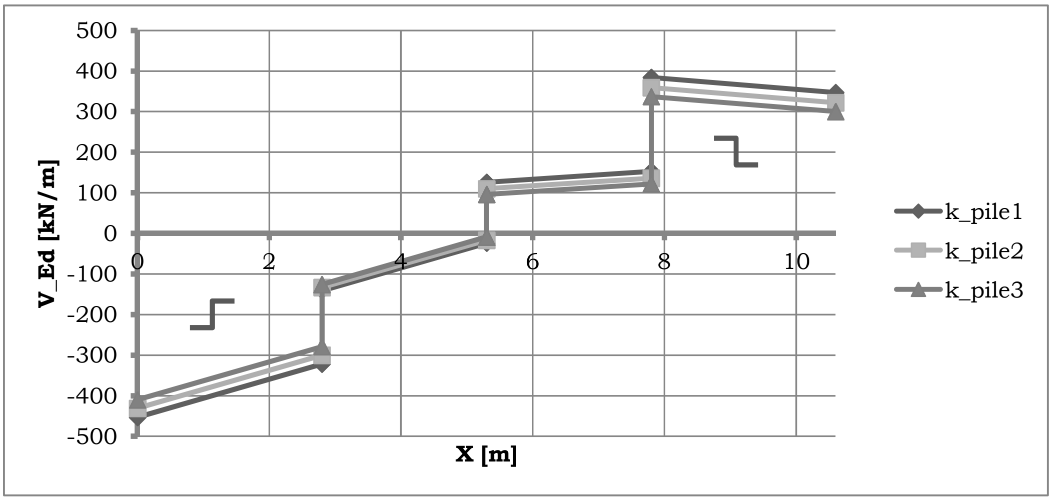
Pile foundation

The occuring shear forces for the pile foundation are shown in the figure below. The figure show the shear forces for the different stiffnesses of the soil.



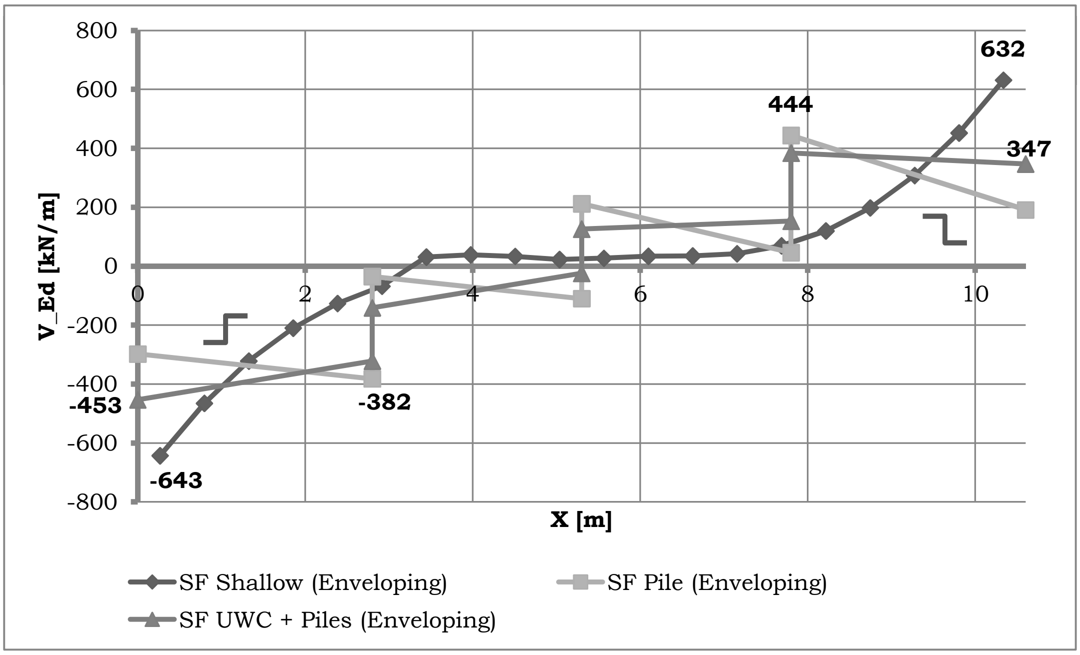
Underwater concrete + piles

The occuring shear forces for the underwater concrete + pile foundation are shown in the figure below. The figure show the shear forces for the different stiffnesses of the soil.



Eveloping shear forces for all types of foundation

The occuring eveloping shear forces for all the different foundation types are shown in the figure below.

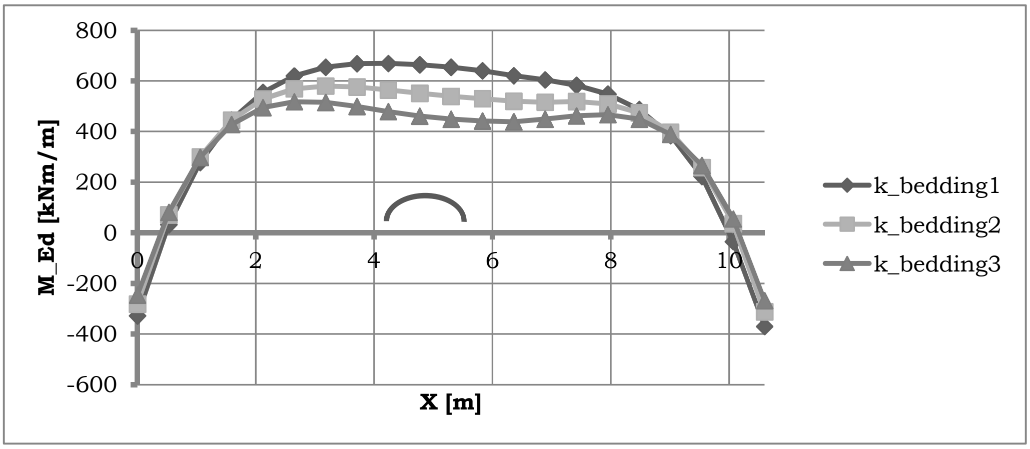


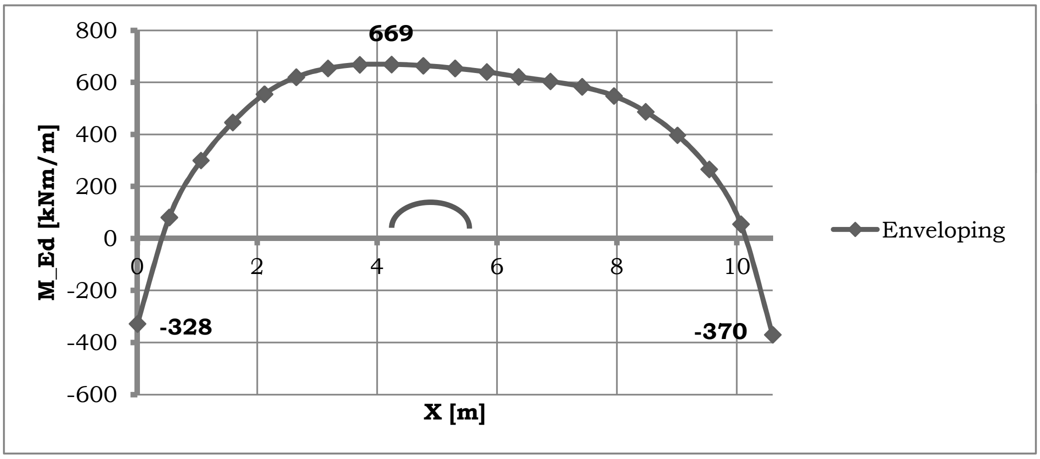
V_Ed,shallow,max =	643 kN/m
V_Ed,pile,max =	444 kN/m
V_Ed,uwc+p,max =	453 kN/m

Bending moments ULS

Shallow foundation

The occuring bending moments for the shallow foundation are shown in the figures below. The first figure shows the bending moments for the different stiffnesses of the soil. The second one shows the enveloping bending for all stiffnesses.





M_Rd,shallow,max,top = 669 kNm/m

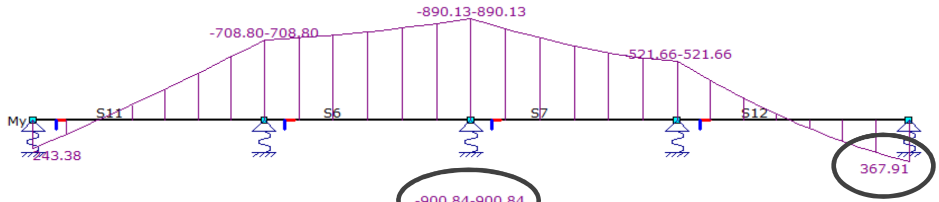
M_Rd,shallow,max,bottom = 370 kNm/m

Pile foundation

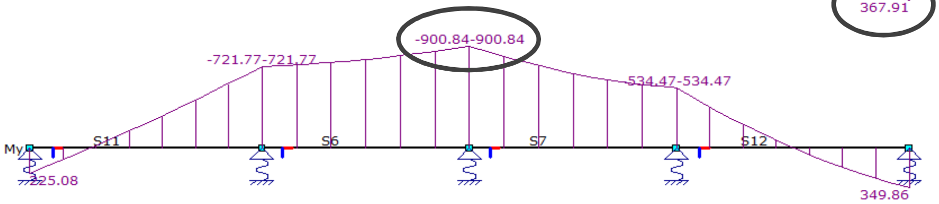
The occuring maximum bending moment for the pile foundation are shown in the figures below. A distinction made is between the variation in the pile stiffnesses.

Stiffness: k_pile1

L.com3

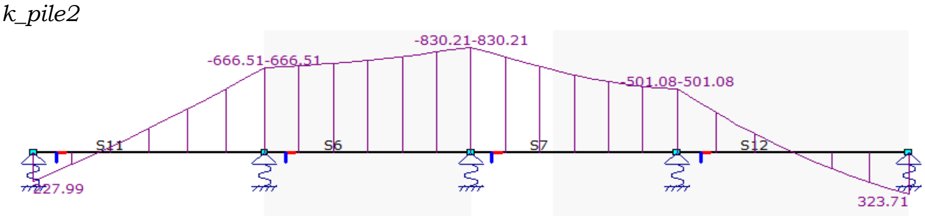


L.com4

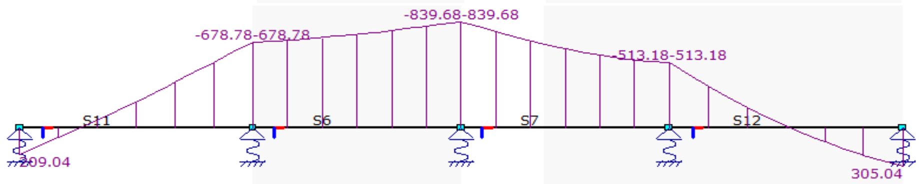


Stiffness: k_pile2

L.com3

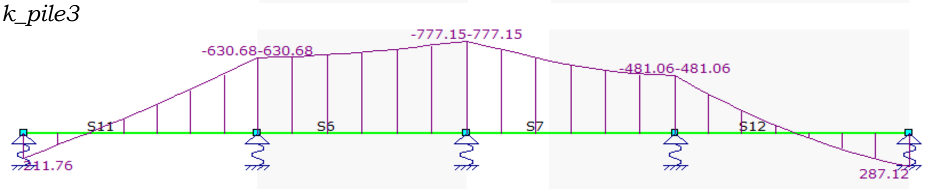


L.com4

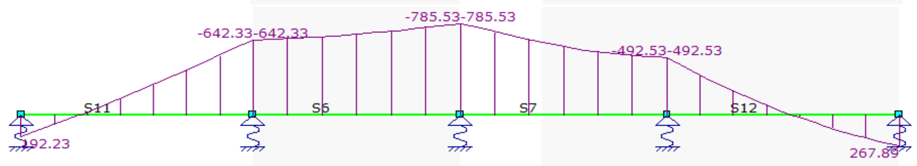


Stiffness: k_pile3

L.com3



L.com4



The maximum bending moments occur for situation with the lowest stiffness of the piles. Where the highest bending moment at the top occur for L.com4 and the highest bending moment at the bottom for L.com3.

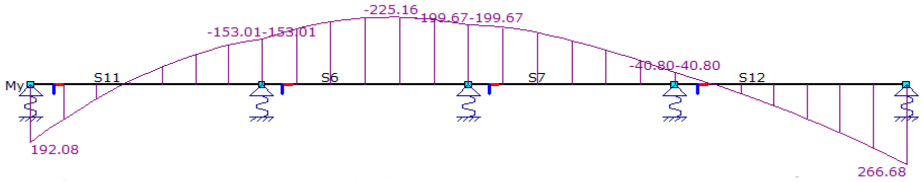
M_Rd,pile,max,top =	901 kNm/m
M_Rd,pile,max,bottom =	368 kNm/m

Underwater concrete + piles

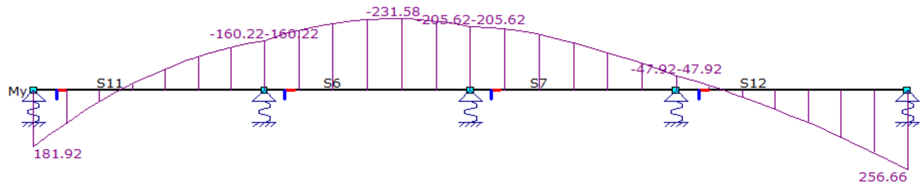
The occuring maximum bending moment for the underwater concrete + pile foundation are shown in the figures below. A distinction is made between the variation in the pile stiffnesses.

Stiffness: k_pile1

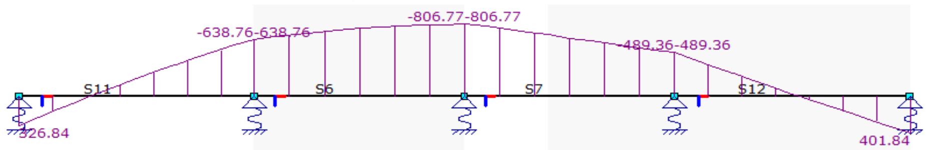
L.com5



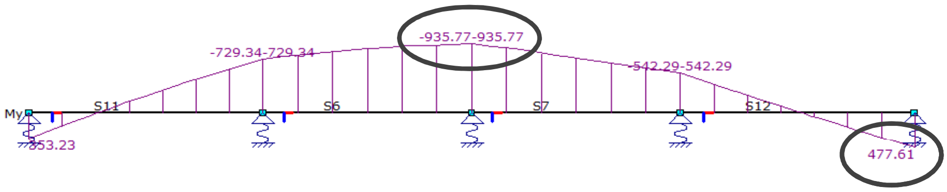
L.com6



L.com7

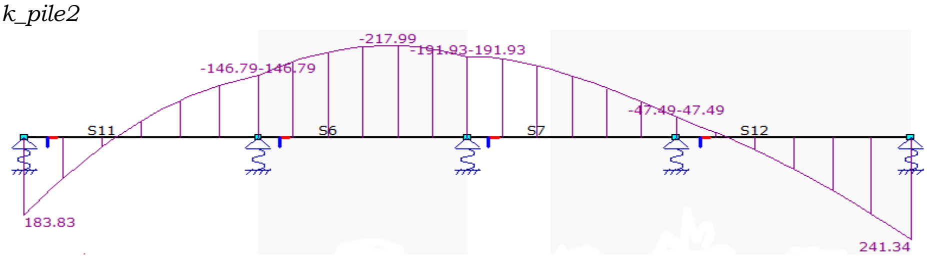


L.com8

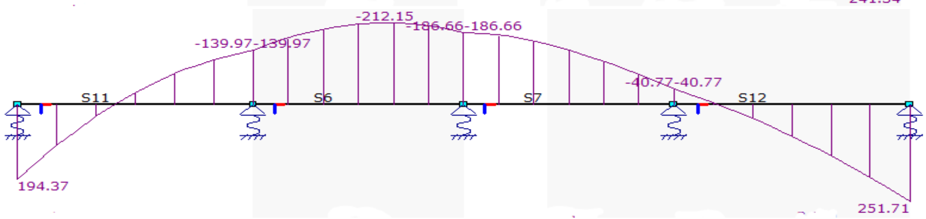


Stiffness: k_pile2

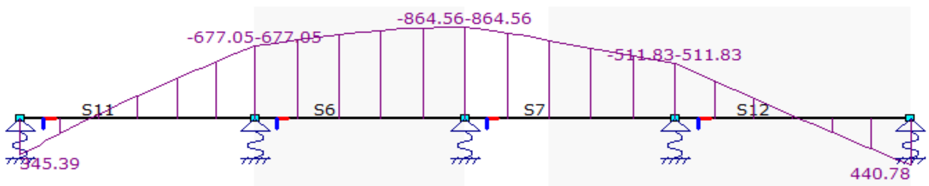
L.com5



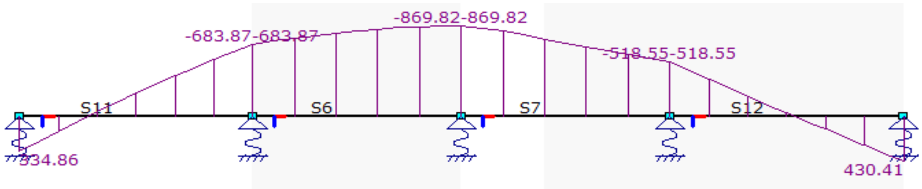
L.com6



L.com7

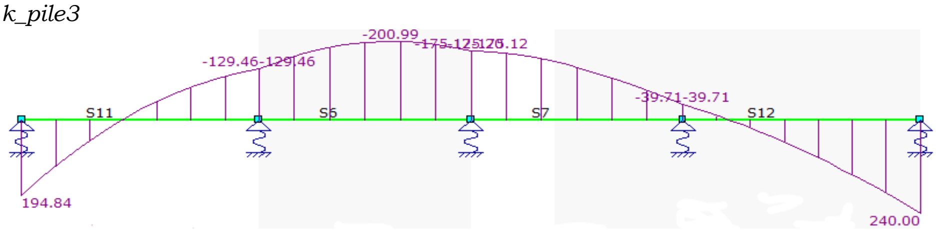


L.com8

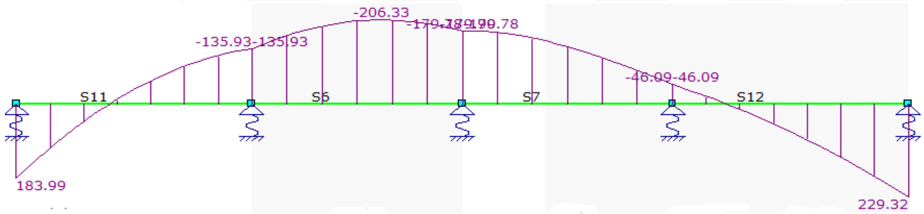


Stiffness: k_pile3

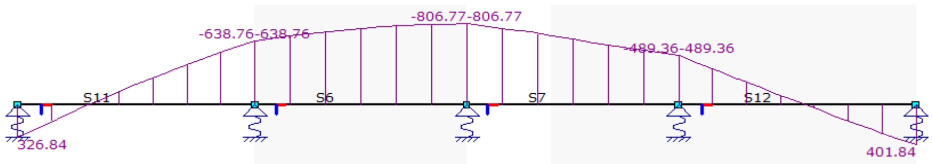
L.com5



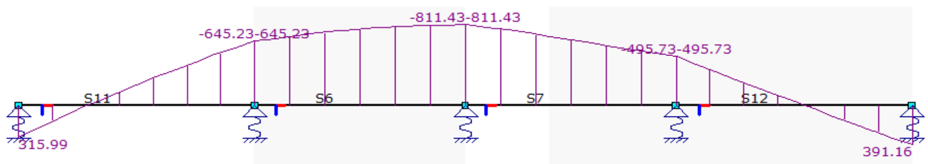
L.com6



L.com7



L.com8



M_Rd,uwc+p,max,top = 936 kNm/m
M_Rd,uwc+p,max,bottom = 478 kNm/m

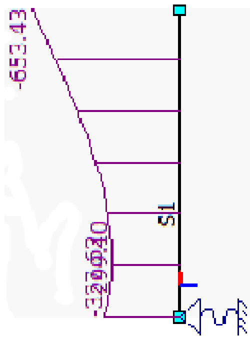
Bending moments walls ULS

<u>Shallow foundation</u>

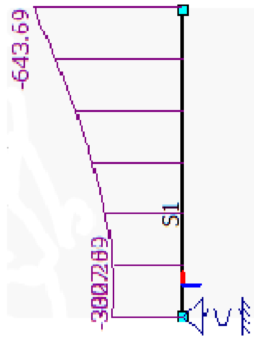
The occuring bending moments in the walls for the shallow foundation are shown in the figures below. The water level is considered to be at the bottom of the structure.

Stiffness: k_bedding1

L.com1

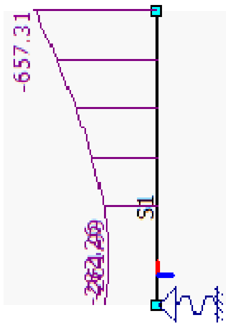


L.com2

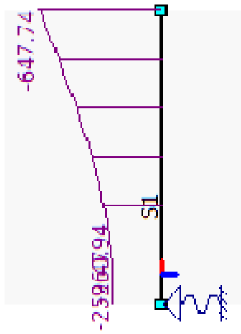


Stiffness: k_bedding2

L.com1

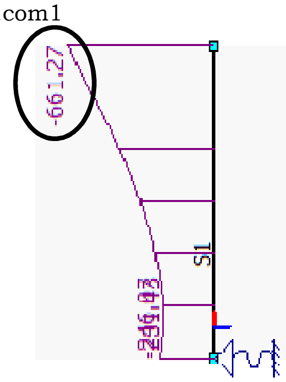


L.com2

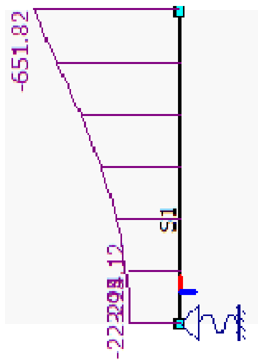


Stiffness: k_bedding3

L.com1



L.com2



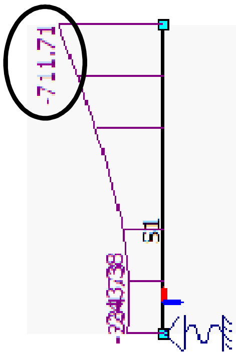
M_Ed,wall,shallow,max = 661 kNm/m

Pile foundation

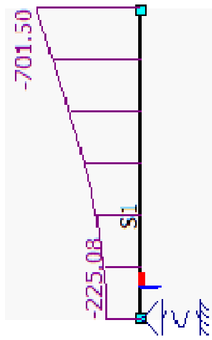
The occuring bending moments in the walls for the pile foundation are shown in the figures below. The water level is considered to be at the bottom of the structure.

Stiffness: k_pile1

L.com3

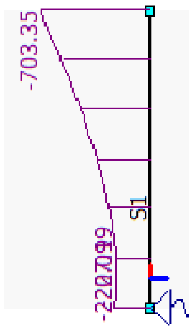


L.com4

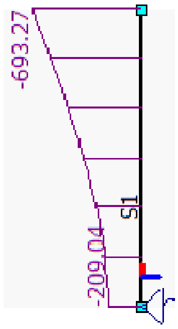


Stiffness: k_pile2

L.com3

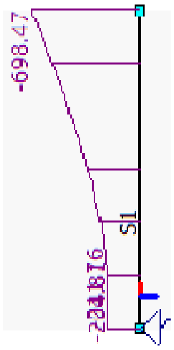


L.com4

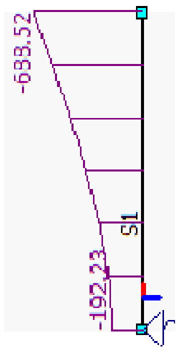


Stiffness: k_pile3

L.com3



L.com4



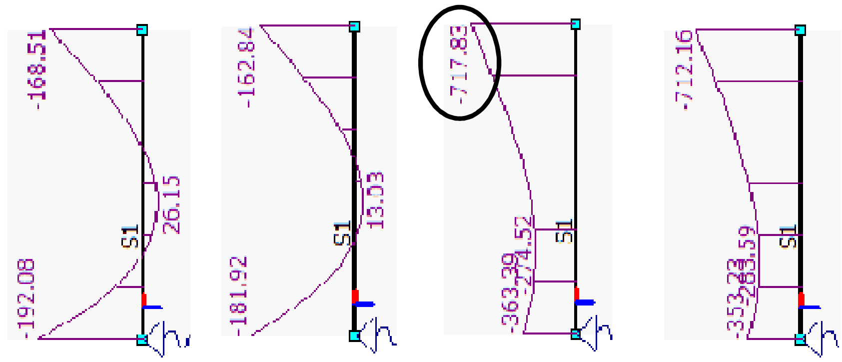
M_Ed,wall,pile,max = 711 kNm/m

<u>Underwater concrete + piles foundation</u>

The occuring bending moments in the walls for the underwater concrete + piles foundation are shown in the figures below. The water level is considered to be at the top of the

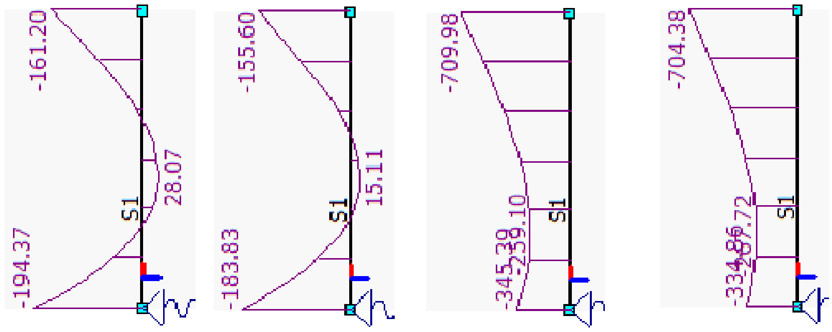
Stiffness: k_pile1

L.com5 L.com6 L.com7 L.com8



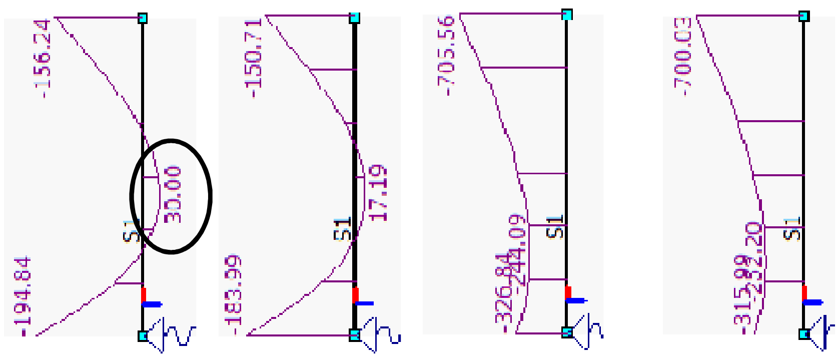
Stiffness: k_pile2

L.com5 L.com6 L.com7 L.com8



Stiffness: k_pile3

L.com5 L.com6 L.com7 L.com8



M_Ed,wall,uwc+p,max = 717 kNm/m

M_Ed,wall,uwc+p,min = 30 kNm/m

Floor thickness

The thickness of the floor is based on the shear resistance and for the situations with piles, also for the punching shear resistance. Shear reinforcement or punching shear reinforcen shall not be applied, since the application is very labour-intensive and the risk of leakage is rather high. Also, the thickness of the floor might differ from the assumption made at the beginning of this calculation. Changing the thickness of the floor might have its influence on the occuring internal forces. However, there won't be an optimization of these calculation, because it will bring a level of specification that is not necessary to draw the right conclusions.

<u>Shear force resistance</u>

Eurocode 2 gives the following equation for the shear resistance:

$V_{Rd,c} = v_{min} * b_w * d$

$v_{min} = 0{,}035 * k^{(3/2)} * f_{ck}^{(1/2)}$

$k = 1 + \sqrt{(200/d)} \leq 2{,}0$

$d \approx 0{,}9 * t_{wall}$

$V_{Rd,c} \geq V_{Ed}$

Occuring maximum shear forces:

$V_{Ed,shallow,max}$ =	643 kN/m
$V_{Ed,pile,max}$ =	444 kN/m
$V_{Ed,uwc+p,max}$ =	453 kN/m

Shear force resistance $V_{Rd,c}$ for C35/45:

t_{floor} [mm]	$V_{Rd,c}$ [kN/m]
600	316
700	369
800	422
900	474
1000	527
1100	580
1200	633
1300	685

<u>Punching shear resistance</u>

Eurocode 2 gives the following equations for the punching shear resistance:

$u_1 = 2 * (c1 + c2) + 4 * pi * d$

c1 and c2 as the thickness of the squared pile in both directions

$V_{Rd,c} = 0{,}035 * k^{(3/2)} * f_{ck}^{(1/2)} * u_1 * d$

$k = 1 + \sqrt{(200/d)} \leq 2{,}0$

$d \approx 0{,}9 * t_{wall}$

v_Rd,c ≥ v_Ed

Occuring maximum punching shear forces:
V_Ed,pile,max = 988 kN

Punching shear resistance V_Rd,c for C35/45; pile with a cross-section of 0,5m x 0,5m:

t_floor [m]	V_Rd,c [kN/m]
600	2779
700	3659
800	4659
900	5777
1000	7016
1100	8373
1200	9849
1300	11445

Conclusions regarding floor thickness

The assumed thickness of 800mm is not sufficient to fulfill all the situations. Therefor, the thickness will be set at 1200mm, based on the required resistance for the shallow foundation. For the pile foundation and the underwater conrete + piles foundation a thickness of 900mm will be sufficient. The floor is 33% thicker than required in these cases, which gives rise to an optimization.

Unity checks

Shallow foundation:
t_floor = 1200 mm

$$\text{U.C.:} \quad \frac{\text{V\_Ed,shallow,max}}{\text{V\_Rd,c,1200}} = \frac{643}{633} = 1{,}0164 \quad \text{O.K.}$$

Pile foundation:
t_floor = 1200 mm

$$\text{U.C.:} \quad \frac{\text{V\_Ed,pile,max}}{\text{V\_Rd,c,shear,1200}} = \frac{444}{633} = 0{,}70196 \quad \text{O.K.}$$

$$\text{U.C.:} \quad \frac{\text{V\_Ed,pile,max}}{\text{V\_Rd,c,punch,1200}} = \frac{988}{9849} = 0{,}10026 \quad \text{O.K.}$$

UWC + piles foundation:
t_floor = 1200 mm

$$\text{U.C.:} \quad \frac{\text{V\_Ed,uwc+p,max}}{\text{V\_Rd,c,shear,1200}} = \frac{453}{633} = 0{,}71619 \quad \text{O.K.}$$

Latitudinal reinforcement floor

Calculation of reinforcement is done with the help of the EC2 table: "Reinforcement ratio for rectangular concrete cross-sections, reinforced with B500 steel".

M_Ed / (f_cd * b * d) = ψ(1 - 0.52 * ψ)

A_s = ρ * b * d

b =	1,00 m
d = 0.9 * t_floor =	1,08 m

Occuring maximum bending moments:

M_Ed,shallow,max,top =	669 kNm/m
M_Ed,shallow,max,bottom =	370 kNm/m
M_Ed,pile,max,top =	901 kNm/m
M_Ed,pile,max,bottom =	368 kNm/m
M_Ed,uwc+p,max,top =	936 kNm/m
M_Ed,uwc+p,max,bottom =	478 kNm/m

A_s [mm]		Centre-to-centre bars [mm]				
		75	100	125	150	200
Bardiameter [mm]	12	1508	1131	905	754	565
	16	2681	2011	1608	1340	1005
	20	4189	3142	2513	2094	1571
	25	6545	4909	3927	3272	2454
	32	10723	8042	6434	5362	4021
	40	16755	12566	10053	8378	6283

<u>Shallow foundation</u>

M_Ed,shallow,max,top / (f_cd * b * d) =	25	→	ρ =	0,0013
M_Ed,shallow,max,bottom / (f_cd * b * d) =	14	→	ρ =	0,00075

ρ_min = 0,0013 (for C35/45)

A_s,top =	1404 mm2	→	Ø	16	-	125
A_s,top =	1404 mm2	→	Ø	16	-	125

<u>Pile foundation</u>

M_Ed,pile,max,top / (f_cd * b * d) =	34	→	ρ =	0,0019
M_Ed,pile,max,bottom / (f_cd * b * d) =	14	→	ρ =	0,00075

ρ_min = 0,0013 (for C35/45)

A_s,top =	2052 mm2	→	Ø	20	-	150
A_s,top =	1404 mm2	→	Ø	16	-	125

Underwater concrete + piles foundation

M_Ed,uwc+p,max,top / (f_cd * b * d) =	35	→	ρ =	0,00192
M_Ed,uwc+p,max,bottom / (f_cd * b * d) =	18	→	ρ =	0,00085

ρ_min = 0,0013 (for C35/45)

A_s,top =	2068 mm2	→	Ø	20	-	150
A_s,top =	1404 mm2	→	Ø	16	-	125

Latitudinal reinforcement walls

Calculation of reinforcement is done with the help of the EC2 table: "Reinforcement ratio for rectangular concrete cross-sections, reinforced with B500 steel".

M_Ed / (f_cd * b * d) = ψ(1 - 0.52 * ψ)

A_s = ρ * b * d

b = 1,00 m
d = 0.9 * t_floor = 0,54 m

Occuring maximum bending moments:
M_Ed,wall,shallow,max = 661 kNm/m
M_Ed,wall,pile,max = 711 kNm/m
M_Ed,wall,uwc+p,max = 717 kNm/m

Shallow foundation

M_Ed,wall,shallow,max / (f_cd * b * d) = 99 → ρ = 0,0056
Inside is minimum reinforcement

ρ_min = 0,0013 (for C35/45)

A_s,out =	3024 mm2	→	Ø	20	-	100
A_s,in =	702 mm2	→	Ø	16	-	150

Pile foundation

M_Ed,wall,pile,max / (f_cd * b * d) = 106 → ρ = 0,00658
Inside is minimum reinforcement

ρ_min = 0,0013 (for C35/45)

A_s,out =	3553,2 mm2	→	Ø	25	-	125
A_s,in =	702 mm2	→	Ø	16	-	150

Underwater concrete + piles foundation

M_Ed,wall,uwc+p,max / (f_cd * b * d) =		107	→		ρ =	0,0069

Inside is minimum reinforcement

ρ_{min} =	0,0013	(for C35/45)

$A_{s,out}$ =	3726 mm2	→	Ø	25	-	125
$A_{s,in}$ =	702 mm2	→	Ø	16	-	150

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Crack width control in the walls

Title
Imposed deformation in the walls

Name
Koen van Viegen

Date
14-dec-14

Software
MS Excel

Starting points
Calculations based on: Eurocode 1 part 2
Eurocode 2

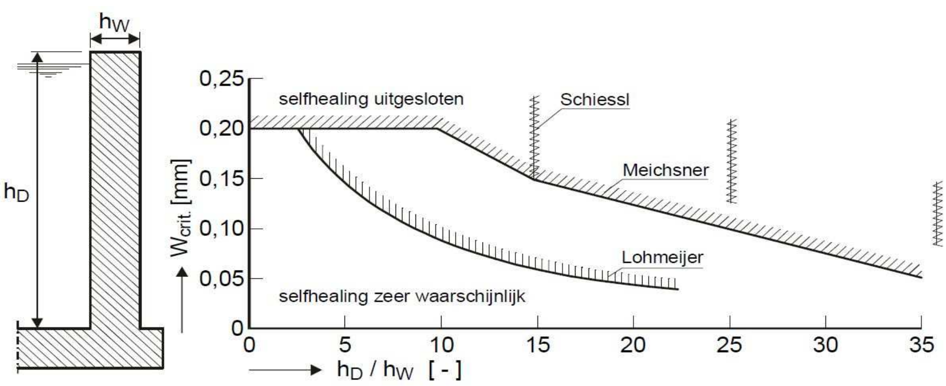
Material properties
Concrete:

Class	f_ck (MPa)	f_ck,cube (MPa)	f_cd (MPa)	E_cm (GPa)	f_ctm (MPa)	
C12/15	12	15	8	27		
C16/20	16	20	11	29		
C20/25	20	25	13	30		
C25/30	25	30	17	31		
C30/37	30	37	20	33		
C35/45	35	45	23	34	34	Used for these calculations
C40/50	40	50	27	35		
C45/55	45	55	30	36		
C50/60	50	60	33	37		

Reinforcement:

Class 500B

Maximum crack width (Lowmeyer)



H_w = 0,60 m

H_d	H_d/H_w	w_crit
0,00	0,00	0,20
0,50	0,83	0,20
1,00	1,67	0,20
1,50	2,50	0,20
2,00	3,33	0,18
2,50	4,17	0,16
3,00	5,00	0,14
3,50	5,83	0,13
4,00	6,67	0,12
4,50	7,50	0,11
4,70	7,83	0,11

Maximum crack width

The determine the maximum crack width it must be checked if a fully developed crack

$\Delta L / L < \varepsilon\_c$ → fully developed crack pattern

$\Delta L / L = f\_ctm * (0.6 + \alpha\_e * \rho\_eff) / (E\_s * \rho\_eff)$

f_ctm = 3,2 N/mm2
α_e = 6,67
E_s = 200000 N/mm2

$\rho\_eff = A\_s/A\_eff$

For A_s lets assume Ø20-100, which gives 6283 mm2

A_eff = 2 * 100 *1000 = 300000 mm2

ρ_eff = 0,02094

The strain in the concrete is determined with the help of Figure 2.8 of the book "Concrete Structures under Imposed Thermal and Shrinkage Deformations" by Prof. K. van Breugel e.a.

ε_c = 0,0001
$\Delta L / L$ = 0,00057 → unfully developed crack pattern

$w\_max,\infty = (1,25 / 8) * (Ø / \rho^2) * \{(f\_ctm / E\_s) * (1 + \alpha\_e * \rho\_eff)\}$

H_d	w_crit	w_max,∞	ρ	A_s,req	n	Ø	c-t-c bar	A_s,app
0,00	0,20	0,20	0,01687	10124	2	20	120	10472
0,50	0,20	0,20	0,01687	10124	2	20	120	10472
1,00	0,20	0,20	0,01687	10124	2	20	120	10472
1,50	0,20	0,20	0,01687	10124	2	20	120	10472
2,00	0,18	0,18	0,01778	10668	2	20	110	11424
2,50	0,16	0,16	0,01884	11304	2	20	110	11424
3,00	0,14	0,14	0,02017	12103	2	20	100	12566
3,50	0,13	0,13	0,02093	12558	2	20	100	12566
4,00	0,12	0,12	0,02178	13067	2	20	90	13963
4,50	0,11	0,11	0,02273	13641	2	20	90	13963
4,70	0,11	0,11	0,02273	13641	2	20	90	13963