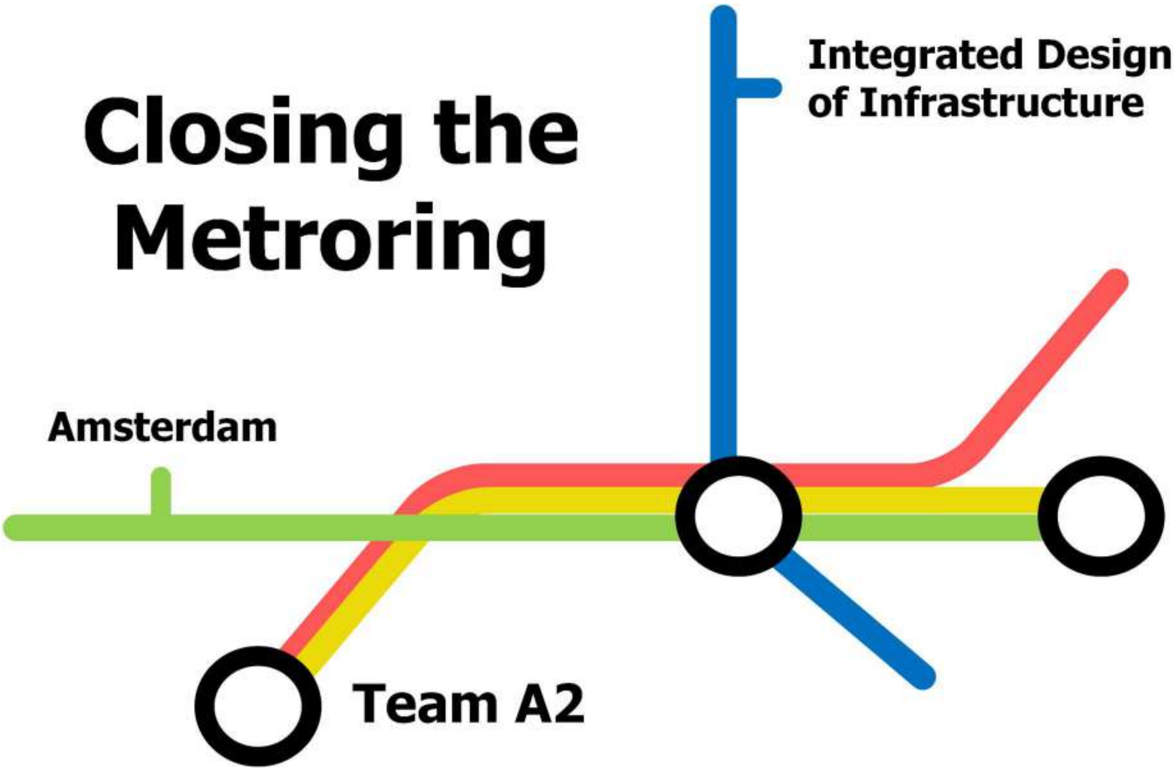
Final report: Closure of the “Kleine Ring”

Metro-line expansion between Amsterdam central station and metro station Isolatorweg



Team A2
Amy Zijlmans, Merel Krämer, Pelle Limburg, Jorn van Steen, Mart de Groote, Pyly Mucuthi, Oussama Abdelouarit, Oualid el Margai, Zakariya Anouz, Amine Damousi, Shahram Omary, Jeroen van Schaik, Tjeerd Thuss, Martijn Stok, Niels Assendelft, Lars Dijkstra, Kenzo Kuramae, Wail Abdellaoui, Kareem El Sayed, Maxime Van Elsué, Simon van Leent, Niels de Vries, Stephan van Eps, Philip Vos, Michel van der Plas, Timo van Dieren, Eva Brouwer, Stijn van Leeuwen

Delft, University of Technology
Faculty CiTG, Civil Engineering
CTB3420 Integrated Design of Infrastructure
Delft, June 2022

Preface

This final report is written by team A2, consisting of 28 Civil Engineering students at the Technical University of Delft. It is written for the course CTB3420 Integrated Design of Infrastructure, where team A2 will design an infrastructure project: the neighbourhood Havenstad and the new metro line that will close the small metro ring in Amsterdam.

Readers that are interested in the analysis of the stakeholders, space, problem and alignment of the track can read this in Chapter 2. The vision of the final area Havenstad can be read in Chapter 3. In Chapter 4, the final designed solution can be found for the metro line and Havenstad. And in the final chapter, a small conclusion can be found. At the end of the document in the Appendices, more information for every discipline can be found. In Appendix A general information about this project can be found. In Appendix B, more information about BIM can be read. In Appendix C, the design of the hydraulic and underground structures can be found. The information about the structural projects can be found in Appendix D. In Appendix E, there is more information about the transport and planning side of the project. Water Management can be found in Appendix F, and in Appendix G interested readers can find more about sustainability.

Team A2 wants to thank Erik-Jan Houwing for his supportive and constructive feedback during the meetings. Also the discussions during the meetings were always very interesting. Furthermore we want to thank the advisors to the disciplines, Wouter Schakel, Mark Voorendt, Gerrit Schoups, Dominika Teigiserova, Hoessein Alkisaei and Sander van Nederveen all helped us in their own way.

Team A2
Delft, June 2022

Summary

In this report the integral solution for the closure of the “Kleine Ring " will be presented. Investments in this infrastructural project are needed to keep the Amsterdam Metropolitan Area liveable and accessible. Different disciplines came together for this design. Therefore this report will focus on the connection between all specialisations in the project.

Various stakeholders are involved in this project. Their main interests are a well-functioning infrastructure network and new job opportunities. In addition, there should be attention to nature and sustainability in the design. To determine the location of the stations a spatial analysis has been conducted. This analysis shows the possibilities of a tram system in Houthavens or Havenstad.
The main pillar of this project design is Transit Oriented Development. The criteria used to determine the eventual track alignment are based on this philosophy. The multicriteria-analyses resulted in track R4a as the preferred track.

An important aspect in this project is the future vision of the area of Havenstad. The goal is to connect human urban life and nature by using guiding principles during the design. The guiding principles that form the basis of the design are green inclusiveness and social cohesion within the neighbourhood. These guiding principles are realised by implementing the following spatial concepts: urban green network, room for water storage and Transit Oriented Development. The urban green network, including the realisation of sustainable energy, is defined as the equal distribution of greenspaces in the neighbourhood where the focus has been laid on renewable energy produced by solar panels, urban wind turbines and geothermal energy. Furthermore, the discharge of water from heavy rainfall is an important concern in new areas. Therefore, so-called Wadi’s have been implemented to prevent future flooding and damage to the structures. The third and final spatial concept is Transit Oriented Development. This is realised by designing the new areas surrounding the mass transit facilities into lively and busy places.

For the connection of the metro ring, a bored tunnel will be realised. Inside the tunnel there will be room for underground farming and wind turbines that generate power from wind caused by the passing of the subway cars. The first new metro line will start at station Isolatorweg. Furthermore, new inhabitants of the area Havenstad should be connected to the metro network of Amsterdam. Therefore, an underground station will be created nearby Transformatorweg in Amsterdam, which will be named Haven-Stad. To increase the traffic capacity in and around Amsterdam, a metro stop will be implemented at Nassauplein.

For the vision Havenstad it is important to realise an infrastructure that fulfils the needs. For the sake of sustainability it is chosen to realise a big number of so-called ”fietsstraten”, which are bike-friendly roads. This is done to prevent heavy car traffic. To implement this, a bike parking facility close to station Havenstad should be realised. Furthermore, to prevent barriers caused by the infrastructure for pedestrians and bikers, a bridge for pedestrians and cyclists connecting Westerpark and Havenstad will be realised.

The implementation of Transit Oriented Development will lead to an increase in the use of the metro network in Amsterdam. This can lead to an increase in pressure to the existing modes of transport. It is therefore important that in the future one keeps investing in the network to fulfil the demand. Therefore, it is recommended that the client pays attention to these challenges as the project progresses.

Multiple sustainable concepts are introduced in this design, however the designers are not familiar with these concepts. Therefore, in order to successfully implement these concepts more knowledge and studies should be carried out to limit the risks when realising these concepts.

Table of contents

1. Introduction

The capital of the Netherlands, Amsterdam, is a large city and it is expected that this city will keep growing. Therefore there is a need for more new houses and more frequent public transport in the city. To provide for this need for more houses, the city of Amsterdam is planning on creating several new neighbourhoods, like for example ‘Havenstad’. The area of Havenstad is one of the places where new houses will be built. This area also needs to be connected to the current infrastructure. Before this can be built, it needs to be designed carefully. This is done in this report. A new design of the Havenstad area is designed, together with new infrastructure to connect this area better with Amsterdam, but also with close by other hotspots, such as Schiphol Airport.

In this report, the area of Havenstad will be analysed and designed. The goal of this report is to deliver a design of this new build area and to design the infrastructure around it, in particular a new metro line. This metro line will ‘close the metro ring’, and therefore stations Amsterdam Isolatorweg and Amsterdam Centraal will be connected directly. This metro line will make sure that the new neighbourhood is connected with the rest of the city, but also that the connection in the city itself will be better.

The structure of the report is as follows: Chapter 2 will focus on the analysing part of the project. In Chapter 3, the vision of the project team on this project is given. In Chapter 4, the final design can be found. In Chapter 5 a short conclusion can be read. In the Appendices of this report, much more information about several disciplines can be found. In Appendix A general information about this project can be found. In Appendix B, more information about BIM can be read. In Appendix C, the design of the hydraulic and underground structures can be found. The information about the structural projects can be found in Appendix D. In Appendix E, there is more information about the transport and planning side of the project. Water Management can be found in Appendix F, and in Appendix G interested readers can find more about sustainability.

2. Analysis

This chapter will focus on the different analysis of the project area and its surroundings.

The different parties involved will discuss their interests in the project. Next, an analysis of the existing infrastructure and what the design problem means in absolute values. Finally, a track will be chosen based on the previously made analyses.

2.1 Stakeholder analysis

In this section a stakeholder analysis will be performed for the new metro line expansion. The stakeholder analysis provides an overview on the interest and influence of different Stakeholders. The stakeholders in this project are every party that has influence or is influenced by the actions, the behaviour and/or the policies of the new metro line expansion.The Stakeholder analysis is performed by describing for each party its role and its interests in the project. The outcome of the stakeholder analysis will be visualised by the power-interest matrix.

2.1.1. Stakeholders

A - Municipality Amsterdam

As Municipality it is the responsibility of Amsterdam to keep the city well accessible, to improve or keep the attractiveness of the city, providing job opportunities and tourism. Amsterdam has a lot of influence on the new area called Haven-Stad and fulfils an important role in decision-making, because this new neighbourhood is in their Municipality. They do not only have influence, they also benefit the new neighbourhood. This benefit will be new houses and more job opportunities in Haven Stad, and therefore also for the municipality of Amsterdam. The vision of Amsterdam is to realise at least 325.000 new houses and 270.000 new jobs Haven stad plays a part to these numbers. Also the new metro line is very interesting for the municipality of Amsterdam, because it will not only influence the accessibility of Haven stad but also of the rest of Amsterdam.

B - Province Noord-Holland

The province Noord-Holland should facilitate a well-functioning infrastructure network for residents and businesses. That is why it is important that the capacity of the roads near this new neighbourhood remains sufficient in the future. The province has less interest in this particular project than the municipality and as a province it also has less influence on decisions. However, it still has a relatively large influence on decision-making.

C - GVB (Gemeentevervoerbedrijf, metro)

The new metro line connects the surrounding neighbourhoods and together with the buses they are the foundation of the public transport of the area. For GVB it is important that the metro line has enough interface, but also the integration of the metroline in the current network is very important.

D - Residents Havenstad

For the future residents in Havenstad it is important that for example the neighbourhood is safe, that there are enough facilities and that there is social cohesion in the neighbourhood. The new residents do not have a lot of influence on the project process itself, but if the neighbourhood does not meet their expectations, they are not going to live there.

E - Residents Nassauplein (Jordaan)
The new metro station will be implemented in Nassauplein. It is important for the residents that the metro station is easily accessible and there is enough space to park the car or the bike. It is also important that the metro arrives at the station at high frequency, so whenever you want to take the metro you wouldn't have to wait very long. For the local residents it is important that the building process wouldn't cause any nuisance.

F - Rijkswaterstaat
Rijkswaterstaat is responsible for managing and developing the main roads, the main waterways and main water systems. With the main task to work on a smooth and safe flow of traffic, the maintenance and improvement of the waterway system and flood protection. The implementation of these principles in the project is also very important and needs to meet the requirements set by Rijkswaterstaat. The vision of Rijkswaterstaat is working on making The Netherlands a safe, liveable and accessible country (Ministerie van Infrastructuur en Waterstaat, 2022)

G - Travellers
For the travellers of the new metroline, it is important that the transportation is fast and frequent. It is also important that the metro stations are easily accessible. For the less agile it is of interest that they can also easily acces the metro stations.

H - Environmental organisations
For environm ental organisations it is very important that the new neighbourhood pays enough attention to nature and sustainability. Neighbourhoods are made of a lot of stone material that heats up quickly in the sun and cools down slowly. This means that the area heats up. With enough nature in the neighbourhood the rise of the temperature will be less. Which is important because of the changing climate with rising temperature (Staal, 2019)

I - Contractors and civil engineering firm
The contractors and the civil engineering firm of the construction process must be clear to know what will be expected of them. The building plans must be thorough and detailed so that the construction process can proceed without any obstacles or delay. They are involved in the project but have no significant interests in the project itself.

J - Cyclists and pedestrians
The interest for cyclists and pedestrians is that the transport is fast and safe. Also the quality of the transportation network is very important for both, just as the cohesion, directness, comfort and the attractiveness of the network. It is also very important for the cyclists that there is enough space to park their bikes.

2.1.2. Power/interest matrix

This section of the report will discuss the power/interest matrix made for this project. The power/interest matrix can be found in figure xx. The overview of the letters hereby is found in figure yy. The goal of making a power/interest matrix is to prioritise the Stakeholders. The Stakeholders for the covered walkway aren't all very interested in the new metroline and have little or high influence on the project. That is why the power/interest matrix is a powerful tool to understand how the Stakeholders should be informed about the progress and what power they have over the project. This power-interest matrix also displays the best manner of communication with the stakeholders. In this way the stakeholders should keep being satisfied.

Letter	*Stakeholder*
A	Municipality Amsterdam
B	Province Noord-Holland
C	GVB (Gemeentevervoerbedrijf, metro)
D	Residents Havenstad
E	Residents Nassauplein (Jordaan)
F	Rijkswaterstaat
G	Travellers
H	Environmental organisations
I	Contractors and civil engineering firm
J	Cyclist and pedestrians

Figure 2.1.1 Power interest matrix (Transport and planning discipline)

2.2 Spatial analysis

The analysis of the physical space results in a good understanding of the area with its different buildings and structures and the cohesion between these. This is an essential part to determine the location of the stations.

Current infrastructure

This section analyses the different types of infrastructure that's currently present in the project area and its surroundings. These include the public transit network like buslines, metro lines and shared mobility, the road network, bicycle and walkability.

- Public transit network

The public transit network in the surrounding neighbourhoods mainly consists of bus lines, tram lines and railway lines. The different modes of public transit are shown in figure 2.1.1 (GVB, 2021). It shows that bus line 48 runs from Station Amsterdam Central to Houthavens. This is the only existing connection to the project area as there are currently no tram lines in Houthavens or Havenstad.

Figure 2.2.1: Public transit map (GVB, 2021)

- Main road network

The main highway is the Ring A10 west. The exit of the highway to Havenstad is the exit 2 to the S102. Furthermore the Transformatorweg from east to west and the Nieuwe Hemweg from northwest to southeast is connected to the Spaarndammerdijk. When continuing on this road to the central station this road changes into Haarlemmerdijk. It can be seen that the neighborhood has a great connection to the road network of Amsterdam and the rest of the country. This can be seen in figure 2.1.2 (Openstreetmap, 2022).

Figure 2.2.2: Road network (Openstreetmap, 2022)

- Bike network

The bicycle network runs from the central station from Haarlemmerdijk and the Spaarndammerdijk to Transformatorweg to the west. It is part of the larger bicycle network of Amsterdam and the region. This can be seen in figure 2.1.3 (Gemeente Amsterdam, 2022)

Figure 2.2.3: Bike network Amsterdam (Gemeente Amsterdam, 2022)

Other services

In this case services refer to other areas and buildings servicing the people or community in the neighbourhoods.

- Green areas

Green areas are important for the health and mental well-being of the citizens. The neighbourhoods surrounding the project area are shown in figure 2.1.4. Here the green areas are shown. As for the current green infrastructure in Houthaven, there is one city park. Other than that, there is no greenery. In the surrounding neighbourhoods there is more significant greenery, with community gardens and bigger urban parks like Westerpark.

Figure 2.2.4: Main green structures Amsterdam Municipality (Gemeente Amsterdam, 2022)

- Education

Education is also an important facility. The existing educational institutes are the secondary school “Het 4e gymnasium” and two primary schools “Onze Amsterdamse School” & “Dalton School”. These can be seen in figure 2.1.5 (Google Maps, 2022)

- Sport facilities

Access to sporting facilities is important for the physical and mental well-being of the citizens. As shown in figure 2.1.5, there are a few sporting facilities in the surrounding neighbourhoods. Aside from a soccer court and one sporting complex, there are not a lot of sports facilities.

Figure 2.2.5: Sporting facilities (Gemeente Amsterdam, 2022)

- Playgrounds and play areas

Playgrounds and play areas are important for the development of children in many different aspects, mainly social and fine motor skills. In figure 2.1.6 the current playgrounds and play areas are shown. As it can be seen there are several playgrounds in the newly developed Houthavens neighbourhood. There are also a significant number of playgrounds in the Spaarndammerbuurt neighbourhood.

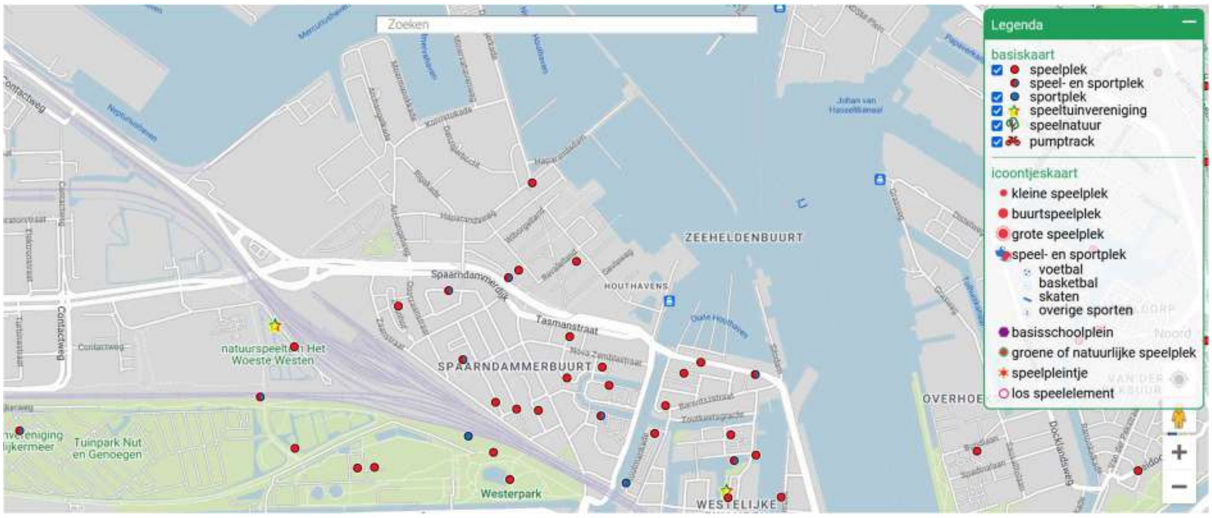


Figure 2.2.6: Playgrounds and play areas (Gemeente Amsterdam, 2022)

2.3 Problem analysis

The region of Amsterdam is growing at a high rate. The ‘’Structuurvisie Amsterdam 2040 Economisch sterk en duurzaam’’ states that 70.000 houses will be realised before 2040. The building process of the houses will start from 2020. About 55.000 of these homes will be located in Haven-Stad and 47.000 jobs will arise at this location. More inhabitants and jobs lead to a growth in mobility needs and cause an increase in heavy load on the existing modes of transport. If the future is taken into consideration this problem will get larger. Therefore, it is necessary to invest in the public transport system, especially if Transit Oriented Development(TOD) is taken into account. Amsterdam is considering a connection of the ring in terms of the metro lines, to optimise the efficiency of the current system. People will be able to travel faster within and through Amsterdam, for living or work. To finish the ring, a track is needed from station Isolatorweg to Amsterdam Central Station. The main pillar of the project is transit oriented development. This project should also take sustainability into consideration, but this is not a main pillar.

2.4 Track alignment analysis

Based on a number of criteria, a track alignment is chosen. This is done to close the metro ring in Amsterdam. For every possible alignment between Amsterdam Centraal and Amsterdam Isolatorweg, scores were given for the different criteria in a Multi Criteria Analysis. These consisted of Feasibility, Obstruction, Technical Requirements, Maintenance facility and stabling zone, Robustness, Spatial Integration, Spatial Development, Sustainability, Land Properties, Dependencies, Costs, Planning. In the table below, the total score for the alignments can be seen.

Table 2.4.1: Total scores for the different alignments

Theme	R1	R1-t	R1a	R1a-t	R2	R3	R4	R4a	R5
Total score	138	140	132	130	131	149	147	151	124

The alignment with the highest score is R4a, and therefore this alignment will be chosen. Next for each criteria a short description will be given corresponding to the R4a track where it stands compared relative to the others. The complete table with the individual scores for the criteria can be found in the midterm report, the previous report of Team A2. In the figure below, all the tracks are visible.

Figure 2.4.1: Different possible alignments (TU Delft, 2022).

3. Vision havenstad area

In this chapter, the vision of team A2 on the area of Havenstad and the metro line will be presented.

This vision is focused on the Havenstad neighbourhood. The goal is to connect human urban life and nature. This vision contains different sections, starting with the guiding principles. These principles can be categorised under a few different main themes: social, environmental, accessible and climate resilience. After this the spatial concepts used in the vision will be elaborated. These contain different aspects that have interfaces with the different disciplines in the project. Following this, the future key activities will be listed and explained. The combination of these different aspects are used in the vision.

3.1 Guiding principles

The definition of a guiding principle is the leading thread for the vision in this report. So in other words, which principles will be taken into account and therefore form the basis for the future vision of Havenstad. The guiding principles that are used focus on green inclusiveness and social cohesion within the neighbourhood. Green inclusiveness means that Havenstad will contain enough green spaces to sustain the bio-environment in that area. The green inclusiveness principle also means that everybody has equal access to the greenery present in the neighbourhood. The second guiding principle is social cohesion. This means that different people, with different backgrounds and income, live together. An example of social cohesion improvement are allotments, where people of all different backgrounds get in contact with each other. Now the spatial concepts following these guiding principles will be elaborated.

3.2 Spatial concepts and reference

The spatial concepts show how the space should be structured in the neighbourhood Havenstad. The spatial concepts complement the guiding principles in defining the final vision. The spatial concepts that are important in this vision and that will be elaborated below are the urban green network, room for water and transit oriented development.

3.2.1 Urban green network and energy scape

The urban green network and sustainable energy are combined in this case as they both have interfaces with sustainability. The urban green network is a spatial concept where the greenery in the neighbourhood is all connected via green corridors. The goal of the urban green network is an equal distribution of greenspaces in the neighbourhood. The green network also has other benefits such as improved conditions for the ecosystem, urban heat and improving the quality of life in the neighbourhood.

The focus lies on renewable energy produced by solar panels, urban wind turbines and geothermal energy. This is visualised in the vision by selecting suitable areas in the neighbourhood where the implementation of these technologies is possible.

3.2.2 Room for water

For a city like Amsterdam, surrounded by water, the discharge of water from heavy rainfall is an important concern in new areas. The room for water concept focuses on this. It prevents future flooding by creating areas for the water to go to, and be stored temporarily. A great example of this are Wadi's where excess water can be stored to make sure the sewers don't overflow.

3.2.3 Transit oriented development

The third and final spatial concept is transit oriented development. TOD means that new areas surrounding mass transit facilities are developed into lively and busy places. This mostly happens near public transit stations or mobility hubs. In this vision, TOD is used to develop the areas near the metro station of Havenstad.

3.3 Vision map

A vision follows from the earlier mentioned principles and concepts. The existing newly built housing in the Havenstad area will remain. The older houses present in the area will be demolished. Furthermore, the neighbourhood will contain many different kinds of buildings, such as commercial, residential and offices. The older industrial complexes will be demolished. The already present and relatively new offices will not be demolished. If they are not used anymore, they will be converted to residential buildings. The map and the legend of this vision are given below. Furthermore, the different elements that are in the vision will be better explained and linked to different concepts and principles of the vision of the project.

Figure 3.3.1: Vision map of Havenstad and Houthavens (Transport and planning discipline)

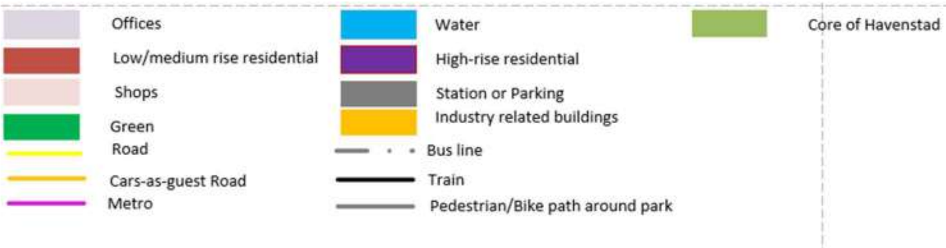


Figure 3.3.2: Legend of vision map (Transport and planning discipline).

3.3.1 Houthavens

The neighbourhood houthavens is part of the vision but although already a completed new area. Houthavens will be a guiding neighbourhood for the other residential areas in Havenstad. The current situation in Havenstad will be illustrated to clarify what exactly is the inspiration for other residential areas in Havenstad. These illustrations are generated from field research in the project area. See figure 3.3.3 and 3.3.4

Figures 3.3.3 and 3.3.4: Housing in Houthavens (Transport en planning discipline).

Havenstad also provides a non-space consuming way for car parking to minimise cars to park on the street itself. This principle is going to be used in the car-friendly streets and the residential of Havenstad. See figure 3.3.5.

Figure 3.3.5: Underground car parking in Houthavens (Transport en planning discipline).

The final element of Houthavens that will form a basis for Havenstad is the green corridor that already exists between Houthavens and the Tasmanstraat/Spaarndammerstraat. This corridor will continue into Havenstad and form the green core of the total Havenstad project area.

3.3.2 Residentials Havenstad-North

This paragraph covers the residential area in the northern part of Havenstad, as visible in figure 3.3.6.

Figure 3.3.6: Residential area in Havenstad-North (Transport and planning discipline).

In this neighbourhood, the same style is used as in Havenstad, so most of the buildings will be mid-rise residential like the ones visible in Figure 3.3.3 and Figure 3.3.4. To increase the number of housing in that neighbourhood (since the demand for new residential in Havenstad was estimated at 20.000 new residents) those mid-rise buildings could be split up in an up- and downstairs apartment. This will not only double the capacity of that residential block, it also makes sure that not only the rich people could afford such housing (Up- and Downstairs apartments are generally cheaper than mid-rise row houses that are double the size). This can improve social cohesion because multiple groups, so not only the rich, could live in Havenstad.
The difference between Houthavens and this neighbourhood is that this neighbourhood will have its waterways on the back instead of in the front of the housing, this means that the design will be based on a neighbourhood in Rotterdam with backyards on the waterside. This concept is illustrated in Figure 3.3.7.

Figure 3.3.7: Neighbourhood built around water (Rotterdam Nesselande) (Van Omme & De Groot, 2022)

This concept also improves the execution of the concept: “room for water”, since water will become the main element on which the design of the neighbourhood is based.
In all the residential areas, some basic elements such as grocery stores and schools. An elementary school is needed in this residential neighbourhood since in The Netherlands, the average distance between residential and elementary school is 600 metres (Stadszaken, 2020). At the moment only in Houthavens, an elementary school already exists and this location is more than 1 km from the furthest located residential plans. The spatial analysis showed that this part of Havenstad lacks sporting facilities and playgrounds too, because this

northern area used to be more industrial. Therefore, in the neighbourhood, one sporting facility and some small playgrounds will be placed. This will also attract more families with children in this neighbourhood.

3.3.3 Green corridor and surrounding housing/shops

In this paragraph, the green corridor through Havenstad and its surrounding infrastructure will be discussed. This green corridor is in line with the guiding principle of green inclusiveness, one of the principles used for the Havenstad vision. In the figure below, a zoomed-in map is provided for clarification of how the area will be described.

Figure 3.3.8: Map of the green corridor and the surrounding infrastructure (Transport and planning discipline)

The housing around the green corridor are going to be low/mid-rise buildings (except for the purple square in the bottom left and centre right, these are high rise residentials). Furthermore, all the streets in this neighbourhood will be a “Car as guest” zone in combination with underground parking places as implemented in Houthavens and visible in Figure 3.3.5. Figure 3.3.9 gives an impression on how this corridor will look like, based on a project proposal in Birmingham, United Kingdom. In this figure, it is clearly visible that a green area merges through the city core with housing on the sides.

Figure 3.3.9: Reference project for green corridor Havenstad (Birmingham What's On, 2019)

The green corridor branches off towards the west into a shopping core of Havenstad (Pink strips around the green branch in Figure 3.3.8). In this area, some shopping facilities, cafés, restaurants and other facilities for leisure will be built for the residents of Havenstad and the neighbourhoods around Havenstad. This can also lead to an increase of the social cohesion in Havenstad, because there is a place where people can meet each other and spend some of their free time with each other.

3.3.4 Office area and highrise

The last part of the vision, the office block and the highrise buildings in the northeast part will be discussed. In Figure 3.3.10, this area is indicated.

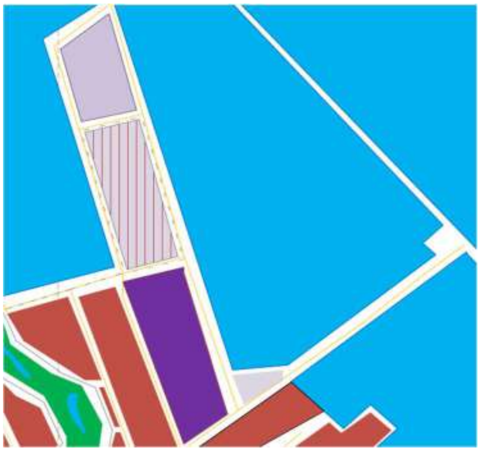


Figure 3.3.10: Vision map office area (Transport and planning discipline)

Parts of the office area are already built (northern most part). The vision for this area is that this area will be expanded towards the south and slowly merges into highrise residentials. The middle block in Figure 3.3.10 is already planned to be a combination of offices and high rise residential and the lowest block (dark purple) is planned to be fully designated to a living function. To give an impression of what this area will look like, the current offices in that location will be illustrated in Figure 3.3.11. As visible, these offices will have a modern character, and that is also the style that will be used for the rest of the office/highrise vision.

Figure 3.3.11: Offices in Havenstad Northeast (ArchitectenWeb, 2019).

To reach this office area even more easily, the bus network that already existed will continue to the furthest possible place in this area. This will increase the accessibility towards the offices from Central Station but also from subway station Havenstad.

3.4 Core of the vision in detail

The triangular area near the subway station where transit oriented development will be located, is elaborated in detail in this section. It goes into detail about the different land use and density in the area, the walkability and accessibility and multi modal transport options, mobility as a service and park & ride options (P+R).

Figure 3.4.1: Illustration of TOD (Institute for Transportation and Development Policy, 2019)

Transit Oriented Development is defined by the Institute for Transportation and Development Policy (Institute for Transportation and Development Policy, 2019) as “TOD, or transit-oriented development, means integrated urban places designed to bring people, activities, buildings, and public space together, with easy walking and cycling connection between them and near-excellent transit service to the rest of the city.”.

3.4.1 Mixed use areas and density

The area is characterised by the design of mixed use areas. These contain different developments into one building, for example residential and commercial. This reduces the distance that needs to be travelled to reach this kind of development. In the transit oriented developed area in the vision the area contains residential, commercial, office, cultural and leisure developments. The area is envisioned to be an active place where different activities take place such as conventions and social events like concerts. The area is also designed to be a local gathering place as the different developments encourage this. The result of this is also improved social cohesion.

3.4.2 Walkability and accessibility

The walkability and accessibility are also important factors in the design of the area. It is important, also for the social cohesion, that the area is accessible by everyone and also for people with disabilities. The walkability of the area can be ensured by providing direct walkways to all the buildings and making it easy to walk between these. Discouraging the use of other modes of transport within the area.

3.4.3 Mobility

Mobility contains many different aspects. Mobility as a service and shared mobility, sustainable mobility, P+R. In the area close to the metro station there will be different modes of micro mobility available, OV-fietsen and shared mobility modes like electric mopeds and cars. There will also be an underground parking garage to facilitate users of the metro line who want to use their car to get to the station. As defined earlier, TOD gives access to different transit options. Therefore there will also be a bus line connecting the station to other neighbourhoods.

3.4.4 Green inclusiveness

Green inclusiveness, one of the guiding principles as defined by the vision, is also important in the design of this area. By providing accessible greenery in the area such as on the rooftops of residential buildings and also on the streets in combination with pedestrian and cyclist paths, everyone in the area has access to greenery. This has several positive impacts on mental and physical well-being (Tarantino, 2017).

3.4.5 Visualisation of the design

The core triangle is about 50.000 square metres. This area becomes the core of the project area. The core becomes the gathering point of the neighbourhood. The idea is to use multiple vertical forest towers with each having multi functional purposes. For the social cohesion there is a green plaza in between the tower, where social gathering takes place, the same applies to the public spaces in the forest towers. There is the possibility to park your car and/or bike underground to prevent cars from being used in the triangle. For an idea of how the area is going to look, see figure 3.4.2.

Figure 3.4.2: Forest Tower (Straver, 2017).

Therefore, with regards to sustainability in the Havenstad infrastructure, this is incorporated for the offices and residential areas with the green roofs and vertical gardens. This forms part of the green corridor. Permeable paving in the residential area (chapter 4.2.3) also forms part of sustainability for flood control and water management. This together with the wadis that collect the surface water and use it for underground farming. Their connection to the Sustainable Development Goals is provided in Appendix G.

3.4.6 Bike parking facility in the core

In the core of Havenstad, near to the subway station, a bike parking facility will be placed containing 4000 places for bikes and possibilities to rent bikes in the form of “OV-Bikes”. The clarification of the number of bike parking places can be found in Section 6.3 in Appendix G.

4. Design solution

In this chapter, the design solution of several key elements will be presented.

The first chapter of design solutions is the metro ring connection in Section 4.1, which consists of the tunnel itself and the 3 different stops before reaching Amsterdam central. Afterwards, the infrastructure of Havenstad will be presented, so the modern look of Havenstad station also fits with its surroundings. Also, the design solution for a fast connection between the new part of the city and the station will be explained in Section 4.2. The final chapter will tell what solutions have been devised to make the city liveable and how to use rainwater and eco-friendly materials as efficiently as possible, so it fits the needs of the modern Havenstad.

4.1 Metro ring connection

In this section, the design of the metro ring connection will be discussed. In the first paragraph the design of the tunnel itself is mentioned. In paragraph two the station of Havenstad is described and in paragraph three the design of the station of Nassauplein is shown. Paragraph 4 goes deeper in depth on the element of underground farming which is designed in the metro tunnel for this project.

4.1.1 Metro tunnel

To connect the metro ring, a tunnel will be constructed between Amsterdam Centraal and Amsterdam Isolatorweg. This tunnel will be a bored tunnel by the use of a Tunnel Boring Machine. In Appendix C, the motivation of this choice can be found. In the figure below, the alignment of the tunnel can be seen, together with the locations of the metro stops.

Figure 4.1.1: Map of the region and horizontal alignment(Hydraulic discipline).

In the vertical direction an alignment needs to be thought of as well. This can be seen in the figure below. In this figure, also the soil profile is visible. The drops in height of the tunnel are there to make sure that there is enough space for the passing ships in the waterways above the tunnel.

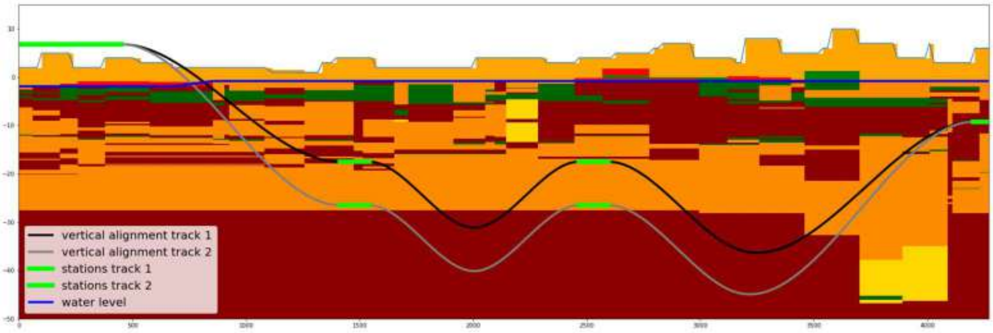


Figure 4.1.2: Underground soil profile where the tunnel will be(Hydraulic discipline)

The cross section of this tunnel can be seen in the figure below.

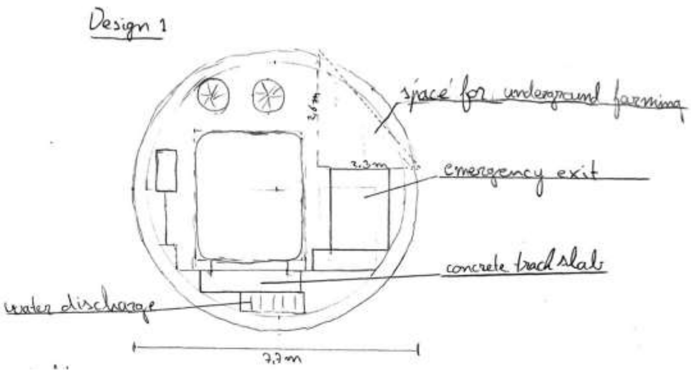


Figure 4.1.3: Cross section of the metro tunnel (Hydraulic discipline)

In the tunnel there is room for the metro itself, but also for underground farming (chapter 4.1.4) for a more sustainable farming future. For sustainability, wind turbines are designed in the tunnels that run by the passing metro trams. The availability of this type of turbines is further elaborated in Appendix G on renewable energy. Also underground farming within the tunnel at Havenstad is considered. Chapter 4.1.4 on underground farming and the appendix on sustainability also provided some more information.

4.1.2 Isolatorweg transition new metro line

The new metro line starts at Metrostation Isolatorweg, where the current metro line doesn't continue. This means the station Isolatorweg will get a more important function as the reach of the station in the metro network will become higher. The metro line also needs to cross a road at the beginning of the new metro line. The depot and the location for the bridge are in figure 4.1.4 below.

Figure 4.1.4: Depot and bridge at metro station Isolatorweg (Google Maps)

The first new addition at Isolatorweg is a parking garage for cars that is made to the east of the metro station of which the structure is shown in figure 4.1.5. On this location is a metro depot, which needs to be upgraded as metros are going to drive on it partially. The depot is just under six metres above ground level and therefore the parking garage is made under the metro depot.

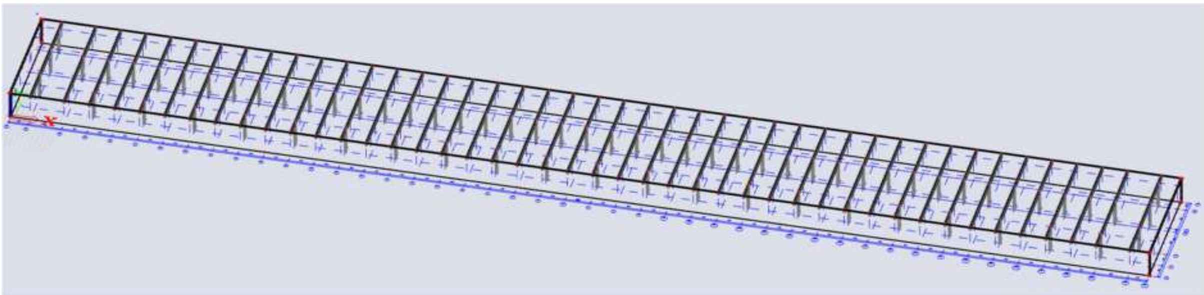


Figure 4.1.5: Structure parking garage Isolatorweg (structural discipline)

The second addition is a bridge that starts at the east end of the depot. The bridge is less wide than the depot because there will only be two metro lines on the bridge compared to the metro depot where much more track is on. To the north of Isolatorweg is already a bridge but this one is for trains. For the new metro bridge inspiration is taken from this bridge, but they are not connected to each other.

4.1.3 Metro stop Havenstad

Also the inhabitants of Havenstad should be connected to the metro network of Amsterdam. In this section, the metro stop of Havenstad will be discussed. This metro stop is located near the Transformatorweg in Amsterdam.

The metro stop is built by using the cut and cover technique. Diaphragm walls are designed to withstand all the horizontal loads. Tension piles are also installed in this building pit, to prevent uplift. The station is built in a compact way to ensure no buildings or infrastructure above ground are lost. A figure of the station can be seen below. The two tunnels will be above each other in this section of the alignment, so also in the station.

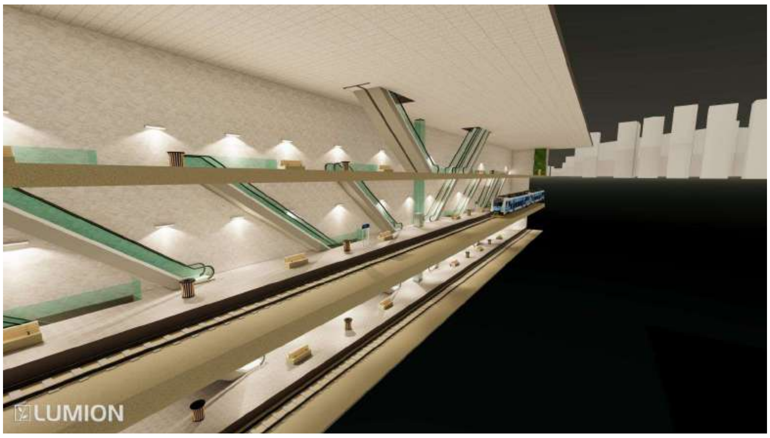


Figure 4.1.6: Havenstad metro station (BIM discipline).

4.1.4 Metro stop Nassauplein

To increase the traffic flow in and around Amsterdam, there is opted for a metro stop at Nassauplein. This metro stop consists of two parts, the underground metro station and a ground level “hub”. Firstly the underground metro station will be discussed, after which the hub is specified.

Besides the metro stop at Havenstad, another metro stop is realised at Nassauplein to stimulate the transportation of people from Nassauplein. This metro stop contains two elevations, for which the first one is sidely connected to the pedestrian tunnel that transports people from the HUB at Nassauplein towards the metro stop at Nassauplein. See Figure 4.1.7.

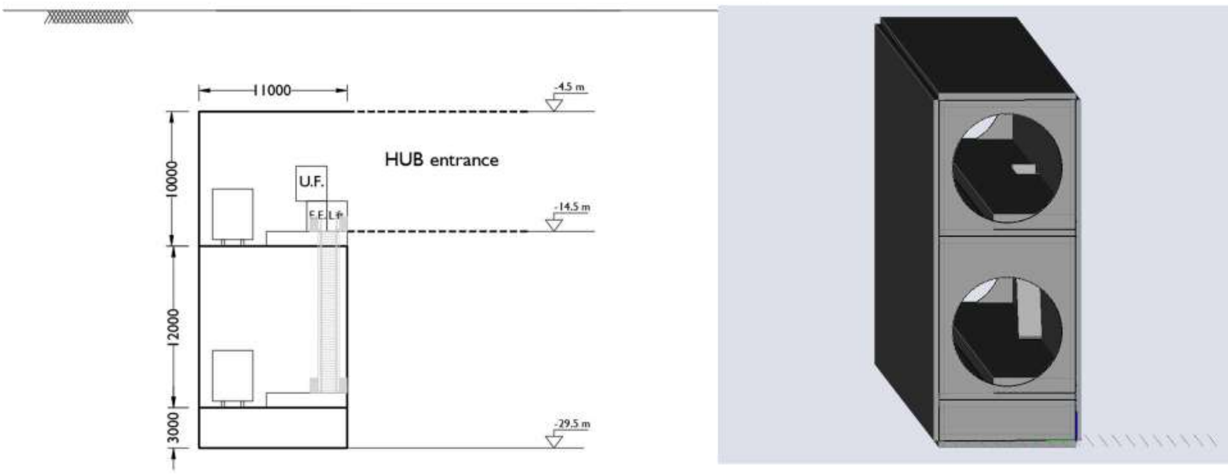


Figure 4.1.7: Nassauplein metro station (Structural discipline).

On the first floor of the tunnel where the pedestrians enter, an escalator is realised to allow people to go from the first to the second floor and vice versa. The built execution of this metro stop is exactly just as for the metro stop at Havenstad. However, it should be mentioned that underneath the second floor, a water storage area is created to comply with the requirements of sustainability and water management. Regarding sustainability, solar panels have been considered on the bicycle parking at this metro stop. The availability of the solar panels is further elaborated in Appendix G on renewable energy.

The hub has multiple functions, not only does it make a passage between the upperground and the metro station, but it also contains bike parking and restaurants or shops. The hub is 45x45*m* and will be placed at Haarlemmerplein. This position was chosen, because it's the only available space in and around Nassauplein for such a construction. In figure 4.1.8 the fitting of the neighbourhood can be seen and figure 4.1.9 shows the layout of the hub.

Figure 4.1.8: Fitting in neighbourhood (BIM discipline).

Figure 4.1.9: Layout of the HUB (BIM discipline).

As sustainability is important in the current day several ideas are implemented in this hub. First off all a green roof with solar panels will be applied. The greenery causes for better insulation and also as a sustainable method to reuse rain water. The solar panels will generate energy which can be used for the energy consumption in the hub and are shown in figure 4.1.10.

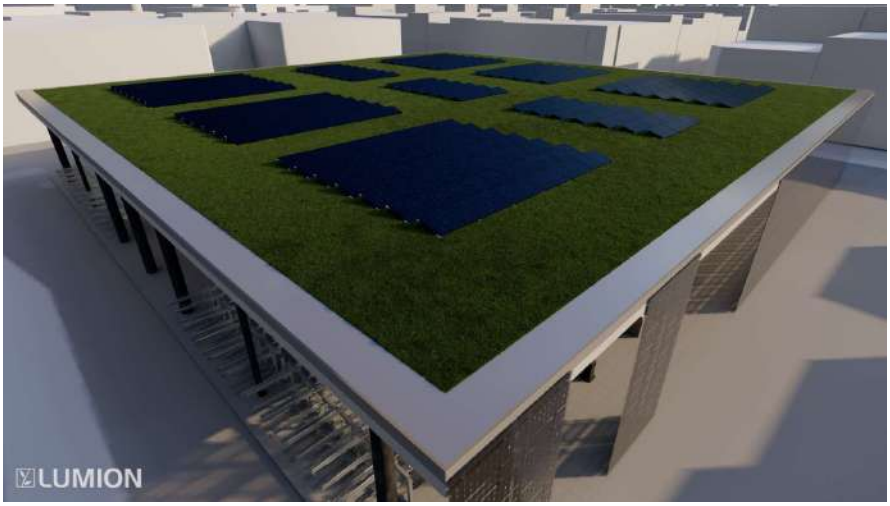


Figure 4.1.10: Green roof and solar panels (BIM discipline).

The hub is 6 metres high, which seems high at first, however this is chosen very carefully. As Amsterdam is still growing, more bike garages or facilities will be needed in the future. To accompany this the height of the hub is quite large. This offers the possibility to eventually add a second level to the hub, for either bike parking, shops or recreational area.

4.1.5 Underground farming

Space has been earmarked in the metro-tunnel at Havenstad for farming, plants will be grown right above the metro tracks in underground-farms. This makes the ground between the surface and tunnel way more useful. Because underground-farms are isolated better they stay heated and moist. Underground-Farms use 70% less water (hydroponics) and produce 6 times more harvests than regular farms WWII bunker underground farm 33m below ground in London (Broom, Douglas (2021, April 22). Therefore, a very sustainable way for growing foods. A sketch of the design by hydraulic discipline, see figure 4.1.11a) and a rendering figure 4.1.11.b) are shown below. An example from London, UK is shown in figure 4.1.11c.

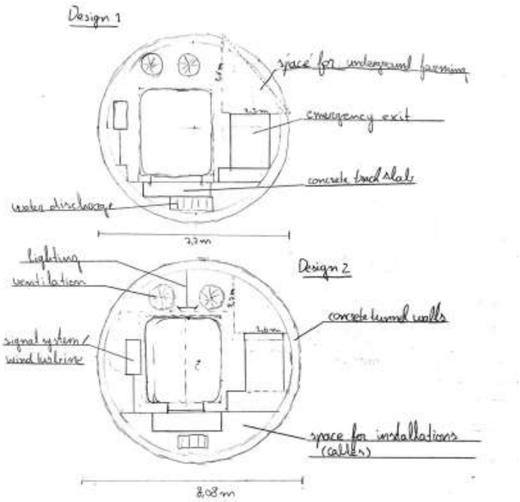


Figure 4.1.11a: Sketch of Metro tunnel with proposed underground farming (Hydraulics and sustainability discipline)

Figure 4.1.11b: Rendering of Metro tunnel with proposed underground farming (BIM and sustainability discipline)

Figure 4.1.11c: Existing underground farming, London, UK (Smedley & Smedley, 2014)

4.2 Havenstad infrastructure

In this section, the design of the infrastructure in Havenstad will be designed. This includes infrastructure alignment, the bridge above the railway and permeable pavement.

4.2.1 Infrastructure alignment

In this paragraph, the infrastructure within Havenstad is explained. The first paragraph covers the different road types in Havenstad, the second paragraph covers the design of the public transport in Havenstad and Houthavens and the third paragraph covers the design of the bike parking facility close to subway station Havenstad.

Roads
This paragraph covers the road lay-out in Havenstad. In Figure 4.2.1, a map is visible for the different roads in the area. The yellow roads indicate normal streets, in which all the in city roads are designed at 30 km/h and the main road at 50 km/h (The road beneath the neighbourhood Havenstad). All the red roads are the “fietsstraten” or bike-friendly roads. These streets prevent heavy car traffic since bikes have priority on that road. In Figure 4.2.2, an example of a “fietsstraat” is given.

Figure 4.2.1: Roads in Havenstad and Houthavens (Transport and planning discipline)
Figure 4.2.2: “Fietsstraat” or bike-friendly road (Dura Vermeer, 2015)

In the pictures below, a clarification through figures is given on what kinds of road the non “fietsstraat” roads will be. In Figure 4.2.3, the 30 km/h roads through the northern residential part of Havenstad and in Figure 4.2.4, the design of the central road through the city centre (yellow line from the main road towards the northeast point, in which the offices are established).

Figure 4.2.3: Indication of the road lay-out in North Havenstad (Google Maps, 2022).
Figure 4.2.4: Indication of the main road lay-out through the centre of Havenstad (Google Maps, 2022).

Public transport
In this paragraph, the public transport (the subway excluded) is drawn and explained.

Figure 4.2.5: Bus network in Havenstad (Transport and planning discipline)

Chosen is to maintain the buslines 48 and 20 from Amsterdam central station to Houthavens and Sloterdijk respectively. The only adjustment that was made on the existing lines, is some extension in the northern part towards the offices. A turning loop was added with a new stop in this area to make the connection between the city and the offices a bit better transportation wise.

It is found that the optimal distance between bus stop and the destination/origin of the travellers in Amsterdam is 250 metre (Rijnmond, 2018) and therefore some new residentials were not connected enough to the network. Also, there was no direct line from the station of

Havenstad and the offices/residents. Based on those shortcomings, a new line (line 23) was set up and is indicated in light blue in Figure 4.2.5.
In Figure 4.2.6, the map is indicated with the area that is covered by the bus lines (based on 250 m radius). The red circle is the area that is covered extra due to the new bus line.

As visible, the whole new residential area is within the radius that is wished and only parts of Houthavens are not in the 250 m radius area, but this part of Houthavens is not too far from the closest bus station. Rijnmond (2018) found out that a radius of 400 to 500 metres is averaged in The Netherlands as an influence radius for bus stations. With this criterium, all the parts of Havenstad are definitely covered and therefore covering the small parts of Houthavens and Havenstad that have to walk slightly more than 250 metres is not really necessary.

Figure 4.2.6: Coverage of bus stations (Transport and planning discipline)

Bike parking facility in the core
In this section, the design of the bike parking facility close to station Havenstad is explained.
According to the government of The Netherlands (n.d.), 27% of the total amount of journeys were made by bike. By assuming this value for the transportation towards the station Havenstad, the total number of bike trips towards that station can be estimated on: 0.27 * 14649 = 3955 total trips (The total number of travellers is calculated in Appendix E). Most of Havenstad is designed as residential and also the surrounding neighbourhoods that use Havenstad station contain mostly housing. Therefore, it is expected that most of the bike movements towards the station are work related. The users will therefore use the facility the entire day (9 to 17) and they will occupy parking slots for the entire time in between.

A facility of around 4000 parking slots is therefore necessary to maintain the availability of free slots throughout the day. Taking this large amount of free spots also encourages bike usage throughout the city and especially in Havenstad.
For travellers who arrive at Havenstad station and want to travel to the core of Havenstad or the offices by bike, some OV-bikes are available at this facility to provide easy options for

travelling by bike. In Figure 4.2.7, an OV-bike station is illustrated to give an indication about what is meant with this concept.

Figure 4.2.7: OV-bike (Algemeen Dagblad, 2022).

4.2.2 Bridge above railway

To create a good connection between Westerpark and Havenstad a bridge has been designed. The bridge will cross the main track to create a good connection between these two areas. The bridge will have to cross the depot, with a span of circa 250 metres. The bridge will be divided into 4 sections which each have a span of circa 60 till 65 metres. The begin- and end section have a span of 65 metres. The two middle sections are 60 metres.
For sustainability, the wood for the bridge is sustainably sourced. The availability of this type of wood with FSC certification is further elaborated in appendix G in the topic on R-strategies.

Figure 4.2.8: Bridge rendering image (BIM discipline)

With a view to the future the bridge will only be accessible to pedestrians and cyclists. With the design of the bridge. Future traffic flows have been taken into account in the design of the bridge. This showed that 2 wide cycle paths and a separate footpath are needed, the footpath will be separated from the cycle path by a railing.

For the design of the bridge it is chosen to design the bridge using the truss principle. A truss bridge is a common type of bridge with medium spans. The bridge derives its load-bearing capacity from a truss structure. Half-timbered structures are made up of triangles and are in theory non-deformable (retaining their shape). Because triangles are rigid, the forces are stabilised. By correctly positioning the triangle, the forces are directed in the right direction, as it were along the material. In this way only tensile and compressive forces are absorbed in the material, bending is not possible because it concerns a triangular construction

Because the loads on the bridge are not extremely large, it is possible to work with wood in combination with steel. Therefore the bridge will have a steel main- and crossbeam construction where all the other parts will be designed in wood. Chosen is to use *Red Angelim* wood. This wood has durability class 1 and strength class 50. It is a good application for Civil Engineering construction work and bridge decks.

4.2.3 Permeable pavement

Permeable paving in the residential area (chapter 4.2.1) also forms part of sustainability for flood control and water management. This together with the wadis (chapter 4.3.2) that collect the surface water and use it for underground farming. Their connection to the Sustainable Development Goals is provided in Appendix G.

Sustainable drainage systems
Stormwater management systems are shifting from traditional drainage systems to adopting sustainable drainage systems. Traditional drainage consists of upgrading large-scale underground drainage systems, but this is costly and sometimes infeasible in built-up urban areas. Whereas sustainable drainage systems adopt both low-impact development measures and drainage systems. Therefore sustainable drainage systems promote the recycling of water and reduce the burden on drainage systems.

Existing permeable pavement
In the Netherlands two stones are commonly used: the bbs drain stone from MBI and the Aquaston from Kloostermann BV. Aquaston has been shown to function the best after multiple years of consistency, so this will be used in Havenstad. This stone is shown in figure 4.2.9, Aquaston is a water-permeable concrete stone. The water enters the stone through small pores which are located on the top of the stone. The layer beneath the top layer is even more porous, therefore the water can infiltrate the ground relatively fast. The stone has a sponge effect, which ensures that the stone can retain water and when the water evaporates, the street cools.

Figure 4.2.9: Aquaston (Kloostermann-beton,2022)

In Groningen (The Netherlands) multiple locations of the two stone types were tested to determine their water permeability. Two locations where Aquaston is used were tested. Figure 4.2.10 shows the results of the water permeability tests of these locations.

The water permeability of P + R Haren-Zuid is the highest, where approximately 8 cm was infiltrated within two minutes. Whereas in Groenhof approximately 8 cm was infiltrated within 4.5 minutes. Both tests were done after more than ten years of the construction, so it is concluded that the stones still function well after existing for more than 10 years.

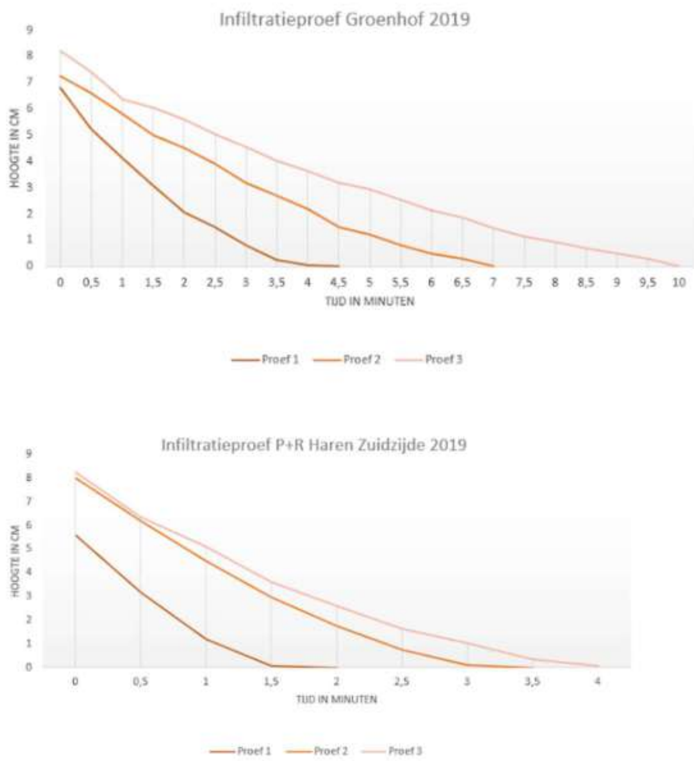


Figure 4.2.10: Results of water permeability tests of 4 locations (Watermanagement discipline)

Heat stress

Permeable pavement can help reduce heat stress in a residential area. Streets and pavements have a relatively high temperature as shown in figure 4.2.11, this is unpleasant for the neighbourhood residents. There are various factors that could affect the pavement's temperature such as solar reflectance, thermal properties, permeability, evaporation and others. However, previous researchers have found that permeable pavement tends to be hotter than conventional pavement during dry seasons. However, it was found that the presence of water could reduce the temperature of the pavement. (Buyung, 2017)

Figure 4.2.11: Heat photo of a residential area (E.A. Brouwer, personal communication, May 2018).

Bufferblocks

Bufferblocks are a solution for rainwater drainage and buffering in residential areas. You could compare the operation to infiltration crates but due to the higher strength, a much thinner top layer is required. This results in a higher buffer capacity and a more cost-friendly solution. Rainwater enters the blocks through permeable pavement or via gullies. Bufferblocks have a storage capacity of 266-532 litres per square metre.

When filled, the water in the buffer block can easily be discharged to the sewerage or better to a reservoir where the water can be stored. Furthermore, because of the permeable material, the water stored in the buffer can easily be infiltrated into the ground underneath. This is shown in figure 4.2.12.

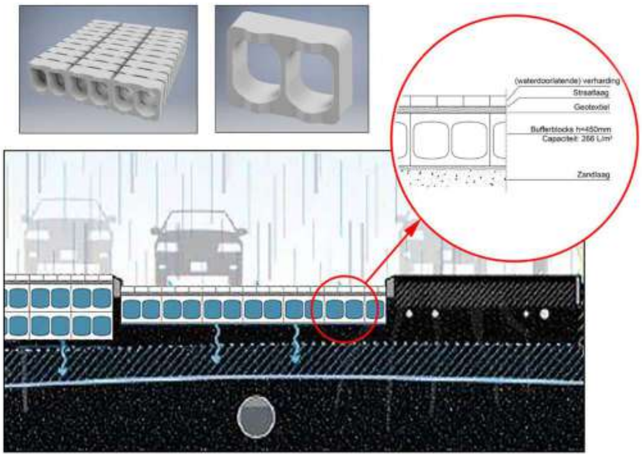


Figure 4.2.12: Cross-section of buffer blocks (Bufferblock, 2022)

Best option Havenstad

As previously stated a large surface of stones with a smaller surface of previous concrete and open-graded gravel base seems best. And considering the research done in Groningen (The Netherlands) Aquoston is the best choice, buffer blocks will be placed underneath the permeable pavement to further improve the storage capacity. At the parking lot in Havenstad and the residential area, the permeable pavement will be placed as shown in figure 4.2.13. It is expected that the water that ends up in the outer parts of the residential area will flow to the IJ. Therefore permeable pavement will be placed in the southern part of the residential area.

Figure 4.2.13: Locations of permeable pavement in Havenstad (Transport and planning discipline)

Pressure on sewerage

To determine the impact of permeable pavement on the sewerage system a rainfall of 103.5 mm/8 hours per cubic metre is considered.The surface is 18300 m^2. To calculate the total precipitation, this area is multiplied by 0.1035m which results in a total precipitation of 1894,05 m^3 the total surface of the permeable pavement infiltrates 0.37 m^3 per minute. This means that during a storm 3.95 m^3 precipitates per minute. This means that once in a 100-year time-lapse, around 3.5 m^3 precipitation cannot be drained through these pavements. This will end up in the sewerage. Yearly, the amount of rainfall is far less, namely 843 mm per year. This will not fall at once but will be spread over the year. All of the precipitation will be drained through the pavements.

4.3 Havenstad environment

In this section, the local environment in Havenstad will be discussed. The area that will be discussed is in alignment with the vision map of Havenstad, which is shown in figure 4.3.1. By looking at the area a new map is formed in which is visible how much and where paved, unpaved, green roofs, wadi's and permeable pavement is present in the new format of Havenstad.

Figure 4.3.1: a) Map of Havenstad(Transport and planning discipline) b) Map of the locations of the wadi's, green roofs and permeable pavement (Watermanagement discipline)

The high-rise residential, shops and offices will have green roofs. Wadis in Havenstad are placed in some green areas and some green areas are left for other recreation. Furthermore, a few roads in the area in the bottom of the map and the parking spot are paved with permeable street bricks.

These innovations from the Green Village at TU Delft and placement of Wadi's will be realised in a spatially integrated way by following the vision of the Transport and Planning discipline. Implementing this in Havenstad, this new part of the city Amsterdam will be Climate proof. Water will be better and more sufficient being stored so it can provide a new purpose for the area. The water can provide supply during droughts or have a cooling effect for the Urban Heat Island problem in cities. The wadi's and green roofs also make up for heavy and unexpected rainfalls, storage of water is increased and water is not spilled. This buffer for water storage makes Havenstad a sustainable region for the future. The design of the water system can be found in Appendix F.

4.3.1 Green corridors

For sustainability an urban green network has been incorporated as a spatial concept where the greenery in the neighbourhood is connected via green corridors. Green corridors in cities can be defined as linear natural infrastructure, such as trees and plants, that link up other green and open spaces to form a green urban network. These networks provide both ecological services, such as habitats for urban wildlife; whilst also providing services to urban populations such as mobility networks and access to green spaces through the provision of sustainable and active transport routes that link transport with mixed land use (residential, commercial, recreation etc) and open spaces. (Lambert, R. (2019). The goal of the urban green network is the distribution of greenspaces in the neighbourhood along the metro line. The green network (chapter 3.3.3) also has other benefits such as improving the quality of life in the neighbourhood.

Another added benefit for having the metro underground instead of an elevated track is the opportunity to have green spaces, i.e. grass verges, plants, gardens and wadis above ground that ensures that there is available space for nature and recreation and creates a pleasant living and working environment. An elevated track would also be a non- aesthetic alternative design. This choice also ensured that the green environment already in existence, like Park Westerpark, was less affected by the metro line.

In a lot of communities an infrastructure project such as a railway or a road divides an entire area into two different areas. The consequence of this is a less walkable area. The part of the community which is less connected will therefore be less attractive because of this created barrier. For this reason, it has been decided that the trace will not become an elevated track or a street level track. The trace will be underground to not divide the area above the ground. This has a lower impact on the division than one at street level and at the same time also allows for the green corridors.

4.3.2 Wadi’s

There are three types of wadi systems: the simple wadi, the improved wadi, and the sustainably improved wadi. To match the Sustainable Development Goals (SDG’s) (Appendix G.4), it is decided to go for the latter wadi system in the design. Figure 4.3.2 shows a cross-section of this wadi system. Provisions have been made for the sustainably improved wadi to promote infiltration and storage.

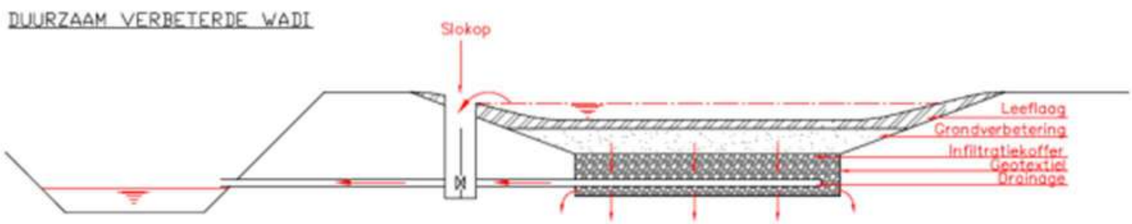


Figure 4.3.2 : Cross-section of a sustainable improved wadi system (de Jong Posthumus, 2014).

The bottom of the wadi is generally made up of various porous layers that together ensure the bottom is air- and water-permeable, and is nutritious so that vegetation can grow on it, and captures as much pollution as possible (Boogaard et al., 2006). The top layer determines the permeability of the wadi and consists of humus-rich soil with sufficient pore volume, so that grass can grow well, but the layer is also drained well. Under the top layer, a layer of coarse-grained sand is usually applied, varying from tens of centimetres to a few metres. Due to the large pore volume of the coarse-grained sand, it can store a lot of water. Instead of coarse sand, other porous media are sometimes used, such as lava slag or gravel. Then the water flows from this layer into an infiltration case. This infiltration case is being constructed to increase storage capacity. Furthermore, it consists of a trench with an aggregate that is packed in a cloth, which is sand proof to prevent soil washes in the trench with aggregate.

Water inflow

Several assumptions are necessary for the dimensioning of the storage capacity and the pipes of the wadis. Based on these assumptions, the various parts that the wadis contain can be dimensioned. The first assumption is that, based on Beersma et al. (2019), a return period of a hundred years and rainfall durations of eight hours and eight days are taken into account. This rainfall duration of eight hours is taken into account because the gulp, as shown in figure 4.3.2, can absorb the heaviest rainfall if the wadi were to overflow. So a wadi has been chosen to handle a rain duration of eight hours. Taking into account the capacity of the gulp, the precipitation is given for the highest rainfall duration.

Table 4.3.1: Rainfall amounts (in mm) at various rainfall duration (Beersma et al., 2019).

	Rainfall duration		
Recurrence time T [years]	**10 minutes**	**8 hours**	**8 days**
100	34,8 mm	103,5 mm	170,9 mm

The surface connected to the wadi, in other words, the surface on which the rainwater will fall and that flow towards the wadi are estimated with the height of the area via AHN (AHN, 2020). Subsequently, a flow area of the wadi is framed and the area of this flow area is determined with Google Maps. These two successive steps are shown in the figures below.

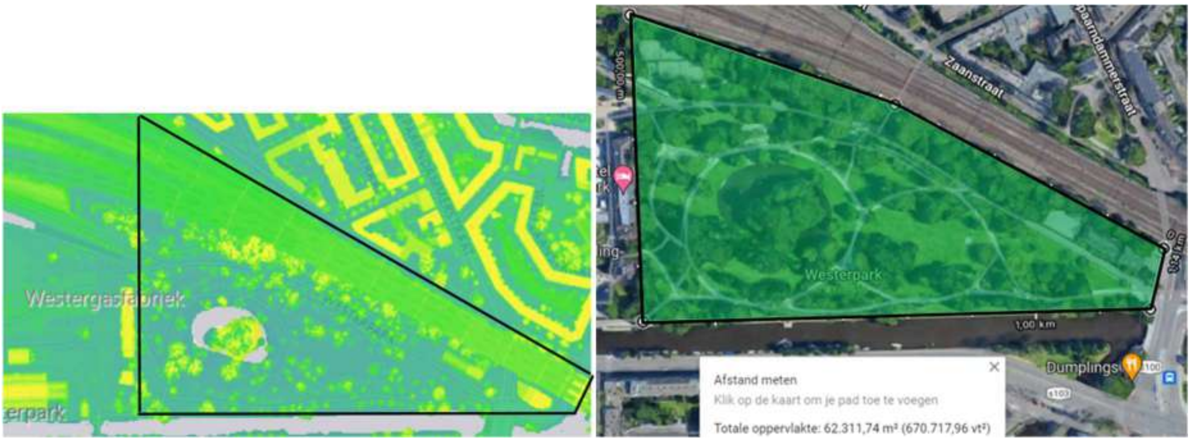


Figure 4.3.3: a) Flow area of the Westerpark wadi (AHN, 2020) & b) Flow area of Westerpark wadi covered in green (Via Google Maps).

The boundaries of the flow area are established by a slightly higher part of the park on the left because the water will no longer flow towards the wadi from that point. Furthermore, the track at the top and the water at the lower limit are the other boundaries, because the water will not be able to flow to the wadi here either.

Water outflow

The wadi will thus eventually be dimensioned based on an eight-hour rain shower of 103,5 mm, which can occur once in a hundred years. When this rain shower occurs, it is assumed that the wadi is completely filled with water, without it being flooded.

With a flow area of 12.400 m^2, as calculated and shown in Appendix F, and an eight-hour rain shower of 103,5 mm, a retainable amount of 1283,4 m^3 (12.400 m^2 x 0,1035 m) of water is supplied to the wadi. A wadi of 6 m wide, of which a bottom length of 2 m, a depth of 0,5 m, and a length of approximately 650 m can accommodate this amount since the wadi has a volume of 2600 m^3 (2 x 2 m x 0,5 m x 650 m). The principle of the cross-section of the wadi is shown in figure 4.3.2.3. The cross-section shows that the value of the wadi is 2:0,5, which corresponds to the requirement that it should not be greater than 3:1 related to mowing and safety aspects (Boogaard et al., 2003). These safety aspects are related to children in particular, e.g. children playing in the wadi. When the eight-day rainfall of 170,9 mm is taken into account, approximately 835,76 m^3 must be collected by the gulp. This excess rainwater will then be discharged into the sewage system. Therefore, only the eight-hour rainfall has to be taken into account for the discharge of the wadi.

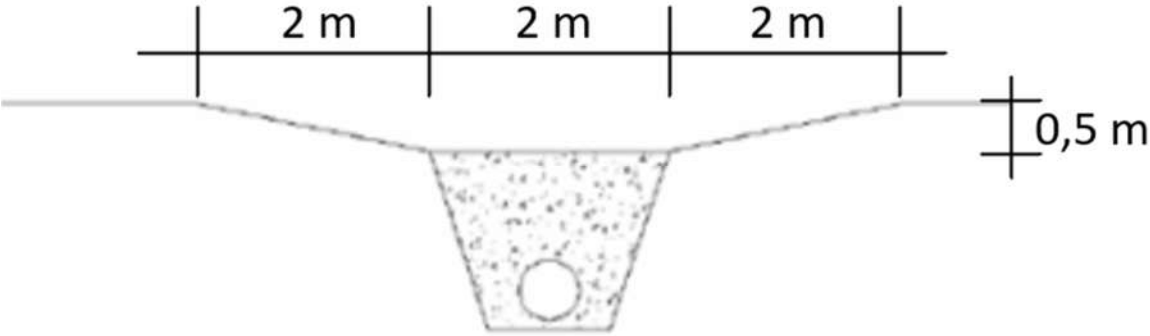


Figure 4.3.4: Principle cross-section wadi (Boogaard et al., 2003).

The location of the wadi in the Westerpark can be seen in the figure below. A circular wadi has been chosen here to ensure that all rainwater is drained off as quickly as possible by realising the shortest possible path to all surfaces within the flow area.

Figure 4.3.5: Possible location of the Westerpark wadi (Google Maps,2022).

To keep the hiking trails as intact as possible as they are now constructed, small and simple wooden bridges will be constructed at the places where the wadi overlaps with a hiking trail. Such a bridge, also called a decking path, was chosen, because it both ensures that the wadi can be built with the correct dimensions and that the sustainability that the park entails is not endangered. An example of the chosen bridge can be seen in the figure below.

Figure 4.3.6: Example of a decking path (Funbreaks, 2020).

From wadi to station reservoir
All water flowing into the reservoir underneath the wadis will, after infiltration, directly flow to the reservoir underneath the stations. When calculating the total discharge which will flow through the pipes to the reservoir underneath the station, an assumption will be made. This assumption is based upon the evaporation and transpiration of the water falling on these green roofs. During winter, green roofs can obtain up to 25-40 percent and during summer 70-90 percent. That menas, in the worst-case scenario, 75% of the total rainfall volume will flow into the wadi. A great part of this will evaporate or transpirate directly back into the atmosphere. Because of the evaporation and transpiration of the biggest part of the precipitation, an estimated 20 percent of the total rainfall will reach the reservoir underneath the wadis. Therefore, a total volume of 513,36 m^3 (0,2 x 2566,8 m^3) is flowing through the wadi to the reservoir underneath. This rainfall volume occurs in eight hours so that the flow through the wadi to the reservoir is 0,0178 m^3/s (513,36 / (8 x 3600)). Furthermore, an assumption is made that the minimum flow velocity through a storm weather sewer is about 1 m/s to resuspend sediment. That's why a flow velocity of 1,2 m/s is assumed for the dimensioning of the pipe which is filled (Nayyar, 2000). An estimation of the diameter of the pipe will be done by the following formula:

$$Q = A * v \rightarrow A = Q/v, with\ A = 1/4 * \pi * D^2, so\ that\ D = \sqrt{(4 * Q)/(v * \pi)}$$

With this formula an estimation of the diameter is calculated to be at least 0,138 m. Therefore, a pipe diameter of 0,20 m is chosen.

Water reserve and supply
When calculating the dimensions of the reservoir underneath the station, intended for underground farming, the total water demand will be taken into account, namely 0,0004-0,0006 m^3 per m^2. A total length of 1270 metres, which is the length of the tunnel between station Havenstad and station Nassauplein, will be provided with the water from this reservoir. According to the dimensions of the tunnel, this will lead to a water usage of 2 m^3 per day (1270 m x 2,7 m x 0,0006 m^3/m^2). The reservoir is dimensioned with a recurrence time of one year and a rainfall duration of eight hours because this peak intensity is good enough to estimate the dimensions of the reservoir. With this recurrence time and duration, a rainfall of 33 mm occurs. Therefore a flow volume through the wadi to the reservoir of 163,68 m^3 (0,033 m x 24.800 m^2 x 0,2) is obtained. A circular tank with a diameter of 8,5 m and a depth of 3 m is sufficient to store this amount of water during a peak rain event.

These wadis are also a part of sustainability. Their link with Sustainable Development Goals is provided in Appendix G.

4.3.3 Green Roofs

Another great opportunity for water management inside the city is green roofs. When heavy rainfall occurs, the sewage system might not be able to process all the water flowing into the system. re-engineering the sewer system might be a solution for the more frequent heavy rainfalls, but green roofs might offer a great alternative.

Benefits of water management
In figure 4.3.7 a section of a green roof is shown. This total of layers can be of help during rainfall. When all rooftops are considered to be impermeable layers, all water falling on these surfaces will directly flow to the sewer system. During heavy rainfall, the sewer system might

overflow. According to research, green roofs can obtain up to 20-40 percent during winters and up to 70-90 percent of the rain during summers. All this water will not end up in the sewer system and will eventually evaporate or transpirate into the atmosphere. The green roofs will prevent or delay the water flow into the system and therefore decrease the stress on the system. The water which runs off is naturally filtered and moderated in temperature (*About Green Roofs*, z.d.).

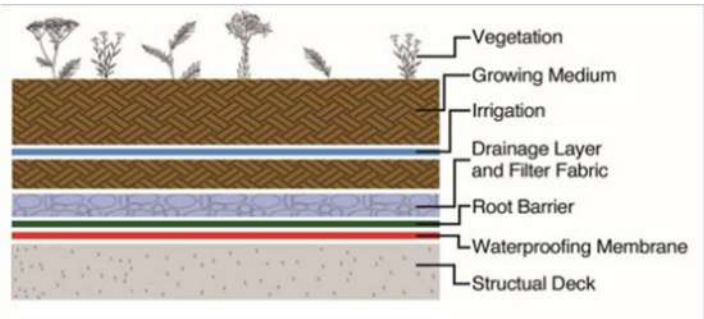


Figure 4.3.7: Cross-section of a green roof (Green roofs | *Soil Science Society of America*, z.d.).

Storm management
Green roofs are normally made of a mixture of high permeable soil layers. Those layers are designed to be highly permeable. There are other kinds of green roofs which can handle these storms better. The names of these green roofs are monolithic green roofs. This type of green roof is tested to be one of the best kinds to handle stormwater. The water can move freely through the roof and is in contact with the plants all the time before leaving the roof. Another factor of drainage capacity is the frequency of the storm. If one follows the other in a small amount of time, there will be more stormwater runoff. Again, percentages between 40-60 percent of the water falling on the roof will be drained through the green roof (*Green Roofs | Soil Science Society of America*, z.d.). According to Dutch standards, 843 mm precipitates every year. This means 0.33 m^3 per year for each square metre will not end up in the sewage system.

5. Conclusion, discussions and recommendations

This section elaborates on conclusions, discussions and recommendations.

The chapter starts with a conclusion section in which the main project research question as well as the sub-questions are answered. This is followed by a section in which the practical contribution of the research is discussed and its limitations are acknowledged. Finally, recommendations for the client, and tips for the future of the project are presented.

5.1 Conclusions

In this report, as stated in the beginning, the area of Havenstad was to be analysed and designed. The goal of this report was to deliver a design of this new build area and a design of the infrastructure around it, in particular a new metro line. The metro line is planned to ‘close the metro ring’ and in this plan the stations Amsterdam Isolatorweg and Amsterdam Centraal are connected directly. The design presented in this report forms a suitable and well thought out design for closing the ring. This involves the design and construction of the following:

- Metro tunnel from Amsterdam Central to Amsterdam Isolatorweg
- Station and metroline Havenstad
- Station and metroline Nassauplein
- Foot and cycling bridge connecting Westerpark and Havenstad
- Parking garage and metro bridge at station Isolatorweg
- Bike-friendly roads around Houthaven and Havenstad
- Bus connection at Havenstad for transit-time

This metro line was also to make sure that the new neighbourhood is connected with the rest of the city, but also that the connection in the city itself will be better. In the design the following has been designed for construction along the metroline: residential neighbourhoods at Houthaven and hubs at metro stations.

The design has been made sustainable and future-proof by incorporating the following:

- Green corridors: i.e. parks, lawns, green roofs, vertical gardens, permeable paving above ground and along the metro line;
- Wadi’s: contributions to the green corridor, are also part of flood control and a source of water;
- Underground farming: placed within the metro tunnel and will use water from the wadi’s (hydroponics) with excess flowing to the water body, het IJ.
- Sustainable energy: includes solar panels above ground and wind turbines in the tunnels.

5.2 Discussions

The discussion is about two parts of the project. The first part is the beginning stage of the project and is about the analysis of the project and the vision that resulted from this. The second part is the final stage of the project and is to use the vision to create the elements of the project and ends with a final design.

5.2.1. Analysing and vision of the project

For the region of Amsterdam, 70.000 houses will be realised before 2040 and that the building process of the houses will start from 2020. About 55.000 of these homes will be located in Haven-Stad and 47.000 jobs will arise at this location. We have taken this into consideration during the analysis to ensure that enough homes are provided in the design of the project.

More inhabitants and jobs in the neighbourhood or around the project area will lead to a growth in mobility needs and cause some pressure on the existing modes of transport therefore investing in the public transport system, especially if we take Transit-Oriented Development by connecting the ring with the metro line will optimise the efficiency of the current system that includes trains and buses. In the design, we also considered within the vision a design with less cars and more of other forms of movement e.g. walking and cycling.

5.2.2. The final design

The final design incorporates all of the above-mentioned design criteria that includes the metro line, the residential neighbourhoods, the hubs and at the end the Ring is Closed.
The design is based on the Transit Oriented Development (TOD) which means that the new areas surrounding mass transit facilities have been developed into integrated, lively and busy places. The new public transit stations and mobility hubs play a big role in this.
Where sustainability was possible, the design choices were made to ensure that this was achieved. The designs incorporated include multi-use of spaces, underground farming, wadis, green roofs, vertical gardens, energy-saving lifts, solar panels, and designs based on the use of less cement and sustainability sourced and certified wood.

5.3 Recommendations

The client can consider all the design proposals presented in this report and it is hoped that the choices we have made also confirms the choice to go for the Metro Track R4-a.

As often with large, integrated, sustainable and multi-disciplinary construction projects, there are few technical barriers to having many stakeholders and many alternatives, but there are other challenges, for example:

- Persuading the client or stakeholder to make the right choice.
- Guaranteeing material quality and performance.
- Ensuring sustainable and constant supply of goods and materials.
- Educating the project team on the goals and needs of the project.
- Identifying economic paybacks that are part of such large projects.
- Measuring benefits and success.

The recommendation is that the client pays attention to these challenges as the project progresses. The different elements worked out in this report could be useful as an inspiration for parts of the project. Also the sustainability aspects of energy-efficiency and carbon neutrality and other aspects of inclusiveness, economical factors and a multi-modal hub of the project could be taken into account.

Literature

About Green Roofs. (z.d.). Green Roofs for Healthy Cities. Retrieved 9 June 2022, from https://greenroofs.org/about-green-roofs

AHN. (2020, February 9). *AHN Viewer*. Retrieved 7 June 2022, from https://www.ahn.nl/ahn-viewer

Algemeen Dagblad. (2022, May 30). *OV-fiets binnenkort ook elektrisch: NS start proef met e-bikes*. Algemeen Dagblad. Retrieved June 17, 2022, from https://www.ad.nl/binnenland/ov-fiets-binnenkort-ook-elektrisch-ns-start-proef-met-e-bikes~a154e551/?referrer=https%3A%2F%2Fwww.google.com%2F

ArchitectenWeb. (2019, 21 juni). PVH Campus. Geraadpleegd op 22 juni 2022, van https://architectenweb.nl/projecten/project.aspx?ID=38355

ATLASX Windturbine (Gemaakt in Europa). (z.d.). TESUP NL. Retrieved 10 June 2022, from https://www.tesup.nl/product-page

Beersma, J. J., Hakvoort, H., Jilderda, R., Overeem, A., Versteeg, R., & Stichting Toegepast Onderzoek Waterbeheer. (2019). *Neerslagstatistiek en -reeksen voor het waterbeheer 2019*. STOWA. https://www.stowa.nl/sites/default/files/assets/PUBLICATIES/Publicaties%202019/STOWA%202019-19%20neerslagstatistieken.pdf

Bennich Therese, S. B.-A. (2021, February 10). The bio-based economy, 2030 Agenda, and strong sustainability – A regional-scale assessment of sustainability goal interactions. Retrieved from ScienceDirect: https://doi.org/10.1016/j.jclepro.2020.125174

Boogaard, F. C., Bruins, G., Wentink, R., & Stichting RIONED. (2006). *Wadi's: aanbevelingen voor ontwerp, aanleg en beheer*. Stichting Rioned.

Boogaard F., Jeurink N & Gels J.; Vooronderzoek natuurvriendelijke wadi's, inrichting, functioneren en beheer, RIONED/Stowa, Utrecht/Ede, 2003

Broom, Douglas. (2021, April 22). We Forum. Org. This WW2 bunker is growing sustainable salad leaves deep underground. Website: https://www.weforum.org/agenda/2021/04/underground-vegetable-garden-sustainable-farming/

Bufferblock BV. (2020). *Bufferblock – De Oplossing Voor Waterberging*. Bufferblock. Retrieved 10 June 2022, from https://www.bufferblock.nl/

Buyung, nuarl Rezuana. (2017). Permeable pavements and its contribution to cooling effect of surrounding temperature. Conference paper https://www.researchgate.net/publication/320446253_Permeable_pavements_and_its_contribution_to_cooling_effect_of_surrounding_temperature

CartoStudio.(2021,december).*Lijnennetkaart*[Kaart].https://www.gvb.nl/sites/default/files/daglijnenkaart2022.pdf

Chun Kit Ang, A. A.-T. (2019, January 15). Development of a footstep power generator in converting kinetic energy to electricity. Retrieved from E3S Web Conference: https://www.e3sconferences.org/articles/e3sconf/abs/2019/06/e3sconf_reee2018_02001/e3sconf_reee2018_02001.html

Circular-Economy-wiki. (2022, March 16). Sustainable materials for construction. Retrieved from Designning Buildings: https://www.designingbuildings.co.uk/wiki/Sustainable_materials_for_construction#:~:text=Use%20natural%20materials%20that%20have,other%20products%20made%20from%20crops.

De Jong Posthumus, E. (2014, June). *WADI of WAD*. https://www.hanze.nl/assets/kc-noorderruimte/Documents/Public/WADI%20of%20WAD_afstudeerrapport_EdeJP_25juni.pdf

Dura Vermeer. (2015). Veiliger fietsen op Gorinchemgracht. Dura Vermeer. Retrieved June 10, 2022, from https://www.duravermeer.nl/projecten/fietsstraat-gorinchemgracht/

Funbreaks. (2020). *Funbreaks - Single Event - Single Wandeling Broekpolder 103* [Foto]. Funbreaks. https://www.funbreaks.nl/single-events/single-wandeling-broekpolder/

Gemeente Amsterdam. (2018). *Haven-Stad Amsterdam*. Stakeholder Engagement Platform. Retrieved 13 May 2022, from https://www.overhavenstad.nl/map/layer/ruimtegebruik-water/c/ruimtegebruik-water/@52.3908,4.8577,12.7391z,!bnwx

Gemeente Amsterdam Klaas-Bindert de Haan. (z.d.). *Plusnetten en hoofdnetten infrastructuur*. www.maps.amsterdam.nl. Retrieved 20 May 2022, from https://maps.amsterdam.nl/plushoofdnetten/

Gemeente Amsterdam, Antea Group, Artz, T., & Lindeboom, H. W. (2017). *Milieueffectrapportage Haven-Stad*. https://www.commissiemer.nl/projectdocumenten/00002556.pdf

Gemeente Amsterdam Klaas-Bindert de Haan. (2021). *Concept Beleidskader Hoofdgroenstructuur - Toetskaart*. Gemeente Amsterdam. Retrieved 20 May 2022, from https://maps.amsterdam.nl/hgs2021/?LANG=nl

Giles-Corti, B., Lowe M., & Arundel, J. (June 2020). Healthy Policy, Volume 124, Issue 6. *Achieving the SDGs: Evaluating indicators to be used to benchmark and monitor progress towards creating healthy and sustainable cities.* https://doi.org/10.1016/j.healthpol.2019.03.001

Giles-Corti Billie, M. J. (n.d.). Achieving the SDGs: Evaluating indicators to be used to benchmark and monitor progress towards creating healthy and sustainable cities. Retrieved from ScienceDirect: https://doi.org/10.1016/j.healthpol.2019.03.001

Goyal, S. (2019, June 5). 60% of Delhi Metro now powered by solar energy from Madhya Pradesh. Retrieved from The World Bank IBRD-IDA: https://www.worldbank.org/en/news/feature/2019/06/05/delhi-metro-goes-solar

Green roofs | Soil Science Society of America. (z.d.). Green Roofs. Retrieved 14 June 2022, from https://www.soils.org/about-soils/green-roofs/?acsSsoAuthCheck=1

Ground-Works-Solutions. (2022). Railroad repair. Retrieved from GroundWorksSolutions: http://groundworkssolutions.com/service/railroad-repair/

GVB. (z.d.). *Lijnennetkaart* [Map]. GVB. https://www.gvb.nl/sites/default/files/daglijnenkaart2022.pdf

Hallostroom. (2021, October). Dit is de opbrengst van je zonnepanelen per m2. Website : https://hallostroom.nl/zonnepanelen/opbrengst/per-m2/

Illankoon, I. M. (2013, June). Use of Sustainable material in construction industry: Contractor's perspective. Retrieved from IRB net: https://www.irbnet.de/daten/iconda/CIB_DC26743.pdf

Kennisbank GroenBlauw. (2021). *Wadi | Effecten | Kennisbank | Groenblauwe netwerken*. Kennisbank Groenblauwe Netwerken. Retrieved 1 June 2022, from https://www.urbangreenbluegrids.com/kennisbank/effecten/wadi/

Kennisportaal klimaatadaptatie. (2020). *'Een wadi kun je eigenlijk overal aanleggen'*. Klimaatadaptatie. Retrieved 13 May 2022, from https://klimaatadaptatienederland.nl/actueel/actueel/interviews/wadi/

Kia, A., Delens, J. M., Wong, H. S., & Cheeseman, C. R. (2021). Structural and hydrological design of permeable concrete pavements. *Case Studies in Construction Materials*, *15*. https://doi.org/10.1016/j.cscm.2021.e00564

Kleerekoper, L., Van Esch, M., & Salcedo, T. B. (2012). How to make a city climate-proof, addressing the urban heat island effect. *Resources, Conservation and Recycling*, *64*, 30–38. https://doi.org/10.1016/j.resconrec.2011.06.004

Kruithof, J. (2021, December 14). Search for the best recipe for circular concrete. Retrieved from TNO Insights: https://www.tno.nl/en/tno-insights/articles/searching-for-the-best-recipe-for-circular-concrete/

Lambert, R. (2019). *Green Corridors – Essential urban walking and natural infrastructure*. Retrieved from Natural Walking Cities: https://naturalwalkingcities.com/green-corridors-essential-urban-walking-and-natural-infrastructure/

Management-Training-Institute. (2020, September 18). *4 Tips for Practicing Consistency in Management*. Retrieved from Management Training Institute: https://managementtraininginstitute.com/4-tips-for-practicing-consistency-in-management/

MASH., W. A. (2020). Mobiliteitssysteem Amsterdam Schiphol Hoofddorp. Brightspace-TU Delft.

Masi, Fabio & Bresciani, Riccardo & Rizzo, Anacleto & Edathoot, Ajith & Patwardhan, Neha & Panse, Dayanand & Langergraber, Günter. (2016). Green walls for greywater treatment and recycling in dense urban areas: A case-study in Pune. Journal of Water, Sanitation and Hygiene for Development. 6. 10.2166/washdev.2016.019.

Website:
https://www.researchgate.net/publication/303716406_Green_walls_for_greywater_treatment_and_recycling_in_dense_urban_areas_A_case-study_in_Pune

MBI De Steenmeesters. (2021, August 9). *Waterpasserende bestrating*. Retrieved 10 June 2022, from https://www.mbi.nl/producten/infra/waterpasserende-bestrating/

Metropoolregio. (2022). Metropolitan Region Amsterdam. Retrieved from About the Metropolitan Region Amsterdam.: https://www.metropoolregioamsterdam.nl/about-mra/

Metropoolregio-Amsterdam. (n.d.). MRA Agenda. Retrieved from metropoolregioamsterdam: www.metropoolregioamsterdam.nl/agenda/

Metropoolregio en Gemeente Amsterdam & Waternet en Waterschap Amstel Vecht en Gooi. (2018). *Ons Klimaat Verandert*. KNMI, Weer- En Klimaatdienstverlening. Retrieved 13 May 2022, from http://klimaatverandering-mra.vormgeving.com/

Moulin, J.-M. (2021, January 21). Tips voor materiaalkeuze in duurzaam productontwerp. Retrieved from Shapes - The aluminium knowledge hub.: https://www.shapesbyhydro.com/nl-NL/materiaaleigenschappen/tips-voor-materiaalkeuze-in-duurzaam-productontwerp/#:~:text=Bij%20duurzaam%20productontwerp%20gaat%20het,die%20opnieuw%20kunnen%20worden%20gebruikt.\

Michon, M. (2005). *Wadi's | Amsterdam Rainproof*. Amsterdam Rainproof. Retrieved 10 June 2022, from https://www.rainproof.nl/toolbox/maatregelen/wadis

Mucuthi, P. W., & Born, J.-P. (2022, 05 13). Water Water, Green Energy e.g. Geothermal Heat, CO2 emissions and how it is measured. (P. W. Mucuthi, Interviewer)

Nayyar, M. L. (2000). *Piping Handbook* (7th ed.). McGraw-Hill Education: New York.

New Scientist . By Kate Douglas &Joe Douglas (2021, 24 March). Green spaces aren't just for nature – they boost our mental health too (Urban Greening)
Retrieved May 2022 from: https://www.newscientist.com/article/mg24933270-800-green-spaces-arent-just-for-nature-they-boost-our-mental-health-too/

Rijnmond. (2018, 2 17). *Wie bepaalt de locaties van tram- en bushaltes?* Rijnmond. Retrieved June 16, 2022, from https://www.rijnmond.nl/nieuws/165016/wie-bepaalt-de-locaties-van-tram-en-bushaltes

Saraogi, V. (2019, July). Riding Sunbeams launch pilot scheme for UK's first solar-powered railways. Retrieved from Railway Technology: https://www.railway-technology.com/analysis/uks-first-solar-powered-railways/

SEARCHING FOR THE BEST RECIPE FOR CIRCULAR CONCRETE. (2021). Retrieved 13 May 2022, from https://www.tno.nl/en/tno-insights/articles/searching-for-the-best-recipe-for-circular-concrete

Sempergreen. (2018). *Benefits of a green roof - Sempergreen*. Retrieved 13 May 2022, from https://www.sempergreen.com/en/solutions/green-roofs/green-roof-benefits

Stam, Rozemarijn. (2018, October 11). These Floor Tiles Can Power Public Lighting While You Walk On Them. Website: https://popupcity.net/observations/these-floor-can-power-public-lighting-while-you-walk-on-them/

Sustainable Development Goals - Knowledge Platform (2022). *Targets and topics related to the Sustainable Development Goals as defined in Transforming Our World - the 2030 Agenda for Sustainable Development.* Retrieved from the Sustainable Development Goals Knowledge Platform website: https://sustainabledevelopment.un.org/topics/sustainabledevelopmentgoals

Teigiserova, D. A. (2021, April). The hidden value of food waste: A bridge to sustainable development in the circular economy. Retrieved from Researchgate: https://www.researchgate.net/publication/351091064_The_hidden_value_of_food_waste_A_bridge_to_sustainable_development_in_the_circular_economy

The Green Village. (2022). *Klimaatadaptieve stad*. Retrieved 13 May 2022, from https://thegreenvillage.org/klimaatadaptief/

TU-Delft-OCT-07-054. (n.d.). Self healing concrete-materials that can repair itself. Retrieved from TU Delft: https://www.tudelft.nl/innovatie-impact/samenwerken-met-tu-delft/octrooien/selectie-van-tu-delft-patent-portfolio/self-healing-concrete-materials-that-can-repair-itself

TU-Delft-OCT-07-054. (n.d.). Self healing concrete-materials that can repair itself. Retrieved from TU DELFT: https://www.tudelft.nl/innovatie-impact/samenwerken-met-tu-delft/octrooien/selectie-van-tu-delft-patent-portfolio/self-healing-concrete-materials-that-can-repair-itself

United Nations Human Settlements Programme(UN Habitat). (August 2004). Urban Indicators Guidelines. *Monitoring the Habitat Agenda and the Millennium Development Goals.* https://unhabitat.org/sites/default/files/download-manager-files/Urban%20Indicators.pdf

United-Nations. (n.d.). Targets and topics related to the Sustainable Development Goals as defined in Transforming Our World - the 2030 Agenda for Sustainable Development. Retrieved from Sustainable Development Goals - Knowledge Platform: https://sustainabledevelopment.un.org/topics/sustainabledevelopmentgoals

United-Nations-Human-Settlements-Programme. (2004, August). Urban Indicators - Monitoring the Habitat Agenda and the. Retrieved from UN Habitat: https://unhabitat.org/sites/default/files/download-manager-files/Urban%20Indicators.pdf

Use of sustainable materials in construction industry contractors perspective. (2013). Retrieved 13 May 2022, from http://www.irbnet.de/daten/iconda/CIB_DC26743.pdf

Van den Berg Hardhout. (2020)

https://www.vandenberghardhout.com/en/hardwood-types/angelim-vermelho/

Waternet. (2022, 4 april). Public Information Map. esri. Retrieved 10 June 2022, from https://maps.waternet.nl/kaarten/peilbuizen.html?_ga=1.67320529.1557047828.1485769328&_gl=1*mt5atu*_ga*NjEyOTU3MDM5LjE2NTIyNzM0OTg.*_ga_4X6RF77ST3*MTY1NDc3ODAyMS4zLjAuMTY1NDc3ODAyMS4w

World Green Infrastructure Network. (2021). *Key Definition: Green Roof*. Retrieved 13 May 2022, from https://worldgreeninfrastructurenetwork.org/key-definition-green-roof/

Yinghan Zhu, L. J. (2021, September 30). Sustainable Development of Urban Metro System: Perspective of Coordination between Supply and Demand. Retrieved from National Library of Medicine - Centre for Biotechnology Information.: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8507609//

Zhu, Yuxin. (2021). Permeable pavement design frameword for urban stormwater management considering multiple criteria and uncertanty. Journal of Cleaner Production, Production 293.
https://www.sciencedirect.com/science/article/pii/S0959652621003346

Appendix A: General

A1. Results Criteria

Table A1.1: Criteria matrix

Theme	Weight factor	R1	R1-t	R1a	R1a-t	R2	R3	R4	R4a	R5
Feasibility	**4**	++	++	+/-	+	-	+/-	+	+	-
Obstruction	**3**	-	-	--	--	--	+	+/-	+/-	+/-
Technical requirements	**5**	++	++	++	++	++	++	+	+	++
Maintenance facility and stabling zone	**2**	+/-	+/-	+/-	+/-	+/-	+/-	++	++	+
Robustness	**3**	-	--	+/-	--	+	+	+	+	+
Spatial integration	**3**	+	+	+	+	+/–	++	++	++	+/-
Spatial development	**5**	+/-	+/-	+/-	+/-	+/-	+/-	+	+	-
Sustainability	**5**	++	++	++	++	++	++	++	++	++
Land properties	**3**	+/-	+/-	+/-	+/-	+/-	+	-	+/-	+/-
Dependencies	**2**	-	+	-	+	+/-	+/-	+/-	+/-	+/-
Costs	**2**	+	++	+	++	+	+/-	-	-	-
Planning	**1**	-	--	+	--	++	+/-	+	+	+/-
Total score		138	140	132	130	131	149	147	151	124

Appendix B: Building Information Model (BIM)

Wail Abdellaoui, Lars Dijkstra, Kareem El Sayed, Kenzo Kuramae

This section reports the work performed by the BIM-discipline. The contribution of each group member is shown and the models of the group are presented. Furthermore an evaluation was carried out on the models made.

Contribution of each group member:

Station Nassauplein (hub): Kenzo Kuramae
Station Havenstad (underground): Kareem El Sayed
Passengers bridge (bridge over railway): Lars Dijkstra
Tunnel entrance & wadi: Wail Abdellaoui
Vlekkenplan: Kenzo Kuramae, Kareem El Sayed, Lars Dijkstra, Wail Abdellaoui

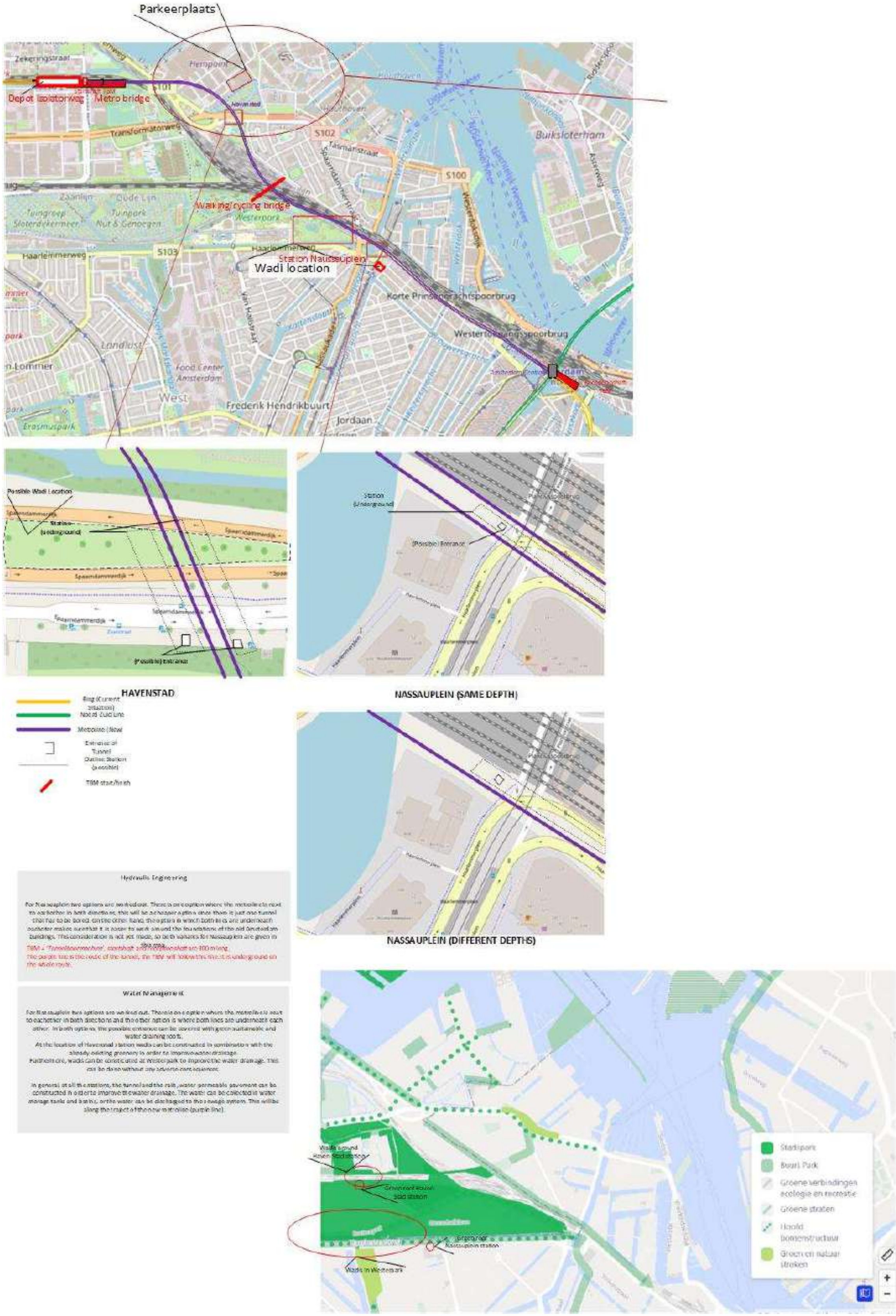
Software used:

Autodesk Revit Architecture 2023
Autodesk InfraWorks
Lumion 12.5 Student
Blender 3
SketchUp 2017

Model

The aim of this chapter is to provide a visualisation of the designs described in the report. In this section images of models are shown including an explanation. Models were made of: Station Nassauplein, Station Havenstad, the passengers bridge, the tunnel entrance and the wadi.

Vlekkenplan



Station Nassauplein

HUB Nassauplein has access to metro, tram and bus lines with bike parking facilities and pedestrian friendly layout. Distance between the HUB and the metro line for the pedestrian tunnel was decided by structural engineering discipline and confirmed to be the correct dimension to reach the metro route.

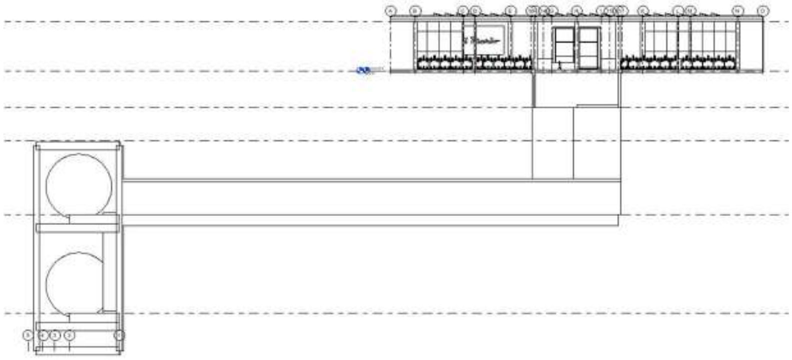


Figure B1.1: Nassauplein HUB northern view.

Layout of solar panels and the green roof have been discussed with sustainability and structural engineering disciplines to make sure the construction can bear the loads by the green roof and solar panels, as well as provide the desired performance. Groundlevel location of the HUB has been decided by transport & planning and structural engineering to be placed off center of the metro route on a square nearby, confirmed to fit by BIM.

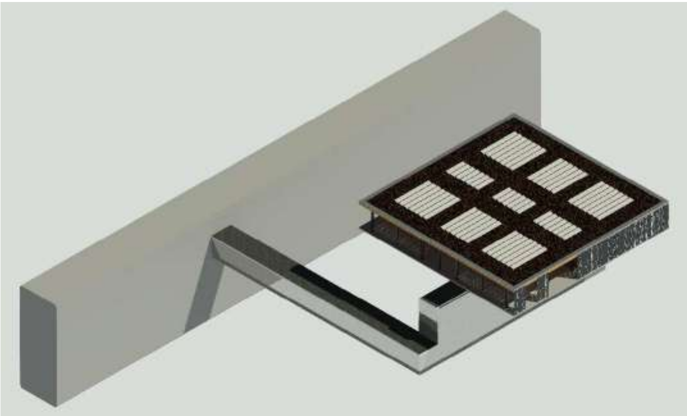


Figure B1.2: Nassauplein HUB overview.

Figure B1.3: Overview of Nassauplein HUB.

Interior of the HUB on the ground level has as main functions the access to the metro and the different facilities. Initial design by structural engineering is in line with this philosophy and does not cause hindrance.

Figure B1.4: Interior shot of the main entrance at ground level. Bike parking on both sides.

Figure B1.5: 400 m^2 of commercial space on the ground level. And enough space for pedestrians to reach their destination.

Panoramic view of the interior on the ground level:
https://view.mylumion.com/?p=n64uqwqwwekgrclu

From the ground level access to the metro lines is mainly provided by escalators. There is also a staircase between level 0.5 and ground level. In these enclosed spaces green walls and ample lighting are used to provide a more comforting feeling as suggested by the sustainability discipline.

Figure B1.6: Interior shot of level -0.5 where green walls and lighting makes it a more appealing place.

Figure B1.7: Interior shot of escalator leading to level -1 to the tunnel that provides access to the metro.

Figure B1.8: Interior shot of the lift at level -1 that leads to level 0.

Structural design has been imported by .ifc file from Scia used by the structural engineering discipline. Walls, floors and roofs have been created in Revit 2022. Larger components have been imported from the online bimobjects library. Signs have been created in SketchUp 2017. Context like the people, vehicles and vegetation have been added in Lumion 12.5 student where the renders and video's have been generated.

Video Nassauplein HUB created in Lumion 12.5 Student

Interior walkthrough

https://tinyurl.com/NassaupleinInterior

Exterior walkthrough

https://tinyurl.com/NassaupleinExterior

Station Havenstad

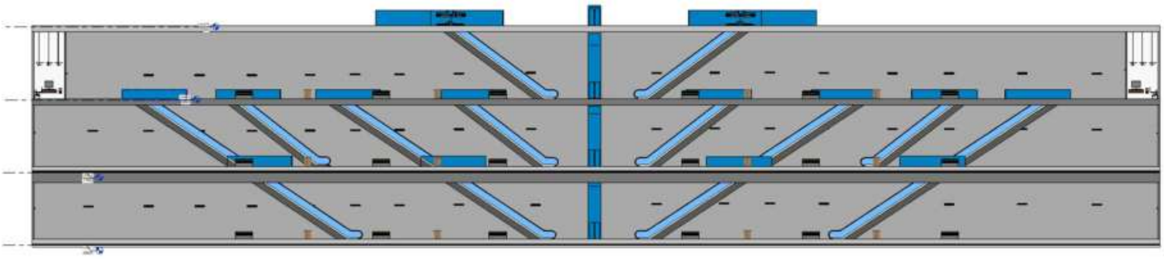


Figure B1.9a: Eastern view of Haven-Stad station.

Figure B1.9b: 3D Orthographic projection of underground Haven-Stad station.

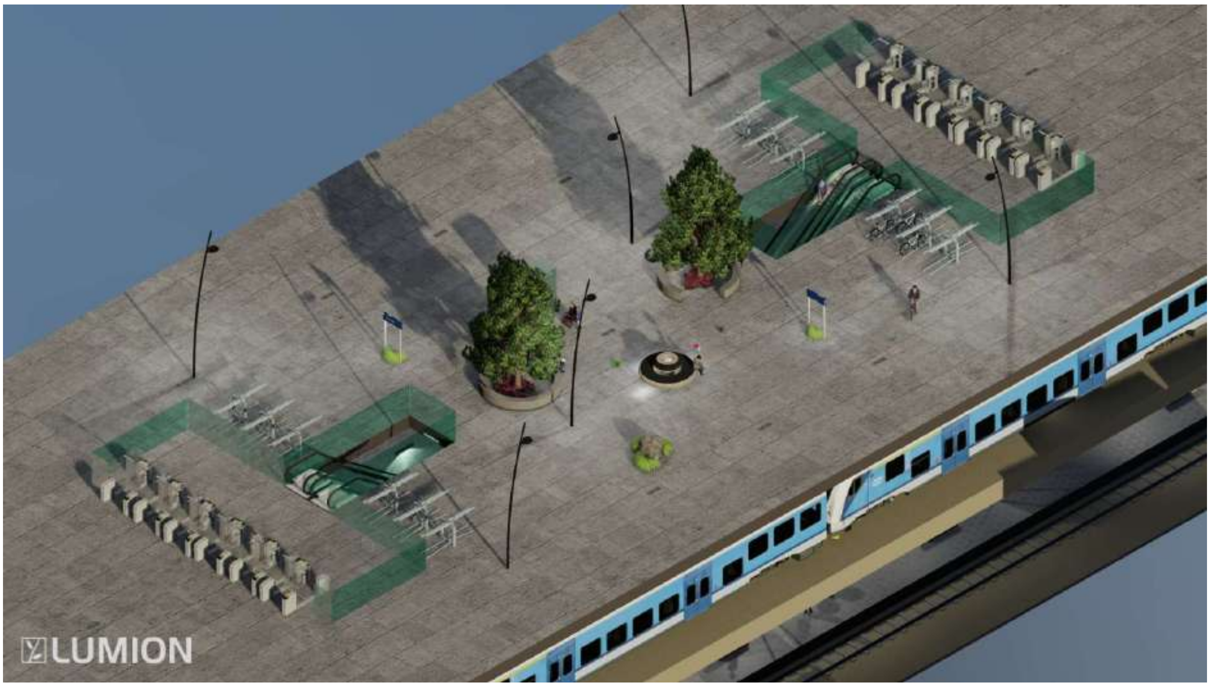


Figure B1.10: Top view Haven-Stad station square

Figure B1.11: Bicycle storage station Haven-Stad.

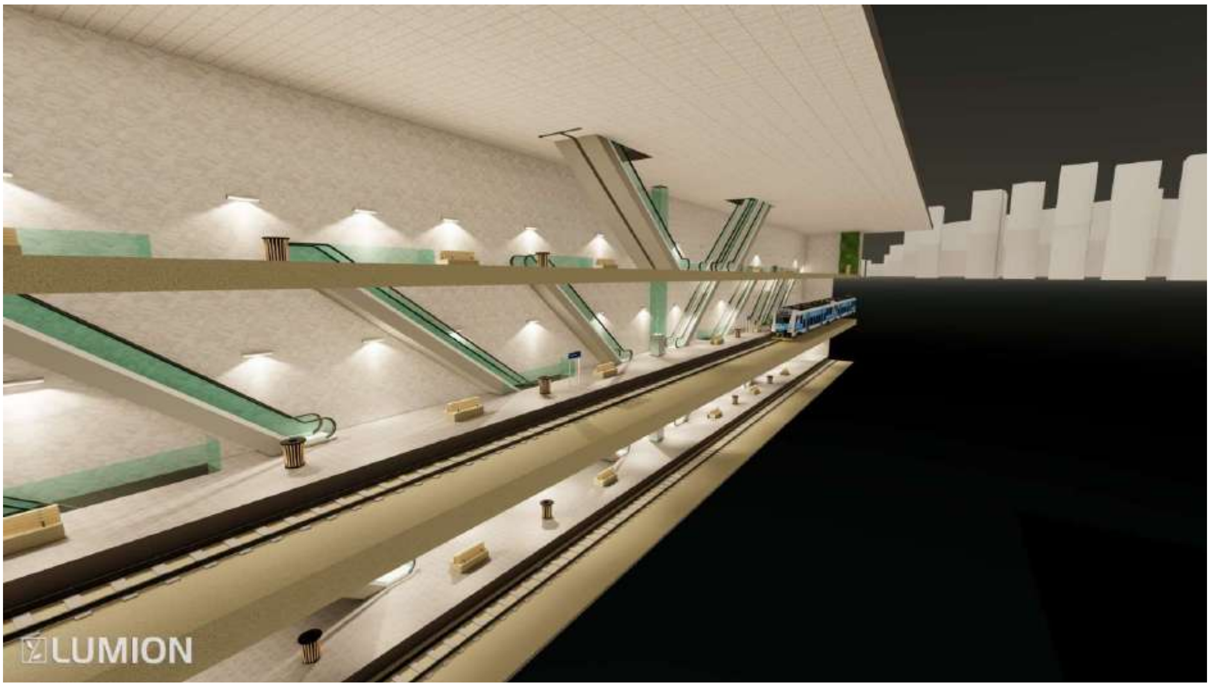


Figure B1.12: Night impression of Haven-Stad Station.

Figure B1.13: Point of view impression Haven-Stad station

These six pictures above are the pictures of station Haven-Stad. This station is an important station for the area of Haven-Stad and its model illustrates the idea of the implementation of all underground stations of the project. This station is an underground subway station. It consists of three underground layers. The first underground layer is designed to receive the passengers and contains bathroom facilities. It increases the capacity of the station. The second underground layer is designed for one direction of the metro. The third underground layer is designed for the other direction of the metro. The escalators starting from the second layer are placed such that the passengers can go to their metro in one go, without exchanging escalators. This is done to prevent congestion in the station.

Figure B1.14: Point of view impression of the core of Haven-Stad area

Figure B1.15: Birdeye impression of the core of Haven-Stad area

These two pictures above are made to give an impression of the area around the station Haven-Stad. It is chosen to build so-called forest towers in this area. These forest towers are multifunctional, containing companies, markets and many facilities. Between these forest towers a green area is placed where social cohesion can find place.

The layout of the station has been designed in Revit 2023. The renders have been made using the software Lumion. Lumion makes it possible to add details such as benches and plants.

Moreover, the lightning and the painting of the floors and walls has been modelled using Lumion. The design of the area around the station is fully made in Lumion. With the painting tool the grass could be laid and the walking routes in the area. From the library trees and fountains are added in the area.

For minor details, such as the entrance ports and the station signs, Blender has been used. Blender is a modelling program that has not been teached during the Bachelor course. It is a very strong tool to model minor details that cannot be found online. A problem that mainly arose during the design of the models is low-performance of the laptop. This could only be solved by having patience. Fortunately, no big problems arose during the designs. However, I had to study the program Blender which required some of my time such that I could start modelling the minor details.

Video Haven-Stad created in Lumion 12.5 Student
https://tinyurl.com/2j6u6khh

Bridge over railway

The bridge over the railway is a connection between Westerpark and Haven-Stad. This is important to create a way for cyclists and pedestrians to cross the railway to and from the new area of Haven-Stad. The bridge is made out of a combination of steel and wood where the wood is chosen from a sustainable source. In this model the on and off ramps are merely suggestions because they can be easily moved to accommodate the current buildings and roads. This is especially the case for the Haven-Stad side as there are a lot of roads and buildings in the way.

This model has been made using Revit 2023, while the renders have been done using Lumion. For reference of the bridge SCIA was used to load the design of the structural discipline. Lumion makes it easier to add items such as pedestrians, cyclists, trains and lighting. Lumion is nice to use because placing items and making renders is very easy and it gives you a lot of options for making nice renders.

The difficulty in making this model was the making of the ramps as they had not been designed by the structural discipline. This made creating the ramps hard because I had to go back and forth between Revit and Lumion to see if the ramps were interfering with current road and building structures. Also creating sloped railing in Revit is a pain.

Figure B1.16: Bridge connecting Westerpark and Haven-Stad.

Figure B1.17: Space for cyclists and pedestrians.

Figure B1.18: The bridge has been designed using the truss principle.

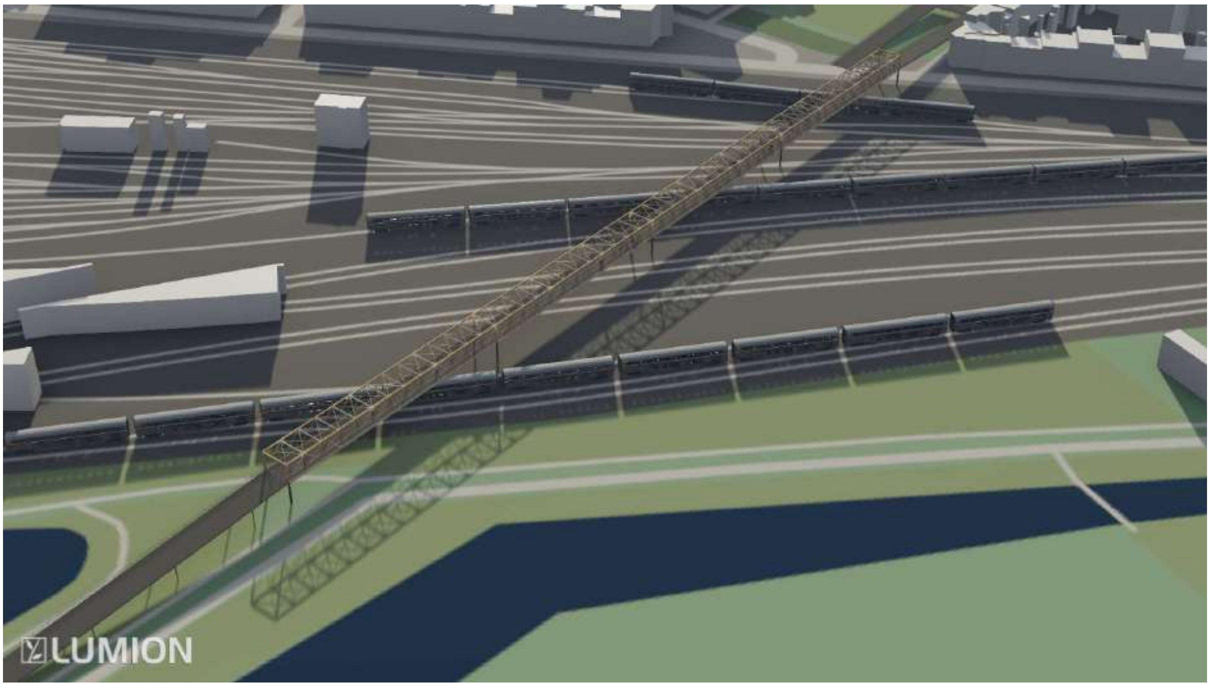


Figure B1.19: Top view of the bridge.

Figure B1.20: Bridge over railway.

Figure B1.21: Bridge has a span of circa 250 metres.

Tunnel
The tunnel will be constructed between Station Amsterdam Centraal and Amsterdam Isolatorweg. In the tunnel there is room for the metro itself. The tunnel also contains a installation of wind turbines, space for underground farming and an emergency exit. The wind turbines generate power from wind caused by the passing of the subway cars. This is linked with the goal of producing renewable energy as suggested by the sustainability discipline.
A model is made to provide a picture of this new construction. The aim of this model is to show how sustainable development goals are integrated in this infrastructural construction.

The layout of the tunnel, the wind turbines and the rail have been designed in Blender. The renders have been made using the software Lumion. Lumion makes it possible to add details such as the plants and the exit sign.

The program Blender has been used to model this tunnel. The circular shape of the tunnel was difficult to model using a program as Revit. Therefore, I chose to use the program Blender. This was a completely new program for me. By watching online tutorials on how to design a tunnel I got better at it. The video provided me with tools to model the construction. Combined with the input from the structural constructors I have realised the model below.

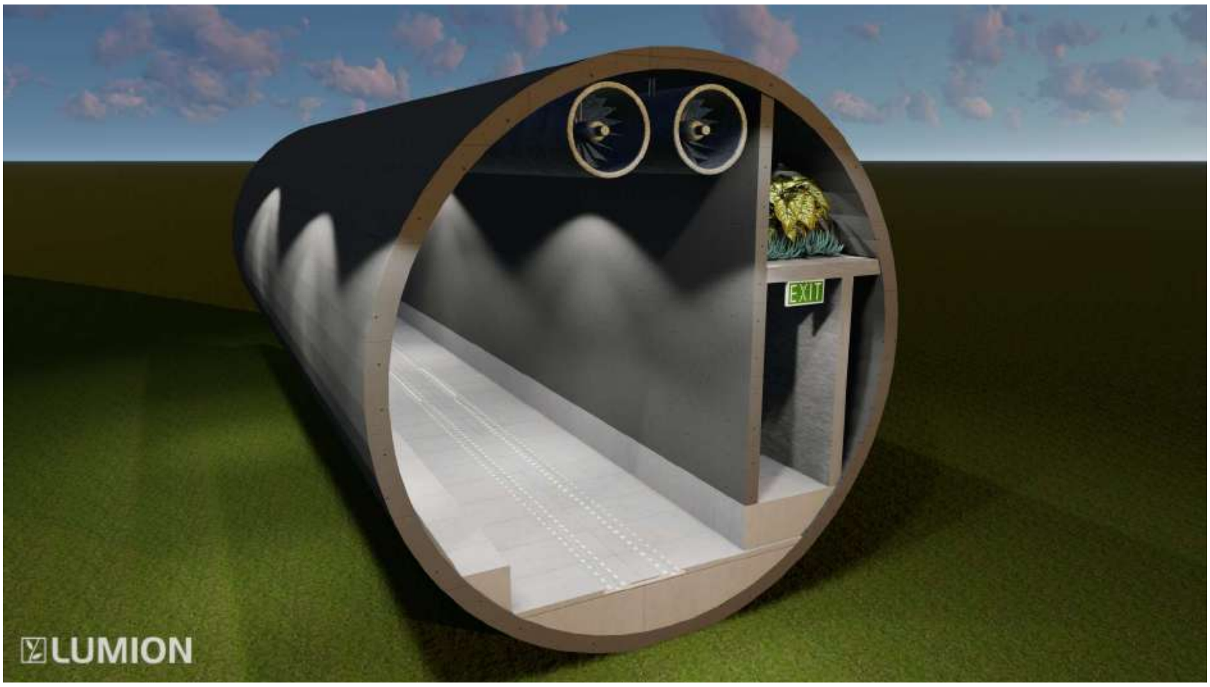


Figure B1.22: 3D Impression tunnel.

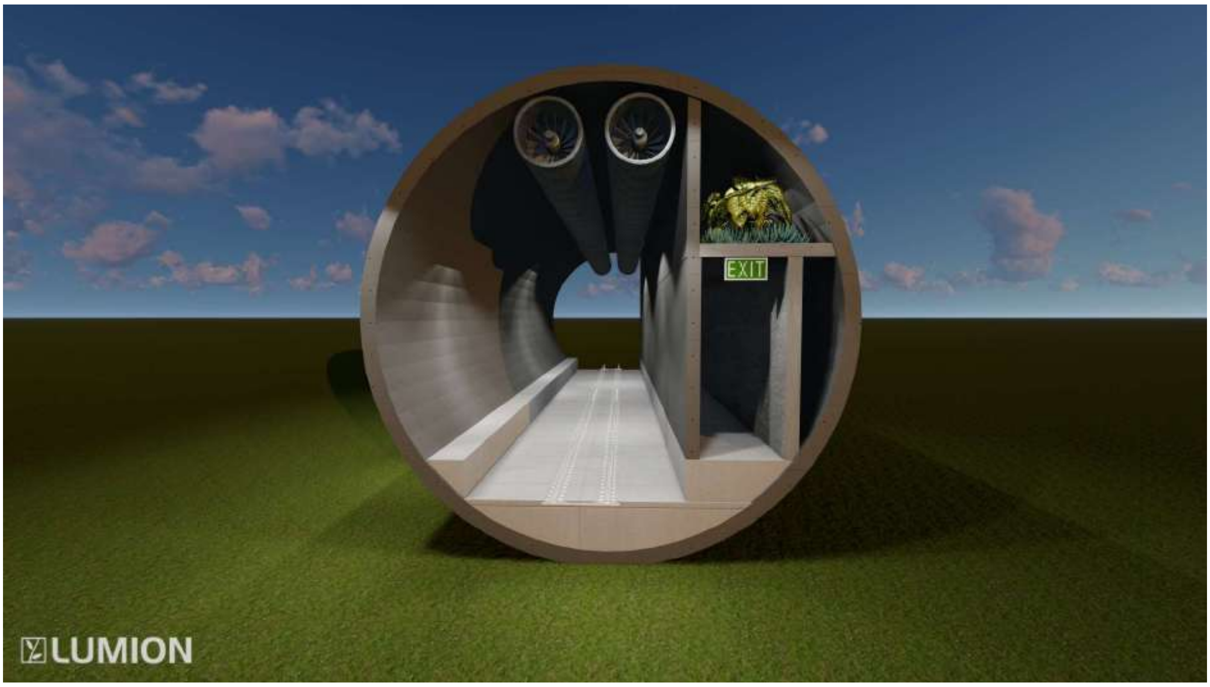


Figure B1.23: Front view tunnel.

Figure B1.24: Side view tunnel.

Wadi

The sustainably improved wadi system has been modelled. The goal of these renders is to give a picture of the system and on how the drainage works.
The wadi system and the drainage pipe have been modelled in Revit. The system is then placed in the environment using Lumion. This software has been used to add grass, plants and trees. In addition, small details like the sunlight and the built environment can be added. This will give a realistic idea of the implementation of this system, which can be shown to stakeholders.
The wadi is located in Westerpark.The images below give an impression of the wadi in the environment.

Figure B1.25: Photo impression integration of the wadi into the environment.

Figure B1.26: Photo impression from above the wadi.

The wadi has been dimensioned based on an eight-hour rain shower, which can occur once in a hundred years. As can seen in the figure below the wadi has a slope. The slope of the wadi has the dimension 2:0.5, which corresponds to the requirement that it should not be greater than 3:1 related to mowing and safety aspects.

The height differences were modelled using the toposurface function in Revit. Modelling a slope with exactly these dimensions was a challenge. By trial-and-error and using my skills from previously taken courses a well designed wadi was modelled.

Next to it, the software Lumion has been used. This was the first time using this program, this presented thereby some difficulties. For example the slope modelled in revit was not visible in Lumion. This problem was solved by making small adjustments to the slope in Lumion.

The bottom of the wadi is made up of various porous layers that together ensure the bottom is air- and water-permeable. All water flowing into the reservoir underneath the wadis will, after infiltration, directly flow to the reservoir underneath the stations. Therefore, a pipe diameter of 0,20 m is implemented in the wadi system. This drainage pipe has been modelled in Revit. The diameter in Revit has been enlarged to highlight the use of the drain in the wadi system.

Figure B1.27: Cross-section wadi.

Reflection:

Before we started modelling the structures we made a so-called ‘vlekkenplan’. This is an 2D map of the region where the planned structures and their reserved places were illustrated. This made it easier for us to know beforehand if there were collisions between the structures.

Moreover, within the other disciplines we emphasised that they should make sure that their structures were not colliding with already existing structures in the region. Thanks to this, when we started modelling and placed the chosen structures in the region, we did not find any collisions and no major problems were detected. Most of the smaller collisions were due to structures that did not have big relevance to the future vision of the region. These structures were planned to be removed for the sake of the project.

For the integration between the disciplines we chose to use the SCIA models of the structural discipline for specific models. The framework of the hub of Nassauplein was imported from the SCIA model into Revit. This made it easier to model the hub and prevent errors in measurements. Moreover, the framework of the bridge was loaded into Revit from SCIA and modelled in the same manner. For the underground station of Haven-Stad the layout was modelled based on 2D drawings of hydraulic discipline. The slope of the escalators was determined by the hydraulic discipline and was chosen to be 30 degrees. The placing of the escalators was done in such a way that passengers would not get stuck and have plenty of room to walk around the escalators. All underground stations in the region will have a similar layout as the station of Haven-Stad. Moreover, the layout of the underground tunnel was modelled based on the 2D drawings from the hydraulic discipline.

During the modelling we needed information about the dimensioning of the different constructions as well as the placement location. Therefore it was important to communicate with the designers of the specific construction of the structural engineering discipline.

There is room for improvement considering the implementation of the Haven-Stad. By making a sketchup model of the buildings in the surrounding area there will be a better overview of the developed area Haven-Stad.

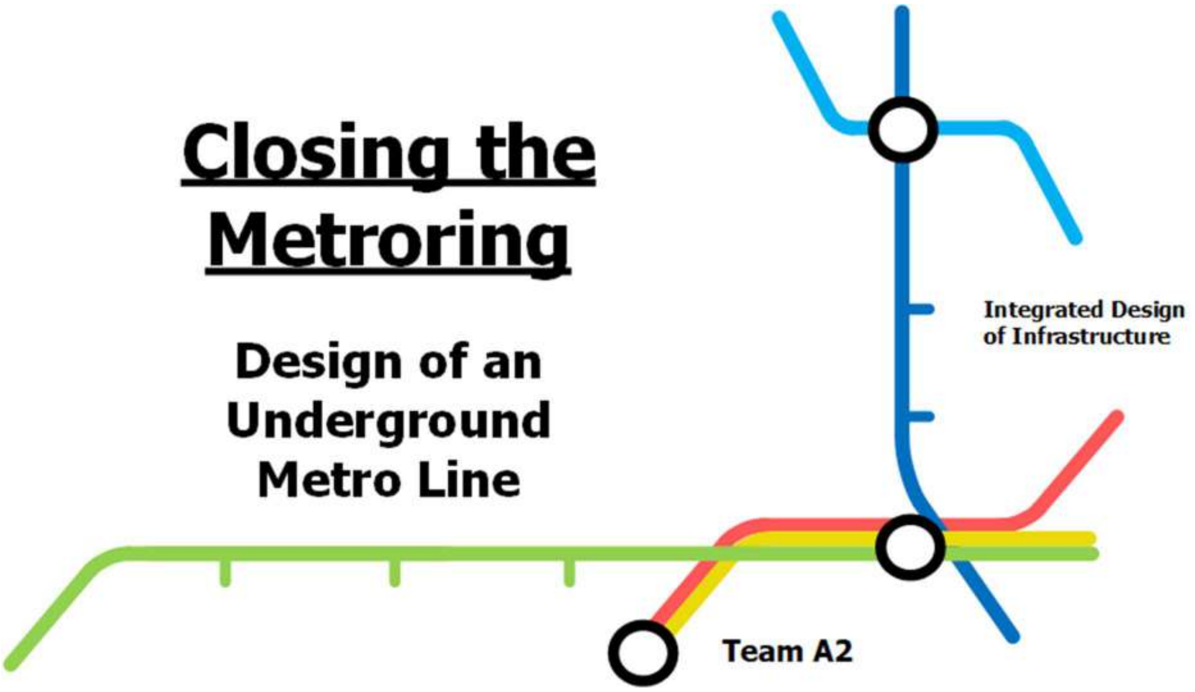
Overall we have learned to get more skilled with Revit and learned to work with some useful software like Lumion and Blender, which we used to create renders and video's. Also integrating the models in the current city plan gives a picture of the design elements of constructions in this area.

Appendix C: Hydraulics & Underground Structures

Design of an Underground Metro Line

Amsterdam Haven-Stad

Hydraulic and Underground Structures Report



General Project Team A2
Discipline of Hydraulic and Underground Structures

Maxime van Elsué	5017351
Niels de Vries	5169348
Philip Vos	5167434
Simon van Leent	5097363
Stephan van Eps	4844343

Supervisor
Mark Voorendt

C1. Analysis and Objective

In this chapter, an analysis is given on the stakeholders, the problem and the functions of the design elements. After this, the objective of this project is stated and the approach is given. The chapter closes with the requirements within the project and the boundary conditions of this specific design.

C1.1 Introduction

To improve public transport in Amsterdam, a new connecting metro line between Amsterdam Central Station and Amsterdam Sloterdijk needs to be developed. In this report, a solution to this problem is presented in the form of the design of a tunnel and underground metro stop. The goal of this report is therefore to present a design solution for this problem. More information about the spatial-functional design and the structural design of the tunnel can be read in Chapter C2 and C4, and more information about the spatial-functional design and the structural design of the metro stop Haven-Stad can be read in Chapter C3 and C5.

C1.2 Stakeholder analysis

In this section, a short stakeholder analysis is held. In the list, the stakeholders can be found.

- Municipality of Amsterdam
    - Create more and new employment opportunities in the new area called Haven-Stad and a better accessibility for the residents and employees. They want a future proof project with an eye on sustainability. They fund the project which means they have a big influence.
- GVB (Transport company of the municipality, metro line)
    - This company will use this metro line. The track must be accessible to the metro type of Amsterdam. They want a future proof metro track.
- Residents Haven-Stad
    - Will also benefit from the new homes and jobs, but do not have a lot of influence in the designing phase.
- Residents Nassauplein (Jordaan)
    - An extra station will give benefits for accessibility. Will not have a big influence in the designing phase. As long as the area is accessible during the building phase and the ground will have no settlement.
- Rijkswaterstaat
    - They are included in every project with technical issues, planning and overseeing. They are responsible for the design, construction, management and maintenance of this project.

C1.3 Problem analysis

Amsterdam as a metropole is growing, and in the near future a lot more travellers are expected to use the public transport system. The metro lines in Amsterdam are not all connected at the moment. The metro line between Isolatorweg and Amsterdam central simply does not exist. This results in longer travel times and less efficient journeys. To solve this problem a metro line between the two stations has to be made. This would reduce the travel time and make Haven-Stad an attractive area for future plans.

C1.4 Function analysis

The main functional and structural requirements of the tunnel and metro stops are written in section C1.4. This is done to relate the main functions to the structural components.

C1.4.1 Tunnel

Primary function

- Fast transportation between multiple above-ground points
- Reducing transit times
- Increase accessibility of inner-city
- Increase the level of service of the metro line, so more people in Amsterdam and surroundings can use it

Preserving functions

- Preserve the buildings and infrastructure above the tunnel
- Preserve nature parks above the tunnel
- Flood defence

Additional functions

- Underground farming in the tunnel
- Space for sustainability goals: wind turbines in tunnel
- Make room for sustainable projects above ground

C1.4.2 Metro stop

Primary function

- Access of the metro tunnel
- Increase accessibility of inner-city

Preserving functions

- Preserve the buildings and infrastructure above the station
- Preserve nature parks above the station
- Flood defence

Additional functions

- Underground farming in the station
- Make room for sustainable projects above ground or in the station itself

C1.5 Objective

The objective of the design is to connect the two metro lines in Amsterdam (Amsterdam CS to Sloterdijk) and to close this metro line ring, so travellers can move more easily across the city. The new metroline will have a positive influence on the surrounding area. This will make the area attractive for residential areas and businesses. The connection of the ring needs to be made without disturbance during the building process and the least inconvenience during the phase of usage. The metro line can not divide the area into two separate areas and the area above the ground needs to be preserved as much as possible. Another objective is that this metro line is future proof and sustainable. For this report the scope of the design of the metro line is reduced into two components. The first scope is the design of the tunnel and the second scope is the design of the metro station at Haven-Stad.

C1.6 Approach

The design cycle of most civil projects starts with an initiative, so a problem which needs to be solved. The problem as outlined in the problem analysis tells us that Haven-Stad will be developed and the current transport system is inadequate for the new residents. To solve this problem a transport system will be designed which can cope with a large number of travellers. In this rapport, the focus will be on connecting both ends of the ring to create a closed-loop. The location of the stop themselves will be determined by the group Transport and Planning, this way they can make hubs for better connecting the new residents of haven-Stad to the metro and the bigger region of Amsterdam.
To test the different concepts a list of requirements and boundary conditions is made which can be found in paragraph C1.7 and C1.8. The clients as well as the stakeholder but also the surrounding area will determine all these requirements and boundary conditions. These requirements will be split into functional and structural requirements. These evaluation criteria will be used to evaluate the chosen methods. This way we can find the most acceptable method in an objective manner. In case that none of the types are sufficient, one of the previous steps needs to be adjusted. The two last steps are the integration of the subsystems, this will be explained in the components section. If this all fits in the designed area we can validate the entire project and in the last step the design can be approved, this can be done for each subsystem of the design. In Figure C1.1 is an overview of the situation given.

Figure C1.1: Map of the region and horizontal alignment

C1.7 Requirements

In this section the requirements for both the tunnel and metro stops are discussed. This is done for the functional and structural requirements.

C1.7.1 Functional requirements tunnel

1. Safe passage for light rail through tunnel
2. Protect the old inner-city above the tunnel (e.g. from displacements)
3. The capacity of the metro needs to be high enough for the expected travellers. This is estimated to have a maximum of 100.000 travellers per day.
4. Design life time of 100 years
5. Possibility to escape from the tunnel in case of emergency
6. Ventilation of the tunnel
7. Maintenance space available
8. Preventing rail infrastructure as a physical barrier of splitting the area into two separate areas.
9. The governing metro type (M7) can fit through the tunnel
10. Traffic control available

C1.7.2 Structural requirements tunnel

1. The structure is constructible
2. The structural elements are strong enough
3. The structural elements are stable in horizontal, vertical and rotational direction
4. The structural elements are rigid enough
5. The structure is dimensional stable
6. The structure meets the service lifetime
7. Consequence class CC3, high consequence of human life or economic, social or environmental.

C1.7.3 Functional requirements metro stop

1. Safe passage for light rail through the metro stop
2. Protect the old inner-city above the station (e.g. from displacements)
3. The capacity of the metro stop needs to be high enough for the expected travellers. The whole station needs to be accessible from the top to the bottom for all travellers without inconvenience.
4. Design life time of 100 years
5. Possibility to escape from the station in case of emergency
6. Ventilation
7. Elevators, benches, bins, speakers, check-in area

C1.7.4 Structural requirements metro stop

1. The structure is constructible
2. The structural elements are strong enough
3. The structural elements are stable in horizontal, vertical and rotational direction
4. The structural elements are rigid enough
5. The structure is dimensional stable
6. The structure meets the service lifetime

7. Consequence class CC3, high consequence of human life or economic, social or environmental.

C1.8 Boundary conditions

In this section the boundary conditions of the area are discussed.

C1.8.1 Natural boundary conditions

The water level is one of the most important geotechnical conditions. The water level is determined at several points over a long period of time, these files are from DINOLoket. The maximum and minimum of this data are calculated for the extreme condition. The maximum water level will be used to determine the maximum weight on the soils. The water table is not equal throughout the design area, the closest test will be used for that part of the track. Adding a safety factor to calculate rising groundwater levels due to ocean level rise is possible at a later stage.

For calculating the stresses of the tunnel it is required to determine which soil layer can be found above our construction. With the help of DINOLoket, the soil is analysed in the project surroundings. Here we got files determining the soil type at certain locations. As shown in the picture on the right you can see all the different tests carried out in a part of Amsterdam. The problem which can already be seen from this picture is that we will need to determine which test we will use for which part of the metro system.

Figure C1.2: Map of Haven-Stad

Next up the alignment was determined of the metro line in Rijksdriehoekstelsel. This is done by plotting different points of the metro system. Here it is visible with the blue line which will be the new metro line connecting Isolaterweg and Amsterdam central together. This alignment is determined by the group Transport & Planning. We see the blue line that makes a curve connecting to Haven-Stad. It is also immediately clear that we will need to go under waterways so a certain depth will be necessary. We also follow the streets of Amsterdam so we influence a minimum of the foundation of old buildings.

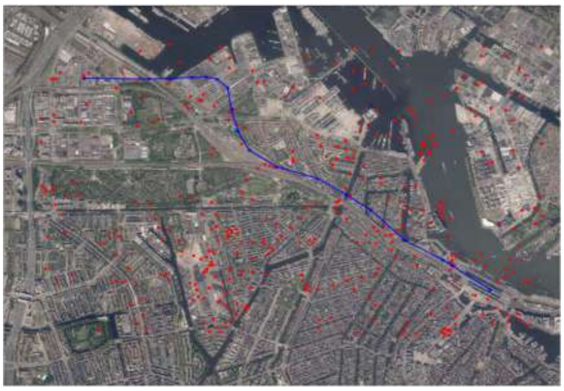


Figure C1.3: Points Haven-Stad

The problem immediately made clear is that we have multiple points for each part of the track that is why the entire track is split into separate sections. This way for every point can be determined which test is closer and should be used. In Figure C1.3, this is made visible with the blue dots. This is everything for horizontal alignment.

Depth beneath ground level (m)	Use
0 – 3 to 5	Cables, pipes, sewers etc.
3 to 5 – 15 to 25	Cellar construction without construction on top and tunnels with a diameter < 3 to 4 m
Under 15 to 25	Tunnels with a diameter > 3 to 4 m
All depths	Weight priority for foundations, groundwater and ecological functions
> 3 to 5	Cellar-constructions (with constructions on top) only with a special permission, because they can harm the construction of tunnels, transport pipes etc. on a strategic level.

Figure C1.4: Depth beneath ground

For the vertical alignment, the height of the tunnel is used and also having enough depth to not interfere with man made construction. The 2 most important requirements are when the metro line passes under the train gate, there should be enough space to prevent sagging. After all, uneven subsidence is undesirable. After Nassuaplein a depth is required to pass under the canals. Because of the reasons mentioned before and that the tunnel is required to follow the streets of Amsterdam, the metro was chosen to run above each other. In Figure C1.4, it is mentioned that for tunnels larger than 4 metres a depth of 15 metres is required (legal requirement). The height of the track to the top of the tunnel is about 5 metres. This last point gives a depth required of 20 metres. In Figure C1.5 and C1.6 is the horizontal alignment made visible in a plot.

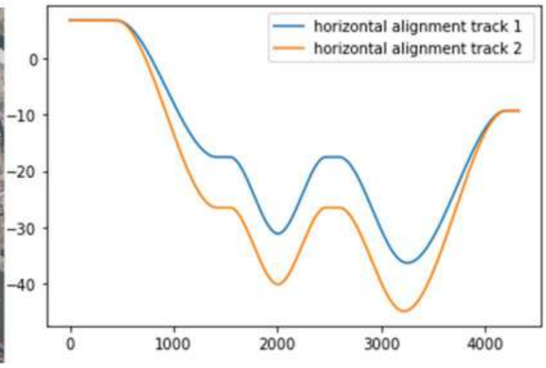


Figure C1.5: Alignment of the metro line

Figure C1.6: Alignment tunnel

This is all combined in a flat map to clearly see in which layers the tunnel is situated. See the picture for the soil layers, red is clay, orange is sand and green is peat. The only geological condition which applies in the design area is the presence of water from rivers and channels. We will look more closely at this specific case later. The stations are coloured in green, on the left Isolaterweg can be found, afterwards, there are Haven-Stad, Nassuaplein and on the right Amsterdam Central. The soil profile is shown in Figure C1.7.

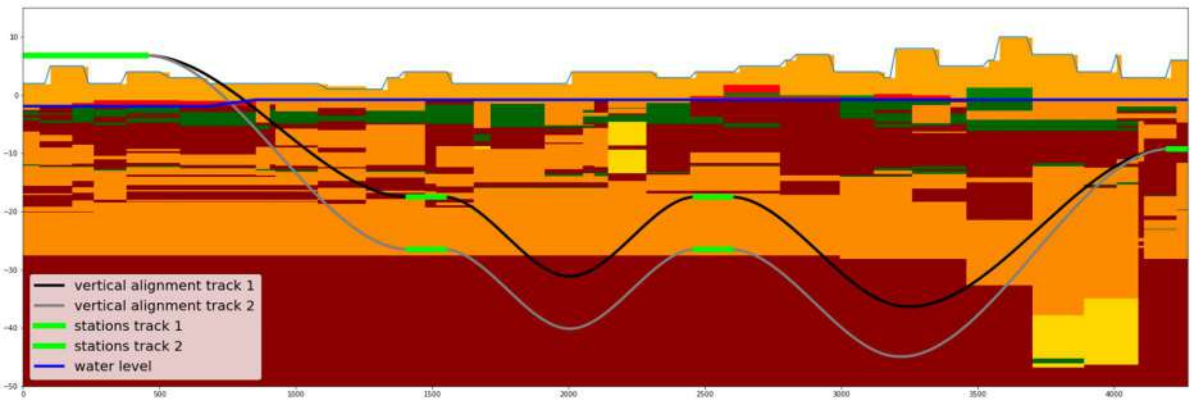


Figure C1.7: Underground soil profile where the tunnel will be

The soil properties are shown in Table C1.1

Table C1.1: Soil properties

Soil type	Dry volumetric weight [kN/m³]	Wet volumetric weight [kN/m³]
Clay	16	20
Loam	16	20
Peat	16	20
Sand	16	17.5

C1.8.2 Artificial boundary conditions

The amount of people using the metro system on a yearly basis will be 20 million (according to Transport and planning see Final Report). This means that the maximum number of people on a given day will be around 100 thousand. The metros we will be using will have a maximum of 960 people. This means that a maximum of 7 metros will be needed in both directions. This means it will need at least 2 tracks, one in both directions, more tracks will not be needed to deal with the number of people.

C1.8.3 Legal boundary conditions

The remaining laws and regulations can be found (Movares, 2022) , the condensed version can be found here:

- Railroads Act 1875 (other railroads) Local Railways and Tramways Act Localrail (Chapter 1 as Dec. 1, 2013, other chapters as of Dec. 1, 2015)
- Wabo (omgevingsrecht)
- Housing Act (general)
- Buildings Decree 2012 (structures not being buildings)
- Regulation Building Act 2012
- Local Railways and Tramways Act
- As a result of the WARVW there are no longer any obligations relating to rail tunnels.
- Safety Requirements for Tram and Metro Tunnels (VEMT), November 2006 (not adopted and no formal status)
- Regulations governing the service of main and local railroads, Metro Regulations, Tramway Regulations, Regulations governing raccordements
- General Transport Regulations

C1.9 Risk analysis

- Miscalculations
    - Double-checking by a third party
- Wrong assumptions
    - Check the assumptions in every new step of the process, if they are still correct
- Research soil type not sufficient
    - Take more CPT samples, use the DINOLoket database
- Leakages during construction
    - Constant monitoring for leakages. After detection, close the leakage and review everything to prevent further leakages.

- Misalignment of tunnel boring machine (vertical, horizontal)
    - Constant monitoring with surveying
- Unexpected objects during tunnel boring
    - Historical geological investigation

C2. Spacial-Functional Design Tunnel

In this chapter, the spacial-functional design of the tunnel is discussed. In the first section the building type of the tunnel is discussed and selected. After the selection the components and dimensions of the tunnel are given.

C2.1 Selection of the tunnel type

In this section all available tunnel types are mentioned and described. Each type is discussed and a conclusion is added whether the tunnel type is suited within the project's objective and boundary conditions.

C2.1.1 Available tunnel types

The objective, as explained in chapter 1, is to not divide the ground above ground into two separate areas and to preserve the space. In order to achieve this objective, it is necessary to choose a suitable tunnel type. There are seven main methods for building a tunnel. These methods are shortly described with advantages and disadvantages.

<u>Earthen cofferdam</u>

In the earthen cofferdam method a whole excavation site is created and the earth itself is used as cofferdam. Much space is needed with this method, which results in a lot of hindrance for the surroundings. Therefore in a highly dense environment such as Amsterdam, this method is not suited.

<u>Braced cofferdam</u>

With the braced cofferdam method, a building pit is constructed with cofferdams. Less space is required than with the earthen cofferdam, however all of the space above the building pit can not be used during construction. Therefore this method is not suitable, because of the requirements that are set up for this project.

<u>Cut and cover</u>

The Cut & Cover method is used for the construction of a small or shallow tunnel. For that, a trench is excavated and the tunnel is constructed (base and side walls are made and it is roofed by concrete slabs) and covered up. The covering up happens as soon as possible to make sure that the space above the tunnel can be used as quickly as possible. The vertical alignment of the stops located in the tunnel will be around 20 metres below NAP. The Cut & Cover method is cheaper but it also disturbs a lot of the above-ground traffic during the first steps of construction so this method is not suitable.

<u>Pneumatic caisson</u>

In this method a pneumatic caisson is lowered from street level. In the space underneath the caisson, a pneumatic work chamber is constructed and in here the earth is removed. Because this uses a lot of space aboveground in the first steps of construction, when a caisson needs to be transported and placed in the middle of Amsterdam, this method is not suitable for this project. Also because the space above ground needs to be free for the pneumatic caisson, this is not the case for some locations in the alignment.

Immersed tunnel
An immersed tunnel consists of one or more prefabricated tunnel elements that are floated to the site, immersed one by one, and connected to one another underwater. This method is used for tunnels under water. This is not suitable for Amsterdam.

Sequential excavation
This method is only suitable for underground rock areas. This is not the case for this tunnel in Amsterdam, as rocks are not encountered here, and therefore this method is not suitable.

Tunnel boring
A tunnel Boring Machine (TBM) is used in the boring method. The TBM is a steel cylinder, which bores to the ground. The ground is excavated in the front and during the excavation, the concrete panels of the tunnel are placed. Commonly adopted for the excavation of long tunnels and boring through different types of soil. A TBM can provide an exact work profile in excavation and reduce casualties in tunnelling. Bored tunnelling is the construction of tunnels underground without opening the soil up to the surface, apart from the shafts or the access portals.

The bored tunnel is chosen because of the limited space above ground and the minimal disturbance for the local resident. Also, the fact that a TBM can run non stop makes the building process faster and less intrusive for the inhabitants. This method is suitable for building in soft soil.

C2.1.2 Available boring techniques
The tunnel boring machine can use different methods. The soil in Amsterdam for this situation is soft soil mostly sand and clay with a high groundwater table. The tunnel will be bored with shields with full excavation. Mechanical full face excavation is done with a machine that is excavating the entire face with each rotation. There are five possible methods that will be discussed.

Shields for hard rock
In hard rock an open TBM may be used. This means that there is no soil support at the face and the soil has to have a natural stand up time. This method can only be used in hard soil so this is not possible in this situation.

Compressed air shield
This method uses compressed air to hold back the water. The compressed air is in equilibrium with the water pressures. Resistance against soil pressures is not possible and the ground therefore has to have a natural stand up time or has to be supported mechanically by the machine pushing against the soil. This method can only be used in hard soil so this is not possible in this situation.

Earth pressure balance (EPB) shield
Earth Pressure Balance Shields use the excavated soil directly as support medium for the tunnel face. The excavated material is mixed with additives such as foam, conditioners, additives, polymers, bentonite into a toothpaste-like material, which is then used as a

support medium. The bulkhead transfers the thrust force (from the hydraulic jacks) to this soil paste in the excavation chamber. The excavated soil is transferred via a screw conveyor from the pressurised excavation chamber to the tunnel, which is under atmospheric pressure. This method can be used in this situation.

Hydro/slurry shield
In slurry shields the support pressure at the face is provided by bentonite mix, that is kept at the required pressure to keep equilibrium at the face. Slurry shields are mainly used in coarse or mixed grain soil types like sand. Slurry machines are not suitable in soils with high fine contents, because it is almost impossible to separate clay from bentonite in the slurry treatment plant. But soils should also not be too permeable because then the slurry would flow in the soil and there would be no formation of a membrane.
Due to the pressure difference between the slurry and the pore water pressures in the soil, the bentonite suspension infiltrates a little bit into the soil. In fine-grained soil, this infiltration length is practically zero. In coarse grained soils, the slurry can infiltrate to distances up to 7 m, which leads to a significant reduction of the support pressure. Therefore slurry machines are not suitable in very permeable soils. This method can be used in this situation.

Mix shields
The dual shield is a combination type of shield that may be altered during construction underground. These types of shields are used if the tunnel crosses different soil formations with different soil properties. For example when a part of the tunnel is in hard rock and another part is in soft clay. The shields are designed such that mechanical modifications can be undertaken to adapt to different geological and hydrogeological conditions. This tunnel only passes clay and sand which are soft soils so this method is not necessary in this situation.

Both the Earth Pressure Balance Shield (EPB) and the Slurry Shield can be used. The application range for EPB and slurry machines is shown for different soil types. Roughly, EPB's are suitable in clayey/silty soils and slurry machines are suitable in granular soils. One of the reasons for this is: when using a slurry machine, the excavated soil-slurry mixture is separated in a separation plant and the slurry is re-used. In soils with a high fine content like silt and clay, it is very difficult to separate the soil from the slurry, and in those cases a slurry machine is often not an economic or feasible option. The soil is mostly clay and sand and therefore a Earth Pressure Balance Shield (EPB) will be used in the boring of this tunnel.

C2.1.3 Launching shaft and Reception shaft
The tunnel will be drilled with a tunnel boring machine. This machine will start drilling near the isolatorweg station until Amsterdam Central. Launching shafts and reception shafts are necessary to start and to receive the tunnel boring machine (TBM) after finishing the boring process. In order to make the launching shaft, a construction pit is necessary. This is a temporary, watertight construction within which excavation takes place for the purpose of realising a tunnel. The tunnel boring machine will be placed in the launching shaft. The launching shaft needs to be low enough so that during the boring, the TBM has ground pressure from the soil above the TBM. The dimensions of the shaft are primarily determined by the operational phase. Often, the required space for the whole TBM in the construction phase determines the dimensions of the shaft: the cutting wheel needs to be lowered into

the shaft and the gantry (trailer train) needs space. The length of this train can be up to 90 m.

C2.2 Inventory of main components

The tunnel dimensions depend on a lot of things, mainly the size of the light rail which runs through, but also on the different installations and evacuation routes in these tunnels, and extra clearance for other things.

The main components of the tunnel (between stations) are split into different categories. An overview of the cross section is shown in Figure C2.3.

Structural

- Concrete tunnel lining
- Concrete track slabs
- Emergency exits

Installations

- Power (electricity) for the metro, third rail
- Installation shelves for cables
- Groundwater pipes and pumps installation/water discharge
- Ventilation
- Fire fighting installations
    - Smoke detectors
    - Hose connector pipes
    - Sprinklers
    - Fire extinguisher
    - Special lighting in case of evacuation
- Lighting
- Traffic control systems
    - Signals for the metro
    - Other installations
    - Detection system

Figure C2.1: Cross-section tunnel elements

C2.3 Determination of main dimensions

In this chapter are the dimensions of the tunnel determined.

C2.3.1 Longitudinal tunnel profile

The main dimensions of the tunnel are determined by the intensity of use and the tunnel type. Also the additional installations in the tunnel have an impact on the dimensions of the tunnel. In Figure C2.2, the longitudinal dimensions of the tunnel can be found.

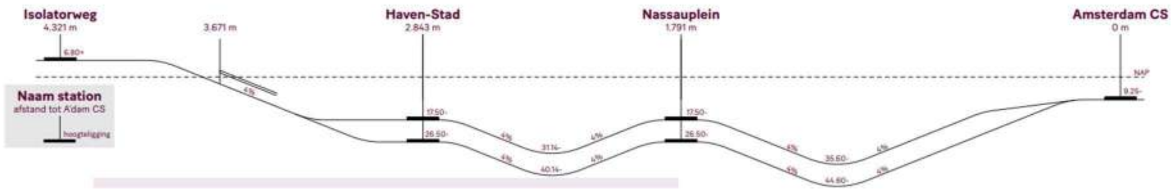


Figure C2.2: Longitudinal dimensions tunnel (MASH Report, 2020)

C2.3.2 Cross-section tunnel profile

The main dimensions of the tunnel are the same for both cross-sections. Therefore only one is considered over here.

General information metro (GVB, 2022)

- M7 metro with M7 train sets
- Max Length Metro: 123 metre
- Mass empty metro: 64.3 ton
- Maximum speed: 80 km/uur
- Capacity: 480 passengers
- Track gauge in the Netherlands is 1435 mm
- Floor height/ entry height metro: 1.1 metre
- Height metro: 3.8 metre
- Width metro: 3.0 metre

General information tunnel

- Minimum tunnel diameter metro 1 track: 5.95 metre
- Tunnel wall thickness: 0.35 metre
- Emergency path: 0.75 metre wide
- Emergency tunnel: 1.50 metre wide, 2,25 metre high

There needs to be an emergency entry present every 1000 metre. The emergency tunnel needs to be 1.50 metre wide and 2.25 metre high. All exits must also be equipped with lighting and escape signs. For tunnels longer than 500 metres, according to the TSI, an escape path must be provided on at least one side of the track. (NS, 2020)

In order to fulfil the required components and design a tunnel in an effective way, a singular circle formed tunnel type is chosen. The two main big components which are taken to form this circular tunnel are the metro M7 itself and the space needed for the emergency exit.

With these two base components a diameter is found which fits both of these components next to each other. This diameter is 7.7 metres for the outer circle (upper design sketch in Figure C2.3). This diameter leaves enough extra space for all the other components and forms an area where underground farming can be installed. At the location of the signal system on the left of the tunnel, small wind turbines can be installed as well. These create electricity whenever a metro passes by. In this project a further examination on the efficiency of these wind turbines is not included. In Figure C2.3, the different main components can be seen.

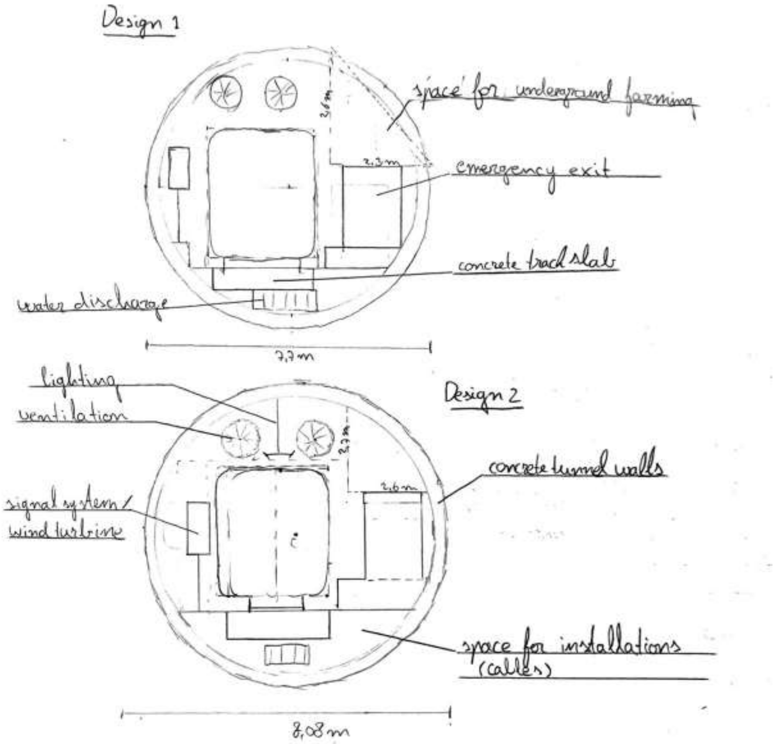


Figure C2.3: Designs of a single metro tunnel

In Figure C2.4, an impression of underground farming can be seen. Shelves like the ones in Figure C2.4 will be installed in the designated space for underground farming in the tunnel.

Figure C2.4: Underground farming design in tunnel area (not the final design)

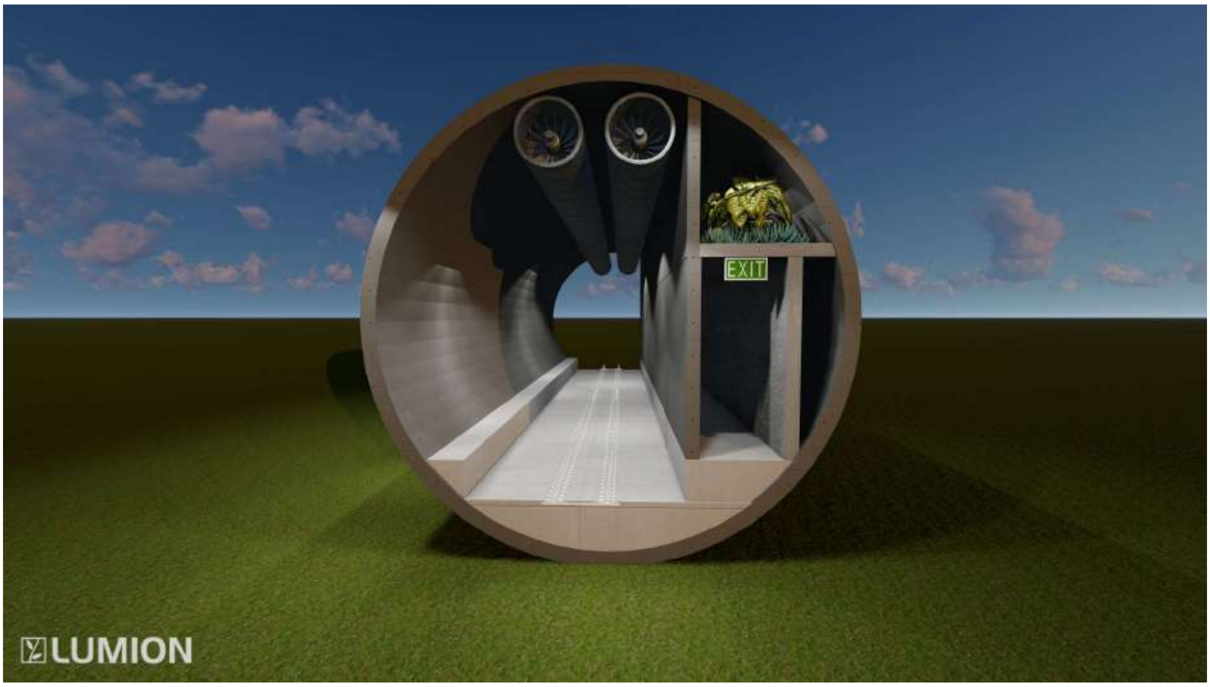


Figure C2.5: Final design cross section of the tunnel

C3. Spacial-Functional Design Metro Stop

In this chapter the spacial-functional design of the metro stop at Havenstad is discussed. In the first section the building type of the metro stop is discussed and selected. After the selection the components and dimensions of the metro stop are given.

C3.1 Selection of the metro stop type

The same potential underground construction methods as with the tunnel type selection apply on the construction method selection for the metro stop. A couple of methods are available, namely pneumatic caissons, cut and cover and open building pits. In the chapter about the tunnel these methods are already discussed, so they will not be discussed again. The objective is to have the least hinder as possible, and therefore the cut and cover method is chosen to apply. Other methods continuously use the above-ground space. The cut and cover method does this only at the start and is therefore the preferable method.

With the cut and cover method, first the diaphragm walls of the building pit are constructed. These are constructed deep enough, into an impermeable layer, in order to prevent water flowing into the building pit. During construction it must be ensured that the load on that layer is big enough to prevent floatation. The construction principle is to dig deep enough to build the roof of the constructure. Then the rest of the excavation is done and the next levels are built, one after the other.

C3.2 Inventory of main components

The main components of the metro stop are listed.

Structural

- Concrete diaphragm walls
- Concrete columns
- Concrete roof
- Underwater concrete floor

Installations and additional components

- Lighting
- Ventilation
- Fire fighting installations
    - Smoke detectors
    - Hose connector pipes
- (Electronic) signs
- Benches
- Timetable signs
- Platform
- Lift / escalator

C3.3 Determination of main dimensions

In this section, the main dimensions of the metro stop are defined. The length of the metro stop should be greater than the maximum length of the train, which is 130 metres. Therefore it is decided to design a stop with a length of 140 metres. The entire construction pit will have a width of 11 metres. This is a combination of the width necessary for the metro rails and for the platform. These are set to be respectively 5 and 6 metres, which makes a total of 11 metres. The platform also consists of the elevators and the escalators necessary to access the platform. The depth of the entire construction for the stop will be 26.5 metres. This depth is necessary to make sure that the two tunnels will have enough distance between them, which prevents a failure. This can be seen in Figure C3.1. In Figure C3.2, C3.3 and C3.4 are some impressions of the station shown.

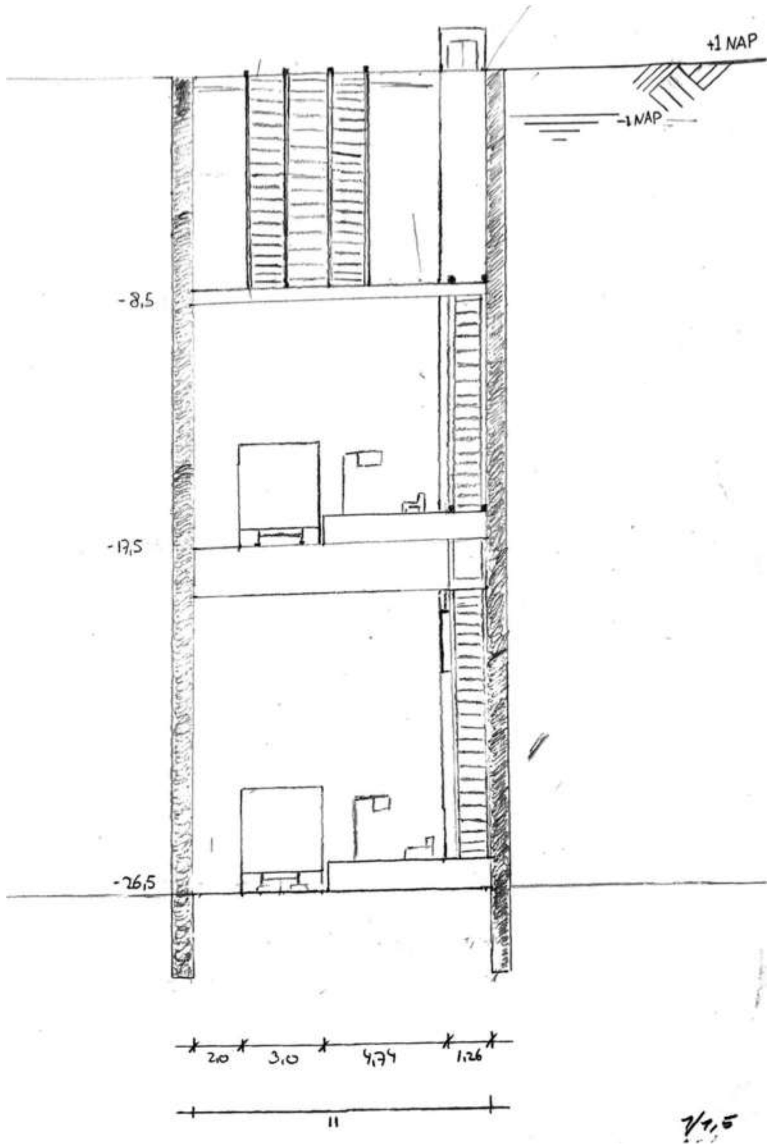


Figure C3.1: Design of underground stop Haven-Stad (main view)

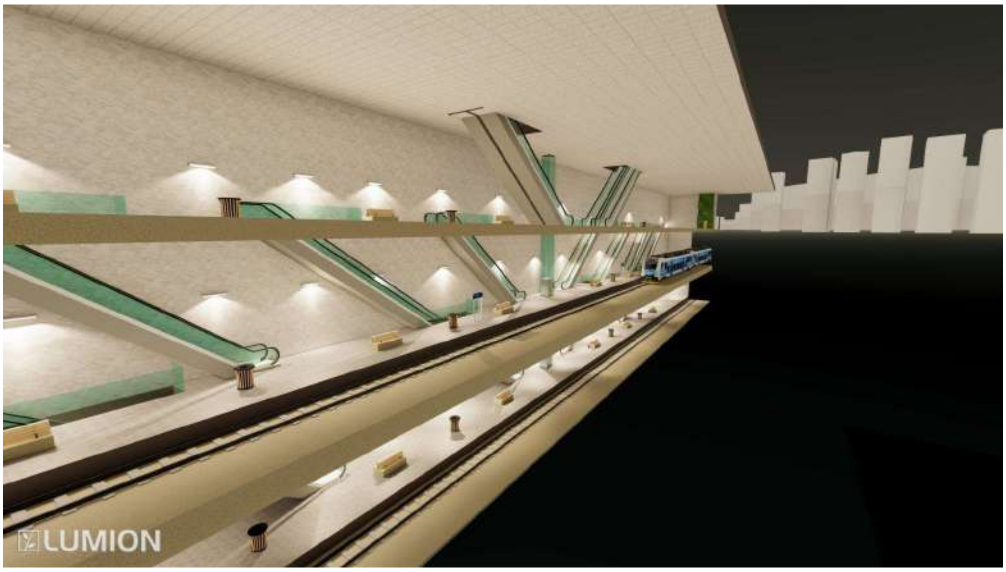


Figure C3.2: Underground station


Figure C3.3: Station Haven-Stad


Figure C3.4: Underground Farming Shop in metro stop

C4. Structural Design Tunnel

In this chapter is the design of the tunnel calculated to check if the face stability, uplift and settlement all satisfied the given conditions in the governing situation. For this calculation are the soil conditions and the groundwater level necessary. These values are given in paragraph 1.8.1. The cross-section of the tunnel is also needed. These are determined in section 2.3. There are three calculations that are performed in this chapter. In section 4.1 will the face stability be calculated. This is calculated at the deepest point. In section 4.2 is the uplift of the tunnel calculated. In section 4.3 is the settlement calculated. The uplift and the settlement are both calculated near the starting shaft where the least deep point is located.

The unknown values are explained or calculated in the footnote underneath each page. Each value has been calculated once and then it is assumed that the value is known for the following calculations.

C4.1 Face stability

In very stiff and strong soils, tunnels can be constructed without supporting the face and the excavated cavity. In those ground conditions, the sequential excavation method or a tunnel boring machine without face support and shield can be used for construction. For soft soils, the face and the cavity both need to be supported. The excavated cavity is supported by the shield, until the final lining is installed and the face can be supported by air pressure, by earth pressure and by slurry pressure. This pressure needs to be in equilibrium with the water and the ground pressure.

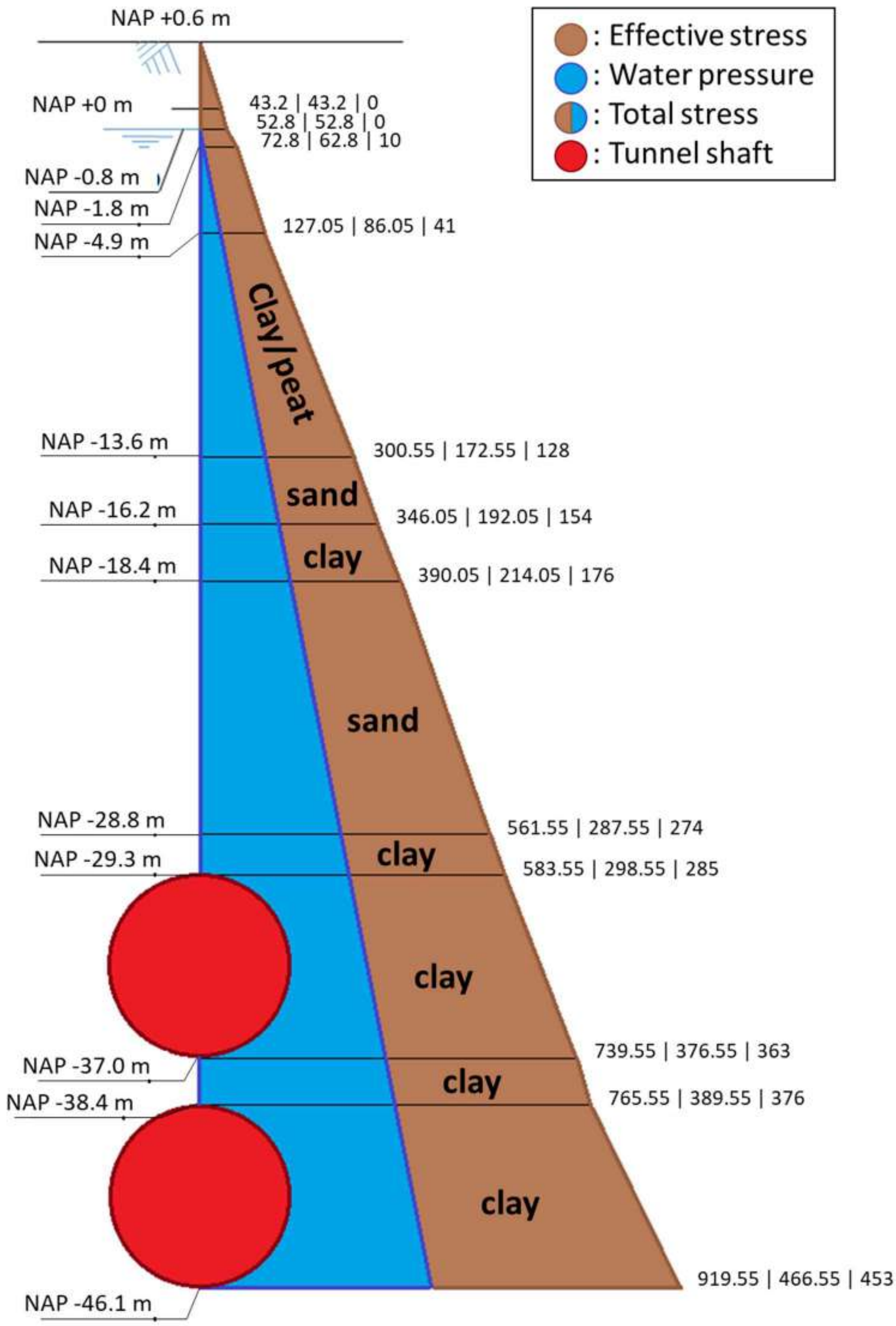


Figure C4.1: Vertical soil stresses (Total stress | Effective stress | Water pressure)

C4.1.1 General face support

The general face support is calculated with the method of Broms & Bennermark. This is an empirical method and considers the failure mechanism shown in Figure C4.2.

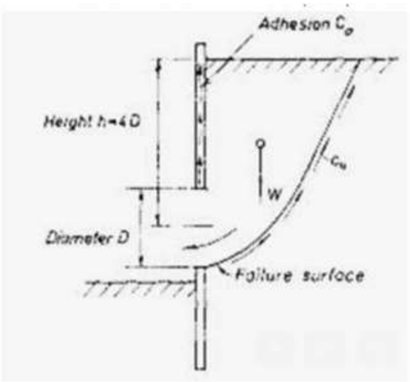


Figure C4.2: General face support

The general face support is dependent on a few variables. The governing situation is a tunnel with the most soil above the tunnel, the lowest support pressure and a high surface load. The tunnel will be bored underneath a road or a park. This means that there is barely extra surface load so this factor will be 0 in the calculation. The S has a very elaborated calculation so the effect of the different factors can not be determined. Therefore, the governing situation is a situation with the most soil above the tunnel. This situation is when the tunnel is at its highest depth. This is for the deepest point between Nassuaplein and Amsterdam Central. This tunnel is located between a depth of NAP -38.4 m and - 46.1 m. In Figure C4.1 is the soil pressure shown. The stability will be calculated with the values of Figure C4.1.

To determine the stability of a tunnel face for a given soil condition, the stability-ratio N can be used. This is the ratio between the total overburden stress and the undrained shear strength. The face is not deforming if N ≤ 1 and large deformations and collapses occur when N > 5. For stability numbers between 1 and 5 some deformation at the face is likely.

$$N = \frac{(qs - s + \gamma(C+D))}{C_u} \leq 1 \qquad \text{(Formula 4.01)}$$

- N = ? stability ratio
- q_s = 0 Surface load at ground surface[1] [kN/m²]
- γ = 18.93 soil unit weight[2] [kN/m³]
- C = 41.0 Overburden above the tunnel face[3] [m]
- D = 7.7 Tunnel diameter[4] [m]
- S = 583.1 Support pressure (Formula 4.13) [kN/m²]
- Cu = 25 Undrained shear strength at tunnel axis level[5] [kN/m²]

$$N = \frac{(0 - 583.1 + 18.93 * (41.0+7.7))}{25} = 13.55\ [-]$$

[1] There is no load above the structure so qs is 0
[2] This values are determined in Figure C4.1 → 919.55 / 48.58 = 18.93
[3] 2.6 NAP + 38.4 NAP = 41.0 NAP, see picture 4.1: overburden + soil above tunnel
[4] Section 2.3
[5] Dinoloket clay soil

The stability ratio is 13.55 and this means that the face is unstable and extra face support is needed. Face support will be provided by bentonite pressure.

C4.1.2 3D face support

The 3D face support is calculated with the theoretical kinematic approach of Horn. This is shown in Figure C4.3. The difference is that this is a 3D calculation and the general face support is in 2D.

The 3D face support is calculated at the same location as the general face support. This is because the critical situation is the situation where the tunnel has the highest depth.

The tunnel face is stable if the minimum support pressure (resistance) is larger than the soil and water pressures (loads). If the pressure is too low, this will lead to an unstable tunnel face, resulting in collapse or surface settlements.

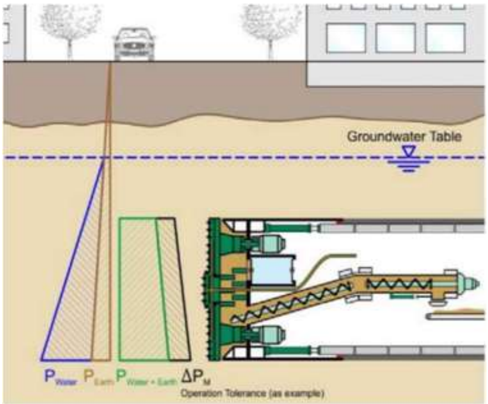


Figure C4.3: Face support

$$P_{min} \geq E_{soil} + E_w$$

(Formula 4.02)

Calculation P_{min}

In Figure C4.4 you can see all the different parameters to find the total P_{min}. In the next paragraphs all these parameters will be calculated. The formula 4.03 till the formula 4.13 are necessary to calculate the unknown P_{min} value.

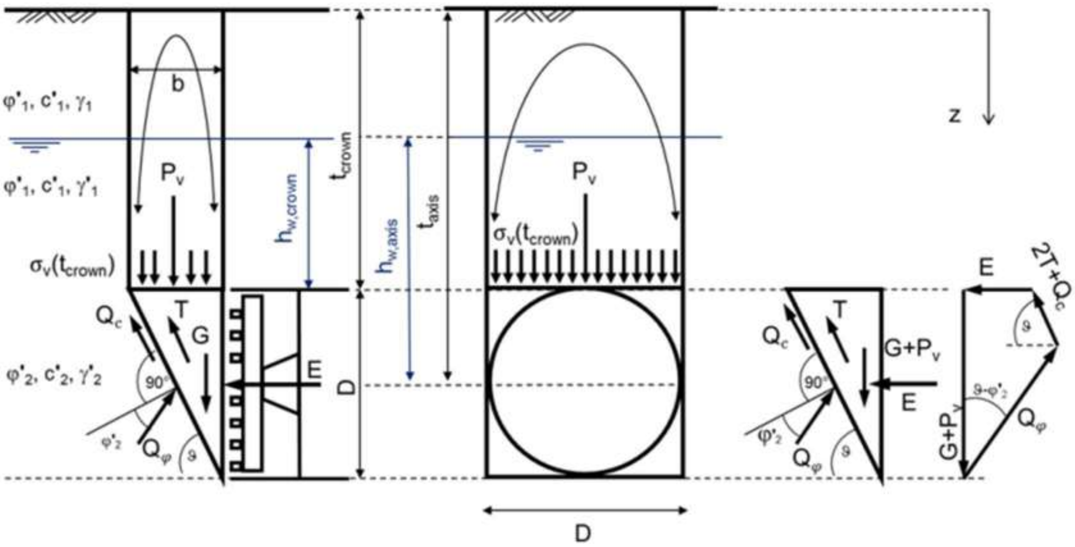


Figure C4.4: Forces face support

Shear forces on the wedge

$$Q_{c(\vartheta)} = c'_2 * \frac{D^2}{sin(\vartheta)}$$ (Formula 4.03)

- Θ = 58.5 Sliding angle of the wedge[6] [°]
- D = 7.7 External diameter of the tunnel [m]
- C'_2 = 15 Average cohesion in the tunnel face area[7] [kN/m²]

$$Q_{c(\vartheta)} = 15 * \frac{7.7^2}{sin(58.5)} = 1043.1\ kN$$

Shear forces on the wedge, due to friction

$$T_{c(\vartheta)} = c'_2 * \frac{D^2}{2 * tan(\vartheta)}$$ (Formula 4.04)

- Θ = 58.5 Sliding angle of the wedge [°]
- D = 7.7 External diameter of the tunnel [m]
- C'_2 = 15 Average cohesion in the tunnel face area [kN/m²]

$$T_{c(\vartheta)} = 15 * \frac{7.7^2}{2 * tan(58.5)} = 272.5\ kN$$

Shear forces on the triangular plane, due to friction

$$T_{R(\vartheta)} = K_2 * tan(\varphi'_2) * \left(\frac{D^2 * (\sigma'_v)}{2 * tan(\vartheta)} + \frac{D^3 * \gamma'_2}{6 * tan(\vartheta)}\right)$$ (Formula 4.05)

- K_2 = 0.4 lateral earth coefficient[8] [-]
- Θ = 58.5 Sliding angle of the wedge [°]
- D = 7.7 External diameter of the tunnel [m]
- γ'2 = 10 Average effective soil unit weight in the tunnel face area[9] [kN/m³]
- σ'v = 389.55 Effective vertical load, if silo theory is applied[10] [kN/m³]
- φ'2 = 27 Average angle of internal friction at the tunnel face[11] [°]

$$T_{R(\vartheta)} = 0.4 * tan(27) * \left(\frac{7.7^2 * (389.55)}{2 * tan(58.5)} + \frac{7.7^3 * 10}{6 * tan(58.5)}\right) = 1537.3\ kN$$

Resistance on the triangular plane of the sliding wedge

$$T_{(\vartheta)} = T_{R(\vartheta)} + T_{c(\vartheta)}$$ (Formula 4.06)

- $T_R(\vartheta)$ = 1537.3 Shear resistance due to friction (Formula 4.05) [kN]

---

6 45 + ½ * φ_{clay} = 45 + ½ * 27 = 58.5, φ_{clay} = 27°

7 See appendix A → Average clay = 15

8 Anagnostou & Kovari

9 Clay soil 20 kN/m³ - 10 kN/m³ = 10 kN/m³, total soil pressure - water pressure for every metre depth

10 From Figure 4.1

11 φ_{clay} = 27° for a clay soil

- $T_c(\vartheta)$ = 272.5 Shear resistance due to cohesion (Formula 4.04) [kN]

$$T_{(\vartheta)} = 1537.3 + 272.5 = 1809.8\, kN$$

Vertical force on the wedge

$$P_{v(\vartheta)} = \frac{D^2 * \sigma'_v}{tan(\vartheta)} \quad \text{(Formula 4.07)}$$

- Θ = 58.5 Sliding angle of the wedge [°]
- D = 7.7 External diameter of the tunnel [m]
- σ'v = 389.55 Effective vertical load, if silo theory is applied. [kN/m³]

$$P_{v(\vartheta)} = \frac{7.7^2 * 389.55}{tan(58.5)} = 14153.5\, kN$$

Self-weight of the wedge

$$G_{(\vartheta)} = \frac{1}{2} * \frac{D^3}{tan(\vartheta)} * \gamma'_2 \quad \text{(Formula 4.08)}$$

- Θ = 58.5 Sliding angle of the wedge [°]
- D = 7.7 External diameter of the tunnel [m]
- γ'_2 = 10 Average effective soil unit weight in the tunnel face area[kN/m³]

$$G_{(\vartheta)} = \frac{1}{2} * \frac{7.7^3}{tan(58.5)} * 10 = 1398.8\, kN$$

Resultant force of earth pressures on the area of diameter²

$$E_{re(\vartheta)} = \frac{(G+P_{v(\vartheta)}) * [sin(\vartheta) - cos(\vartheta) * tan(\varphi'_2)] - 2 * T - Q_C}{sin(\vartheta) * tan(\varphi'_2) + cos(\vartheta)} \quad \text{(Formula 4.09)}$$

- Θ = 58.5 Sliding angle of the wedge [°]
- φ'2 = 27 Average angle of internal friction at the tunnel face [°]
- G = 1398.8 Self-weight of the wedge (Formula 4.08) [kN]
- $P_{v(\theta)}$ = 14153.5 Vertical force on the wedge (Formula 4.07) [kN]
- T = 1809.8 Shear resistance on sliding wedge (Formula 4.06) [kN].
- Q_c =1043.1 Shear resistance on wedge (Formula 4.03)

$$E_{re(\vartheta)} = \frac{(1398.8 + 14153.5) * [sin(58.5) - cos(58.5) * tan(27)] - 2 * 1809.8 - 1043.1}{sin(58.5) * tan(27) + cos(58.5)} = 4657.9\, kN$$

Resultant force of earth pressures on the tunnel face

$$E_{max,ci} = E_{re(\vartheta)} * \frac{\frac{\pi * D^2}{4}}{D^2} \quad \text{(Formula 4.10)}$$

- D = 7.7 External diameter of the tunnel [m]
- $E_{re(\theta)}$ = 4657.9 Resultant force of earth pressures on the area (Formula 4.09) [kN]

$$E_{max,ci} = 4657.9 * \frac{\frac{\pi * 7.7^2}{4}}{7.7^2} = 3658.3\ kN$$

Resultant force of water pressures

$$E_{w,ci} = \frac{\pi * D^2}{4} * \sigma_w \qquad \text{(Formula 4.11)}$$

- D = 7.7 External diameter of the tunnel [m]
- σ_w = 414.5 Water pressure at the axis of the tunnel[12] [kN/m^2]

$$E_{w,ci} = \frac{\pi * 7.7^2}{4} * 414.5 = 19301.7$$

Minimum support force

$$S_{ci} = \eta_E * E_{max,ci} + \eta_W * E_{w,ci} \qquad \text{(Formula 4.12)}$$

- η_E = 1.5[13] Safety factor for effective earth pressure [-].
- η_W = 1.05[14] Safety factor for water pressure [-].
- $E_{max,ci}$ = 3658.3 Resultant force of earth pressures for tunnel face (Formula 4.10) [kN]
- $E_{w,ci}$ = 19301.7 Resultant force of water pressures for tunnel face (Formula 4.11) [kN]

$$S_{ci} = 1.5 * 3658.3 + 1.05 * 19301.7 = 25754.3\ kN$$

Minimal required support pressure

$$P_{min} = \frac{S_{ci}}{\frac{\pi * D^2}{4}} + \Delta p_{op} \qquad \text{(Formula 4.13)}$$

- S_{ci} = 25754.3 Required minimum support force (Formula 4.12) [kN]
- D = 7.7 External diameter of the tunnel [m]
- Δp_{op} = 30 Operation tolerance[15]

$$P_{min} = \frac{25754.3}{\frac{\pi * 7.7^2}{4}} + 30 = 583.1\ \frac{kN}{m^2}$$

Conclusion face support

$$P_{min} \geq E_{soil} + E_w \qquad \text{(Formula 4.02)}$$

- P_{min} = 583.1 Required minimum support pressure (Formula 4.13) [kPa]
- E_{soil} = 77 Soil pressures on the tunnel face[16] [kPa]
- E_w = 414.5 Water pressures at tunnel axis[12] [kPa]

$$583.1 \geq 77 + 414.5 \geq 491.5\ kPa$$

[12] From Figure C4.1, (453 + 376) / 2 = 414.5
[13] In German codes this value is 1.5
[14] In German codes this value is 1.05
[15] EPB shield a variation of +/- 30 kPa
[16] From Figure C4.1 (919.55 - 765.55) / 2 = 77

The required minimum support pressure is higher than the soil and water pressure. The support pressure is higher so the face stability is satisfied. The face will not fail due to the water and soil pressure.

C4.1.3 Maximum support pressure

In case of a shallow tunnel and high groundwater, it should be verified that the maximum support pressure does not cause a blowout in case of compressed air or a breakup/heave (geotechnical failure in vertical direction) in case of a slurry machine. Usually safety against blowout and heave is guaranteed if the maximum support pressure is lower than the soil and water load. However, when the face is supported by air, and not completely sealed with a filter cake, air will leak out of the working chamber and flow into the soil. Figure C4.5 shows the forces that influence this calculation.

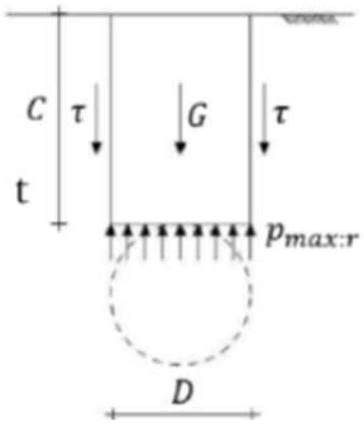


Figure C4.5: Maximum support pressure forces

Maximum support pressure

$$P_{max} \leq \gamma G * (\sigma_v + \frac{2c\prime + t * K0 * \gamma\prime * tan(\varphi)}{D}) \quad \text{(Formula 4.14)}$$

- P_{max} = ? Maximum support pressure [kN/m²]
- σ_v = 765.55 Total soil pressure at top of tunne[17]l [kN/m²]
- c' = 15 Cohesion of soil layer on top of the tunnel [kN/m²]
- t = 41.0 Distance tunnel crown to surface [m]
- γ' = 18.93 Average effective soil unit weight on top of the tunnel crown [kN/m³]
- φ' = 27 Angle of internal friction of soil layer on top of the tunnel [°]
- K_0 = 0.4 Coefficient of earth pressure at rest[18] [-]
- D = 7.7 External diameter of the tunnel [m]
- G = 0.9 Safety factor for permanent loads[19] [-].

$$P_{max} \leq 0.9 * (765.55 + \frac{2* 15 + 41 * 0.4 * 18.93 * tan(27)}{7.7}) = 711.0 \frac{kN}{m^2} \quad \text{(Formula 4.14)}$$

Both the minimum and the maximum support pressure is calculated. The minimum support pressure is calculated with formula 4.13 and is 583.1 kPa. The maximum support pressure is calculated with formula 4.14 and is 711.0 kPa.

[17] From Figure C4.1
[18] Anagnostou & Kovari
[19] In German and Dutch codes this value is 0.9

C4.2 Uplift

Tunnels in soils with a high groundwater table need to have sufficient soil covering on top of the tunnel to prevent uplift. In accordance with Archimedes' law, this force is equal to the weight of the displaced groundwater. The total vertical equilibrium is assessed by checking whether the effective weight of the ground, directly above the tunnel is sufficient to resist the uplift force. For the uplift calculation, we assume that the tunnel does not deform: It stays perfectly round. To check if uplift does not appear we check this during the following two phases namely:
1. In the construction phase when the tunnel is still empty.
2. In the final phase, when all equipment and ballast has been installed, that increases the self-weight of the tunnel.

- During the construction phase
  $F_A \leq G_{1,1} + G_2$ (Formula 4.15)
- During the operational phase
  $F_A \leq G_{1,1} + G_{1,2} + G_2$ (Formula 4.16)
- $G_{1,1}$ Weight tunnel lining (Formula 4.18) [kN/m]
- $G_{1,2}$ Weight concrete in tunnel (Formula 4.20) [kN/m]
- G_2 Effective ground weight (Formula 4.19) [kN/m]
- F_A Buoyant force (Formula 4.17) [kN/m]

The uplift is dependent on a few variables such as the F_A, the $G_{1,1}$, $G_{1,2}$ and G_2. The F_A and the $G_{1,1}$ are dependent on the diameter of the tunnel and this does not influence the governing situation. The $G_{1,2}$ is an extra load after the construction. This load will not be there during the construction of the tunnel so this load does not influence the governing load during construction. The G_2 is dependent on the depth of the tunnel. This will influence the governing situation so the tunnel with the least depth is the governing situation. The situation is near the start shaft. When the tunnel enters the soil, there is the least soil above the tunnel. This is shown in Figure C4.6 at the border between the blue and red tunnel. This is location 1. The depth of the tunnel will be 7.7 metre.

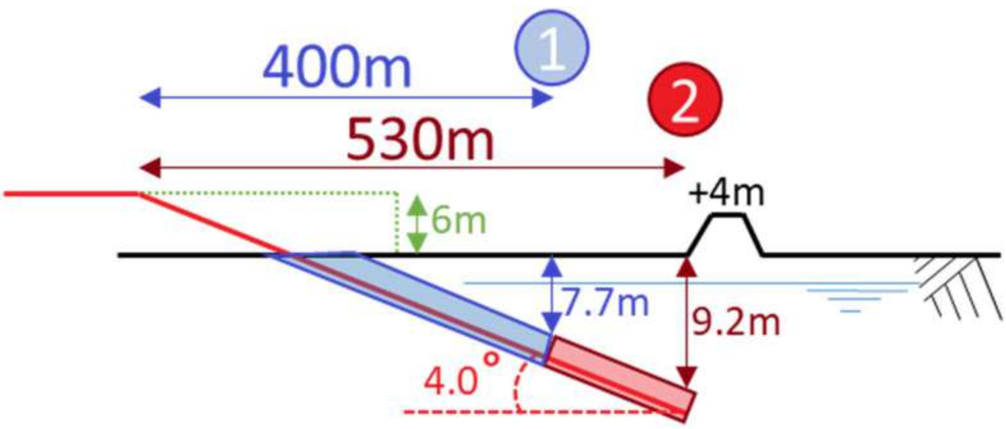


Figure C4.6: Locations

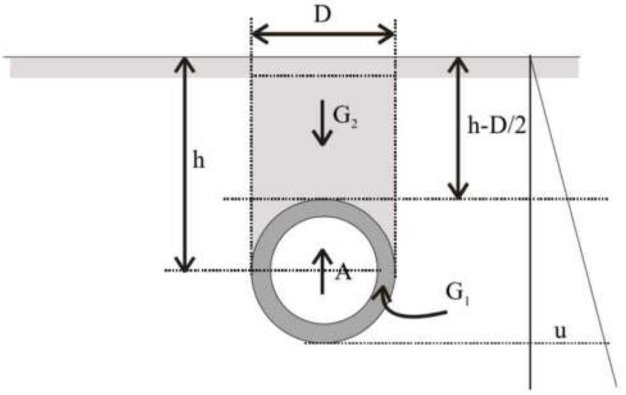


Figure C4.7: Forces uplift

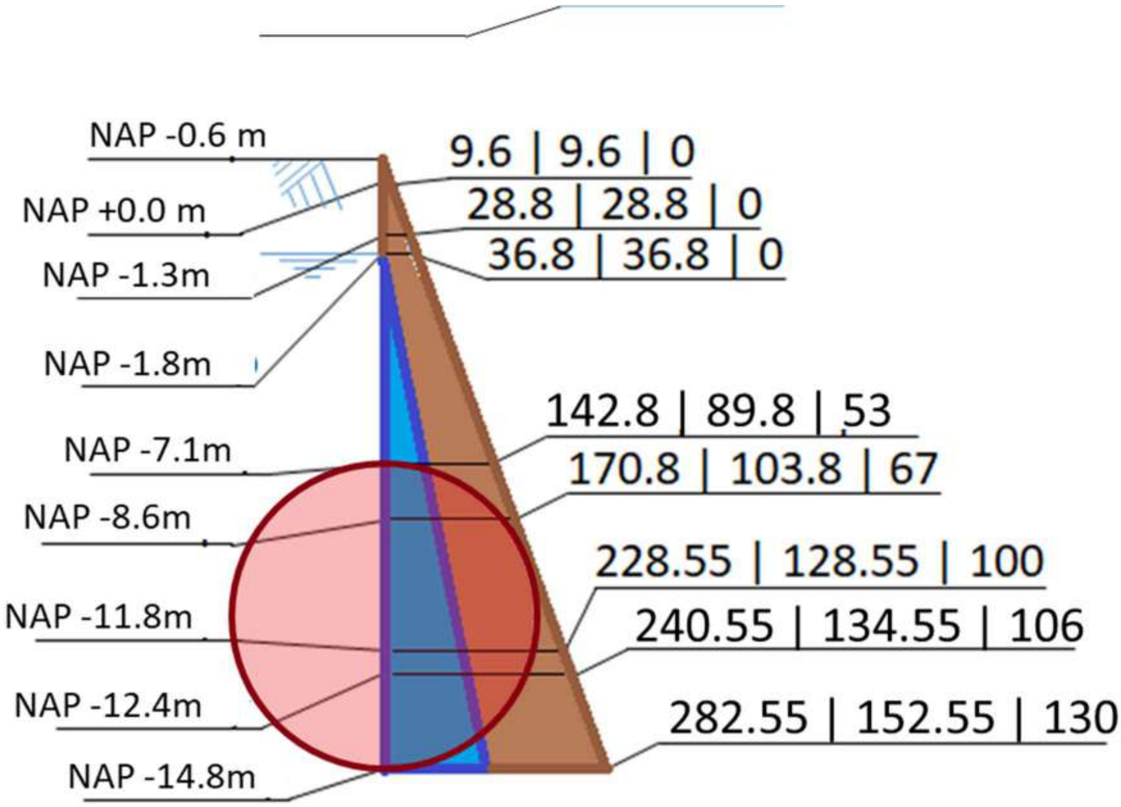


Figure C4.8: Vertical soil stresses (Total stress | Effective stress | Water pressure)

C4.2.1 Stability During Construction Phase

The buoyant force

$$F_A = \frac{\pi}{4} * D_{ext}^2 * \gamma_w \qquad \text{(Formula 4.17)}$$

- $\gamma_w = 10$ Unit weight of water [kN/m³]
- $D_{ext} = 7.7$ Outer diameter tunnel [m]

$$F_A = \frac{\pi}{4} * 7.7^2 * 10 = 465.7 \ \frac{kN}{m}$$

Weight tunnel lining

$$G_{1,1} = \frac{\pi * (D_{ext}^2 - D_{int}^2)}{4} * \gamma_c$$ (Formula 4.18)

- $\gamma_c = 25$ Unit weight of concrete [kN/m^3]
- $D_{int} = 7$ internal diameter tunnel [m]
- $D_{ext} = 7.7$ External diameter tunnel [m]

$$G_{1,1} = \frac{\pi * (7.7^2 - 7^2)}{4} * 25 = 202.0 \frac{kN}{m}$$

Effective ground weight

$$G_2 = D_{ext} * h * \gamma'_g - \frac{\pi}{8} * D_{ext}^2 * \gamma'_g$$ (Formula 4.19)

- $\gamma'_g = 9.91$ Effective soil unit weight[20] [kN/m^3]
- $D_{ext} = 7.7$ External diameter tunnel [m]
- $h = 11.55$ Depth of tunnel axis[21] [m]

$$G_2 = 7.7 * 11.55 * 9.91 - \frac{\pi}{8} * 7.7^2 * 9.91 = 650.6 \frac{kN}{m}$$

The vertical equilibrium in the construction phase is checked with:

$$F_A \leq G_{1,1} + G_2$$ (Formula 4.15)

- $F_A = 456.7$ Uplift force (Formula 4.17) [kN/m]
- $G_{1,1} = 202.0$ Weight tunnel lining (Formula 4.18) [kN/m]
- $G_2 = 650.6$ Effective ground weight (Formula 4.19) [kN/m]

$$465.7 \leq 202.0 + 650.6 \leq 852.6 \frac{kN}{m}$$

[20] 152.55 /(0.6+14.8) = 9.91 (From Figure C4.8)
[21] 7.7 + ½ * D = 7.7 + ½ * 7.7 = 11.55

C4.2.2 Operational Phase

Weight concrete in tunnel lining

$$G_{1,2} = \left[D_{int}^2 * \frac{\pi}{4} * \frac{\zeta}{360} - \frac{D_{int}}{2} * sin(\frac{1}{2} * \zeta) \ * \ y\right] * \gamma_c \qquad \text{(Formula 4.20)}$$

- γ_c = 25 Unit weight of concrete [kN/m3]
- D_{int} = 7 internal diameter tunnel [m]
- ζ = 90.2 Angle in degrees[22] [°]
- y = 2.47 Height middel tunnel to track[23]

$$G_{1,2} = \left[7^2 * \frac{\pi}{4} * \frac{90.2}{360} - \frac{7}{2} * sin(\frac{1}{2} * 90.2) \ * \ (2.47)\right] * 25 \ = 163.4 \frac{kN}{m}$$

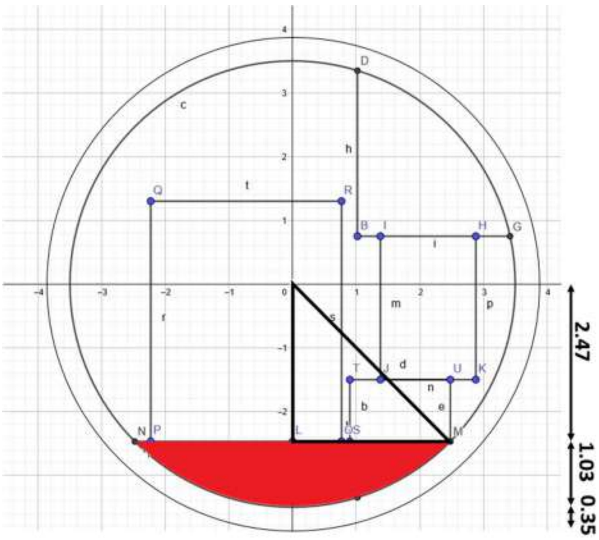


Figure C4.9: y value

The vertical equilibrium in the operation phase is checked with:

$$F_A \ \leq \ G_{1,1} + G_{1,2} + G_2 \qquad \text{(Formula 4.16)}$$

- F_A = 465.7 Buoyant force (Formula 4.17) [kN/m]
- $G_{1,1}$ = 202.0 Weight tunnel lining (Formula 4.18) [kN/m]
- $G_{1,2}$ = 185.1 Weight concrete in tunnel (Formula 4.20) [kN/m]
- G_2 = 650.6 Effective ground weight (Formula 4.19) [kN/m]

$$465.7 \leq \ 202.0 + 163.4 + 650.6 \quad \leq 1037.7 \ \frac{kN}{m}$$

Conclusion

The buoyant force is in both the construction and the operation phase lower than than the other forces. This means that the uplift of the tunnel is not a problem in the governing situation.

[22] 2 * arcos (2.47 / 3.5) = 90.2

[23] See Figure C4.9

C4.3 Settlement trough

The volume of the settlement through V_s includes settlements due to insufficient face support, tunnelling machine passage and the annular gap grouting. In this subsection, the maximum settlement needs to be calculated.

The maximum settlement is dependent on a few variables. The V_{tunnel} and the V_s are dependent on the size of the tunnel. This dimension can not be changed. The last parameter is the i. This is dependent on the depth and can be changed to find the governing situation. The S_{max} will be higher if the i is lower. This means that the governing situation is the situation in which the depth is the lowest. This is the same location as the uplift in section 4.2.

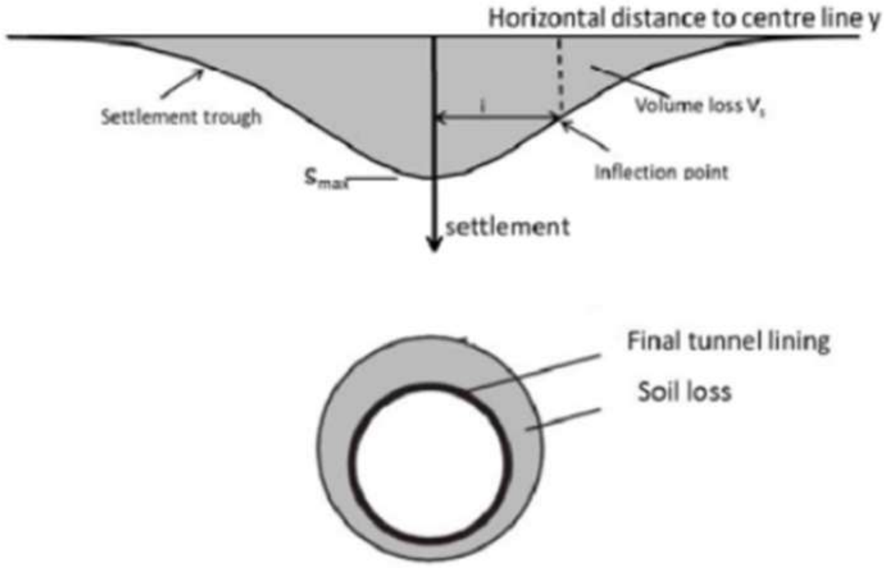


Figure C4.10: Settlement

Maximum settlement calculation

$$S_{max} = \frac{V_S}{i * \sqrt{2 * \pi}}$$

<u>Volume of the tunnel per m</u>

$$V_{tunnel} = \frac{\pi * D_{ext}^2}{4} \qquad \text{(Formula 4.20)}$$

- D_{ext} = 7.7 External diameter tunnel [m]

$$V_{tunnel} = \frac{\pi * 7.7^2}{4} = 46.57\ m^2$$

<u>Volume of the settlement trough per m</u>

$$V_s = V_L * V_{tunnel} \qquad \text{(Formula 4.21)}$$

- $V_L = 0.01$ Volume loss influence factor[24]
- $V_{tunnel} = 46.57$ Volume of the tunnel per m (Formula 4.20) [m^3/m]

$$V_s = 0.01 \quad * 46.57 = 0.466\, m^2$$

Settlement trough factor

$$i = 0.43 \ * z + 1.1 \qquad \text{(Formula 4.22)}$$

- Z = 11.55 Depth of tunnel axis[25] [m]

$$i = 0.43 \ * 11.55 \ + 1.1 = 6.07\, m$$

Maximum settlement at ground level

$$S_{max} = \frac{V_S}{i * \sqrt{2 * \pi}} \qquad \text{(Formula 4.23)}$$

- i = 6.07 Settlement trough factor (Formula 4.22) [m]
- $V_s = 0.466$ Volume of the settlement trough (Formula 4.21) [m^3/m]

$$S_{max} = \frac{0.466}{6.07 \ * \ \sqrt{2 \ * \ \pi}} = 0.03062\, m$$

In practice a settlement below 10 mm is acceptable and we have a total of 30.62 mm. This is too much settlement so measurements need to be taken to reduce the settlement during and after the boring of the tunnel. This settlement could be reduced by placing extra sand on top of the soil to increase the depth of the tunnel and therefore increase the i which will result in a reduction on the maximum settlement.

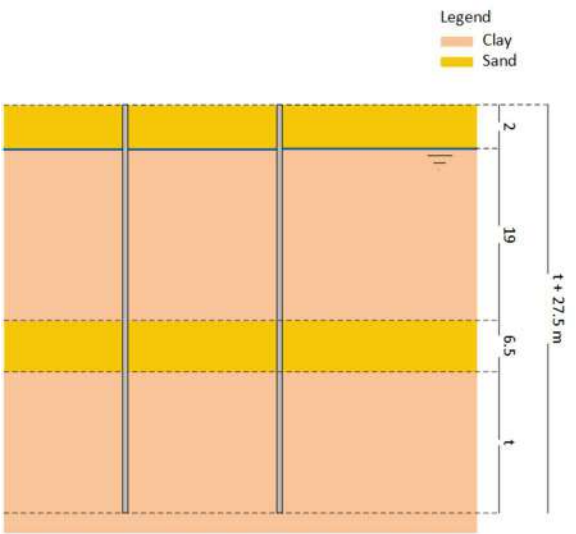
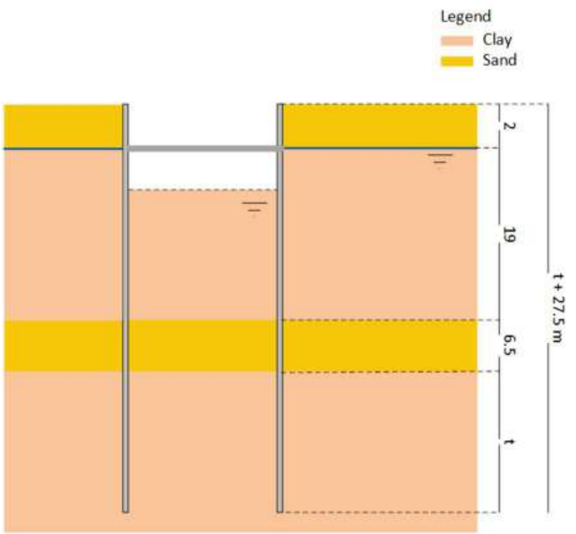
[24] 1 % for EPB
[25] 7.7 + ½ * D = 7.7 + ½ * 7.7 = 11.55

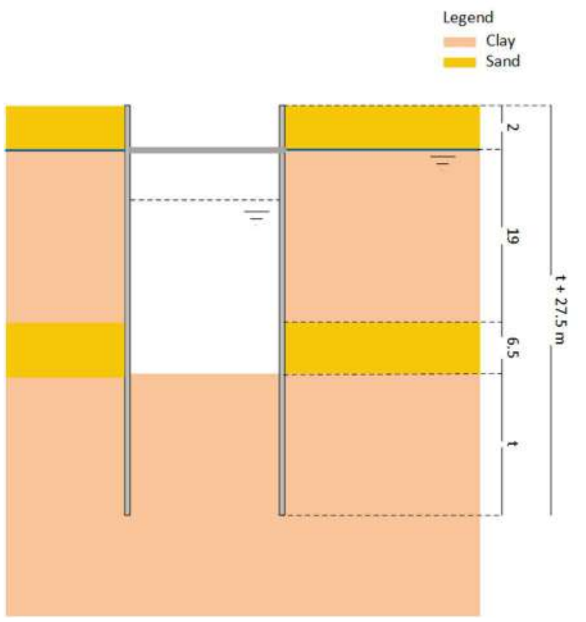
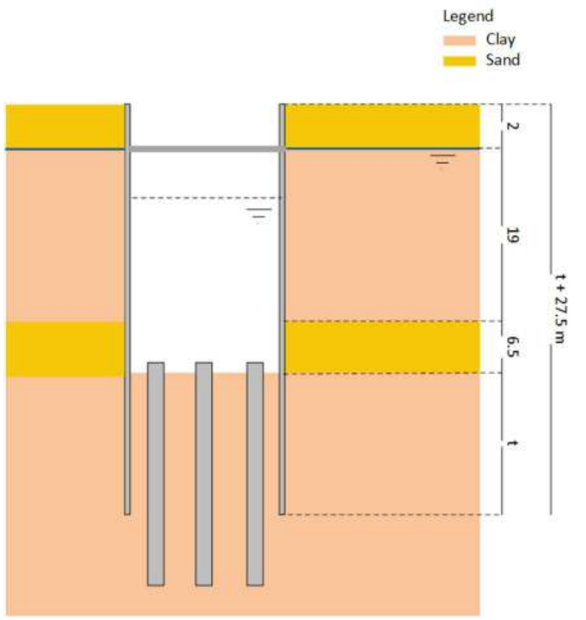
C5. Structural design metro stop Haven-Stad

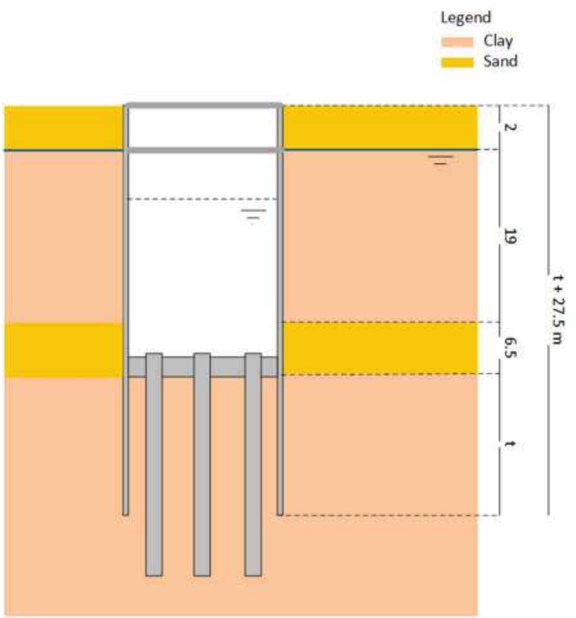
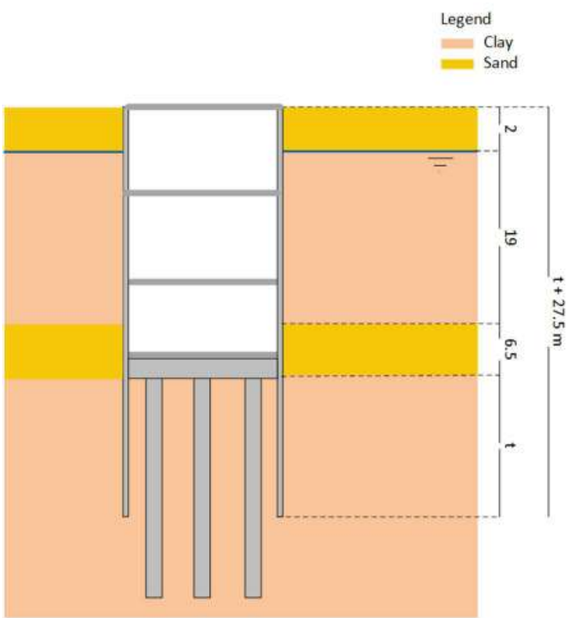
In this chapter, the structural design of the metro stop Haven-Stad is discussed.

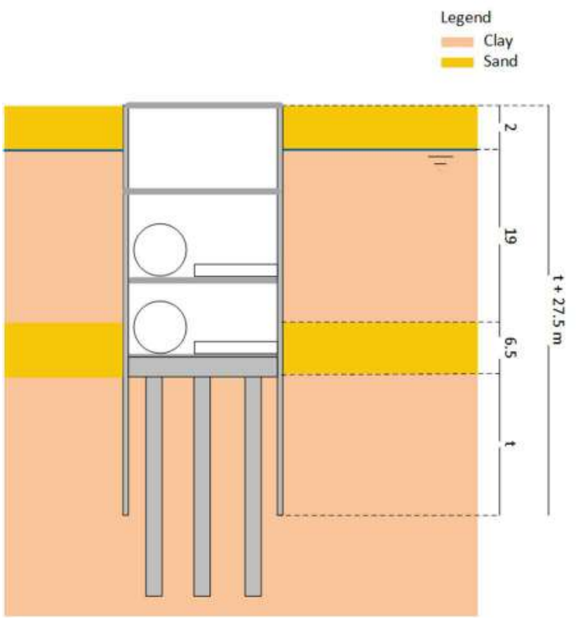
C5.1 Construction and use sequence

In this section, the construction and use sequence for the construction of the metro stop Haven-Stad can be found.

Construction and use sequence sketch	Information
	**Step 1** Construction of the diaphragm walls. This is done by digging a trench, filling it with bentonite. After this, reinforcement is placed and concrete is cast in this trench while the bentonite is pumped out from above.
	**Step 2** Excavation of 3 metres of soil, placing of the struts and wales according to the struts and wales plan. Lowering water level by 1 metre. Therefore the struts and wales will be placed above water.

	**Step 3** Excavation until 27.5 metre. Water level stays at 3 metres.
	**Step 4** Pile driving of the tension piles. The piles will stick out above the ground to make sure the underwater concrete floor will not cover them up completely.

	**Step 5** Pouring underwater concrete floor, constructing roof (cut and cover method).
	**Step 6** Lowering the water table until the underwater concrete floor. We now have an empty building pit. After this, the construction of different floors in the metro stop can take place. After this, the struts and wales can be removed, since the floors can take the forces now.

	**Step 7** Placing platforms and other components in the building pit. Start of the use phase.

C5.2 Stability

To determine the stability, first the governing load circumstances have to be determined. This is done for different governing situations, for the uplift and diaphragm walls for example.

C5.2.1 Uplift

To prevent the structure from floatation, tension piles are installed. The weight of the underwater concrete floor needs to be great enough to resist the water pressure. Since the metro stop is constructed until a depth of 25.5 metres under the water table, this water pressure is enormous.

<u>Uplift</u> (Formula 5.1)

$$F_{up} < G$$
$$h * \gamma_{water} < d * \gamma_{underwater\ concrete}$$
$$25.5 * 10 < d * 23$$
$$d > \ 11.09\ metre$$

The depth of the underwater concrete floor needs to be 11.09 metres, which is not convenient. This can be seen in Figure C5.1.

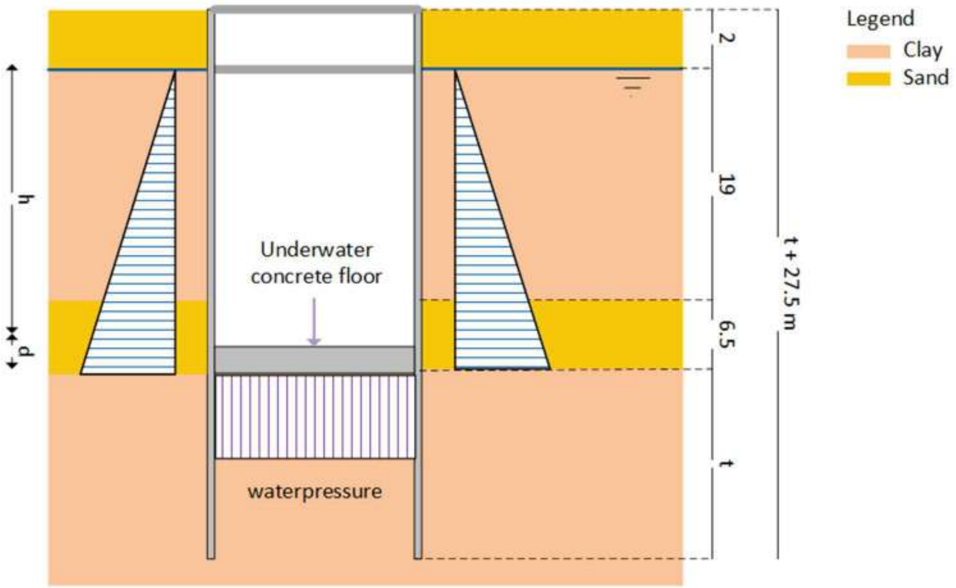


Figure C5.1: The weight of the underwater concrete floor needs to counterbalance the water pressure.

C5.2.2 Tension piles: Shaft friction

Tension piles are therefore needed to keep the stop on the correct place, otherwise uplift will take place. To determine how much force the tension piles can deliver, information about the soil is needed.

The soil profile on the location of the metro stop Haven-Stad can be seen in Figure C5.2.

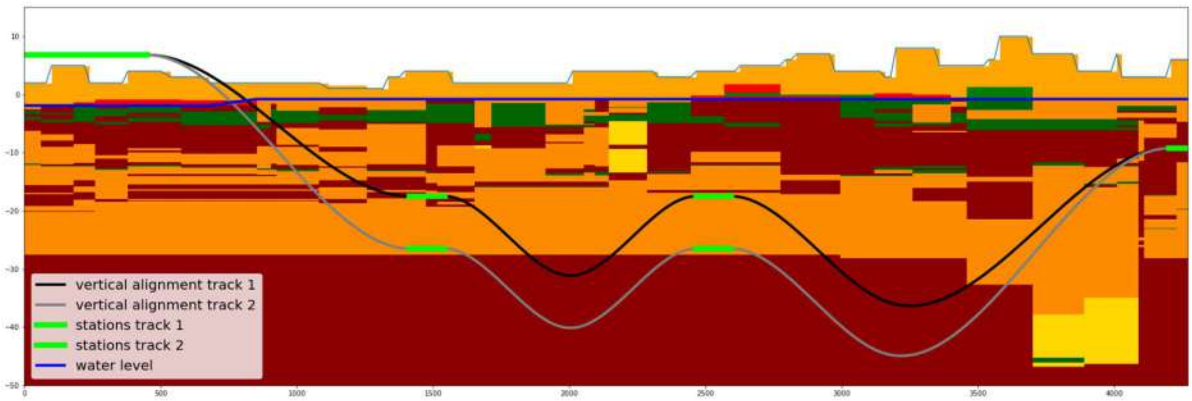


Figure C5.2: Soil profile at Haven-Stad, below station Haven-Stad there is only clay (red).

It is assumed that the chosen length of the tension piles is 30 metres, and the size is chosen to be 0.4x0.4 m. This is done after iterating 3 times for the tension force in the tension piles, these dimensions fitted the best for this design. The maximal tension force this tension pile can take, is determined with the following formula of the cone resisting method:

Maximum tension force (Formula 5.2)

$$F_{r,tension} = \alpha_t \cdot O_{p,mean} \int_{z=0}^{L} f_1 f_2 q_{c,z,d} dz$$

α_t = 0.007 (Pile class factor for a concrete prefab pile) (Manual HS Table 39-2)
$O_{p,\ mean}$ = 1.6 m (Mean circumference of the tension pile)
f1*f2 = 1 (Assumption)
L = 30 m (depth of the tension piles)
$q_{c,z,d}$ = ? (Formula 5.3)

$Q_{c,z,d}$ (Formula 5.3)

$$q_{c,z,d} = \frac{q_{c,z,a} / \xi}{1{,}35 * \gamma_{m,var,qc}}$$

ξ = 1.29 (correlation factor with m>3, n=1) (Manual HS, 2022)
$\gamma_{m,var,qc} = 1.5$ ($\gamma_{m,var,qc} \leq 1.5$), chosen for a conservative value of 1.5 .
$q_{c,z,a}$ = 5 5 MPa (mean value of the cone resistance in clay based on the CPT)

Therefore $q_{c,z,d}$ will be: (Formula 5.3)

$$q_{c,z,d} = \frac{q_{c,z,a} / \xi}{1{,}35 * \gamma_{m,var,qc}} = \frac{5/1.29}{1.35 * 1.5} = 1.91\ MN/m^2$$

And therefore $F_{r,\ tension}$ will be: (Formula 5.2)

$$F_{r,tension} = \alpha_t \cdot O_{p,mean} \int_{z=0}^{L} f_1 f_2 q_{c,z,d} dz = 0.007 * 1.6 * 1.91 * 30 = 0.64\ MN$$

The maximum tension force is therefore 640 kN for every tension pile. The underwater concrete floor will be 1 metre thick, so this floor will take 23 kN/m² of tension force. The needed tension force from the piles will be:

Water pressure - weight underwater concrete floor
(25.5 + 1.0) * 10 - 23 = 242 kN/m²

Maximum tension force per pile / needed tension force
640 / 242 = 2.64 m²

So every 2.7 m² there needs to be a tension pile underneath the concrete floor.

The length and width of the building pit are 11 metres by 130 metres. Therefore the area of the underwater concrete floor is 1430 metres squared. And thus, 530 tension piles are needed with a centre to centre distance of 1.65 m. These will be placed in a grid of 7 by 76. This will result in a total of 532 tension piles.

C5.2.3 Tension piles: Clump criterion

The clump criterion also needs to be checked. This is done in the following section. The clump criterion is checking if the weight of the pile and the ground around the pile is bigger than the tension force. This can be done with the following formula:

$$F_{clump} = F_{r,tension,max,d} = (V_{cone} + V_{cylinder} - V_{pile}) \cdot \gamma'_{d,soil} + V_{pile} \cdot \gamma'_{d,concrete} > F_{tension}$$

(Formule 5.4)

- F_{clump} = $F_{r,tension,max,d}$ = ? maximum tensile force the soil can absorb
- V_{cone} = 1.49 m^3 volume of the conical soil volume at the tip of the pile
- $V_{cylinder}$ = 81.68 m^3 volume of the soil near the pile tip, below the conical part
- V_{pile} = 4.8 m^3 Volume of the pile
- $\gamma'_{d,soil}$ = 8 kN/m^3 Volumetric weight of the ground
- $\gamma'_{d,\ concrete}$ = 15 kN/m^3 Volumetric weight of the concrete

Every 1.65 metres a tension pile will be located. Therefore V_{cone} will be:

- $V_{cone} = \frac{1}{3} \cdot 1.65^3 = 1.49\ m^3$
- $V_{cylinder} = bhL$ (b = h = 1.65m, L = 30m) = $81.68\ m^3$
- $V_{pile} = b * h * L\ (b = h = 0.4, L = 30) = 0.4 \cdot 0.4 \cdot 30 = 4.8\ m^3$
- $\gamma'_{d,soil} = 18 - 10 = 8\ kN/m^3$
- $\gamma'_{d,concrete} = 25 - 10 = 15\ kN/m^3$

$$F_{clump} = F_{r,tension,max,d} = (1.49 + 81.68 - 4.8) \cdot 8 + 4.8 \cdot 15 = 698.96\ kN$$

(Formule 5.4)

r = $6D_{eq}$ = 6*1.13D_{square} = 6*1.13* 400 = 2840 mm2 a

This is higher than the 640 kN per tension pile, so the clump criterion is met.

This radius unfortunately overlaps with other tension piles. Therefore it can be displayed in the following way:

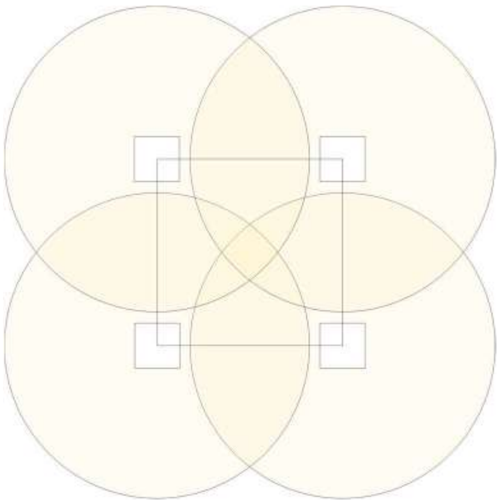


Figure C5.3: Tension piles and the ground around them.

C5.2.4 Diaphragm walls stability

In this section, the diaphragm walls are designed. This is done by calculating the passive and active ground pressures on the wall, and calculating how much the strut force has to be, to keep the moment in the anchor point at 0.

The walls need to be at least as deep as the metro stop is, so 26.5 metres. However, also the horizontal ground pressure needs to be resisted. Therefore, to make use of the passive ground pressure, the walls will be made deeper than 26.5 metres. This can be seen in Figure C5.4.

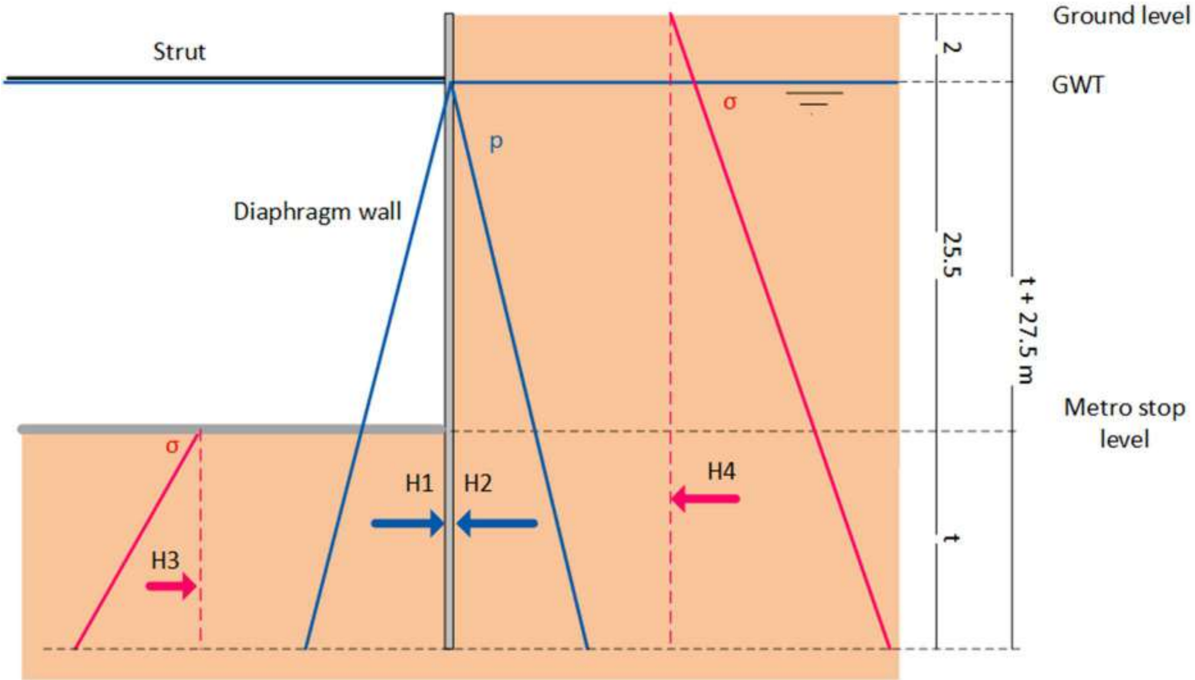


Figure C5.4: Diaphragm walls

The walls need to be stable at all times, or the building pit can collapse. Therefore the needed depth t is determined here. To do that, first the magnitude of the forces need to be determined. This is done for the governing load situation, when the building pit is just made and all forces are working on it.

Assumptions about the ground and water
γ_{water} = 10 kN/m³
$\gamma_{ground,\ clay}$ = 20 kN/m³
φ = 15° (clay)
c' = 0 (clay)

This parameter about the diaphragm walls are assumed:
α = 90°
β = 0° (the ground next to the wall is horizontal)
δ = 10° (perpendicular diaphragm wall, δ = ⅔ φ)

This leads to the following loads on the diaphragm wall. The ground layers are a bit simplified for the calculations, so there is just one layer of clay. Also, this is not the governing load situation. This is the situation where the underwater concrete floor is placed and the water has just been removed. But this can not be calculated by hand, and therefore this situation will be calculated. The support force can become up to 40% higher and the maximum moment 30% higher than in this case. This is the rule of thumb for designing diaphragm walls.

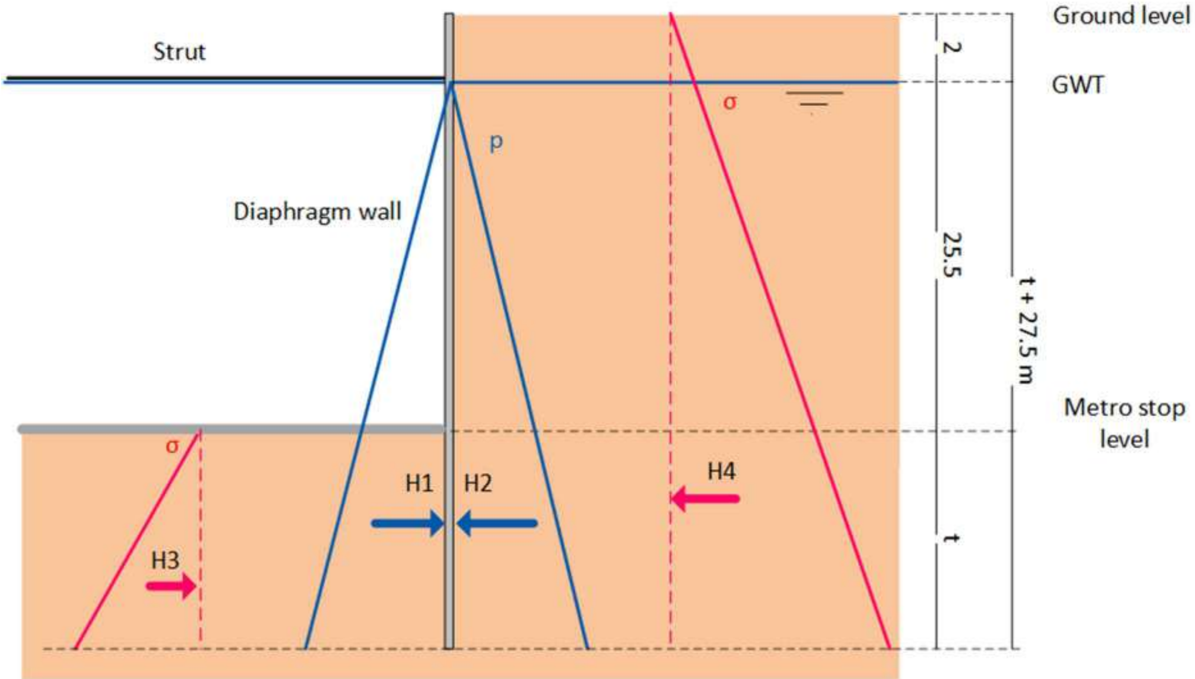


Figure C5.5: Loads on diaphragm wall

There is a passive and active ground pressure. The passive ground pressure is on the left, the active on the right. These pressures have different coefficients and are defined by the following formulas:

$$K_a = \frac{1 - sin\phi\prime}{1 + sin\phi\prime} = \frac{1 - sin15}{1 + sin15} = 0.525 \quad \text{(Formule 5.5)}$$

$$K_a = \frac{1 + sin\phi\prime}{1 - sin\phi\prime} = \frac{1 + sin15}{1 - sin15} = 2.099 \quad \text{(Formule 5.6)}$$

With these coefficients, the horizontal force against the diaphragm wall can be defined. This is done in Table C5.1 with the unknown t.

Table C5.1: Horizontal forces diaphragm wall

Name	Force [kN]	Arm [m]
H1	$3781.3 + 275t + 5t^2$	$17 + ⅔t$
H2	$3781.3 + 275t + 5t^2$	$17 + ⅔t$
H3	$10.5t^2$	$25.5 + ⅔t$
H4	$1985.2 + 144.4t + 2.63t^2$	$16.3 + ⅔t$

The sum of the moments has to be zero in the anchor point, where the strut is located. This is done in the following formula (Force = F, arm = a).

$$\Sigma M = 0 \qquad \text{(Formule 5.7)}$$
$$F_{H1} * A_{H1} - F_{H2} * A_{H2} + F_{H3}A_{H3} - F_{H4} * A_{H4} = 0$$
$$F_{H3}A_{H3} - F_{H4} * A_{H4} = 0$$
$$10.5t^2 * (25.5 + 2/3t) - (1985.2 + 144.4t + 2.63t^2) * (16.3 + 2/3t) = 0$$
$$5.25t^3 + 128.61t^2 - 3677.19t - 32358.76 = 0$$
$$t = 21.5\,m$$

The driving depth t therefore is 21.5 metres. With this value now known, this leads to Table C5.2 for the horizontal forces.

Table C5.2: Horizontal forces

Name	**Horizontal Force [kN]**
H1	12005 →
H2	12005 ←
H3	4854 →
H4	6306 ←
strut	1452 →
sum	*0*

The force in the strut therefore has to be 1452 kN for every metre in the length of the building pit. Since this is not the governing load situation (as explained before), this value is multiplied with 1.4, to correct for this factor (Manual Hydraulic Structures, 2022). This leads to a value of 2033 kN.

C5.2.5 Foundation and pile plan

Earlier to prevent the uplift, a pile foundation was chosen for the station. Therefore also the use phase of the station must be checked. In the use phase, a lot more weight is pushing on the piles, therefore they may become normal piles instead of tension piles. The weight of the station in the use phase is estimated in Table C5.3.

Table C5.3: Estimation of the loads of the station

Element	**Calculation**	**Load [kN/m²]**
Underwater concrete floor	1[m] * 1[m] * 23[kN/m3]	23
Diaphragm wall	26.5[m] * 2[m] * 24[kN/m3] / 11[m]	116
Platform	0.5[m] * 24[kN/m3] * 2 * 6[m] / 11[m]	13
Escalator	150[kN] / 11[m] * 2	28
Floor	2 * 0.75[m] * 24[kN/m3]	36
Roof	0.75[m] * 24[kN/m3]	18
Train track	0.6[kN/m] * 4 / 11[m]	0.22
Installations	estimation	1
Metro	630[kN] / 123[m] * 2 / 11[m]	1
People	Quick Reference	5
Total		*241*

Per square metre, the force is 241 kN. Every 2.64 m² there is a pile, so on every pile the pressure force will be 636.24 kN. The tension force is determined in formula 5.2 and is 640 kN for every tension pile. The total force in the use phase on the ground will therefore be:

$$Pressure\ -\ Tension\ =\ 636.24 - 640 =\ -3.76\ kN$$

This leads to the following pile plan, with 7 by 76 piles, so 532 in total, as defined before. In Figure C5.6, a small section of this pile plan is shown.

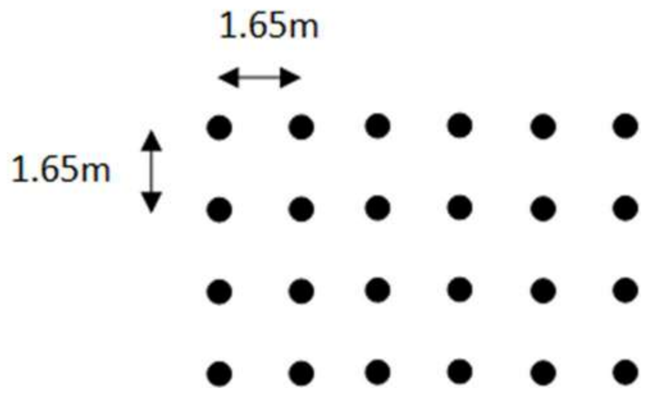


Figure C5.6: Section of pile plan. The whole pile plan is 7x76 piles all with a c.t.c. distance of 1.65 metre.

C5.3 Strength

In this section, the strength of the diaphragm walls and the struts and wales are determined.

C5.3.1 Diaphragm wall

With the forces on the wall determined in the previous section, now the shear force diagram and moment diagram can be determined.

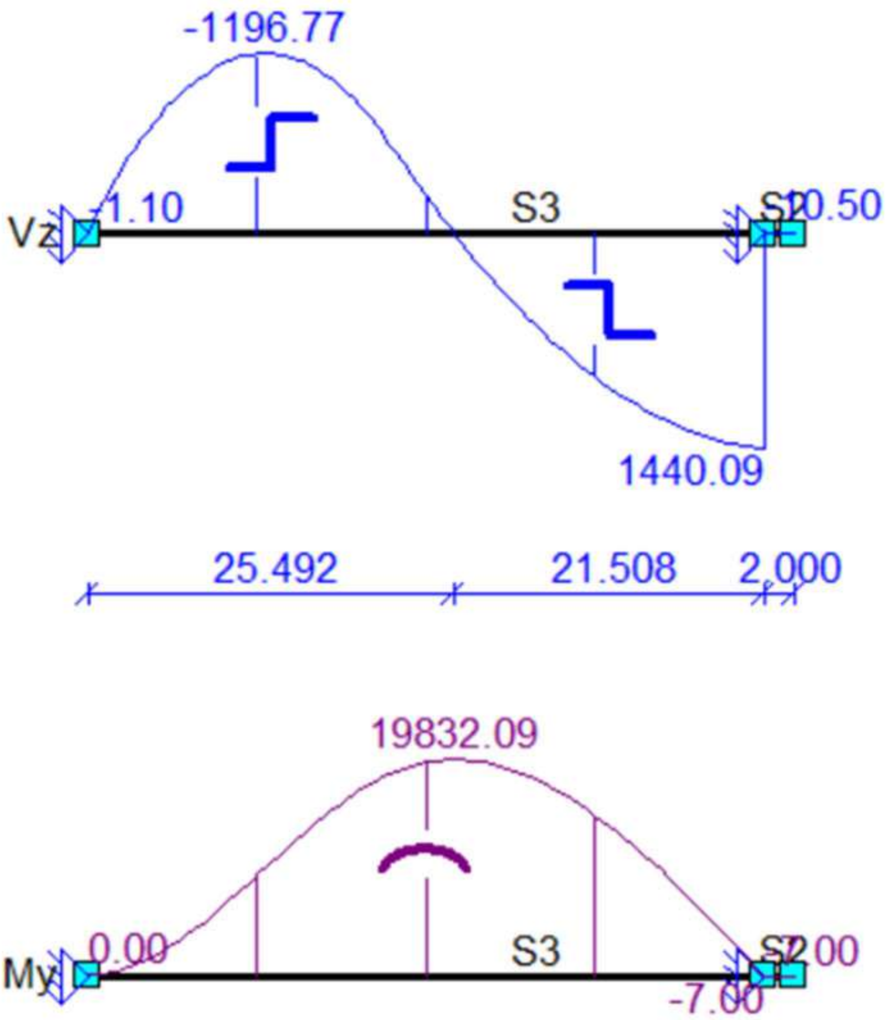
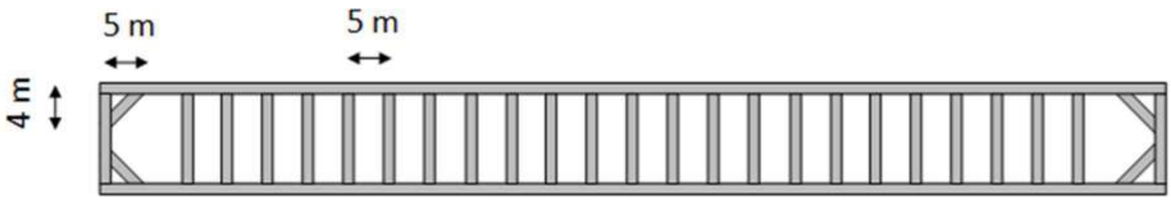


Figure C5.7: The transverse force- and momentum line for the diaphragm wall

The maximum moment has to be multiplied with a factor of 1.3, for the critical situation, as explained before. Therefore the maximum moment will be 19832 * 1.3 = **25781.6 [kNm]**. This is very large, so a very thick concrete diaphragm wall needs to be designed. This moment could be lower, if more struts are placed over the depth of the building pit. This however is not a hand calculation.

C5.3.2 Struts and wales

The struts and wales have to resist a force of **2033 [kN/m]**. In Figure C5.8, the struts and wales plan can be found. The centre to centre distance is 5 metres for all struts, for the diagonal it is 4 by 5 metres. All struts are 11 metres long. This is done, so that the pile driving installation has enough space for driving in the tension piles.



Figuur C5.8: Strut and wales plan

Every strut needs to resist 5 * 2033 = 10164 kN of force. This is too much for most of the available struts. Therefore a new plan should be made, with struts on multiple levels over the height of the building pit. Unfortunately, this can not be calculated by hand (too many unknowns) and is therefore out of the scope of this project.

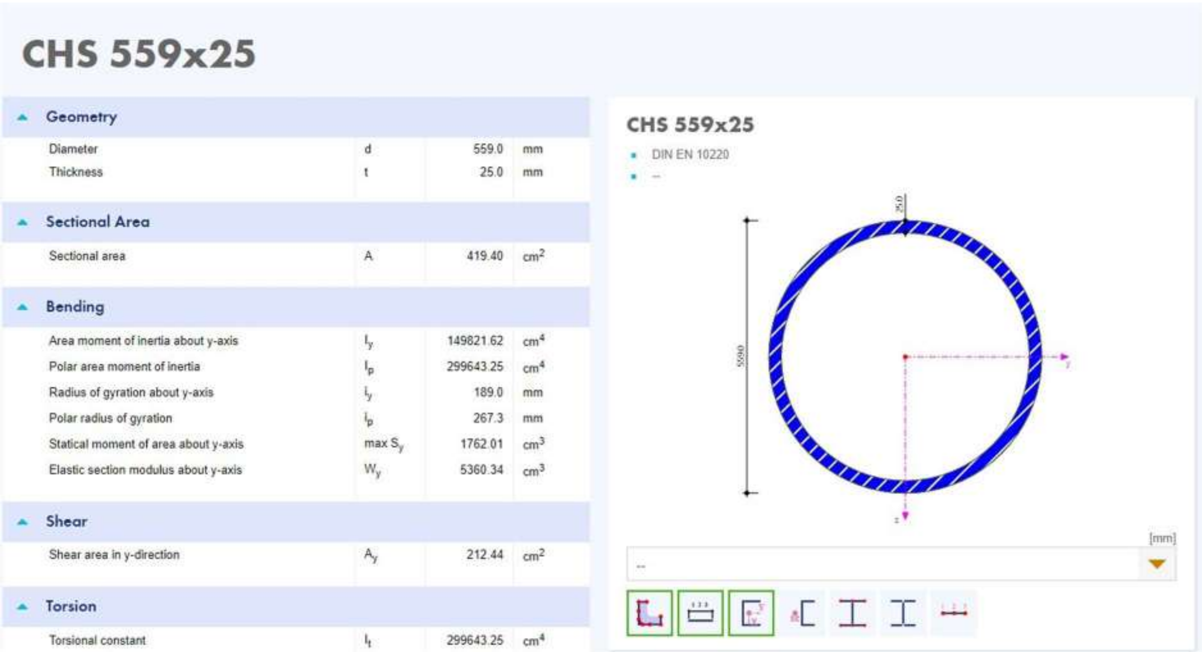


Figure C5.9: Strut parameters

The unity check:

$$\frac{N_{Ed}}{N_{Rd}} + \frac{M_{y,Ed}}{M_{el,y,Rd}} + \frac{M_{z,Ed}}{M_{el,z,Rd}} \leq 1 \qquad \text{(Formule 5.8)}$$

$$N_{Ed} = 675\ kN$$

$$N_{Rd} = A * f_y$$

- N_{Rd} = ? compressive strength
- A = 41940 mm² Area of the strut
- F_y = 355 N/mm² steel strength (S355)

$$N_{Rd} = 41940 * 355 = 14888.7\ kN$$

$$M_{y,Ed} = 0$$

$$M_{z,Ed} = 0$$

$$\frac{10164}{14888.7} = 0.68 \leq 1$$

Buckling failure:
The buckling of the struts is calculated and checked where the struts have enough resistance against buckling. The buckling is calculated with formula 5.9.

$$\frac{N_{b,Rd}}{N_{Ed}} = \frac{\chi_z * N_{Rd}}{N_{Ed}} \leq 1$$ (Formule 5.9)

To calculate the buckling resistance, the formulas 5.10, 5.11, 5.12 and 5.13 are needed.

<u>Axial force at Euler load</u>

$$F_{euler,z} = \frac{\pi * E * I}{L^2_{buck,z}}$$ (Formule 5.10)

- E = 210 000 [N/mm²]
- I = 1498216200 [mm^4] (Figure C5.9)
- $L_{buck,s}$ = 0.5 * L = 5500 [mm]

$$F_{euler,z} = \frac{\pi * 210000 * 1498216200}{5500^2} = 32675201.7\ [N]$$

<u>relative slenderness</u>

$$\lambda = \sqrt{\frac{N_{Rd}}{F_{Euler,z}}}$$ (Formule 5.11)

- N_{Rd} = 14888700 N
- $F_{Euler,s}$ = 32675201.7 N

$$\lambda = \sqrt{\frac{14888700}{32675201.7}} = 0.675$$

Buisprofielen		warmvervaardigd	elke as	a	a_0
		koudgevormd en gelast	elke as	c	c

Instabiliteits curve	a_0	a	b	c	d
Imperfectie factor a	0.13	0.21	0.34	0.49	0.76

Figure C5.10: Imperfection factor

<u>Imperfection parameter</u>

$$\phi = 0{,}5 * [1 + \alpha * (\lambda - 0.2) + \lambda^2]$$

- α = 0.49 (Imperfection factor) (Formule 5.12)
- λ = 0.675

$$\phi = 0{,}5 * [1 + 0.49 * (0.675 - 0.2) + 0.675^2] = 0.844$$

<u>reduction factor for buckling</u>

$\chi_s = \frac{1}{\phi + \sqrt{\phi^2 - \lambda^2}}$ (Formule 5.13)

- ϕ = 0.844 (formula 5.12)
- λ = 0.675 (formula 5.11)

$$\chi_s = \frac{1}{0.844 + \sqrt{0.844^2 - 0.675^2}} = 0.740$$

<u>Buckling failure</u>

$\frac{N_{Ed}}{\chi_z * N_{Rd}} \leq 1$ (Formule 5.9)

- χ_s= 0.740
- N_{Rd} = 14888700 N
- N_{Ed} = 10164000 N

$$\frac{10164000}{0.740 * 14888700} = 0.923 \leq 1$$

The value is less than 1 so the strut will not fail in buckling.

C6. Start shaft

In this chapter, the structural design of the start shaft will be discussed. Most calculations are exactly the same structure as in chapter 5, it is therefore recommended to read the full explanation there. If one of the parameters is different, this will be explained.

C6.1 Stability

For the construction of the shaft the same method will be used as for Havenstad (cut and cover). This is done for different governing situations, for the uplift and diaphragm walls. The shaft as seen in Figure C6.1, goes from ground level all the way to -14.8 NAP. This is done so there is the required amount of earth on top of the tunnel so boring will be possible. This required distance is equal to one diameter of the TBM, which is exactly 7.7 metres. The respective total, effective, water -pressure can also be seen in this picture. The highest water pressure will have the highest uplift force therefore we calculate the uplift at the end point of the shaft.

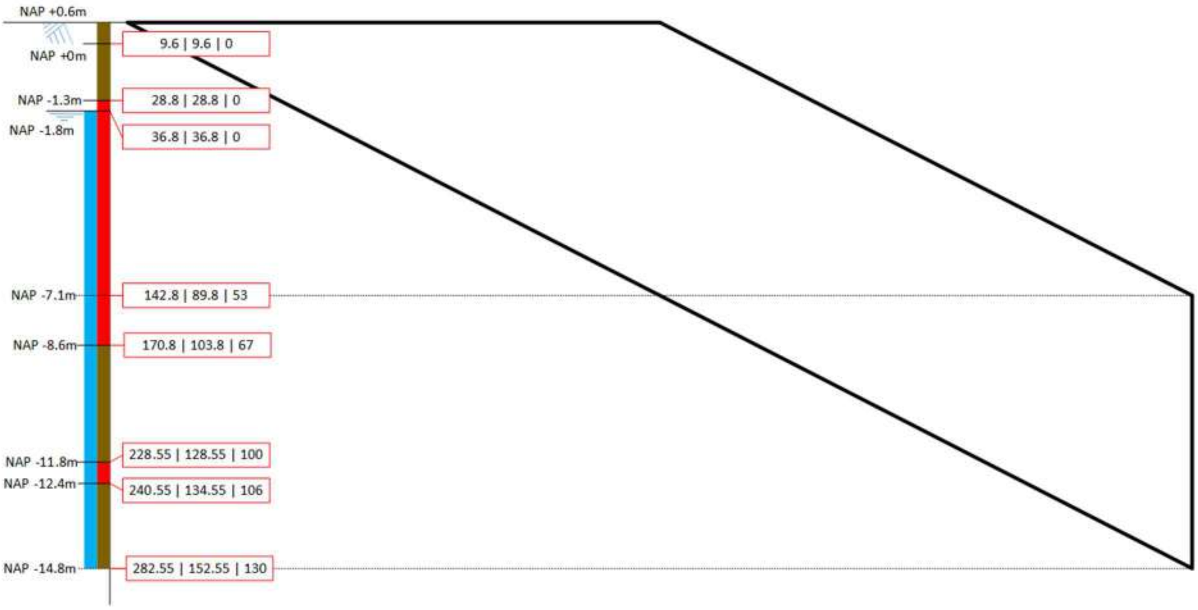


Figure C6.1: Stability of metro shaft, side view

C6.1.1 Uplift

The uplift can be counteracted by having a thick concrete slab under the building. The thickness of this slab will be calculated to see if foundation piles will be required.

<u>Uplift</u> (Formula 6.1)

$$F_{up} < G$$
$$h * \gamma_{water} < d * \gamma_{underwater\ concrete}$$
$$(15.4 - 1.8 - 0.6) * 10 < d * 23$$
$$d > \frac{13}{23} = 5.65\ metre$$

The depth of the underwater concrete floor needs to be 5.65 metres, which is not convenient. That is why a pile foundation will be used.

C6.2.2 Tension piles: Shaft friction

Tension piles are therefore needed to keep the stop on the correct place, otherwise uplift will take place. To determine how much force the tension piles can deliver, information about the soil is needed. The soil profile on the location of the start shaft can be seen in Figure C6.2.

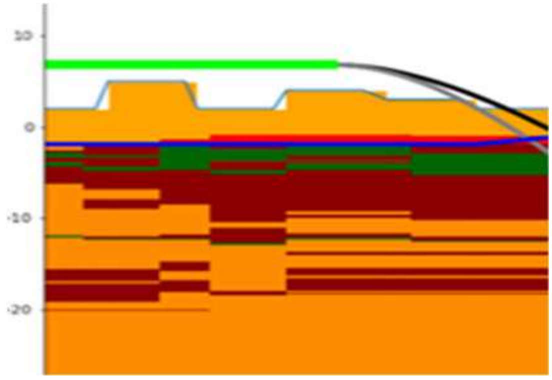


Figure C6.2: Soil profile at start shaft, below station mostly sand (orange).

To be the most economical during the construction the same piles will be used (0.4x0.4 m), although the length will be way shorter also to save costs. The length used will be 15 metres instead of the 30 metres before. The maximal tension force this tension pile can take, is determined with the following formula of the cone resisting method:

<u>Maximum tension force</u> (Formula 6.2)

$$F_{r,tension} = \alpha_t \cdot O_{p,mean} \int_{z=0}^{L} f_1 f_2 q_{c,z,d} dz$$

- L = 15 m (depth of the tension piles)

<u>$Q_{c,z,d}$</u> (Formula 6.3)

$$q_{c,z,d} = \frac{q_{c,z,a} \,/\, \xi}{1{,}35 * \gamma_{m,var,qc}}$$

- $q_{c,z,a}$ = 10 (see cpt test avg 15-25)

$$q_{c,z,d} = \frac{q_{c,z,a} \,/\, \xi}{1{,}35 * \gamma_{m,var,qc}} = \frac{10/1.29}{1.35 * 1.5} = 3.83\ MN/m^2$$

$$F_{r,tension} = \alpha_t \cdot O_{p,mean} \int_{z=0}^{L} f_1 f_2 q_{c,z,d} dz = 0.007 * 1.6 * 3.83 * 10$$
$$= 0.643\ MN$$

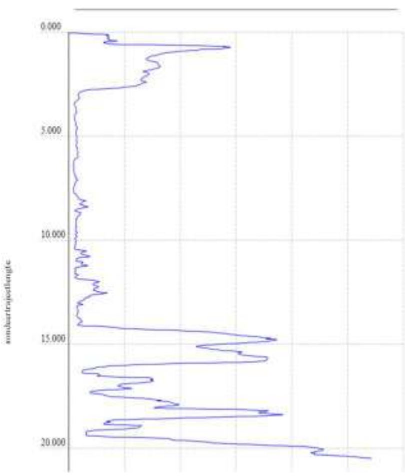


Figure C6.3: Cpt test at shaft

The maximum tension force is therefore 643 kN for every tension pile. The underwater concrete floor will be 1 metre thick, so this floor will take 23 kN/m² of tension force. The needed tension force from the piles will be:

Water pressure - weight underwater concrete floor
(13 + 1.0) * 10 - 23 = 117 kN/m²

Maximum tension force per pile / needed tension force
643 / 117 = 4.76 m²

So every 4.76 m² there needs to be a tension pile underneath the concrete floor.

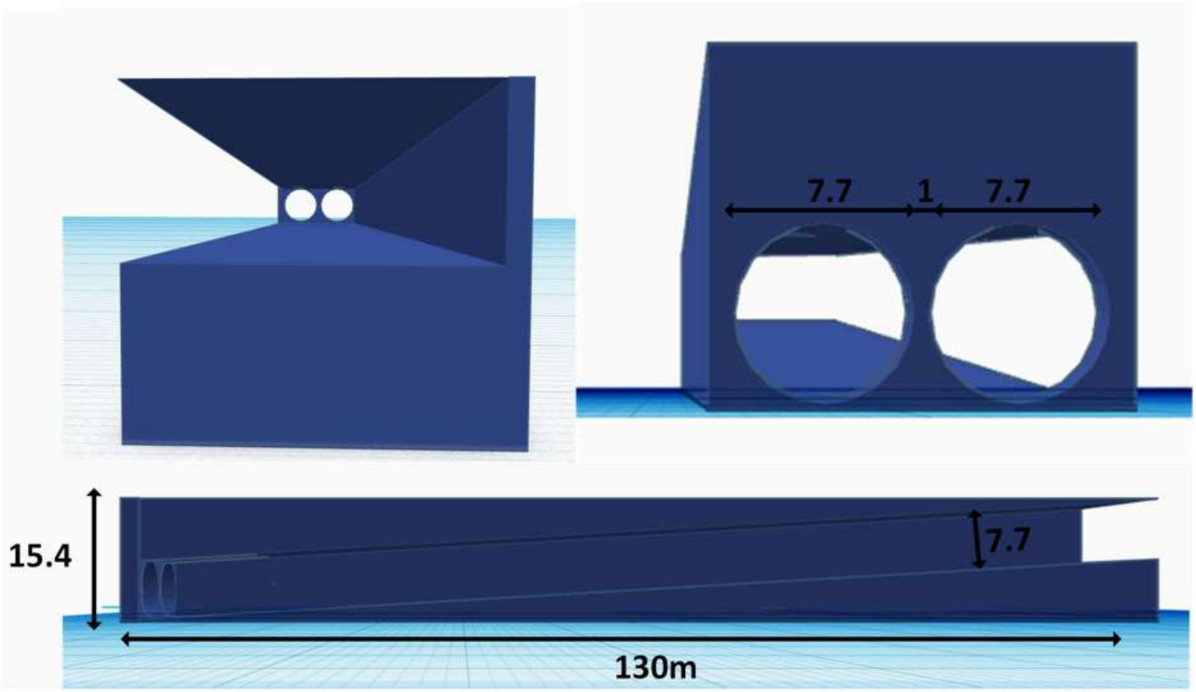


Figure C6.4 sketch + dimensions tunnel shaft

The length and width of the building pit are 17 metres by 130 metres. Therefore the area of the underwater concrete floor is 2210 metres squared. And thus, 465 tension piles are needed with a centre-to-centre distance of 2.18 m. These will be placed in a grid of 8 by 60. This will result in a total of 480 tension piles.

C6.2.3 Tension piles: Clump criterion

The clump criterion also needs to be checked. This is done in the following section. The clump criterion is checking if the weight of the pile and the ground around the pile is bigger than the tension force. This can be done with the following formula:

$$F_{clump} = F_{r,tension,max,d} = (V_{cone} + V_{cylinder} - V_{pile}) \cdot \gamma'_{d,soil} + V_{pile} \cdot \gamma'_{d,concrete} > F_{tension}$$

(Formule 6.4)

- $F_{clump} = F_{r,tension,max,d}$ = ? maximum tensile force the soil can absorb
- V_{cone} = 3.47 m^3 volume of the conical soil volume at the tip of the pile
- $V_{cylinder}$ = 81.68 m^3 volume of the soil near the pile tip, below the conical part
- V_{pile} = 4.8 m^3 Volume of the pile
- $\gamma'_{d,soil}$ = 8 kN/m^3 Volumetric weight of the ground
- $\gamma'_{d,\ concrete}$ = 15 kN/m^3 Volumetric weight of the concrete

Every 1.65 metres a tension pile will be located. Therefore V_{cone} will be:

$$V_{cone} = \frac{1}{3} \cdot 2.18^2 = 3.47\ m^3$$

$V_{cylinder} = bhL$ (b = h = 2.18m, L = 15m) = $71.45\ m^3$

$$V_{pile} = b * h * L\ (b\ =\ h\ =\ 0.4, L =\ 15) = 0.4 \cdot 0.4 \cdot 30 =\ 2.4\ m^3$$

$$\gamma'_{d,soil} = 18.5 - 10\ =\ 8.5\ kN/m^3$$

$$\gamma'_{d,concrete} = 25 - 10\ =\ 15\ kN/m^3$$

$$F_{clump} = F_{r,tension,max,d} = (3.47 + 71.45 - 2.4) \cdot 8.5 + 2.4 \cdot 15 = 652.45\ kN$$

This is higher than the 643 kN per tension pile, so the clump criterion is met.

C6.2.4 Diaphragm walls stability

In this section, the diaphragm walls are designed. This is done by calculating the passive and active ground pressures on the wall, and calculating how much the strut force has to be, to keep the moment in the anchor point at 0.

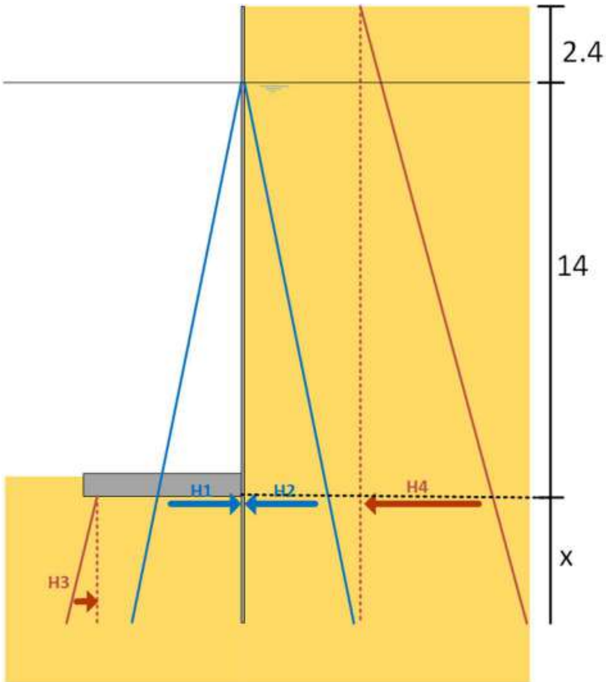


Figure C6.5: Diaphragm walls

Assumptions about the ground and water
γ_{water} = 10 kN/m³
$\gamma_{ground,\ sand}$ = 18.5 kN/m³
φ = 37° (clay)
c' = 0 (clay)

This parameter about the diaphragm walls are assumed:
α = 90°
β = 0° (the ground next to the wall is horizontal)
δ = 25° (perpendicular diaphragm wall, δ = ⅔ φ)

There is a passive and active ground pressure. The passive ground pressure is on the left, the active on the right. These pressures have different coefficients and are defined by the following formulas:

$$K_a = \frac{1 - sin\phi\prime}{1 + sin\phi} = \frac{1 - sin37}{1 + sin37} = 0.248 \text{ (Formule 6.5)}$$

$$K_a = \frac{1 + sin\phi\prime}{1 - sin\phi} = \frac{1 + sin37}{1 - sin37} = 4.022 \text{ (Formule 6.6)}$$

With these coefficients, the horizontal force against the diaphragm wall can be defined. This is done in Table C6.1 with the unknown t.

Table C6.1: Horizontal forces diaphragm wall

Name	Force [kN]	Arm [m]
H1	$980 + 140t + 5t^2$	$28/3 + ⅔t$
H2	$980 + 140t + 5t^2$	$28/3 + ⅔t$
H3	$17.1t^2$	$14 + ⅔t$
H4	$283.5 + 34.6t + 1.1t^2$	$8.533 + ⅔t$

The sum of the moments has to be zero in the anchor point, where the strut is located. This is done in the following formula.

$$\Sigma M = 0 \qquad \text{(Formule 6.7)}$$
$$10.67t^3 + 207t^2 - 484t - 2419 = 0$$
$$t = 4.21\ m$$

The driving depth is therefore 4.21 metres. With this value now known, this leads to Table C6.2 for the horizontal forces.

Table C6.2: Horizontal forces

Name	Horizontal Force [kN]
H1	1658 →
H2	1658 ←
H3	314 →
H4	449 ←
strut	135 →
sum	*0*

The force in the strut therefore has to be 135 kN for every metre in the length of the building pit. Since this is not the governing load situation (as explained before), this value is multiplied with 1.4, to correct for this factor (Manual Hydraulic Structures, 2022). This leads to a value of 189 kN.

C6.2.5 Foundation and pile plan

Earlier to prevent the uplift, a pile foundation was chosen for the station. Therefore also the use phase of the station must be checked. In the use phase, a lot more weight is pushing on the piles, therefore they may become normal piles instead of tension piles. The weight of the station in the use phase is estimated in Table C6.3.

Table C6.3: Estimation of the loads of the station

Element	**Calculation**	**Load [kN/m²]**
Underwater concrete floor	1[m] * 1[m] * 23[kN/m3]	23
Diaphragm wall	26.5[m] * 2[m] * 24[kN/m3] / 11[m]	116
TBM	60 MN / 150[m]	400
Train track	0.6[kN/m] * 4 / 11[m]	0.22
Installations	estimation	1
Metro	630[kN] / 123[m] * 2 / 11[m]	1
People	Quick Reference	5
Total		*546.22*

Per square metre, the force is 546.22 kN. Every 2.33 m² there is a pile, so on every pile the pressure force will be 1273kN. The total force in the use phase on the ground will therefore be:

$$pressure \; - \; tension \; = \; 1273 - 643\;/2.33 = 997\;kN$$

C6.3 Strength

In this section, the strength of the diaphragm walls and the struts and wales are determined.

C6.3.1 Diaphragm wall

With the forces on the wall determined in the previous section, now the shear force diagram and moment diagram can be determined.

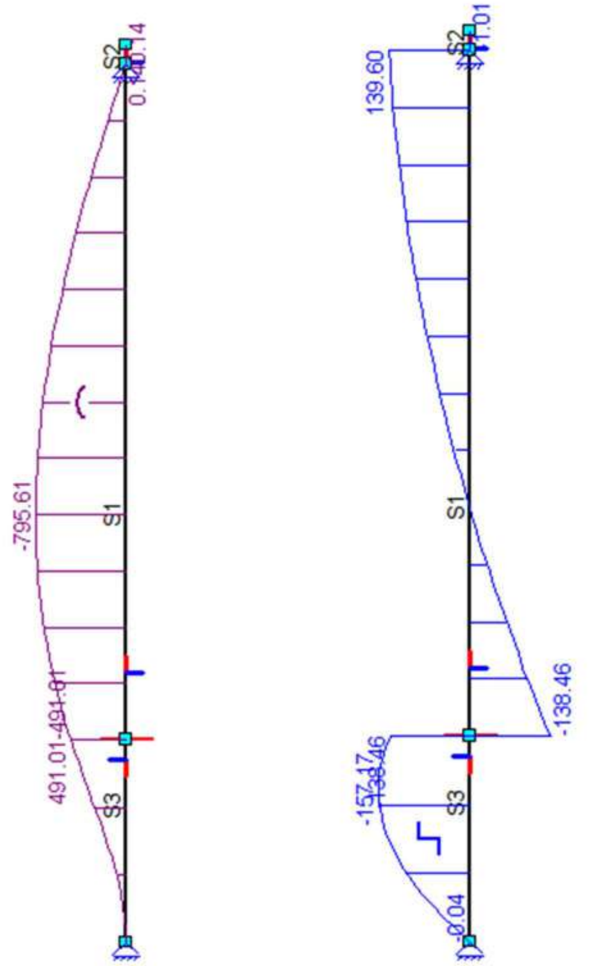
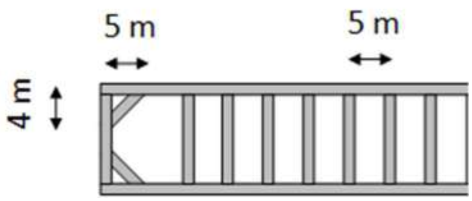


Figure C6.7: The transverse force- and momentum line for the diaphragm wall

The maximum moment has to be multiplied with a factor of 1.3, for the critical situation, as explained before. Therefore the maximum moment will be 795* 1.3 = **1033.5 [kNm]**. This is very large, so a very thick concrete diaphragm wall needs to be designed. This moment could be lower, if more struts are placed over the depth of the building pit. This however is not a hand calculation.

C6.3.2 Struts and wales

The struts and wales have to resist a force of **135 [kN/m]**. In Figure C6.8, the struts and wales plan can be found. The centre to centre distance is 5 metres for all struts, for the diagonal it is 4 by 5 metres. All struts are 17 metres long. This is done, so that the pile driving installation has enough space for driving in the tension piles.



Figuur 6.8: Strut and wales plan

Every strut needs to resist 5 * 135 = 675kN of force. This is too much for most of the available struts. Therefore a new plan should be made, with struts on multiple levels over the height of the building pit. Unfortunately, this can not be calculated by hand (too many unknowns) and is therefore out of the scope of this project.

The chosen design of the strut is based on the force this strut needs to withstand. The formula for the calculation of the strength of the strut is. A CHS hollow section is used with the properties given in Table C6.4.

Table C6.4: CHS profile properties

Dimensions [mm]	Thickness [mm]	Area [mm]	Iy [mm]
323.9	8	7940	99100000

The unity check:

$$\frac{N_{Ed}}{N_{Rd}} + \frac{M_{y,Ed}}{M_{el,y,Rd}} + \frac{M_{z,Ed}}{M_{el,z,Rd}} \leq 1 \qquad \text{(Formule 6.8)}$$

$$N_{Ed} = 675\ kN$$

$$N_{Rd} = A * f_y$$

- N_{Rd} = ? compressive strength
- A = 7940 mm² Area of the strut
- F_y = 355 N/mm² steel strength (S355)

$$N_{Rd} = 7940 * 355 = 2818.7\ kN$$

$$M_{y,Ed} = 0$$

$$M_{z,Ed} = 0$$

$$\frac{675}{2818.7} = 0.24 \leq 1$$

This satisfies the given conditions.

Buckling failure:

The buckling of the struts is calculated and checked where the struts have enough resistance against buckling. The buckling is calculated with formula 6.9.

$$\frac{N_{b,Rd}}{N_{Ed}} = \frac{\chi_z * N_{Rd}}{N_{Ed}} \leq 1 \qquad \text{(Formule 6.9)}$$

To calculate the buckling resistance, the formulas 6.10, 6.11, 6.12 and 6.13 are needed.

Axial force at Euler load

$$F_{euler,z} = \frac{\pi * E * I}{L_{buck,z}^2} \qquad \text{(Formule 6.10)}$$

- E = 210 000 [N/mm²]
- I = 99100000 [mm^4] (Table C6.4)
- $L_{buck,s}$ = 0.5 * L = 0.5 * 17 = 8500 [mm]

$$F_{euler,z} = \frac{\pi * 210000 * 99100000}{8500^2} = 904909\ [N]$$

relative slenderness

$$\lambda = \sqrt{\frac{N_{Rd}}{F_{Euler,z}}}$$ (Formule 6.11)

- N_{Rd} = 2818700 N
- $F_{Euler,s}$ = 904909.7 N

$$\lambda = \sqrt{\frac{2818700}{904909}} = 1.76$$

Buisprofielen		warmvervaardigd	elke as	a	a_0
		koudgevormd en gelast	elke as	c	c

Instabiliteits curve	a_0	a	b	c	d
Imperfectie factor a	0.13	0.21	0.34	0.49	0.76

Figure C6.10: Imperfection factor

<u>Imperfection parameter</u>

$$\phi = 0{,}5 * [1 + \alpha * (\lambda - 0.2) + \lambda^2]$$

- α = 0.49 (Imperfection factor) (Formule 6.12)
- λ = 1.76

$$\phi = 0{,}5 * [1 + 0.49 * (1.76 - 0.2) + 1.76^2] = 2.44$$

<u>reduction factor for buckling</u>

$$\chi_s = \frac{1}{\phi + \sqrt{\phi^2 - \lambda^2}}$$ (Formule 6.13)

- ϕ = 2.44
- λ = 1.76

$$\chi_s = \frac{1}{2.44 + \sqrt{2.44^2 - 1.76^2}} = 0.24$$

<u>Buckling failure</u>

$$\frac{N_{Ed}}{\chi_z * N_{Rd}} \leq 1$$ (Formule 6.9)

- χ_s= 0.24
- N_{Rd} = 2818700 N
- N_{Ed} = 675000 N

$$\frac{675000}{0.24 * 2818700} = 0.989 \leq 1$$

The value is less than 1 so the strut will not fail in buckling.

C7. Literature

- Daub Ita. (2017). GTC Rec 10. Daub Ita DE. Geraadpleegd op 14 juni 2022, van https://www.daub-ita.de/fileadmin/documents/daub/gtcrec1/gtcrec10.pdf
- Dlubal Software. (2020, juli). Cross-Section Properties & Analysis | Dlubal Software. DLubal. Geraadpleegd op 22 juni 2022, van https://www.dlubal.com/en/cross-section-properties/chs-559x25-din-en-10220&sa=D&source=docs&ust=1655823176526755&usg=AOvVaw3oJTYGwOMjhvIzUn_17X7K
- EcoRisq. (2022, maart). Soilclasses. Geraadpleegd op 20 juni 2022, van https://www.ecorisq.org/docs/USCS_soilclasses
- GVB. (2022, 4 april). Nieuwe M7-metro's. Over GVB. Geraadpleegd op 9 juni 2022, van https://over.gvb.nl/nieuwe-m7-metros/
- Mishra, H. (2020, 6 juli). Tunnel Construction Methods. Civil Wale. Geraadpleegd op 9 juni 2022, van https://civilwale.com/tunnel-construction-methods/
- Movares. (2014, mei). Tunnelregelgeving. Geraadpleegd op 20 juni 2022, van https://movares.nl/wp-content/uploads/2014/05/Pages-from-tunnelregelgeving-2014-DEF-lowres.pdf
- NS. (2020, februari). Veiligheid in Spoortunnels. https://zoek.officielebekendmakingen.nl/blg-119280.pdf
- Reinders, I. K. (2019, augustus). Tunnelontwerp dictaat. TU Delft.
- TU Delft. (2014). Quick Reference. TU Delft.
- Voorendt, M.Z., Molenaar, W.F. (2021, February). Manual Hydraulic Structures. TU Delft
- Voorendt, M.Z., Molenaar, W.F. (2022, February). General Lecture notes Hydraulic Structures. TU Delft

Appendix C1: Soil Properties

USCS Soil-class	Description	Cohesion (kPa)	Friction angle (°)
GW	well-graded gravel, fine to coarse gravel	0	40
GP	poorly graded gravel	0	38
GM	silty gravel	0	36
GC	clayey gravel	0	34
GM-GL	silty gravel	0	35
GC-CL	clayey gravel with many fines	3	29
SW	well-graded sand, fine to coarse sand	0	38
SP	poorly graded sand	0	36
SM	silty sand	0	34
SC	clayey sand	0	32
SM-SL	silty sand with many fines	0	34
SC-CL	clayey sand with many fines	5	28
ML	silt	0	33
CL	clay of low plasticity, lean clay	20	27
CH	clay of high plasticity, fat clay	25	22
OL	organic silt, organic clay	10	25
OH	organic clay, organic silt	10	22
MH	silt of high plasticity, elastic silt	5	24

Appendix D: Structural

Members of the structural engineering sub-group:

Niels Assendelft	4777212
Shahram Omary	5359015
Jeroen van Schaik	5655021
Martijn Stok	5070740
Tjeerd Thuss	5104734

Supervisor:
Hoessein Alkisaei

Date: 22-6-2022

Preface

This report is about the constructed structures whilst expanding Amsterdam Havenstad and is written for the course CTB3420 Integral Design of Infrastructure. We would like to thank E.J. Houwing for giving input and feedback during the planned meetings in the course. We would also like to thank H. Alkisaei for the input and feedback during the meetings and for insight in engineering software during the course.

Niels Assendelft
Shahram Omary
Jeroen van Schaik
Martijn Stok
Tjeerd Thuss

Delft University of Technology
June 22, 2022

Summary
With the expansion of Amsterdam Havenstad and the closure of the metro line, multiple constructions will need to be added. Constructions such as stations, offices, garages and many more. In this report the following constructions will be analysed: Station Nassauplein HUB, Station Nassauplein, Bridge at the Isolatorweg, Bridge at the Westerpark and Havenstad and at last a parking garage.

The HUB at station Nassauplein offers much functionality in and around the neighbourhood. As well as transport to the underground metro station it also acts as bike parking and shopping mall. The structure has concrete pile foundations and the main structure consists of concrete columns supporting steel IPE beams and a concrete roof. As façade glass walls are used. It also has a stairwell leading to the underground metro station at NAP - 12.5m.

Connected to this hub is an underground metro station. This metrostation will help in connecting the metro line and increase the traffic flow in the newly designed area. The metro station consists of two platforms placed on top of each other. The first level is positioned at NAP - 12.5m and the second platform is placed at NAP - 26.5m. The construction is fully made out of reinforced concrete.

In the process of connecting the metro ring, changes to the original track need to be made. One of these changes is adding metro rail next to already existing rail. This already existing metro rail crosses a bridge, with no additional space. So a new bridge is designed at the Isolatorweg, spanning roughly 45 metres. Made fully out of reinforced concrete.

In the new design of the area connectivity is a key aspect. To accomplish this, a steel and wooden bridge is placed at the Westerpark crossing the train track, spanning 250 metres. Because of the large span, the bridge will have a steel main- and crossbeam construction. The other parts of the bridge will be designed in wood.

Under the metro depot at isolatorweg is a lot of unused space and this is a perfect location for a parking garage. The garage starts directly to the east of the metro station until the road that is directly to the east of the depot itself. The depot is supported with concrete columns and concrete walls. This helps with creating as much as possible column free space for the parking spots.

All the constructions were modelled using the engineering software Scia Engineer. This software allowed for difficult calculations and simplified the process over hand calculations. This software made time consuming calculations calculating reinforcements, displacements, yield stresses, crack width and many more possible.

Inhoudsopgave

1. Introduction

The structures that are elaborated in several structural aspects in this document undergo a couple stages. First of all, the design is set-up during the synthesis phase of this project. When this is done, a more definitive and detailed design is transferred to the structural engineers. Once this phase is reached, the last dimensions of the structure are determined to resist and transmite the forces imposed by its dead load (e.g. self-weight) and life load (e.g. people and vehicles) that will be in attendance during the using phase. After this part of the structural analysis is executed, the ideas of this project can be put onto paper that can be used on the construction site to start building.

In this document the structural analysis of the Isolatorweg station, Havenstad station, Nassauplein station, Transformatorweg bridge and Isolatorweg parking garage are performed. Per structure the design, loads, foundation, dimensioning and costs are elaborated. The structural analysis is applied using all the knowledge from the bachelor Civil Engineering and is assisted using the software engineering package SCIA Engineer 21.1©.

The first chapter is about the Nassauplein HUB which is designed by Niels Assendelt. The second chapter is about station Nassauplein which is designed by Shahram Omary. The third chapter is about the bridge next to station Isolatorweg which is designed by Tjeerd Thuss. The fourth chapter is about the Transformatorweg bridge which is designed by Jeroen van Schaik. The fifth and last chapter is about the Isolatorweg parking garage which is designed by Martijn Stok.

2. Station Nassauplein hub

The first chapter will discuss the HUB positioned directly above the underground metro station. The first subchapter will discuss the design and functions of the construction. Secondly the different loads exerted on the structure are listed. After these assessments the structure was modelled in SCIA Engineer©**.** The responsible team member for this structure is Niels Assendelft.

2.1 Design

In order to create a better flow of transport at Nassauplein, a hub will be positioned above the underground metro station. The main function of this hub will be to efficiently transport passengers of the metro from ground level to the metro station, or vice versa. This will be achieved by placing a large escalator- and stairwell, plus an additional two lifts, as seen in Figure 1.

Figure 1: Display of stairwell

Since space is scarce in Amsterdam, the hub will be utilised for different purposes. One of the secondary uses will be two bicycle parkings. Biking is an important mode of transport in a crowded city like Amsterdam, thus large bicycle parkings will be needed to suffice the capacity. The bicycle parkings will be placed in the southern part of the station, as found in Figure 2.

Figure 2: Display of bike parking

At last the station will be utilised for shops or restaurants. The station is placed central in the city with a relatively large passenger flow. Because of this large passenger flow shops such as supermarkets or small food stations will be in demand. To fulfil this demand, two placements have been made for shops, seen in Figure 3.

Figure 3: Display HUB

Initial assumptions for the dimensions of the model were made to start designing. The roof and floor are estimated to be 300*mm* thick C40/50 concrete. The initial steel beams supporting the roof are IPE300. The columns are assumed to be 300x300mm^2, made out of C40/50 concrete. At last 3*cm* thick glass façade walls are assumed. The layout of the hub can be found in Figure 4.

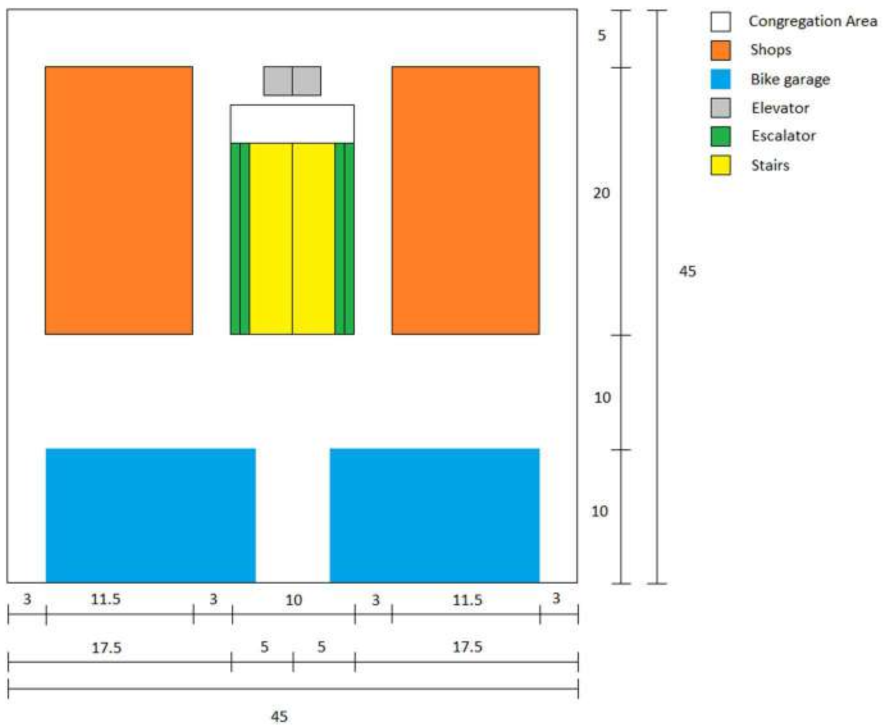


Figure 4: Layout of the HUB

For the staircase the initial walls are assumed to be 500*mm* thick C40/50 concrete. The concrete simulating the stairs is assumed to be 200*mm* thick C40/50. The layout for staircase can be found in Figure 5 and Figure 6. The HUB is 6 metres high and the stairwell is 14.5 metres deep.

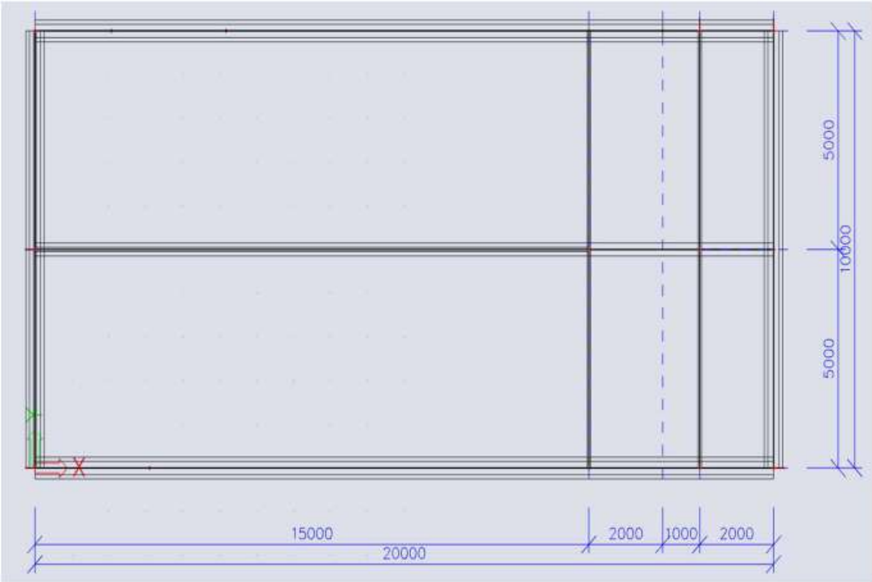


Figure 5: Top view stairwell

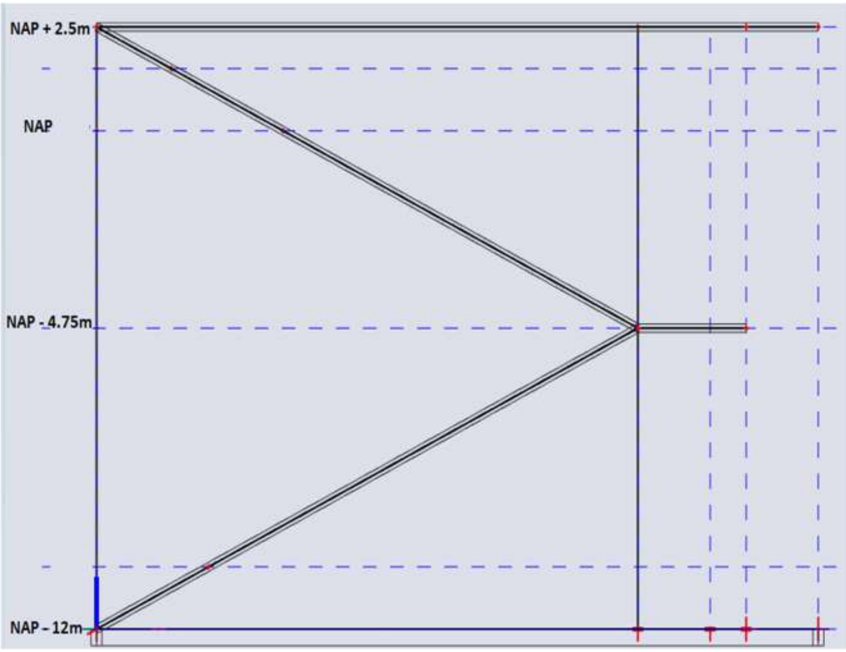


Figure 6: Side view stairwell

2.2 Loads

The ground level HUB will be split up into two parts, the upper structure of the HUB itself and the staircase. This was done so no possible conflicts could occur between the models. Firstly all the loads on the HUB are stated after which all the loads on the stairwell are discussed.

2.2.1 HUB

The structure will be split up into two parts, namely the roof and the ground floor. This has been done, because every part has different loads that need to be taken into account. A short summation can be found in Table 1.

Table 1: Table 1: HUB loads

Description	Category	Magnitude
Roof	**-**	**-**
Self-weight	Permanent	From SCIA
Green roof	Permanent	1 kN/m^2
Snow	Variable	0.7 kN/m^2
Solar panels	Permanent	0.1 kN/m^2
Wind	Variable	0.69 kN/m^2
Ground floor	**-**	**-**
Self-weight	Permanent	From SCIA
Bike parking	Variable	3 kN/m^2
Shops / restaurants	Variable	4 kN/m^2
Congregation area	Variable	5 kN/m^2
Wind	Variable	0.69 kN/m^2

There are four main loads exerted on the roof of the hub, namely the self-weight of the structure, the weight of the greenery, possible snow load and wind load. The self-weight of the structures is automatically calculated in SCIA. To apply sustainability in the project there has been opted for a green roof. A green roof of approximately 70 - 120*mm* thick exerts roughly 1 kN/m^2 (Singleply. (n.d.)). Snow load can occur during the winter times, this set in The Netherlands according to the Eurocode as 0.7 kN/m^2. At last solar panels are installed on the roof. These weigh roughly 10*kg* per m^2 (Solar Bay. (2020)). The wind loads will be calculated later on. The SCIA roof load can be seen in Figure 7.

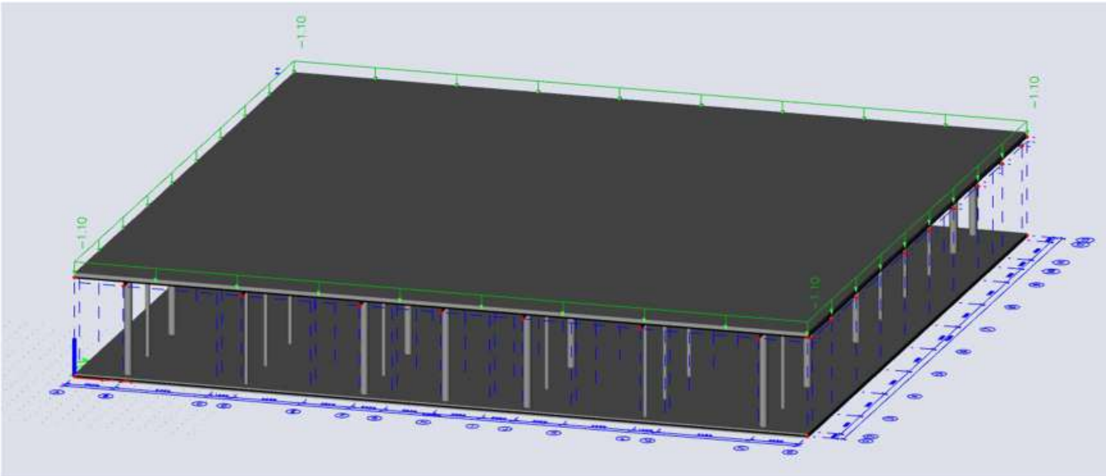


Figure 7: Permanent roof load

The ground floor has several different loads, because of the design layout. For the bike parking a load of 3 kN/m^2 has been applied. For the shops and congregation area a magnitude of 4 and 5 kN/m^2, respectively, were applied see Figure 8. These values have all been found in the Quick Reference (TU Delft. (2016)). The wind load has also been calculated with the use of the Quick Reference, 0.69 kN/m^2 is found.

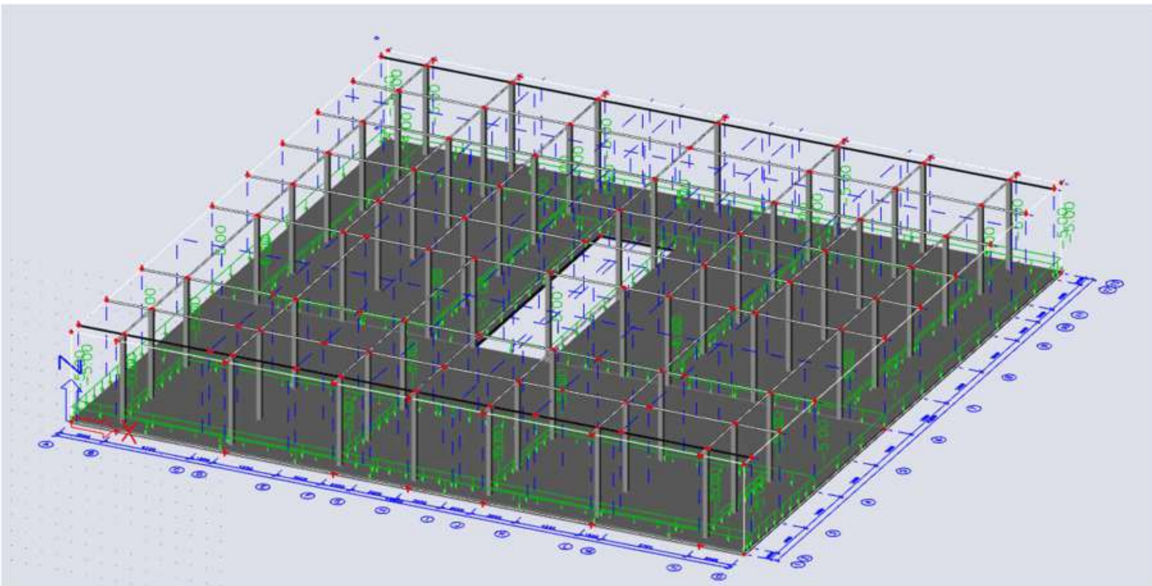


Figure 8: Ground floor loads

At last the wind load is present on the building. This load is divided into multiple parts as stated in the Quick Reference. For the calculation of the wind force a “northern” side was assumed. Using the Quick Reference this resulted in the following scheme of loads, depicted in Figure 9.

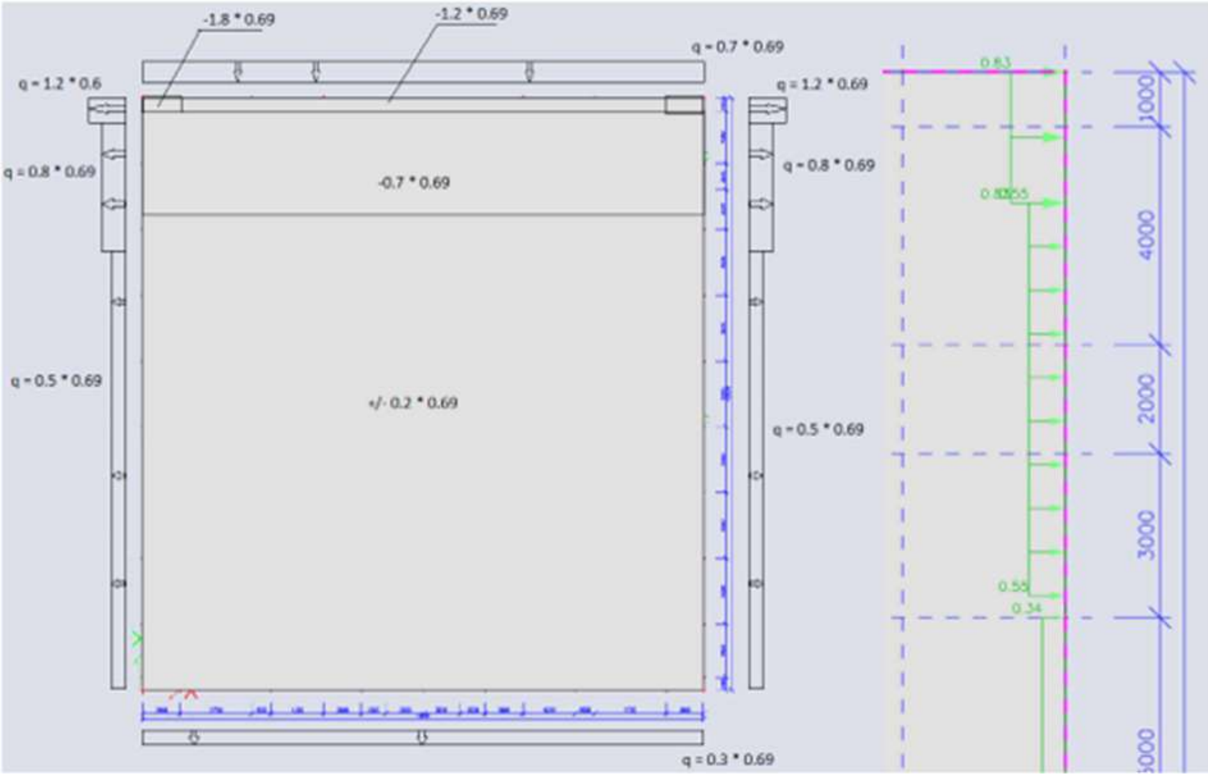


Figure 9: Wind loads

2.2.2 Stairwell

The main loads exerted on the stairwell are the self-weight, the congregation area on the stairs and the side pressure of the ground. The self-weight will once again be calculated by SCIA and the magnitude of the congregation area will stay the same. However, the largest component is the ground pressure. As the tunnel shouldn't horizontally collapse a permanent side pressure is assumed. The stairwell and tunnel can be seen in Figure 10.

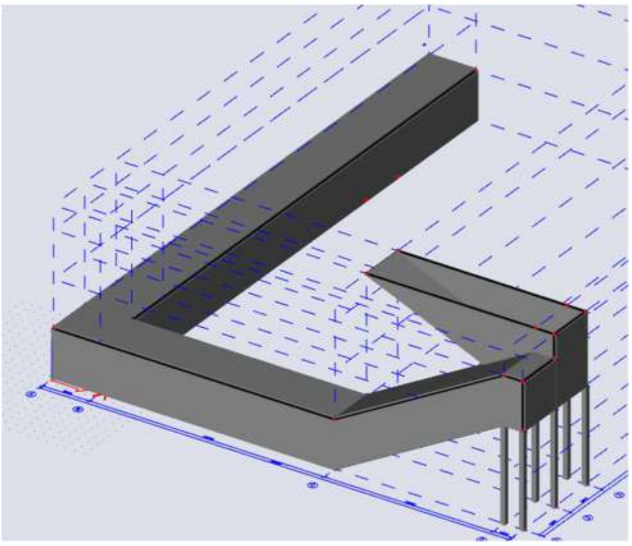


Figure 10: Stairwell model

For the modelling a simplified version was made. This model makes it easier to apply the ground loads to the walls. As the self-weight becomes larger of the simplified structure it is a more conservative approach. Thus the actual model would suffice as well. As the tunnel has the same wall and roof dimensions as the underground station, seen in chapter 2, this is not modelled as it would result in the same calculations. The reinforcement calculations and thickness of the tunnel can be found in chapter 2. The model which is calculated can be seen in Figure 11.

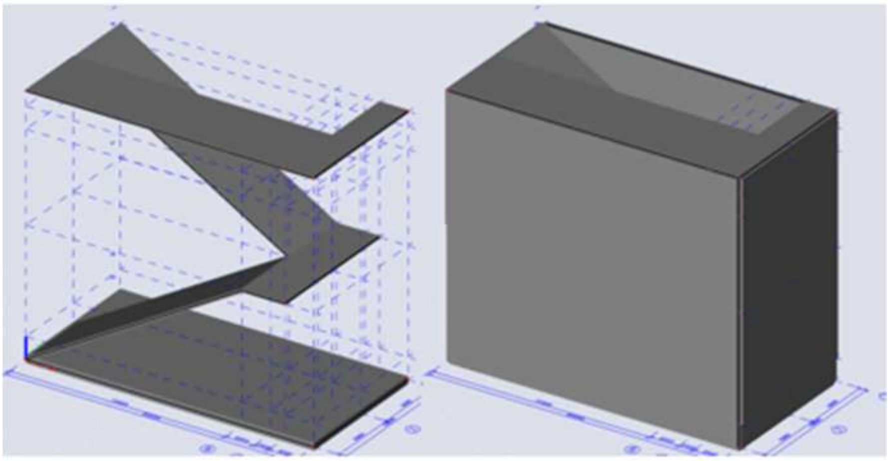


Figure 11: Simplified model stairwell, staircase (left) and walls (right)

In order to apply the horizontal ground forces, firstly the vertical forces need to be calculated. This was done by retrieving data from DINOloket, as seen in Figure 12.

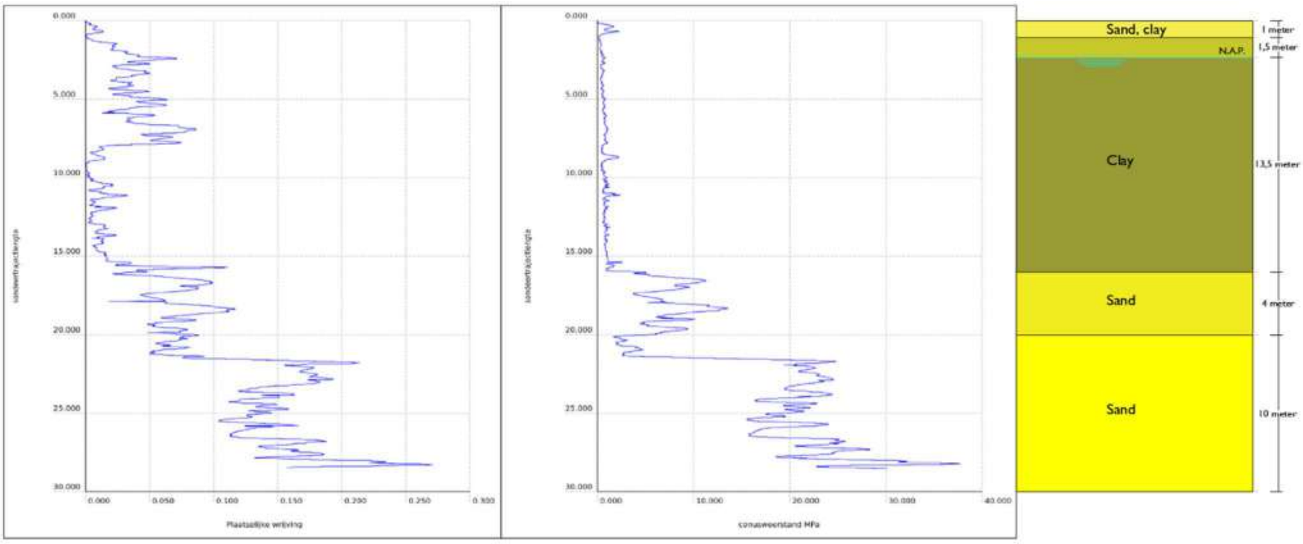


Figure 12:The local friction and conus resistance of the soil (DINOloket, 2021)

The points of interest will be split up into 3 parts, the lowest point of the ground layer will be calculated. The assumed volumetric weights of the soils (Grondverzet. (n.d.)), with the corresponding ground pressure coefficients can be found in Table 2 (J. de Vree, (n.d.)).

Table 2: Volumetric weight soil

Soil type	**Volumetric weight [kN/m^3]**	**Ground pressure coefficient [λ_{max}]**
Sand (dry)	15	0,4
Sand (wet)	17.5	
Clay (dry)	16	0,6
Clay (wet)	20	

This results in the following effective vertical and horizontal stress values. The modelling of the forces can be found in Figure 13.

Table 3: Vertical and horizontal stress

Layer	Vertical stress [kN/m^2]	Horizontal stress [kN/m^2]
Sand at NAP + 1m	15	6
Clay at NAP - 12m	174	101.4

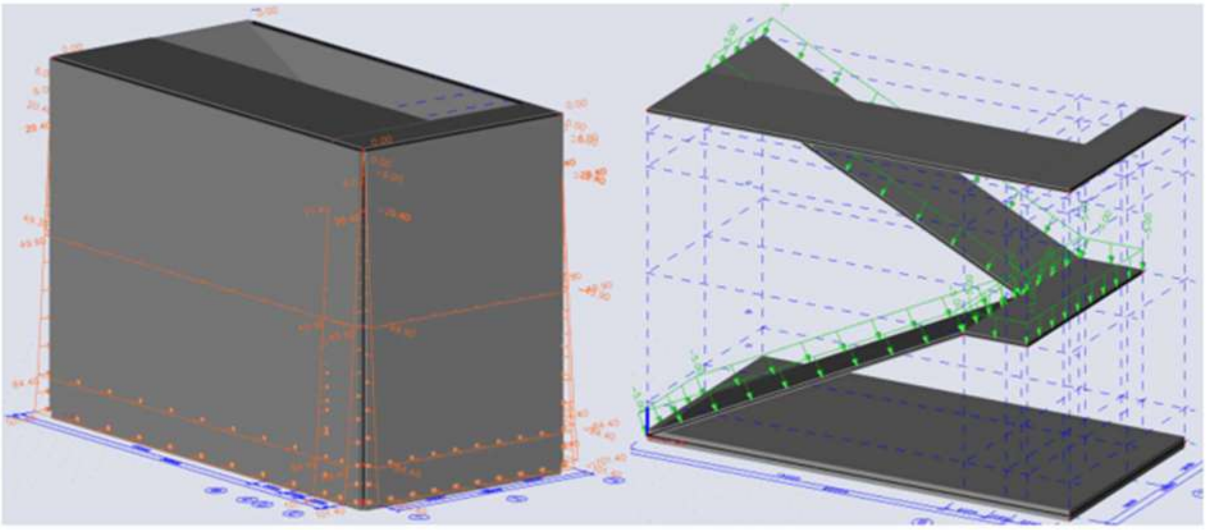


Figure 13: Modelling of the forces in SCIA

2.3 Structure

After taking all the loads into account the calculations on both structures can be made. Firstly the HUB aspects were calculated, after which the stairwell was calculated. In both cases the ULS and SLS were calculated by SCIA, following the foundations for both structures. After these the reinforcements for all elements were calculated. At last the dimensioning was considered for the needed elements.

2.3.1 HUB

To test if the structure upholds the forces the normative ULS and SLS will be used. These were calculated by SCIA Engineer itself and can be seen in table 4. The ULS will be used to calculate the elements such as reinforcement and the SLS will be used to calculate the displacement in the model.

$$BG_1 = self\ weight$$
$$BG_2 = green\ roof\ and\ solar\ panel$$
$$BG_3 = snow\ load$$
$$BG_4 = bike\ parking\ +\ congregation\ area\ +\ shops$$
$$BG_5 = wind\ load$$

Table 4: Normative ULS and SLS combinations

	Normative combination
ULS	1.35*BG1 + 1.35*BG2 + 1.5*BG3 +1.5*BG4 + 1.5*BG5
SLS	1*BG1 + 1*BG2 + 1*BG3 + 1*BG4 + 1*BG5

Displacements

The structure was checked if the occurring deflections are within some rule of thumbs. The maximum deflection for the roof as well as the glass façades need to be checked. The maximum deflection for the SLS needs to be smaller than the distance between the supports over 250.The largest distance that occurs is 10*m*, so the maximum allowed displacement is 40*mm*. The largest displacement did also occur at the 10*m* span. The occurring displacement measured in SCIA is 8.7*mm*, so it suffices, see Figure 14.

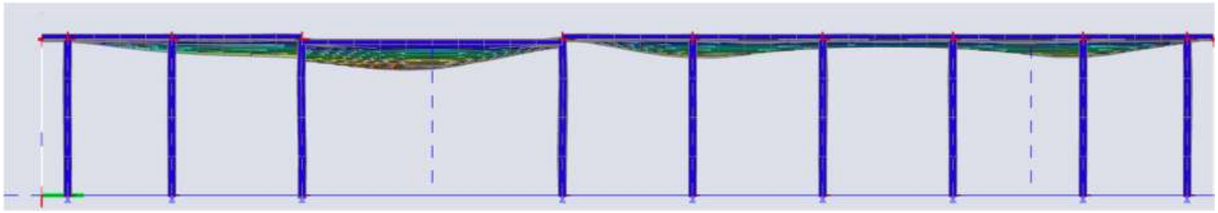


Figure 14: 3D Displacement of the roof

For the glass façades the maximum span is 6*m*, resulting in maximum displacement of 24*mm*. The largest displacement occurs at the wall which undergoes the largest wind load. In this case this is the northern wall. The maximum displacement occurring at 3*cm* thickness was 16.2*mm*, so it suffices as well. Dimension changes were tried, however at 2.5 or 2*cm* the displacement didn't suffice anymore, see Figure 15.

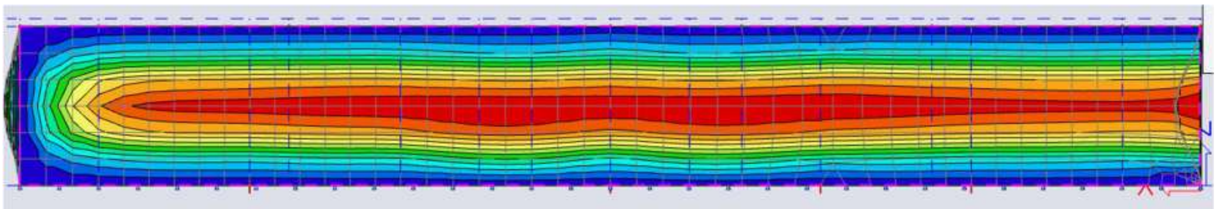


Figure 15: 3D displacement of the northern wall

Foundation

To design the foundation of the structure, a soil analysis is required to determine the bearing capacity of the structure. The CPT-test used for the information about the soil at the location of the Station Nassauplein is illustrated in Figure 12.

With this information from the DINOloket it can be concluded that the ground model is constructed and hence the dimension of the necessary depth of the piles can be determined. Since, the bearing layer of sand is at a depth of approximately 23 - 25 metres, this is also the depth where the piles of the metro stations will be found at.

The most important job of the piles is to support the forces exerted on the columns. The largest reaction force exerted on the pile is 2168*kN* and the smallest being 1152*kN*. To support these forces the floors will be supported by a strip foundation, seen in Figure 16. The foundations will be placed in the sand layer from 23*m* to 30*m*.

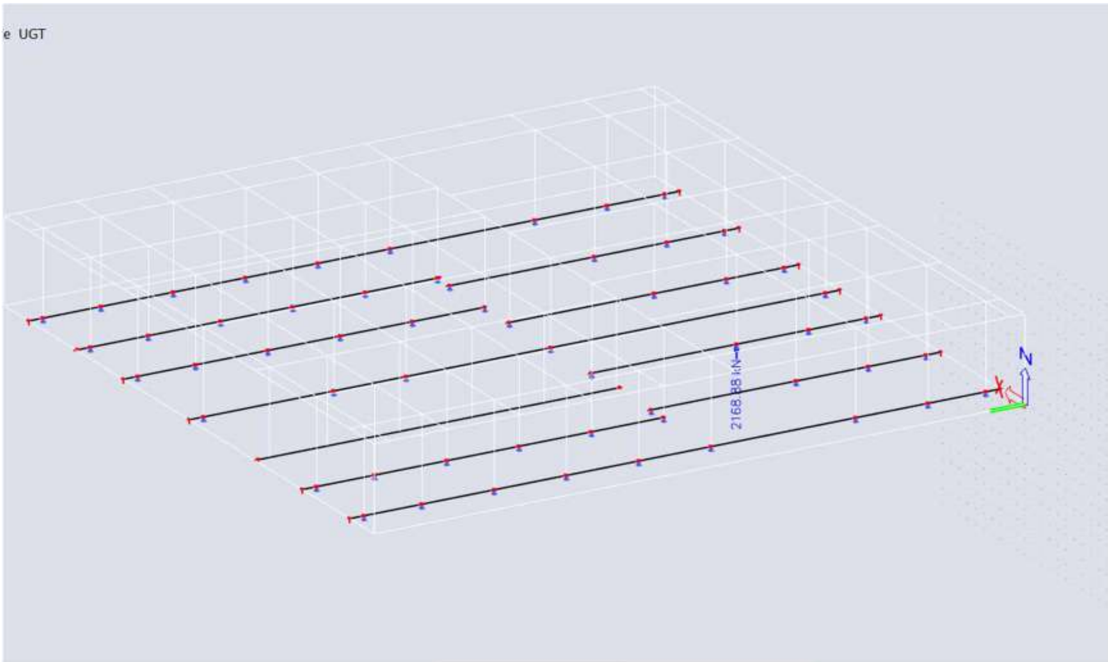


Figure 16: Reaction forces from SCIA

For the calculation of the pile foundation multiple aspects need to be taken into account. First of all the point bearing capacity of the pile, secondly the shaft bearing capacity of the pile. This results in the following formula.

$Q_{max} = R_b + R_s$

whereby - R_b = Point bearing capacity;
- R_s = Shaft bearing capacity;

To calculate the point bearing capacity the following computations are made:

D_{eq} = 1.13 * a = 1.13 * 0.3 = 0.339

q_{cI} = 21 MPa
q_{cII} = 18 MPa
q_{cIII} = 6.9 MPa

$q_{b;max;i} = \alpha_p * \beta * s * 0.5 * ((q_{cI} + q_{cII}) / 2 + q_{cIII})$, with $\alpha_p = 0.7$, $\beta = 1$, $s = 1.0$

$R_b = A * q_{b;max;i} = (0.7 * 1.0 * 1.0 * 0.5 * 26.4) * 0.3 * 0.3 = 831kN$ for $A = 0.3x0.3m^2$

To calculate the shaft bearing capacity the following formula is applied.

$R_{s;cal;i} = O_{s;gem} * \alpha_s * q_{c;gem} * L_{pk}$

In order to be able to calculate the shaft load capacity, the average shaft resistance must be determined over the length of the positive adhesive zone. Resulting in the following bearing capacity:

$R_{s;cal;i}$ = (4*0.3) * 0.01 * 11 * 8 = 1267 kN

This results in the total bearing capacity of a 300x300mm^2 pile of 831 + 1267 = 2098kN. A safety factor of 1.3 to 1.5 is taken into account. This results for the largest exerted force 2 piles would need to be placed. However, not all forces exerted on the piles are this large. Applying 300x300mm^2 piles on every beam would be too conservative. So the layout is split up into two parts, piles of 300x300mm^2 and 200x200mm^2. The latter piles have a total bearing capacity of 1073kN, resulting in the following layout of the piles, depicted in Figure 17.

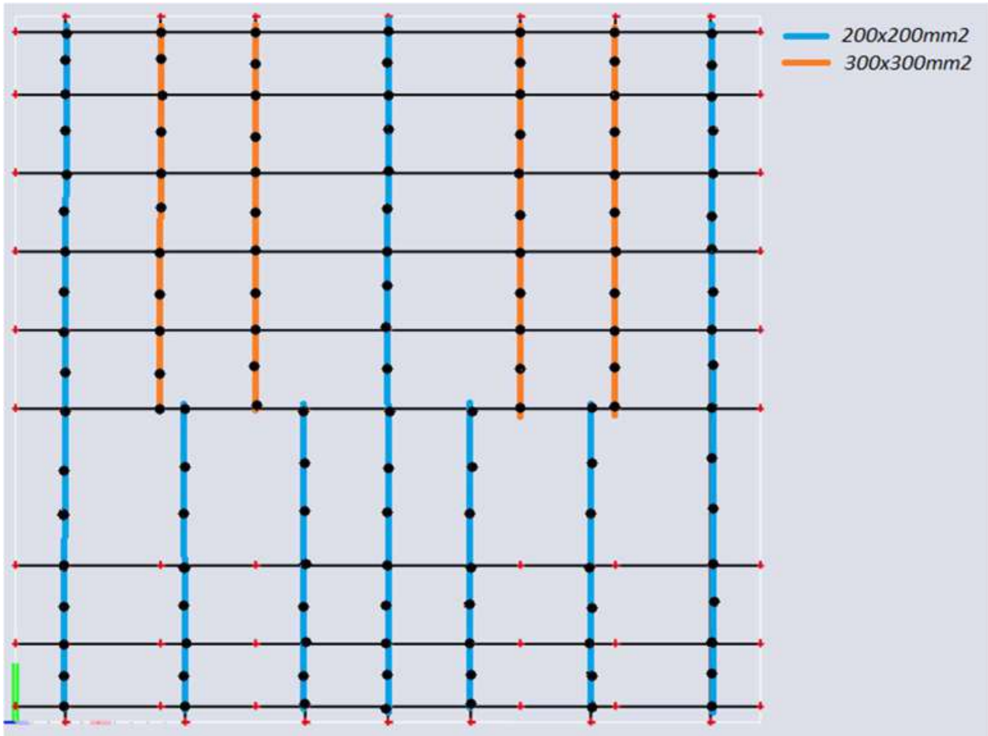


Figure 17: Pile foundation layout

Reinforcement

Now that the pile foundations are decided, the reinforcement of the concrete elements can be calculated. These elements are the columns, the roof and the flooring. First of all the columns will be calculated. The largest occurring force in the columns is -682.6 *kN*. There still needs to be reinforcement to compensate for the shear forces and the torsion occurring in the column. The needed amount of reinforcement area can be found in Table 5. The required amount of reinforcement was calculated using the SCIA “UGT and BGT 2D-wapeningsontwerp” interface. This interface showed where the maximum reinforcement area was needed and the magnitude of this. This value was then noted down and based on this the actual reinforcement was calculated. However, some of the calculations provided further in the report show that the reinforcement is over dimensioned. This is not the case as all reinforcement is based on the actual required amount of reinforcement.

Table 5: Required reinforcement column

$A_{sz,req+}$ in [mm^2/m]	$A_{sz,req-}$ in [mm^2/m]	$A_{sy,req+}$ in [mm^2/m]	$A_{sy,req-}$ in [mm^2/m]	$A_{sz,req}$ in [mm^2/m]	$A_{sy,req}$ in [mm^2/m]	$A_{s,req}$ in [mm^2/m]	$A_{swm,req}$ in [mm^2/m]
616	0	1232	0	616	1232	1848	335

The reinforcement model can be found in Figure 18. As seen it needs 30*mm* longitudinal reinforcement at each corner plus 8/115*mm* stirrups. As this is the normative column, this reinforcement design is viable for all the columns in the HUB.

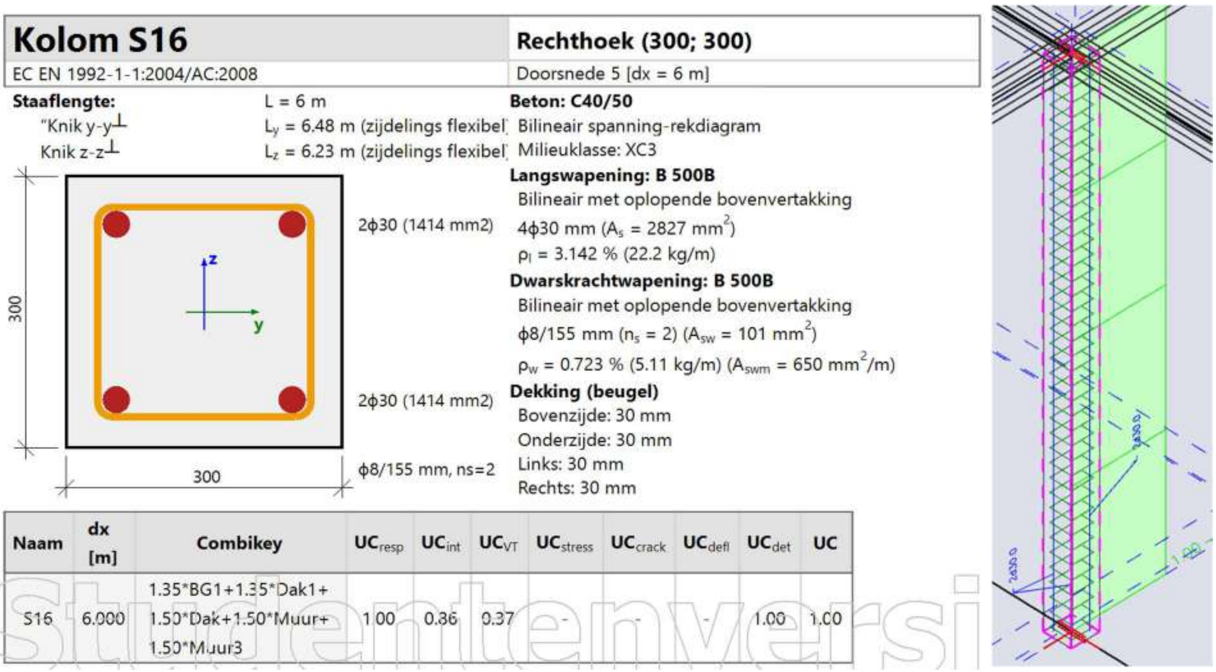


Figure 18: Column reinforcement

For the flooring the most crucial flooring was calculated. As the floors only rest on the foundation strips, it can be seen as a one way bending slab instead of two ways. By calculating the needed amount of reinforcement in SCIA, the actual reinforcement model can be calculated. This led to the following needed reinforcement, found table 6 and the final reinforcement, found in Figure 19.

$A_{s,req,1}$ in [mm^2/m]	$A_{s,req,1-}$ in [mm^2/m]	$A_{s,req,2}$ in [mm^2/m]	$A_{s,req,2-}$ in [mm^2/m]
1164	852	862	832

Table 6: Required reinforcement floor

Uitgangspunten van het ontwerp

Wapening

Langsrichting: **B 500B**

Bovenzijde

[1+] Eerste laag (0°)	Ø16 mm / Primair
[2+] Tweede laag (90°)	Ø14 mm / Primair
Dekking:	c_{nom} = 26 mm

Onderzijde

[1–] Eerste laag (0°)	Ø14 mm / Primair
[2–] Tweede laag (90°)	Ø14 mm / Primair
Dekking:	c_{nom} = 25 mm

Afschuiving: **B 500B** Ø8 mm

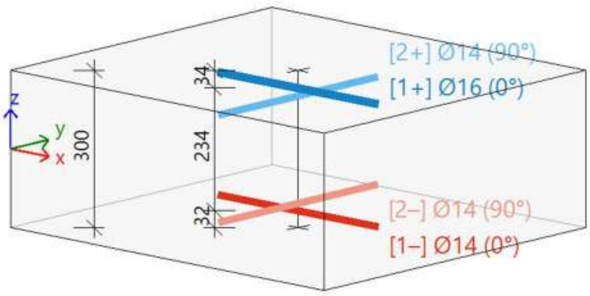


Figure 19: Flooring reinforcement

The unity check has been done for both the longitudinal and shear reinforcement:

Langswapening - samenvatting

Ontworpen wapeningslagen (in de richting van de lokale x-as van het element):

	Basis	Extra Gebruike...	Extra Auto	α [°]	$A_{s,min}$ [mm^2]	$A_{s,ult}$ [mm^2]	$\Delta A_{s,serv}$ [mm^2]	$A_{s,req}$ [mm^2]	$A_{s,prov}$ [mm^2]	$A_{s,max}$ [mm^2]	$s_{min(cl)}$ [mm]	s_{max} [mm]	Status
[1+]	ϕ16/150	---	---	0.0	810	1164	---	**1164**	**1340**	20000	134	150	**OK**
								0.23%	0.27%		≥37	≤400	
[2+]	ϕ14/150	---	---	90.0	775	628	---	**775**	**1026**	20000	136	150	**OK**
								0.16%	0.21%		≥37	≤400	

Afschuifwapening - samenvatting

	Geval	θ [°]	v_{Ed} [kN/m]	$A_{sl,x}$ [mm^2]	$A_{sl,y}$ [mm^2]	ρ_l [%]	$v_{Rd,c}$ [kN/m]	$v_{Rd,max}$ [kN/m]	$A_{sw,req}$ [mm^2/m^2]	Status
[+]	Maatgevende UGT/4	40.0	**230.8**	1340	1026	0.254	216.9	3009.0	**1012**	**OK**

Figure 20: Unity check for floor reinforcement

The crack width check for the flooring with the calculated reinforcement is shown in Figure 20.

Bovenzijde

Naam	Net	Positie [m]	Belasting	m_{1+} [kNm/m] m_{2+} [kNm/m]	n_{1+} [kN/m] n_{2+} [kN/m]	$A_{s,1+}$ [mm²] $A_{s,2+}$ [mm²]	$\sigma_{s,1+}$ [MPa] $\sigma_{s,2+}$ [MPa]	$s_{r,max,1+}$ [mm] $s_{r,max,2+}$ [mm]	$\varepsilon_{(sm-cm),1+}$ [1e-4] $\varepsilon_{(sm-cm),2+}$ [1e-4]	w_{1+} [mm] w_{2+} [mm]	w_{max+} [mm]	UC_{1+} [-] UC_{2+} [-]
E19	Element: 254 Knoop: 5	22.500 44.000 0.000	Maatgevende BGT/1	-81.77 -21.98	3.27 -3.08	1539 0	216.7 0.0	209.836 0.000	6.5 0.0	0.136 0.000	**0.300**	**0.45** **0.00**

Figure 21: Crack width unity check

The last element which was calculated on reinforcement was the concrete roof. In the process of calculating the reinforcement, the thickness was sized down to 200*mm* thick. The design for the roof isn't as straightforward as the design for the flooring. This is because different roof slabs have different maximum required reinforcement. In the case of the flooring, one slab had all the maximum required reinforcement. To compensate for this, the maximum needed reinforcement area in each direction, $A_{s,req,1}$, $A_{s,req,1-}$, $A_{s,req,2}$, $A_{s,req,2-}$, are calculated and combined into one design, see Table 7. This yields the following results:

Table 7: Required reinforcement roof

$A_{s,req,1}$ in [mm^2/m]	$A_{s,req,1-}$ in [mm^2/m]	$A_{s,req,2}$ in [mm^2/m]	$A_{s,req,2-}$ in [mm^2/m]
2809	1057	3214	873

The corresponding reinforcement model can be found in Figure 22.

Uitgangspunten van het ontwerp

Wapening

Langsrichting: **B 500B**

Bovenzijde

[1+] Eerste laag (0°)	Ø20 mm / Primair
[2+] Tweede laag (90°)	Ø20 mm / Primair
Dekking:	c_{nom} = 30 mm

Onderzijde

[1–] Eerste laag (0°)	Ø16 mm / Primair
[2–] Tweede laag (90°)	Ø12 mm / Primair
Dekking:	c_{nom} = 26 mm

Afschuiving: **B 500B** Ø8 mm

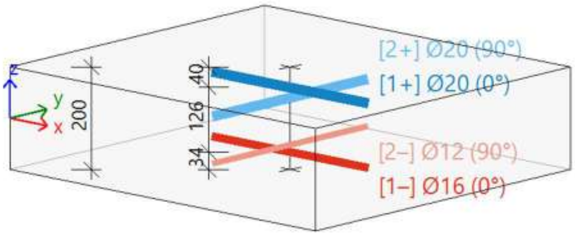


Figure 22: Roof reinforcement

Langswapening - samenvatting

Ontworpen wapeningslagen (in de richting van de lokale x-as van het element):

	Basis	Extra		α	$A_{s,min}$	$A_{s,ult}$	$\Delta A_{s,serv}$	$A_{s,req}$	$A_{s,prov}$	$A_{s,max}$	$s_{min(cl)}$	s_{max}	Status
		Gebruike...	Auto	[°]	[mm^2]	[mm^2]	[mm^2]	[mm^2]	[mm^2]	[mm^2]	[mm]	[mm]	
[1+]	ϕ20/100	---	---	0.0	291	201	---	**291**	**3142**	8000	80	100	**OK**
								0.15%	1.57%		≥37	≤400	
[1-]	ϕ16/150	---	---	0.0	302	48	---	**302**	**1340**	8000	134	150	**OK**
								0.15%	0.67%		≥37	≤400	
[2-]	ϕ12/125	---	---	90.0	277	676	---	**676**	**905**	8000	113	125	**OK**
								0.34%	0.45%		≥37	≤400	

Afschuifwapening - samenvatting

	Geval	θ	v_{Ed}	$A_{sl,x}$	$A_{sl,y}$	ρ_l	$v_{Rd,c}$	$v_{Rd,max}$	$A_{sw,req}$	Status
		[°]	[kN/m]	[mm^2]	[mm^2]	[%]	[kN/m]	[kN/m]	[mm^2/m^2]	
[-]	Maatgevende UGT/16	40.0	**7.0**	1340	905	0.693	115.4	1021.4	---	**OK**

Figure 23: Unity check roof reinforcement

The crack width check for the flooring with the calculated reinforcement is shown in Figure 24.

Bovenzijde

Naam	Net	Positie [m]	Belasting	m_{1+} [kNm/m] m_{2+} [kNm/m]	n_{1+} [kN/m] n_{2+} [kN/m]	$A_{s,1+}$ [mm²] $A_{s,2+}$ [mm²]	$\sigma_{s,1+}$ [MPa] $\sigma_{s,2+}$ [MPa]	$s_{r,max,1+}$ [mm] $s_{r,max,2+}$ [mm]	$\varepsilon_{(sm-cm),1+}$ [1e-4] $\varepsilon_{(sm-cm),2+}$ [1e-4]	w_{1+} [mm] w_{2+} [mm]	w_{max+} [mm]	UC_{1+} [-] UC_{2+} [-]
E50	Element: 4332 Knoop: 156	27.500 10.000 6.000	Maatgevende BGT/1	-126.38 -77.40	5.77 0.49	3352 3352	323.6 197.6	143.857 143.857	13.3 7.0	0.192 0.101	**0.300**	**0.64** 0.34
E49	Element: 4331 Knoop: 156	27.500 10.000 6.000	Maatgevende BGT/2	-140.27 -83.77	3.27 0.12	3377 3326	294.1 209.9	144.267 144.280	11.9 7.6	0.171 0.110	0.300	0.57 **0.37**

Onderzijde

Naam	Net	Positie [m]	Belasting	m_{1-} [kNm/m] m_{2-} [kNm/m]	n_{1-} [kN/m] n_{2-} [kN/m]	$A_{s,1-}$ [mm²] $A_{s,2-}$ [mm²]	$\sigma_{s,1-}$ [MPa] $\sigma_{s,2-}$ [MPa]	$s_{r,max,1-}$ [mm] $s_{r,max,2-}$ [mm]	$\varepsilon_{(sm-cm),1-}$ [1e-4] $\varepsilon_{(sm-cm),2-}$ [1e-4]	w_{1-} [mm] w_{2-} [mm]	w_{max-} [mm]	UC_{1-} [-] UC_{2-} [-]
E50	Element: 4346 Knoop: 4387	29.500 15.000 6.000	Maatgevende BGT/3	26.62 1.88	-0.06 0.62	912 0	176.1 0.0	366.462 0.000	5.3 0.0	0.194 0.000	**0.300**	**0.65** **0.00**

Figure 24: Crack width unity check

At last for the HUB the IPE profiles can be checked and dimensioned. As IPE300 was assumed from the beginning it is probably over dimensioned. First of all the stresses in all the beams are checked in order to see if over dimensioning is present. The initial UC for the IPE300 beams is shown in Figure 25.

Naam	dx [m]	Belasting	Doorsnede	Materiaal	Algehele eenheidscontrole [-]	Doorsnedecontrole [-]	Stabiliteitscontrole [-]
S124	20.000	Maatgevende UGT/1	CS5 - IPE300	S 235	**0.57**	0.46	0.57

Figure 25: Unity check IPE300

It can be seen that the beams are larger than needed, thus smaller dimensions can be applied. The dimension of the beams differ for every beam, as each situation is different. The stability check is the normative value for most beams as the cross section always suffices on stress. The final layout for the beams can be found in Figure 26.

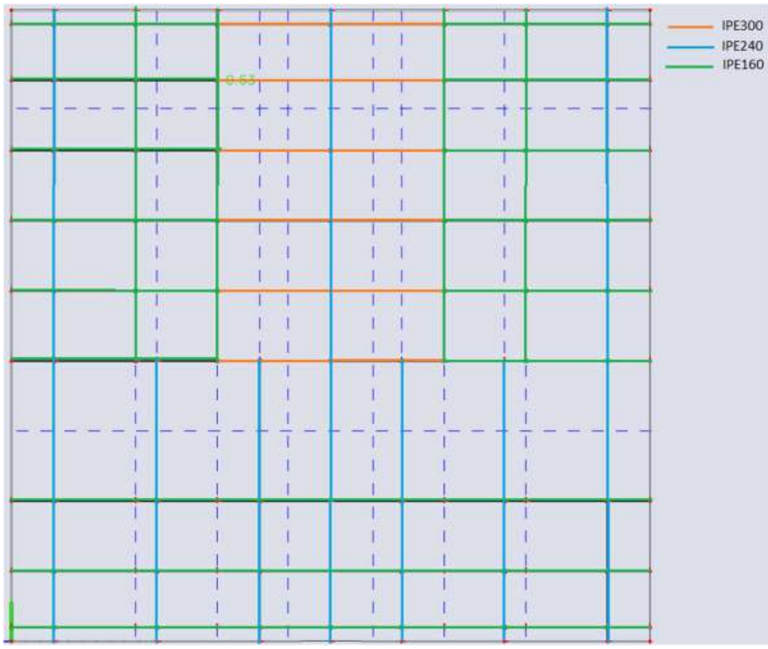


Figure 26: Final layout steel cross sections

2.3.2 Stairwell

Before any foundation or reinforcement calculations can be made, the ULS and the SLS need to be calculated again. These were once again calculated by SCIA Engineer and can be seen in Table 8.

$BG_1 = Self\ weight$
$BG_2 = Sand\ layer\ 0 - 1m$
$BG_3 = Clay\ layer\ 1 - 14.5m$
$BG_4 = Staircase$

Table 8: Normative combination ULS and SLS

	Normative combination
ULS	1.35*BG1 + 1.35*BG2 + 1.5*BG3 +1.5*BG4
SLS	BG1 + BG2 + BG3 + BG4

Displacement

As stated in the HUB calculation, the model will be tested on the displacements. The maximum occurring displacement are at the largest side walls. The displacement is 44.2*mm* inwards, see Figure 27. Using the rule of thumb the maximum allowed displacement occurring is 14.5*m* / 250 = 58*mm*. This shows that the occurring displacement is within limits and suffices.

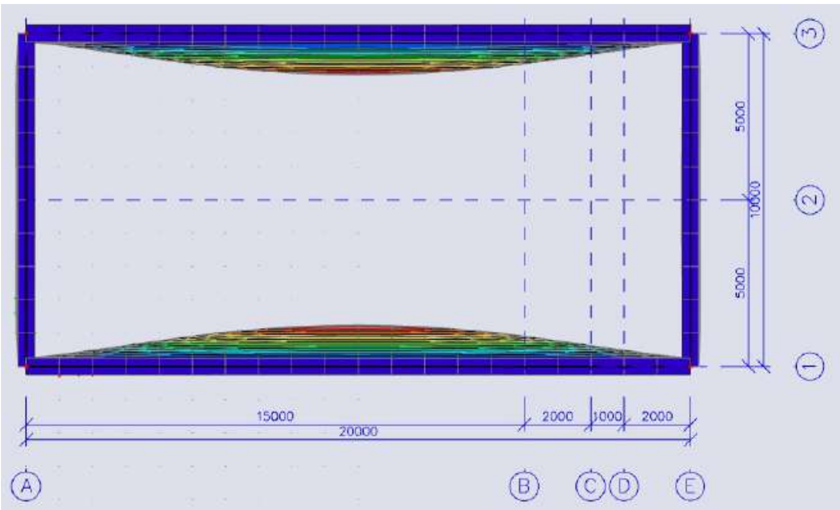


Figure 27: Displacement of the walls

Foundation

For the foundation a relatively simple hand calculation can be made. The only vertical load exerted on the soil is the self-weight of the walls. For the sidewalls this is:

$$\rho * height * g = 2500 * 14.5 * 10 = 362.5\ kN/m^2$$

With a safety factor of 1.5 taken into account this becomes 544*kN/m*^{2}. With a total surface area of 20*m* x 0.5*m* the total force becomes 5440*kN*. Using the previously calculated 200x200*mm*^{2} this would mean that 6 piles would need to be used on both sides.

For the rear and the front wall the load would be, over an area of 10*m* x 0.5m, 2720*kN*. So three piles would suffice in this case. On all the corners foundation piles will be applied as well in order to make sure that the columns exerting forces from the HUB are supported as well. The layout of the foundation can be found in Figure 28.

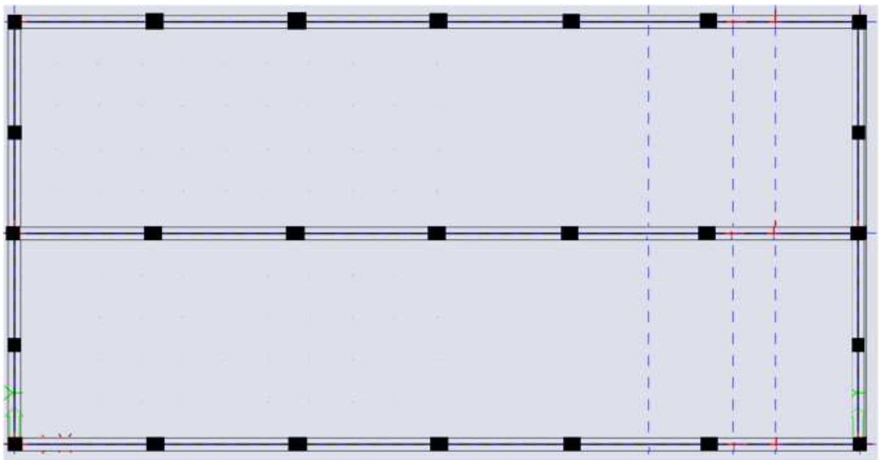


Figure 28: Foundation layout stairwell

Reinforcement

For the stairs the normative reinforcement is decided by analysing in which direction each amount of reinforcement area is needed. First of all the reinforcement for the staircase is calculated. The minimum required amount can be found in Table 9.

$A_{s,req,1}$ in [mm^2/m]	$A_{s,req,1-}$ in [mm^2/m]	$A_{s,req,2}$ in [mm^2/m]	$A_{s,req,2-}$ in [mm^2/m]
1316	1482	2310	2454

Table 9: Required reinforcement staircase

This yields the following results for the reinforcement in the stairs, see Figure 29 and Figure 30:

Uitgangspunten van het ontwerp

Wapening

Langsrichting: **B 500B**

Bovenzijde

[1+] Eerste laag (0°) Ø14 mm / Primair

[2+] Tweede laag (90°) Ø18 mm / Primair

Dekking: c_{nom} = 30 mm

Onderzijde

[1–] Eerste laag (0°) Ø14 mm / Primair

[2–] Tweede laag (90°) Ø18 mm / Primair

Dekking: c_{nom} = 30 mm

Afschuiving: **B 500B** Ø8 mm

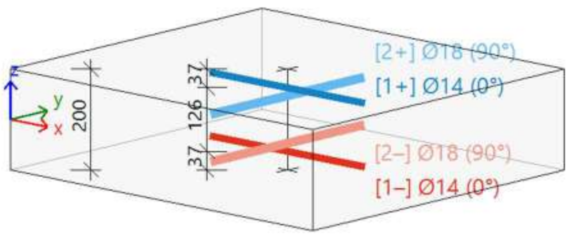


Figure 29: Staircase reinforcement

Langswapening - samenvatting

Ontworpen wapeningslagen (in de richting van de lokale x-as van het element):

	Basis	Extra Gebruike...	Extra Auto	α [°]	$A_{s,min}$ [mm^2]	$A_{s,ult}$ [mm^2]	$\Delta A_{s,sen}$ [mm^2]	$A_{s,req}$ [mm^2]	$A_{s,prov}$ [mm^2]	$A_{s,max}$ [mm^2]	$s_{min(cl)}$ [mm]	s_{max} [mm]	Status
[2+]	ϕ18/100	---	---	90.0	234	2310	---	**2310**	**2545**	8000	82	100	**OK**
								1.16%	1.27%		≥37	≤400	
[2-]	ϕ18/100	---	---	90.0	234	1133	---	**1133**	**2545**	8000	82	100	**OK**
								0.57%	1.27%		≥37	≤400	

Afschuifwapening - samenvatting

	Geval	θ [°]	v_{Ed} [kN/m]	$A_{sl,x}$ [mm^2]	$A_{sl,y}$ [mm^2]	ρ_l [%]	$v_{Rd,c}$ [kN/m]	$v_{Rd,max}$ [kN/m]	$A_{sw,req}$ [mm^2/m^2]	Status
[+]	Maatgevende UGT/2	40.0	**92.4**	0	5090	2.000	194.9	748.8	---	**OK**

Figure 30: Unity check staircase

As the concrete shear strength was large enough without reinforcement, there was no need to apply stirrups.

The calculations for the crack width also need to be calculated. The results can be found in Figure 31. As seen the lower side just reaches out of the unity check limit. As mitigation additional reinforcement can be applied or larger reinforcement rods can be used. As a mitigating measure the reinforcement at the lower side was increased from 14*mm* to 16*mm*.

Bovenzijde

Naam	Net	Positie [m]	Belasting	m_{1+} [kNm/m] m_{2+} [kNm/m]	n_{1+} [kN/m] n_{2+} [kN/m]	$A_{s,1+}$ [mm²] $A_{s,2+}$ [mm²]	$\sigma_{s,1+}$ [MPa] $\sigma_{s,2+}$ [MPa]	$s_{r,max,1+}$ [mm] $s_{r,max,2+}$ [mm]	$\varepsilon_{(sm-cm),1+}$ [1e-4] $\varepsilon_{(sm-cm),2+}$ [1e-4]	w_{1+} [mm] w_{2+} [mm]	w_{max+} [mm]	UC_{1+} [-] UC_{2+} [-]
E55	Element: 310 Knoop: 15	0.000 10.000 14.500	BGT-quasi (automatisch)/1	-26.31 -6.00	1237.70 365.05	2492 0	352.1 0.0	184.880 0.000	15.7 0.0	0.290 0.000	**0.300**	**0.97** 0.00
E55	Element: 226 Knoop: 289	14.118 5.000 7.676	BGT-quasi (automatisch)/2	1.18 -12.22	1234.25 476.56	2565 1540	235.7 214.8	254.339 227.637	9.9 7.9	0.252 0.179	0.300	0.84 **0.60**

Onderzijde

Naam	Net	Positie [m]	Belasting	m_{1-} [kNm/m] m_{2-} [kNm/m]	n_{1-} [kN/m] n_{2-} [kN/m]	$A_{s,1-}$ [mm²] $A_{s,2-}$ [mm²]	$\sigma_{s,1-}$ [MPa] $\sigma_{s,2-}$ [MPa]	$s_{r,max,1-}$ [mm] $s_{r,max,2-}$ [mm]	$\varepsilon_{(sm-cm),1-}$ [1e-4] $\varepsilon_{(sm-cm),2-}$ [1e-4]	w_{1-} [mm] w_{2-} [mm]	w_{max-} [mm]	UC_{1-} [-] UC_{2-} [-]
E55	Element: 226 Knoop: 289	14.118 5.000 7.676	BGT-quasi (automatisch)/2	6.15 -15.72	1293.55 388.91	2417 0	286.5 0.0	244.071 0.000	12.4 0.0	0.302 0.000	**0.300**	**1.01** **0.00**

Figure 31: Crack width unity check

At last the individual walls need to be dimensioned on reinforcement. First of all the rear and front wall will be calculated, these are the walls with the smallest span. The required reinforcement can be found in Table 10

Table 10: Required reinforcement rear and front wall

$A_{s,req,1}$ in [mm²/m]	$A_{s,req,1-}$ in [mm²/m]	$A_{s,req,2}$ in [mm²/m]	$A_{s,req,2-}$ in [mm²/m]
5451	5437	1786	1787

Resulting in the following reinforcement of the rear and front wall, see Figure 32, Figure 33 and Figure 34.

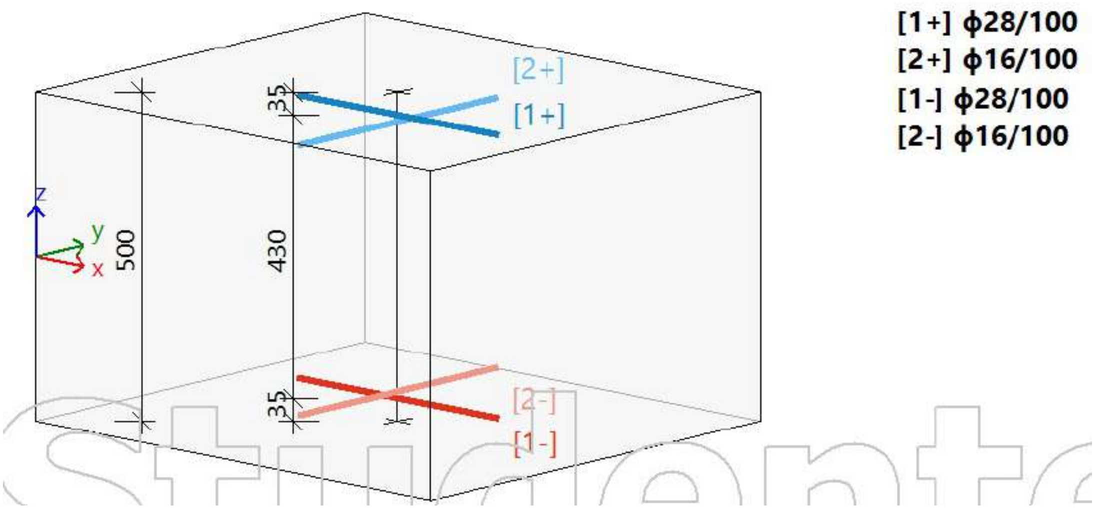


Figure 32: Reinforcement rear and front wall

Langswapening - samenvatting

Ontworpen wapeningslagen (in de richting van de lokale x-as van het element):

	Basis	Extra		α	$A_{s,min}$	$A_{s,ult}$	$\Delta A_{s,serv}$	$A_{s,req}$	$A_{s,prov}$	$A_{s,max}$	$s_{min(cl)}$	s_{max}	Status
		Gebruike...	Auto	[°]	[mm^2]	[mm^2]	[mm^2]	[mm^2]	[mm^2]	[mm^2]	[mm]	[mm]	
[1+]	ϕ28/100	---	---	0.0	500	473	---	**500**	**6158**	---	72	100	**OK**
								0.10%	1.23%		≥37	≤400	
[2+]	ϕ16/100	---	---	90.0	500	915	---	**915**	**2011**	10000	84	100	**OK**
								0.18%	0.40%		≥37	≤400	
[1-]	ϕ28/100	---	---	0.0	500	1197	---	**1197**	**6158**	---	72	100	**OK**
								0.24%	1.23%		≥37	≤400	
[2-]	ϕ16/100	---	---	90.0	500	1787	---	**1787**	**2011**	10000	84	100	**OK**
								0.36%	0.40%		≥37	≤400	

Afschuifwapening - samenvatting

	Geval	θ	v_{Ed}	$A_{sl,x}$	$A_{sl,y}$	ρ_l	$v_{Rd,c}$	$v_{Rd,max}$	$A_{sw,req}$	Status
		[°]	[kN/m]	[mm^2]	[mm^2]	[%]	[kN/m]	[kN/m]	[mm^2/m^2]	
[-]	Maatgevende UGT/1	40.0	**272.1**	6158	2011	0.765	196.2	2339.7	**1167**	**OK**

Figure 33: Unity check rear and front wall

Bovenzijde

Naam	Net	Positie [m]	Belasting	m_{1+} [kNm/m] m_{2+} [kNm/m]	n_{1+} [kN/m] n_{2+} [kN/m]	$A_{s,1+}$ [mm^2] $A_{s,2+}$ [mm^2]	$\sigma_{s,1+}$ [MPa] $\sigma_{s,2+}$ [MPa]	$s_{r,max,1+}$ [mm] $s_{r,max,2+}$ [mm]	$\varepsilon_{(sm-cm),1+}$ [1e-4] $\varepsilon_{(sm-cm),2+}$ [1e-4]	w_{1+} [mm] w_{2+} [mm]	w_{max+} [mm]	UC_{1+} [-] UC_{2+} [-]
E87	Element: 360 Knoop: 406	20.000 10.000 5.800	BGT-kar (automatisch)/1	-742.94 -145.68	-470.55 -227.34	6204 0	262.9 0.0	219.102 0.000	11.5 0.0	0.251 0.000	**0.300**	**0.84** **0.00**

Onderzijde

Naam	Net	Positie [m]	Belasting	m_{1-} [kNm/m] m_{2-} [kNm/m]	n_{1-} [kN/m] n_{2-} [kN/m]	$A_{s,1-}$ [mm^2] $A_{s,2-}$ [mm^2]	$\sigma_{s,1-}$ [MPa] $\sigma_{s,2-}$ [MPa]	$s_{r,max,1-}$ [mm] $s_{r,max,2-}$ [mm]	$\varepsilon_{(sm-cm),1-}$ [1e-4] $\varepsilon_{(sm-cm),2-}$ [1e-4]	w_{1-} [mm] w_{2-} [mm]	w_{max-} [mm]	UC_{1-} [-] UC_{2-} [-]
E89	Element: 801 Knoop: 636	0.000 10.000 5.800	BGT-kar (automatisch)/1	741.00 145.31	-470.30 -226.63	6203 0	262.1 0.0	219.098 0.000	11.4 0.0	0.251 0.000	**0.300**	**0.84** **0.00**

Figure 34: Crack width unity check rear and front wall

At last the calculations needed to be done for both side walls. This was done at the same time, since the load case is exactly the same. The minimal needed reinforcement can be found in Table 11.

Table 11: Minimal required reinforcement

$A_{s,req,1}$ in [mm²/m]	$A_{s,req,1-}$ in [mm²/m]	$A_{s,req,2}$ in [mm²/m]	$A_{s,req,2-}$ in [mm²/m]
5597	5597	4883	4883

Wand E88	**h=500 mm**
EC EN 1992-1-1:2004/AC:2008	Knoop 607/362 [X= 9.000, Y=10.000, Z=4.833 m]

Uitgangspunten van het ontwerp

Wapening

Langsrichting: **B 500B**

Bovenzijde

[1+] Eerste laag (0°)	Ø28 mm / Horizontaal
[2+] Tweede laag (90°)	Ø28 mm / Verticaal
Dekking:	c_{nom} = 38 mm

Onderzijde

[1–] Eerste laag (0°)	Ø28 mm / Horizontaal
[2–] Tweede laag (90°)	Ø28 mm / Verticaal
Dekking:	c_{nom} = 38 mm

Afschuiving: **B 500B** Ø8 mm

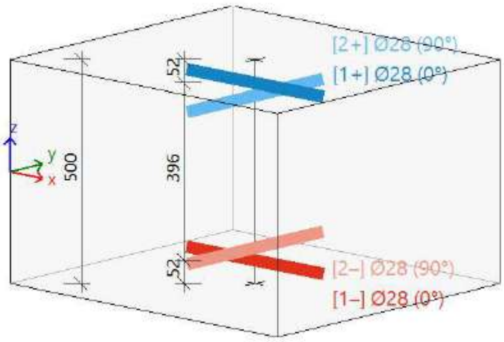


Figure 35: Reinforcement side walls

At last the unity check for the reinforcement in the wall was made, see Figure 35. This showed that the applied reinforcement, 28/100 throughout, in the walls was sufficient for the situation, see Figure 36.

Langswapening - samenvatting

Ontworpen wapeningslagen (in de richting van de lokale x-as van het element):

	Basis	Extra Gebruike...	Extra Auto	α [°]	$A_{s,min}$ [mm²]	$A_{s,ult}$ [mm²]	$\Delta A_{s,zen}$ [mm²]	$A_{s,req}$ [mm²]	$A_{s,prov}$ [mm²]	$A_{s,max}$ [mm²]	$s_{min(cl)}$ [mm]	s_{max} [mm]	Status
[1+]	ϕ28/100	---	---	0.0	500	0	---	**500**	**6158**	---	72	100	**OK**
								0.10%	1.23%		≥37	≤400	
[2+]	ϕ28/100	---	---	90.0	500	0	---	**500**	**6158**	10000	72	100	**OK**
								0.10%	1.23%		≥37	≤400	
[1-]	ϕ28/100	---	---	0.0	500	2987	---	**2987**	**6158**	---	72	100	**OK**
								0.60%	1.23%		≥37	≤400	
[2-]	ϕ28/100	---	---	90.0	500	5437	---	**5437**	**6158**	10000	72	100	**OK**
								1.09%	1.23%		≥37	≤400	

Afschuifwapening - samenvatting

	Geval	θ [°]	v_{Ed} [kN/m]	$A_{sl,x}$ [mm²]	$A_{sl,y}$ [mm²]	ρ_l [%]	$v_{Rd,c}$ [kN/m]	$v_{Rd,max}$ [kN/m]	$A_{sw,req}$ [mm²/m²]	Status
[-]	Maatgevende UGT/1	40.0	**56.5**	6158	6158	1.419	323.0	1954.3	**201**	**OK**

Figure 36: Unity check side walls

The unity check for the crack width however showed that it didn't suffice for this case, as seen in Figure 37.

Bovenzijde

Naam	Net	Positie [m]	Belasting	m_{1+} [kNm/m] m_{2+} [kNm/m]	n_{1+} [kN/m] n_{2+} [kN/m]	$A_{s,1+}$ [mm²] $A_{s,2+}$ [mm²]	$\sigma_{s,1+}$ [MPa] $\sigma_{s,2+}$ [MPa]	$s_{r,max,1+}$ [mm] $s_{r,max,2+}$ [mm]	$\varepsilon_{(sm-cm),1+}$ [1e-4] $\varepsilon_{(sm-cm),2+}$ [1e-4]	w_{1+} [mm] w_{2+} [mm]	w_{max+} [mm]	UC_{1+} [-] UC_{2+} [-]
E86	Element: 90 Knoop: 116	10.000 0.000 4.833	BGT-kar (automatisch)/1	-623.40 -409.32	-29.48 -169.52	6220 6220	273.2 152.5	334.761 230.542	11.9 5.9	0.400 0.137	**0.300**	**1.33** 0.46
E86	Element: 130 Knoop: 158	10.000 0.000 6.767	BGT-kar (automatisch)/1	-592.60 -435.60	-1.35 -175.84	6220 6220	261.9 162.7	334.975 230.605	11.4 6.4	0.381 0.149	0.300	1.27 **0.50**

Onderzijde

Naam	Net	Positie [m]	Belasting	m_{1-} [kNm/m] m_{2-} [kNm/m]	n_{1-} [kN/m] n_{2-} [kN/m]	$A_{s,1-}$ [mm²] $A_{s,2-}$ [mm²]	$\sigma_{s,1-}$ [MPa] $\sigma_{s,2-}$ [MPa]	$s_{r,max,1-}$ [mm] $s_{r,max,2-}$ [mm]	$\varepsilon_{(sm-cm),1-}$ [1e-4] $\varepsilon_{(sm-cm),2-}$ [1e-4]	w_{1-} [mm] w_{2-} [mm]	w_{max-} [mm]	UC_{1-} [-] UC_{2-} [-]
E88	Element: 540 Knoop: 606	10.000 10.000 4.833	BGT-kar (automatisch)/1	623.40 409.32	-29.48 -169.52	6220 6220	277.2 154.0	351.768 240.787	12.1 6.0	0.427 0.145	**0.300**	**1.42** 0.48
E88	Element: 580 Knoop: 646	10.000 10.000 6.767	BGT-kar (automatisch)/1	592.60 435.60	-1.35 -175.84	6220 6220	265.6 164.2	351.976 240.849	11.6 6.5	0.407 0.157	0.300	1.36 **0.52**

Figure 37: Crack width unity check

To counter this different reinforcement was tried, however this didn't give the wanted results. The only other option in this case was to increase the thickness of the wall. The wall was increased by 110*mm* to a total thickness of 610*mm*, results are shown in Figure 38.

Bovenzijde

Naam	Net	Positie [m]	Belasting	m_{1+} [kNm/m] m_{2+} [kNm/m]	n_{1+} [kN/m] n_{2+} [kN/m]	$A_{s,1+}$ [mm²] $A_{s,2+}$ [mm²]	$\sigma_{s,1+}$ [MPa] $\sigma_{s,2+}$ [MPa]	$s_{r,max,1+}$ [mm] $s_{r,max,2+}$ [mm]	$\varepsilon_{(sm-cm),1+}$ [1e-4] $\varepsilon_{(sm-cm),2+}$ [1e-4]	w_{1+} [mm] w_{2+} [mm]	w_{max+} [mm]	UC_{1+} [-] UC_{2+} [-]
E86	Element: 110 Knoop: 137	10.000 0.000 5.800	BGT-kar (automatisch)/1	-643.34 -436.53	-17.38 -175.84	6220 6220	217.0 125.4	340.972 228.690	8.8 4.5	0.300 0.102	**0.300**	**1.00** 0.34
E86	Element: 130 Knoop: 158	10.000 0.000 6.767	BGT-kar (automatisch)/1	-617.19 -440.38	-2.57 -174.59	6220 6220	209.3 126.7	341.146 228.690	8.4 4.5	0.287 0.104	0.300	0.96 **0.35**

Onderzijde

Naam	Net	Positie [m]	Belasting	m_{1-} [kNm/m] m_{2-} [kNm/m]	n_{1-} [kN/m] n_{2-} [kN/m]	$A_{s,1-}$ [mm²] $A_{s,2-}$ [mm²]	$\sigma_{s,1-}$ [MPa] $\sigma_{s,2-}$ [MPa]	$s_{r,max,1-}$ [mm] $s_{r,max,2-}$ [mm]	$\varepsilon_{(sm-cm),1-}$ [1e-4] $\varepsilon_{(sm-cm),2-}$ [1e-4]	w_{1-} [mm] w_{2-} [mm]	w_{max-} [mm]	UC_{1-} [-] UC_{2-} [-]
E88	Element: 560 Knoop: 626	10.000 10.000 5.800	BGT-kar (automatisch)/1	643.34 436.53	-17.38 -175.84	6220 6220	217.0 125.4	340.972 228.690	8.8 4.5	0.300 0.102	**0.300**	**1.00** 0.34
E88	Element: 580 Knoop: 646	10.000 10.000 6.767	BGT-kar (automatisch)/1	617.19 440.38	-2.57 -174.59	6220 6220	209.3 126.7	341.146 228.690	8.4 4.5	0.287 0.104	0.300	0.96 **0.35**

Figure 38: Crack width unity check

This increase in thickness causes the self-weight of the walls to increase as well. This has impact on the calculated foundations. However, since the foundations were calculated with factor 1.5 and two additional reinforcement piles were added, this would not be a problem

3. Station Nassauplein

This chapter will discuss the stacked layer of tunnel-elements above each other at Nassauplein. Firstly, the design of the structure is illustrated including the functionality. In the second subchapter, the loads exerted on the structure are listed. After this, the structure is modelled in SCIA Engineer©. The responsible team member for this structure is Shahram Omary.

3.1 Design

In cooperation with the hydraulic engineering discipline, it is decided to create a tunnel with two elevations for two metro's that will provide a connection between Havenstad and Amsterdam Centraal. The tunnel structure contains two elements, the first tunnel element has a height of 10 metres and the second tunnel element has a height of 12 metres. The following dimensions are the same for both:

- 11 metres width
- 1 metre floor thickness
- 1 metre roof thickness
- 0,75 metres wall thickness

The tunnel structure has a length 140 metres, which is perfectly fitted for the M7 metro with M7 train sets with a maximum length of 123 metres. The metro is designed to transport 271 passengers. The weight of the metro is 64.3 ton (643 kN). To cope with this in the calculations we consider a 5 kN/m² load for the maximum capacity if the station is crowded with this amount of people. The weight of the metro is variable and is calculated in kN/m for the SCIA model. Besides that, the weight/load of the HUB entrance is also taken into account which is calculated in section 1 of this report.

The station consists of an elevator and an escalator necessary to access the platform. The depth of the entire construction for the stop will be 29.5 metres. This depth is necessary to make sure that the two tunnels will have enough distance between them, see Figure 39.

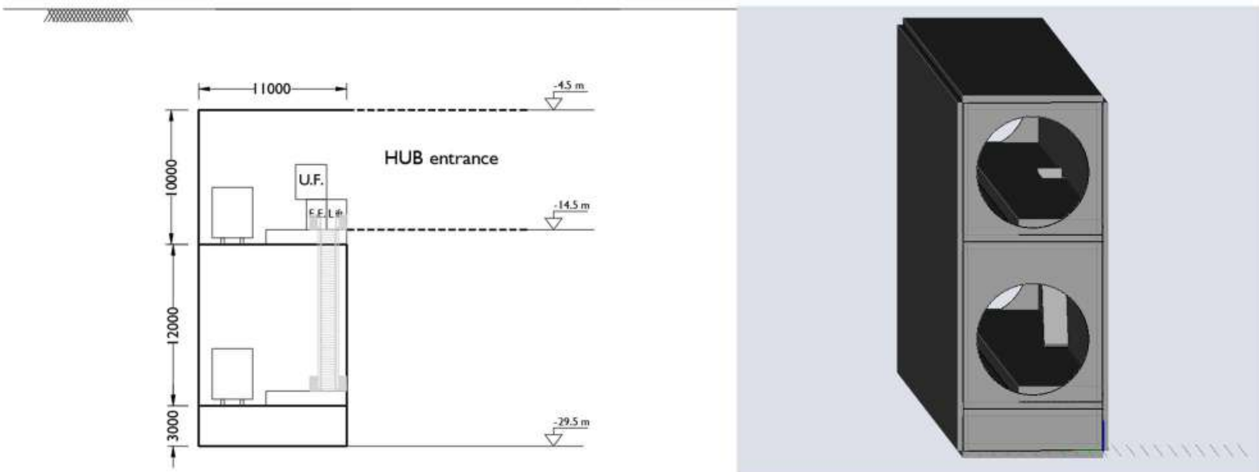


Figure 39: Autocad drawing and SCIA-model incuding dimensions

It should be noticed that in the SCIA model this HUB entrance is only taken into account as a separate load and therefore not modelled.

3.2 Loads

The loads that are taken into account for this structure are the loads exerted by the ground, the second stairwell and the tunnel elements such as the floors and walls. This is summed up in Table 12.

Table 12: Type of loads and its magnitude

Description	Category	Magnitude
Tunnel	-	-
Roof	-	-
Self-weight	Permanent	From SCIA
(Vertical) ground pressure	Permanent	79.0 kN/m² (See calculation)
Ground floor	-	-
Self-weight	Permanent	From SCIA
People	Variable	5.0 kN/m²
Walls	-	-
Self-weight	Permanent	From SCIA
(Horizontal) ground pressure	Permanent	71.0 kN/m² to 430.5 kN/m² (See calculation)
Escalator	-	-
Self-weight	Permanent	9.63 kN/m² (See calculations)
People	Variable	
Water storage	-	-
Weight of the water storage	Variable	6.7 kN/m² (See calculations)
Metro	-	-
Weight of the metro sets per elevation	Variable	20.0 kN/m² (See calculations)

3.2.1 Roof

The roof contains two main loads, namely its self-weight and the load that is originated by the ground. The self-weight of the structure is automatically calculated by SCIA. The second load is the load of the ground pressure given by the layers of the underground that are on top of the roof of the tunnel, which contains 79.0 kN/m² in Figure 40. This is calculated later in this report given the retrieved groundmodel from DINOloket.

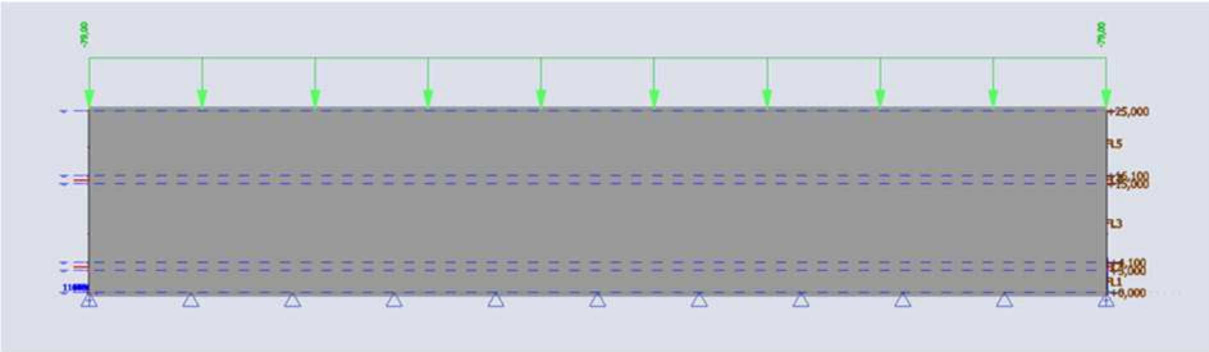


Figure 40: The load on the roof in SCIA

3.2.2 Ground floor

The floor contains two main loads from which one is a variable load. The first load is a permanent load, its self-weight. The second one is a variable load in the form of a crowd of people for which a 5 kN/m² is applied in Figure 41.

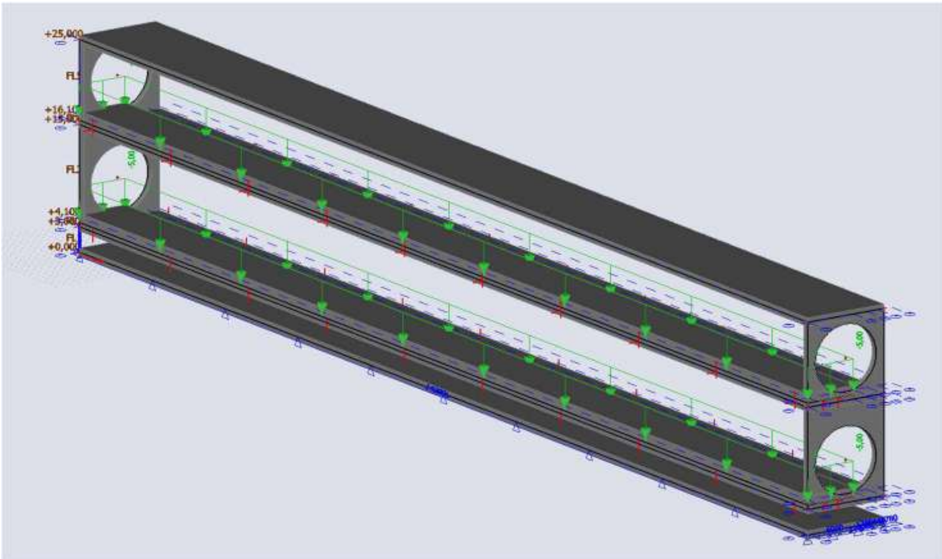


Figure 41: The ground floor load in SCIA

3.2.3 Walls

The walls contain two main loads, namely its self-weight and the horizontal forces exerted due to the underground. The self-weight is calculated again automatically by SCIA. The horizontal ground pressure is calculated later in this report given the groundmodel. This type of ground pressure is obtained by multiplying the vertical pressure with a ground pressure coefficient.

3.2.4 Escalator

The stairwell contains two main loads. Which are its self-weight, the load from the people transporting from the first elevation to the second one. The loads of the escalator is determined given the information of the escalator manufacturer of Schindler, specifically their model of the Schindler 9300. The required type of this model is type 15 since the height that must be overbridged is 10 metres. Considering the thickness, we assume a height of approximately 12.5 metres. We design an escalator with a width of 1000 mm (1 metre), this will bring us to the design of Schindler of maximum height difference of 13 metres. The weight of the escalator itself will be 163 kN. This will be recalculated as an equal distributed permanent load on the 2D-element in SCIA. The maximum angle of an escalator is considered between 30 – 35°. This maximum situation given the height of 12.5 metres will give a horizontal distance of approximately 17.5 metres. Now we don't need this amount of space to unnecessarily cover the escalator, so we take 15 metres, see . Using the Pythagoras theorem gives a total length of the escalator itself of:

$$l_{elevator} = \sqrt{(12.5)^2 + (15)^2} \approx 19.5\ metres$$

Distributing its self – weight over this length gives:

$$q_{elevator} = \frac{163}{19.5} \approx 8.4\ kN/m^2$$

Now this is its own weight and taking into account the transportation of people we consider a factor of 1.2:

$$q_{elevator} = 8.4\ \times\ 1.2 \approx 10.1\ kN/m^2$$

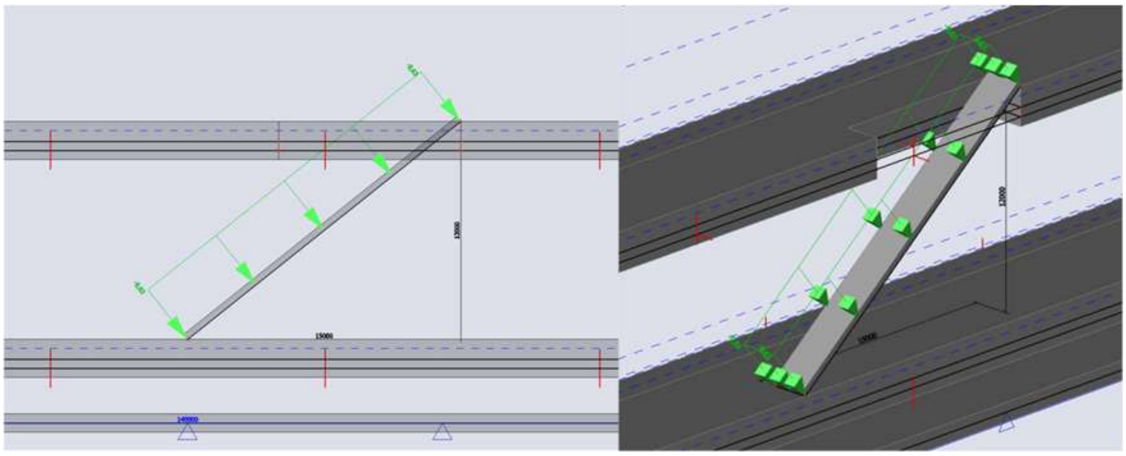


Figure 42: The load of the escalator modelled in SCIA

3.2.5 Metro load

The variable metro load is determined given the M7 metro with M7 trains sets. The max length of the metro is 123 metre considering two train sets, with an empty mass of 64.3 ton per train set. The capacity of the metro is 271 passengers. With this information one can calculate the line load on the rail, see Figure 43:

$$64.3\ ton\ =\ 64300\ kg\ =\ 643\ kN$$
$$Weight\ of\ an\ average\ person\ (assumption)\ =\ 75\ kg$$
$$Load\ per\ elevation: 643\ \times\ 2\ +\ (75\ \times\ \frac{271}{100})\ =\ 1489.25\ kN$$
$$Load\ on\ elevation\ in\ \frac{kN}{m^2}: \frac{1489.25}{123} = 12.1\ \frac{kN}{m^2}$$
$$Load\ per\ rail\ on\ elevation: \frac{12.1}{2} = 6.05\ kN/m^2$$

As not every person on the metro weighs 75 kg on average, we use a safety factor of 1.1 to determine the definitive load:

$$Load\ per\ rail\ on\ elevation: 6.05\ \times\ 1.1\ \approx\ 6.7\ kN/m^2$$

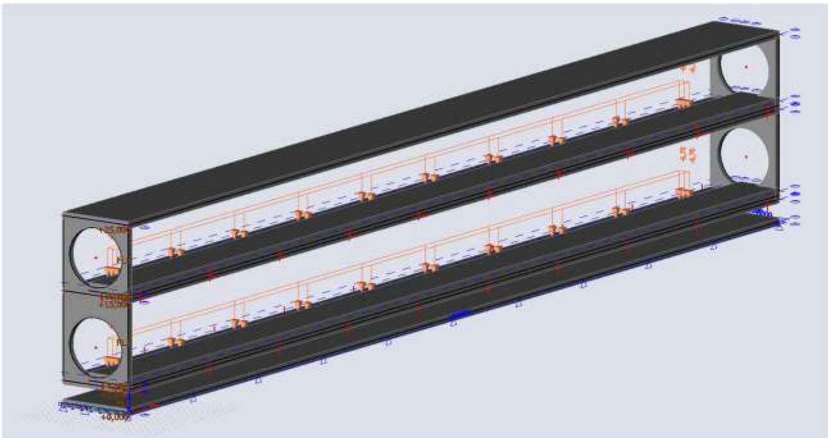


Figure 43: The load on the elevation per rail in SCIA

3.2.6 Water storage

From the ideas of the water management discipline a water storage area is modelled underneath the lowest tunnel elevation. This is also calculated as a variable load in the model, see Figure 44:

$$\lambda_{water} = 10\ kN/m^3$$
$$h = height\ of\ the\ area\ =\ total\ height\ -\ (2 \times floor\ thickness)\ =\ 3 - (2\ \times\ t_{floor})$$
$$q_{water} = \lambda_{water}\ \times\ h$$
$$q_{water} = 10\ \times\ (3 - (2\ \times\ 0.5))\ =\ 10\ \times\ 2 = 20\ kN/m^2$$

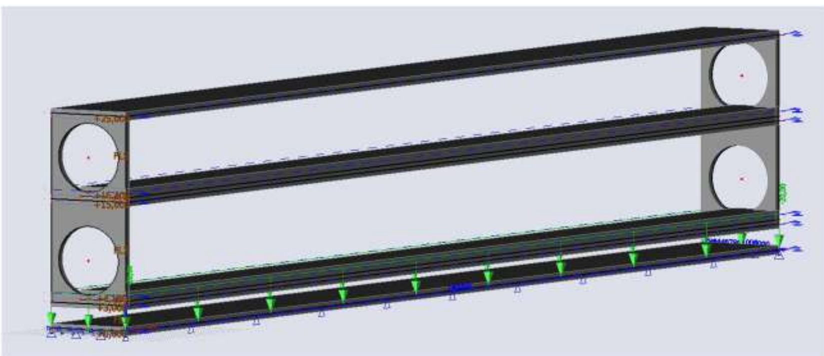


Figure 44: The water storage load in SCIA

3.3 Structure

In this chapter the ground loads is calculated and the approach that is used given the results of the SCIA model to calculate the necessary reinforcement for the structure.

3.3.1 Ground load

The loads that are calculated given the ground model are as following:

<u>Vertical load</u>

$$\sigma_v = (1 \times 15) + (1.5 \times 16) + (2 \times 20) = 79\ \mathrm{kN/m^2}$$

<u>Horizontal load</u>

$$\sigma_{h,top} = (1 \times 15) + (1{,}5 \times 16) + (2 \times (20 - 10)) \times 0{,}6 + 2 \times 10 = 71\ \mathrm{kN/m^2}$$

$$\sigma_{h,bottom} = 71 + ((11.5 \times (20 - 10) \times 0.6) + 11.5 \times 10) + ((13.5 \times (17.5 - 10) \times 0.4) + (13.5 \times 10))$$

$$= 71 + 184 + 175.5 = 430.5\ \mathrm{kN/m^2}$$

The ground pressure model looks as following, given the ground information from DINOloket, see Figure 45:

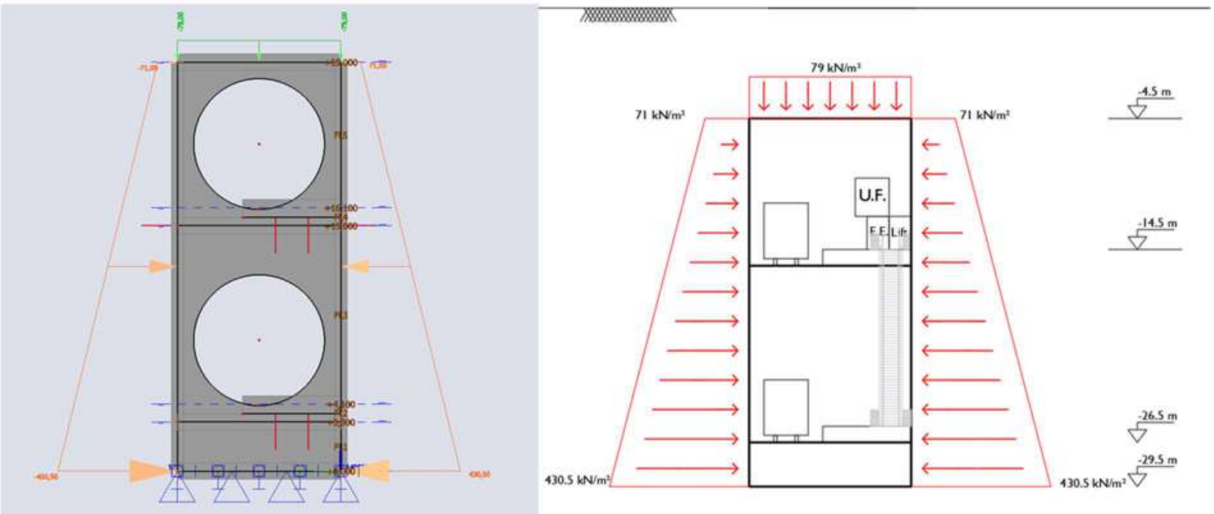


Figure 45: The ground load within the SCIA model and situation in AutoCad

It should be mentioned that for the foundation of the tunnel a rigid bedding system is modelled with a significant stiffness value to simulate the practical reaction of the underground soil.

3.3.2 Approach

Given the load combinations that are generated automatically by SCIA by appending the right settings, we pick the most vulnerable situation to determine how the structure is designed (for ULS + SLS) given the stability, strength and deformation. The load cases are as following:

$BG_1 = self\ weight\ concrete\ area$
$BG_2 = ground\ load$
$BG_3 = people$
$BG_4 = water\ load$
$BG_5 = self\ weight\ metro$
$BG_6 = escalator$

Given the load cases, the next load combinations are generated, from which the most critical one is chosen to calculate, see Table 13:

Table 13: The load ULS load combinations

Ultimate limit state (ULS) B1: $1.35BG_1 + 1.35BG_2$	Ultimate limit state (ULS) B2: $1.00BG_1 + 1.00BG_2$
Ultimate limit state (ULS) B3: $1.35BG_1 + 1.35BG_2 + 1.50BG_3 + 1.50BG_4 + 1.50BG_5 + 1.50BG_6$	
Ultimate limit state (ULS) B4: $1.00BG_1 + 1.00BG_2 + 1.50BG_3 + 1.50BG_4 + 1.50BG_5 + 1.50BG_6$	

This resulted in an enveloping characteristic load combination of ULS-B3 which is normative for the situation and hence used to calculate the necessary reinforcement. The option 'ULS and SLS 2D-reinforcement design' in SCIA engineer did work for the structure as a whole. Therefore, the approach for the design will be:
- Identify the highest moments (in x- and y-direction per 2D-element
- Determine which elements are mandatory to reinforce given the internal forces from the results
- Apply the reinforcement and see whether the structure is safe given the stability, deformation and strength (check fase for; shear reinforcement, longitudinal reinforcement and crack width)

This procedure is done for the elements that are undergoing the most stresses and displacements to design an appropriate reinforcement model for the tunnel, this is shown as following, see Figure 46:

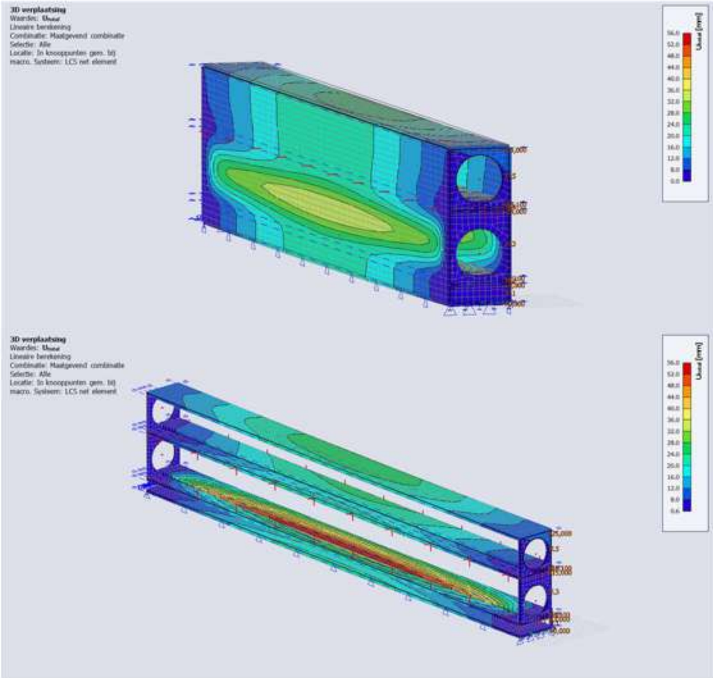


Figure 46: The total 3D-displacement of the whole structure given the normative situation

3.4 Results

Figure 46 shows that the ULS-B3 combination results in the maximum deformations and stresses on the roof, the walls and the floor of the second elevation. Hence we will go more into details for these sub-objects in this report.

3.4.1 Roof

It is checked if the global deformation (with matching stress-value) of the roof construction meets the requirement of the maximum deformation in Figure 47:

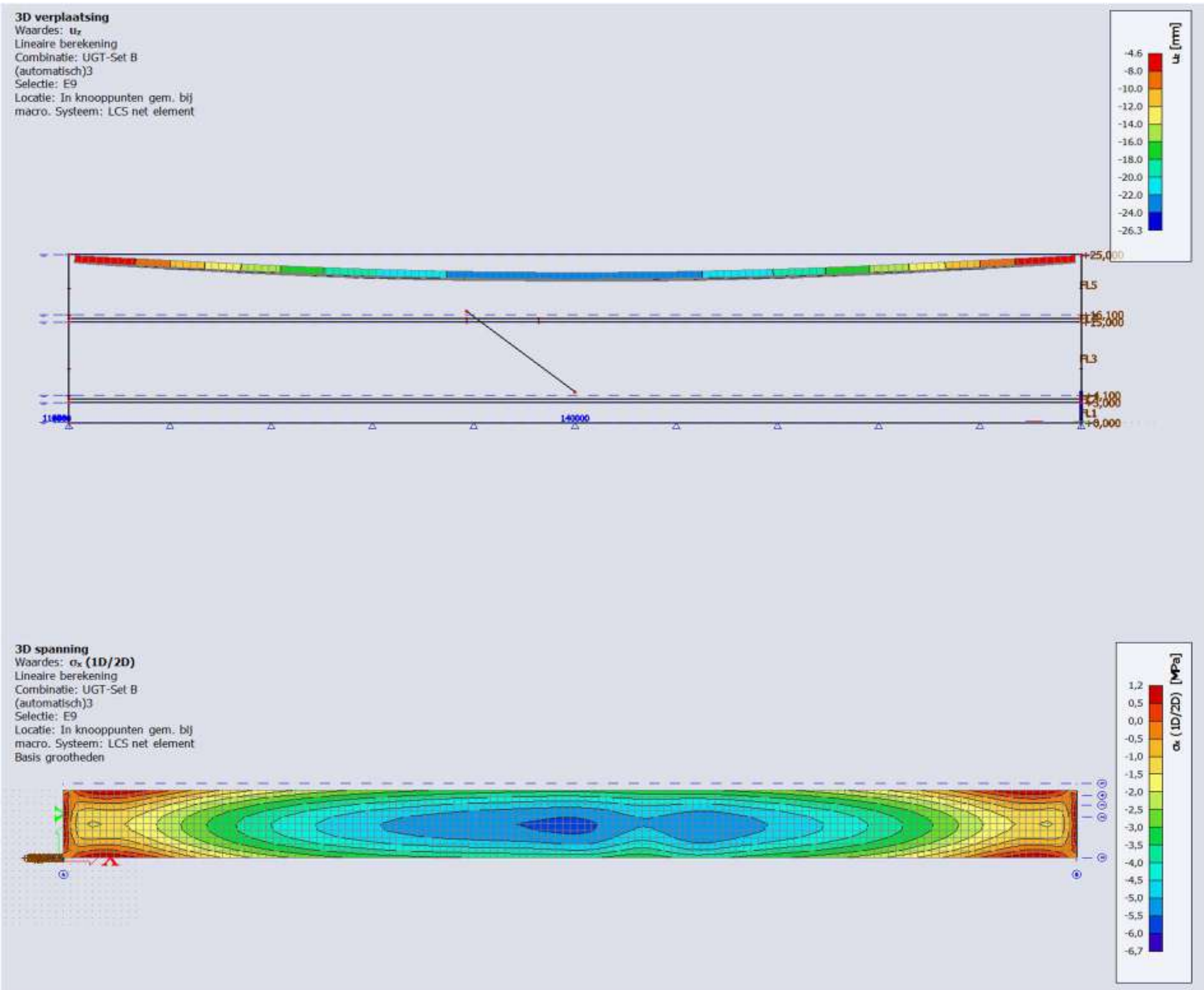


Figure 47: Maximum deformation and stresses of the roof given the normative situation

-26.3 mm < -40.6 mm, satisfies!

With this information we are able to determine what kind of reinforcement (see Figure 48) is at least required for the roof of the tunnel, give the following figure about the required reinforcement (see Figure 48) and the resulting stresses originated by the internal forces (see Figure 47):

Figure 48: Reinforcement design of the roof

From the ULS and SLS reinforcement calculations from the model it is mandatory to apply the following reinforcement (see Figure 49, Figure 50, Figure 51 and Figure 52) :

<u>Basis reinforcement</u>

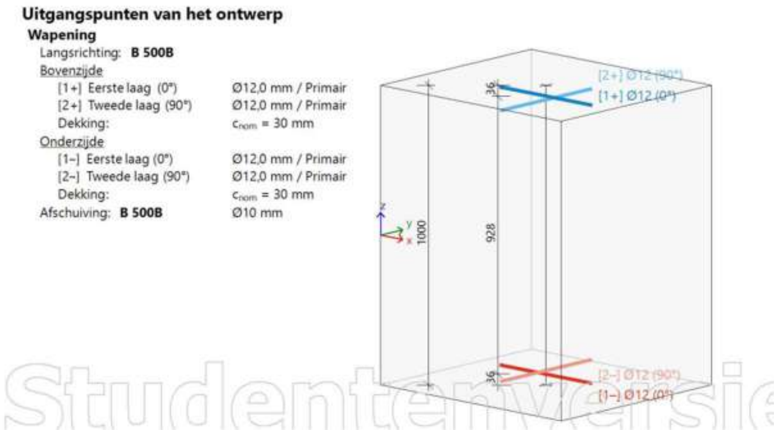


Figure 49: Basis reinforcement of the roof

<u>Longitudinal reinforcement</u>

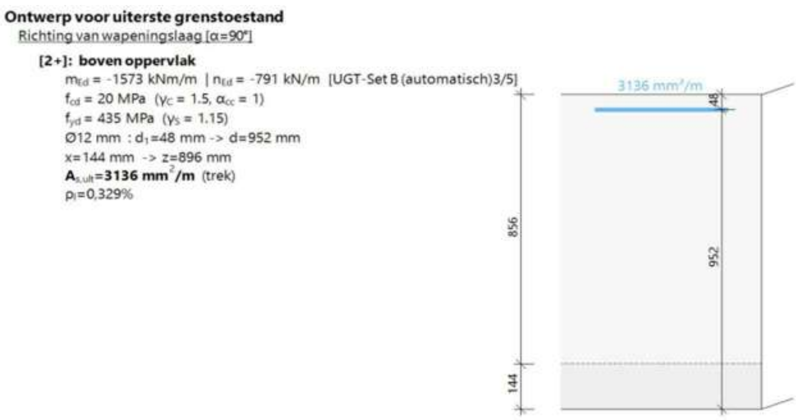


Figure 50: Longitudinal reinforcement of the roof

Shear reinforcement

The calculations given the report highly recommend shear reinforcement, since without the shear reinforcement of the roof, the check proved that $v_{Ed} \geq v_{Rdc}$, hence it is necessary. The roof requires 23 ⌀10 per m² this estimated as $A_{sw,req} = 1747\ mm^2/m^2$. Applying this, shows that:

Afschuifwapening - samenvatting

	Geval	θ [°]	v_{Ed} [kN/m]	$A_{sl,x}$ [mm^2]	$A_{sl,y}$ [mm^2]	ρ_l [%]	$v_{Rd,c}$ [kN/m]	$v_{Rd,max}$ [kN/m]	$A_{sw,req}$ [mm^2/m^2]	Status
[+]	UGT-Set B (automatisch)3	40,0	**815,3**	0	1179	0,123	673,3	4682,1	**1747**	**OK**

v_{Ed} - ontwerpafschuifkracht, $A_{sl,x/y}$ - treklangswapening, ρ_l - corresponderend wapeningspercentage, v_{Rdc} - weerstand dwarskracht zonder dwarswapening, $v_{Rd,max}$ - maximale dwarskracht weerstand van beton, $A_{sw,req}$ - vereiste dwarswapening

Figure 51: Shear reinforcement of the roof

Crack width check

This application of the reinforcement for the roofs definitely influences that crack width for example. From the crack width check it appears to be:

Berekende scheurwijdte

$$w_k = s_{r,max} \cdot \varepsilon_{sm\_}\varepsilon_{cm} = 238\text{ mm} \cdot 1.19\ ‰ = 0.283\text{ mm} \qquad (7.8)$$

Grenswaarde van scheurwijdte

$$w_{max} = 0.3\text{ mm} \qquad (§7.3.1(5))$$

Berekening eenheidscontrole

$$UC = \frac{w}{w_{max}} = \frac{0.283}{0.3} = \mathbf{0.944}$$

Controle scheurwijdte

$$\mathbf{w = 0.283\ mm = < w_{max} = 0.3\ mm}$$

Figure 52: Crack width check of the roof reinforcement

3.4.2 Walls

Again is checked if the global deformation (with matching stress-value) of the walls construction meets the requirement of the maximum deformation:

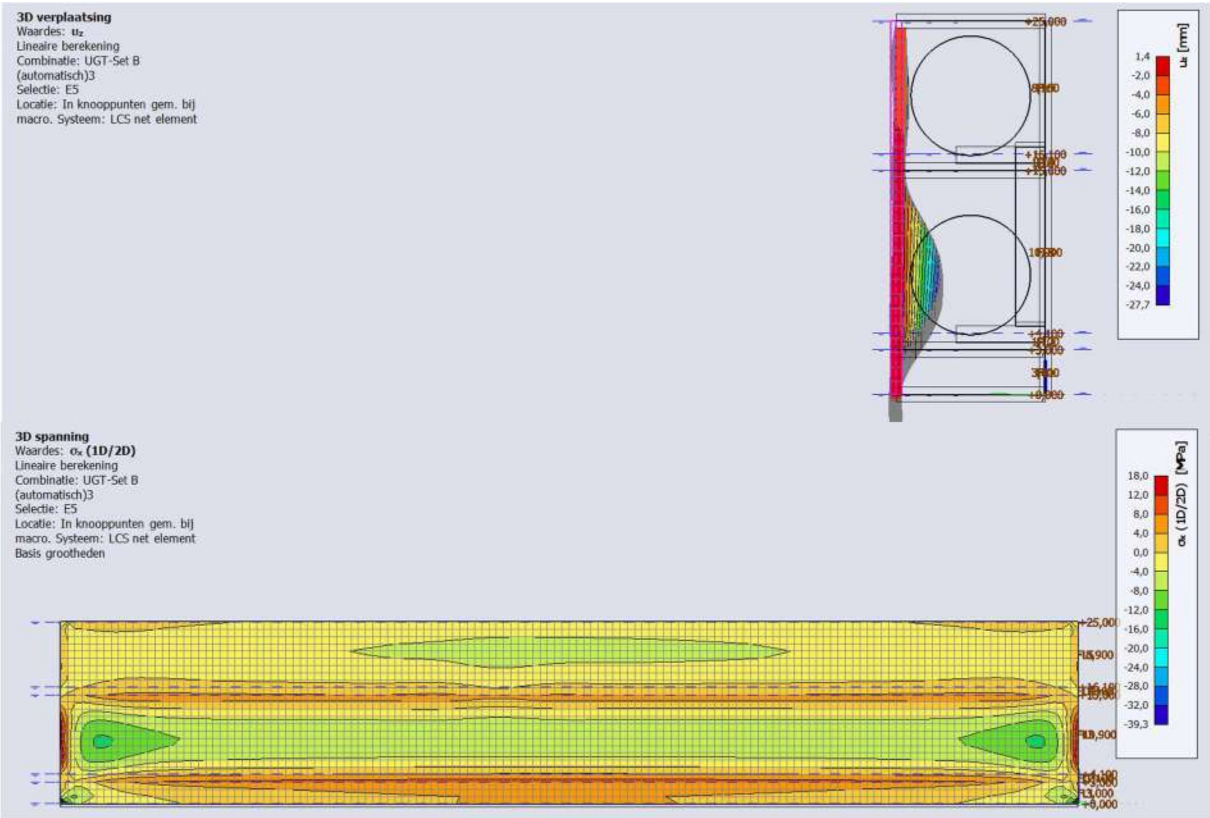


Figure 53: Maximum deformation and stresses of the walls given the normative situation

-27.4 mm < -40.6 mm, satisfies!

With this information we are able to determine what kind of reinforcement (see Figure 54) is at least required for the walls of the tunnel, give the following figure about the required reinforcement (see Figure 54) and the resulting stresses originated by the internal forces (see Figure 53):

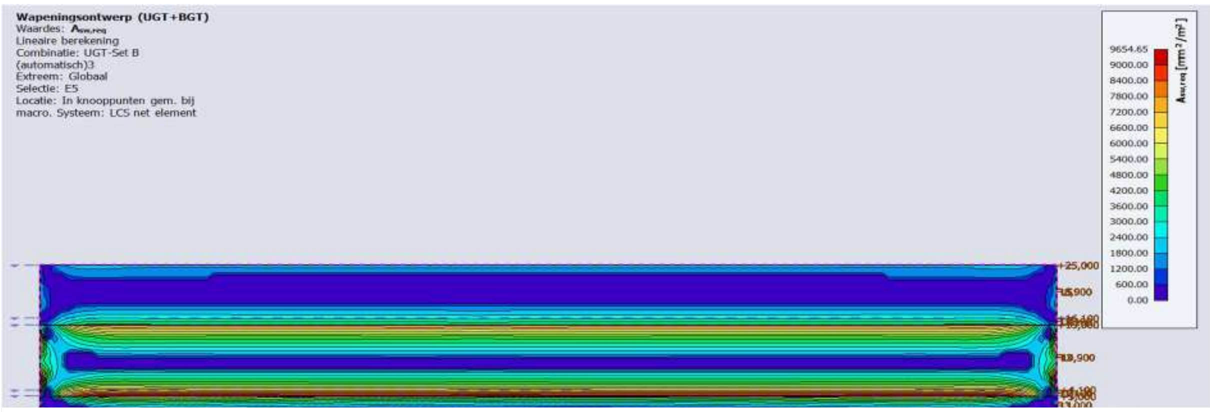


Figure 54: Reinforcement design of the walls

From the ULS and SLS reinforcement calculations from the model it is mandatory to apply the following reinforcement (see Figure 55, Figure 56, Figure 57 and Figure 58):

Basis reinforcement

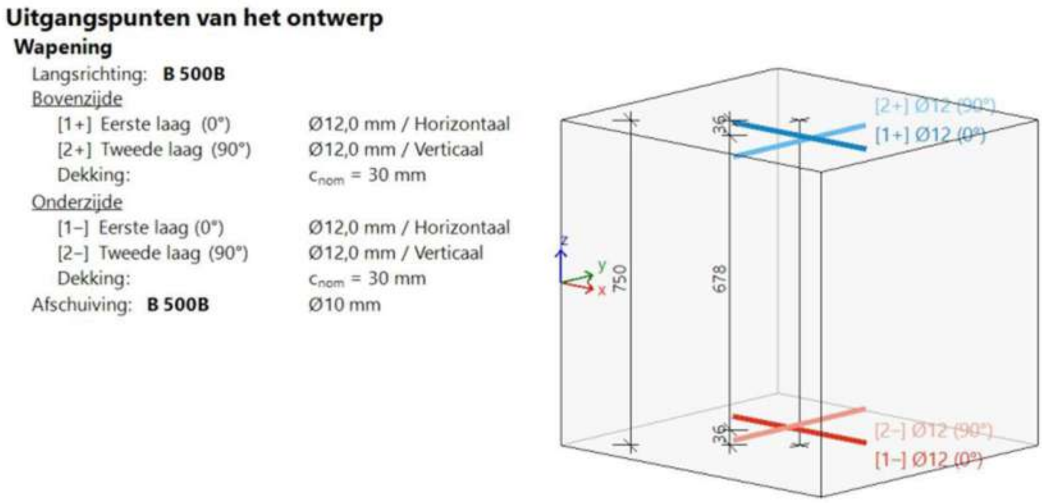
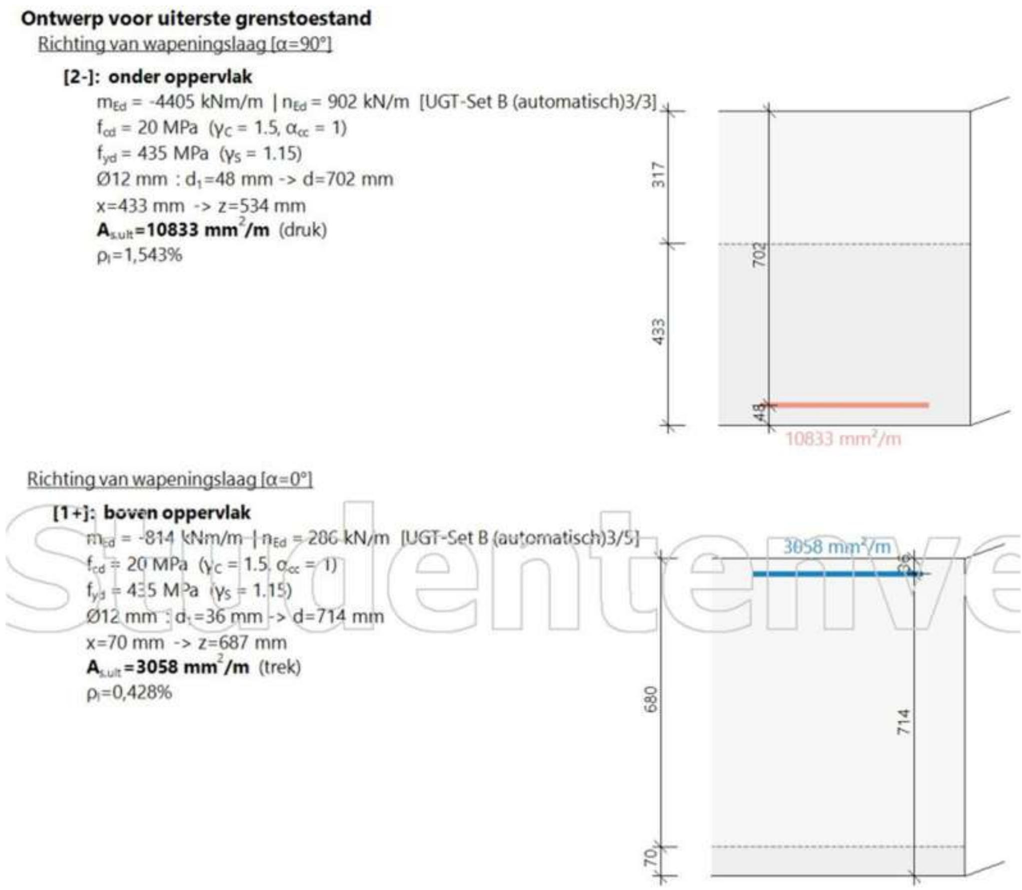


Figure 55: Basis reinforcement of the walls

Longitudinal reinforcement



Richting van wapeningslaag [α=90°]

[2+]: boven oppervlak

m_{Ed} = -4417 kNm/m | n_{Ed} = 1073 kN/m [UGT-Set B (automatisch)3/5]

f_{cd} = 20 MPa (γ_C = 1.5, α_{cc} = 1)

f_{yd} = 435 MPa (γ_S = 1.15)

Ø12 mm : d_1=48 mm -> d=702 mm

x=433 mm -> z=534 mm

$A_{s,ult}$=28086 mm²/m (trek)

ρ_l=4,001%

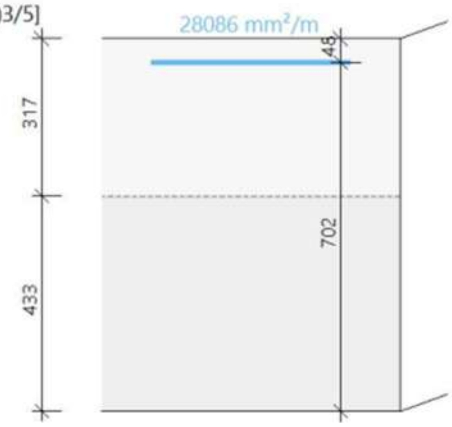


Figure 56: Longitudinal reinforcement of the walls

<u>Shear reinforcement</u>

The calculations given the report highly recommend shear reinforcement, since without the shear reinforcement of the wall, the check proved that $v_{Ed} \geq v_{Rdc}$, hence it is necessary. The wall requires 124 ⌀10 per m² this estimated as $A_{sw,req} = 9682\ mm^2/m^2$. Applying this, shows that:

Afschuifwapening - samenvatting

	Geval	θ [°]	v_{Ed} [kN/m]	$A_{sl,x}$ [mm²]	$A_{sl,y}$ [mm²]	ρ_l [%]	$v_{Rd,c}$ [kN/m]	$v_{Rd,max}$ [kN/m]	$A_{sw,req}$ [mm²/m²]	Status
[+]	UGT-Set B (automatisch)3	40,0	**2699,8**	1310	0	0,185	392,6	2798,3	**9682**	**OK**

v_{Ed} - ontwerpafschuifkracht, $A_{sl,x/y}$ - treklangswapening, ρ_l - corresponderend wapeningspercentage, v_{Rdc} - weerstand dwarskracht zonder dwarswapening, $v_{Rd,max}$ - maximale dwarskracht weerstand van beton, $A_{sw,req}$ - vereiste dwarswapening

Figure 57: Shear reinforcement of the walls

<u>Crack width check</u>

This application of the reinforcement for the walls definitely influences that crack width for example. From the crack width check it appears to be:

Berekende scheurwijdte

$$w_k = s_{r,max} \cdot \varepsilon_{sm\_}\varepsilon_{cm} = 260\ mm \cdot 1.14\ ‰ = 0.296\ mm \quad (7.8)$$

Grenswaarde van scheurwijdte

$$w_{max} = 0.3\ mm \quad (§7.3.1(5))$$

Berekening eenheidscontrole

$$UC = \frac{w_k}{w_{max}} = \frac{0.296}{0.3} = \mathbf{0.988}$$

Figure 58: Crack width check of the wall reinforcement

3.4.3 Second floor elevation

Again is checked if the global deformation (with matching stress-value) of the second floor of the construction meets the requirement of the maximum deformation, see :

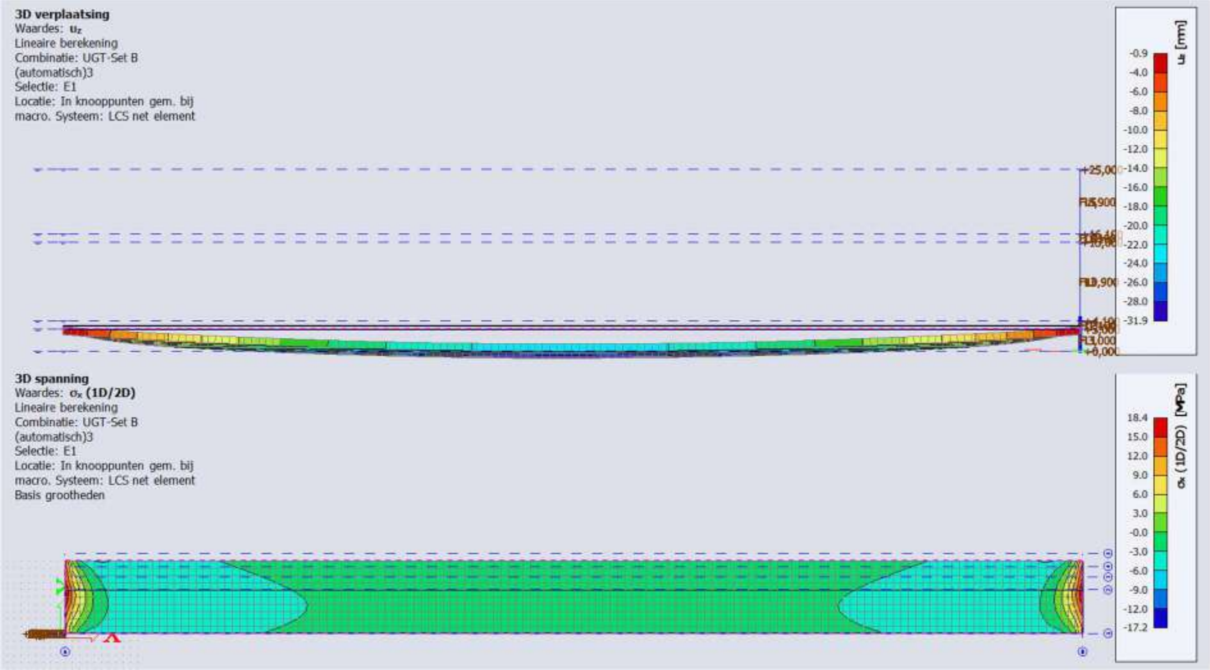


Figure 59: Maximum deformation and stresses of the second-floor elevation

-30.2 mm < -40.6 mm, satisfies!

With this information we are able to determine what kind of reinforcement (see Figure 60) is at least required for the second floor of the tunnel, give the following figure about the required reinforcement (see Figure 60) and the resulting stresses originated by the internal forces (see Figure 59):

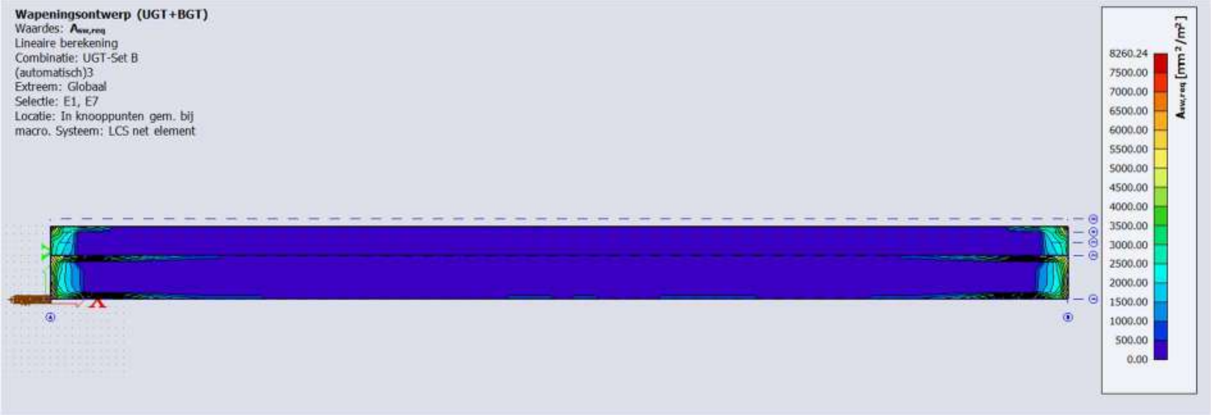


Figure 60: Reinforcement design of the second-floor

From the ULS and SLS reinforcement calculations from the model it is mandatory to apply the following reinforcement (see Figure 61, Figure 62, Figure 64, Figure 63 and Figure 65):

Basis reinforcement

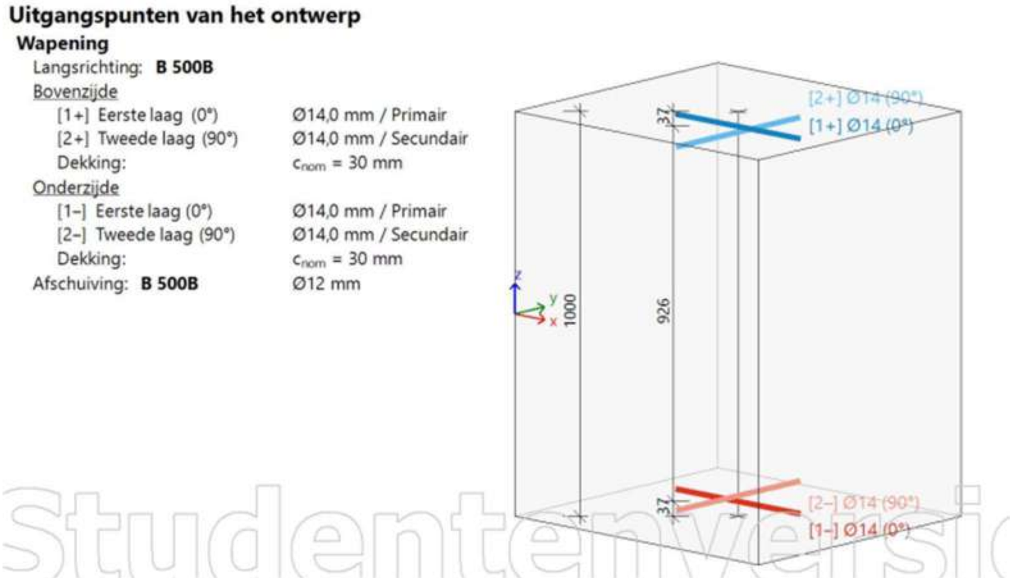


Figure 61: Basis reinforcement

Longitudinal reinforcement

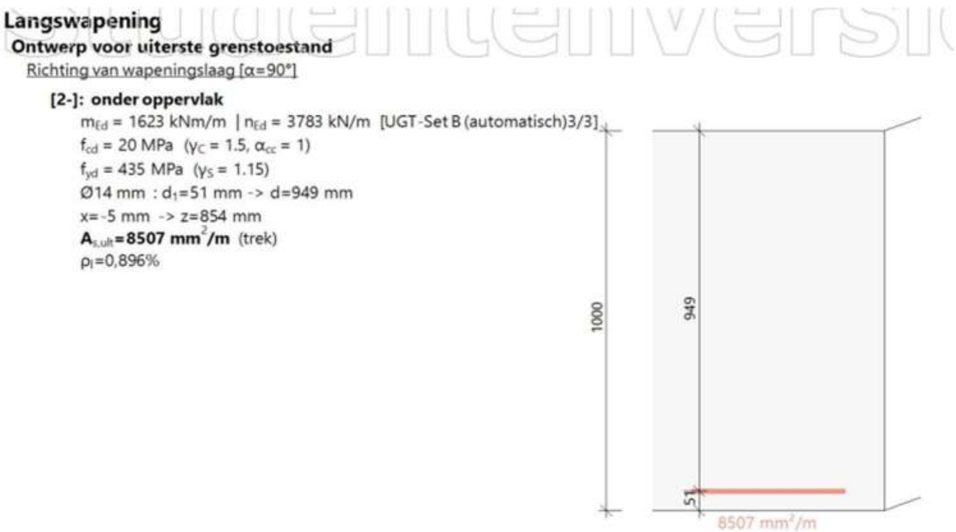


Figure 62: Longitudinal reinforcement

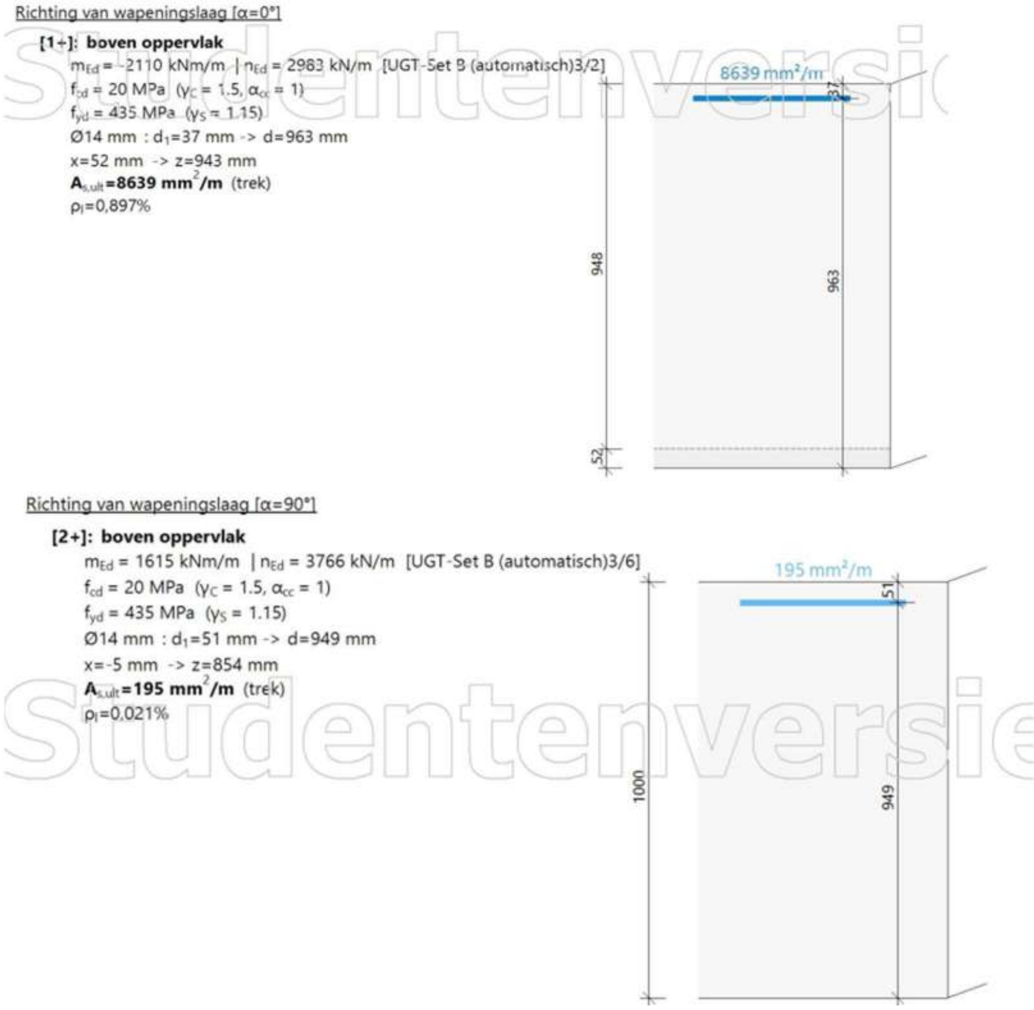


Figure 63: Longitudinal reinforcement

Shear reinforcement

The calculations given the report highly recommend shear reinforcement, since without the shear reinforcement of the floor, the check proved that $v_{Ed} \geq v_{Rdc}$, hence it is necessary. The floor requires 102 ⌀12 per m² this estimated as $A_{sw,req} = 11\ mm^2/m^2$. Applying this, shows that:

Afschuifwapening - samenvatting

	Geval	θ [°]	v_{Ed} [kN/m]	$A_{sl,x}$ [mm²]	$A_{sl,y}$ [mm²]	ρ_l [%]	$v_{Rd,c}$ [kN/m]	$v_{Rd,max}$ [kN/m]	$A_{sw,req}$ [mm²/m²]	Status
[+]	UGT-Set B (automatisch)3	40,0	**5464,1**	1179	0	0,123	4,9	5781,5	**11460**	**OK**

v_{Ed} - ontwerpafschuifkracht, $A_{sl,x/y}$ - treklangswapening, ρ_l - corresponderend wapeningspercentage, v_{Rdc} - weerstand dwarskracht zonder dwarswapening, $v_{Rd,max}$ - maximale dwarskracht weerstand van beton, $A_{sw,req}$ - vereiste dwarswapening

Figure 64: Shear reinforcement

Crack width check

This application of the reinforcement for the floor definitely influences that crack width for example. From the crack width check it appears to be:

Berekende scheurwijdte

$$w_k = s_{r,max} \cdot \varepsilon_{sm\_}\varepsilon_{cm} = 193 \text{ mm} \cdot 1.11 ‰ = 0.214 \text{ mm} \quad (7.8)$$

Grenswaarde van scheurwijdte

$$w_{max} = 0.3 \text{ mm} \quad (§7.3.1(5))$$

Berekening eenheidscontrole

$$UC = \frac{w}{w_{max}} = \frac{0.214}{0.3} = \mathbf{0.714}$$

Controle scheurwijdte

$$\mathbf{w = 0.214\ mm = \ < w_{max} = 0.3\ mm}$$

Figure 65: Crack width check for second-floor reinforcement

An overall intermediate conclusion about this tunnel can be reproduced, with the information of the results. As the unity checks of the crack widths and used dimensions of the reinforcement shows, the tunnel can be optimised given the thicknesses of the elements, such as the roof, floor and walls. It should also be mentioned that the connection of the escalator on the first floor and the second floor does not fully support the reality and hence the overall calculation might have some sort of lack of accuracy. Given the relatively short amount of time, this could not be pleased. In further investigation one can take these aspects into account to represent a more realistic view on this structure.

4. Bridge Westerpark and Havenstad

In this chapter of the report, the bridge across the main track is designed. Jeroen van Schaik is the team member of the structural engineering group that is responsible for this.

4.1 Design

In consultation with T&P, it is decided to create a bridge between Westerpark and Havenstad. The bridge will cross the main track to create a good connection between these two areas. The bridge will have to cross the depot, with a span of circa 250 meters. The bridge will be divided into 4 sections which each have a span of circa 60 to 65 meters. The beginning- and end sections have a span of 65 meters. The two middle sections are 60 meters.

Figure 66 Bridge Havenstad

Figure 67 Bridge Havenstad

The bridge will only be accessible to pedestrians and cyclists. The bridge will have two lanes for cyclists with a total width of 4 meters, and one lane for pedestrians, with a total width of 2.00 meters. For handrail and lighting, there is a space reservation of meters. The total width of the bridge is 7 meters. There are no hard requirements regarding the gradient. The height of the bridge is 4.50 meters. The bridge will cross the main track and should therefore pass the track at a minimum height of 5.50 meters.

Figure 68 Bridge Havenstad

Because of the large span, the bridge will have a steel main- and crossbeam construction. The other parts of the bridge will be designed in wood.

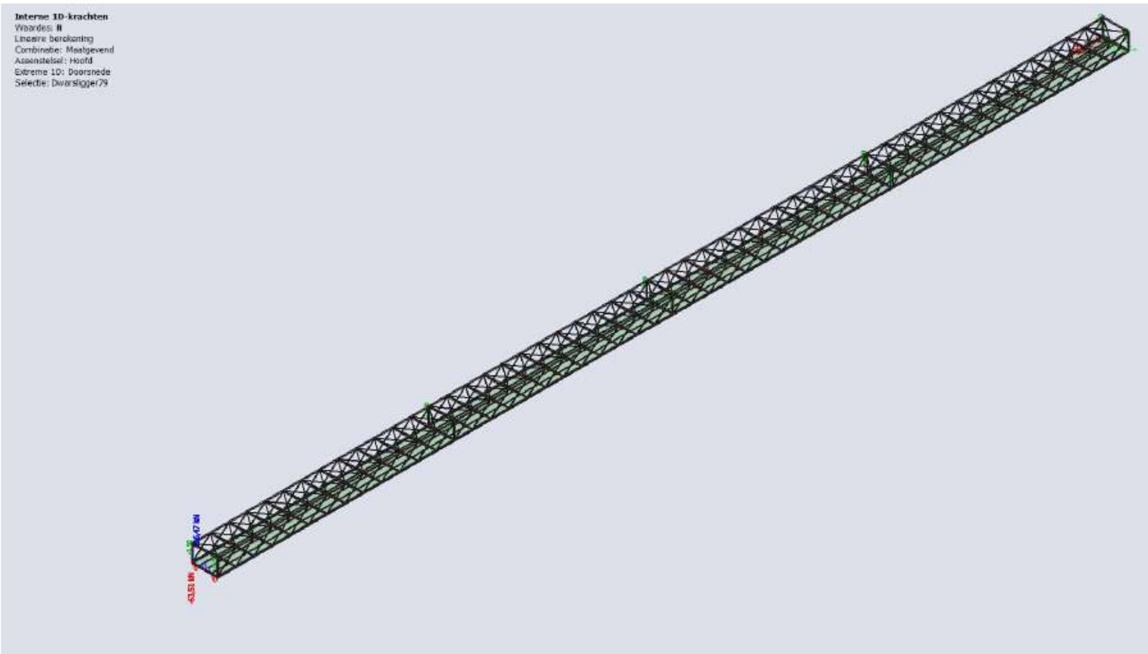


Figure 69 Bridge model in SCIA Engineer

4.2 Loads

The bridge will have to be designed for the loads acting on them. In *Table 14* the loads are explained and their placing is specified. Using NEN-EN-1991 Chapter 5: Loads on footpaths, cycle paths, pedestrians paths,

The following loads should be taken into account. These consist of:

- An evenly distributed load q_{fk} with a minimum of 2.5 kN/m^2 and a maximum of 5 kN/m^2
- Force Q_{serv} representing the service vehicle. The service vehicle should have the following characteristic:
  - Two axles with a wheelbase of 3 meters
  - Axle load = 25 kN, two wheels for each axle with a track width of 1.75 meters
  - Each wheel has a contact area of 0.25 x 0.25 meters
- People crowd with a value of 5 kN/m^2
- Other objects (handrail / street lights) : 0.35 kN/m^2

Table 14 Loads

Description	Category	Magnitude
Self weight	Permanent	Determined by SCIA
Cyclist traffic	Variable	3.5 kN/m^2
Service vehicle	Variable	12.5 kN/m^2
People crowd	Variable	5 kN/m^2
Other objects	Permanent	0.35 kN/m^2
Snow	Variable	0.70 kN/m^2
Wind	Variable	0.69 kN/m^2

BG1: Self-weight
The self-weight of the structure is automatically calculated by SCIA Engineer.

BG2 / BG3: Cyclists and people crowd
For cyclists, traffic is chosen to add a force of 3.5 kN/m^2 to the model. For people crowd a force of 5.0 kN/m^2 is added to the model. This force is mentioned in the NEN-EN-1991. This force is evenly distributed over the bridge.

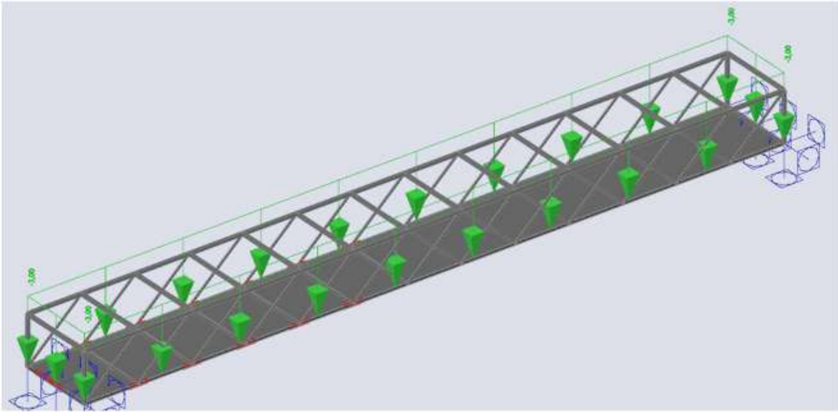


Figure 70 Distribution BG2 / BG3

BG4: Service vehicle
If there is maintenance at the bridge, the bridge must be accessible for vehicles. This force is added to the model in different places to determine the normative force. It is added to the following places:

- Above support point to determine the maximum support reaction
- Middle bridge deck to determine the maximum displacement of deck and beam

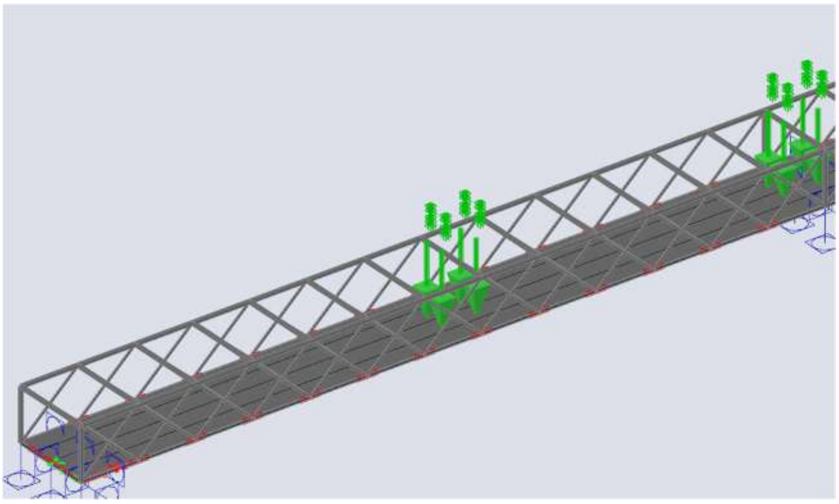


Figure 71 Distribution BG4

BG5: Other objects
On both sides of the bridge, a force of 0.35 kN/m^2 is added to the model. The force is added as an evenly distributed load on a surface of the total length of the bridge and a width of 0.50 meters at each side.

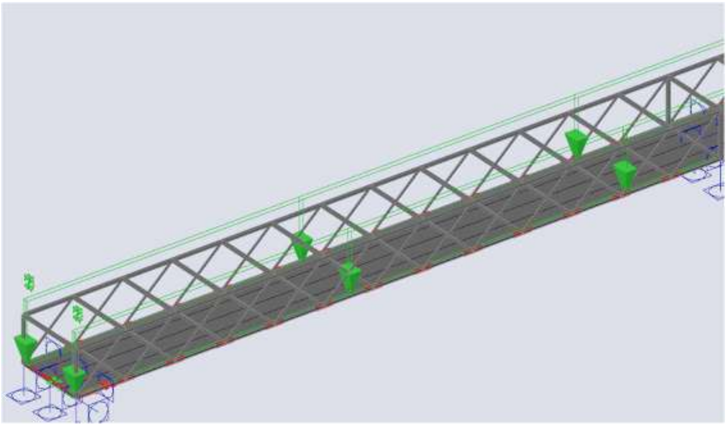


Figure 72 Distribution BG5

BG6: Snow
At last variable snow load can occur during the winter times, this set in The Netherlands according to the Eurocode as 0.7 kN/m^2. The calculation model can be seen in figure 73.

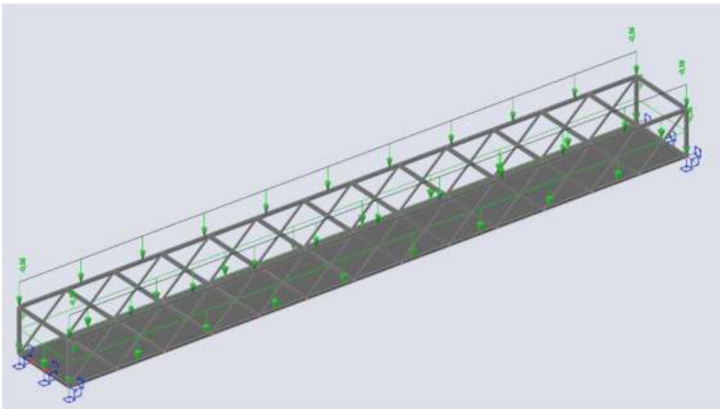


Figure 73 Distribution BG6

BG7: Wind
The wind load has been decided with the use of the Quick Reference, 0.69 kN/m^2 is found.

Load groups
All parts of the bridge must be checked in two states. The Ultimate Limit State, or ULS, and the serviceability state. The calculations are done by following the NEN standards in combination with the Dutch National Appendix. Each state has its own factors, which are automatically applied in SCIA Engineering by choosing the correct NEN standards. SCIA Engineer creates automatically load groups from all available load cases.

4.3 Structure

Foundation

Basically, every foundation must meet the following criterion:

Force F < Load capacity R

The soil type can be determined on the basis of the cone resistance and the friction number. The soil types have been determined using the Reader Geotechnics, *Hogeschool van Arnhem en Nijmegen*, table 2.5.1. Based on the CPT (Figure 74), the soil structure used in Table 15 is established:

It is decided to use a pile diameter of 400x400 mm with a base plate of 610x610 mm. The foundation piles will also be the bridge support point. So the two piles need to carry all the load that works on the bridge.

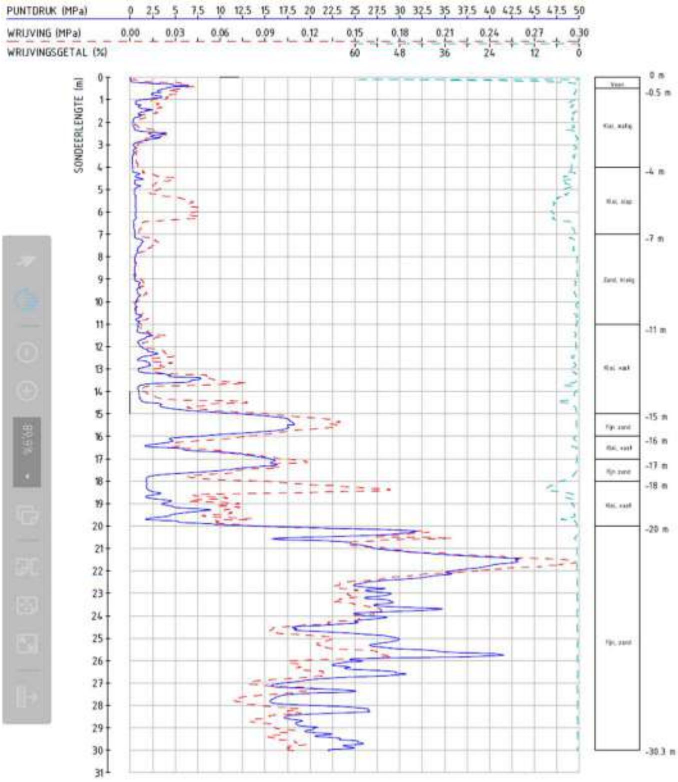


Figure 74 CPT Havenstad

Table 15 Soil structure

Data drill sample							
Layer	Soil Type	Layer Thickness	Top Layer	Bottom Layer	Specific weight	Angle φ	Cohesion
1	Peat	0,5 m	0 m	-0.5 m	12 kN/m³	15 º	2,5 kN/m²
2	Clay, moderate	3,5 m	-0.5 m	-4 m	17 kN/m³	17,5 º	5 kN/m²
3	Clay, limp	3 m	-4 m	-7 m	14 kN/m³	17,5 º	0 kN/m²
4	Sand, clayey	4 m	-7 m	-11 m	21 kN/m³	25 º	0 kN/m²
5	Clay, solid	3,5 m	-11 m	-14.5 m	20 kN/m³	17,5 º	15 kN/m²
6	Fine sand	1,5 m	-14.5 m	-16 m	22 kN/m³	40 º	0 kN/m²
7	Clay, solid	1 m	-16 m	-17 m	20 kN/m³	17,5 º	15 kN/m²
8	Fine sand	1 m	-17 m	-18 m	22 kN/m³	40 º	0 kN/m²
9	Clay, solid	2 m	-18 m	-20 m	20 kN/m³	17,5 º	15 kN/m²
10	Fine sand	10,3 m	-20 m	-30.3 m	22 kN/m³	40 º	0 kN/m²

In order to calculate the bearing capacity of a pile, three components must be calculated. This looks like this in formula form:

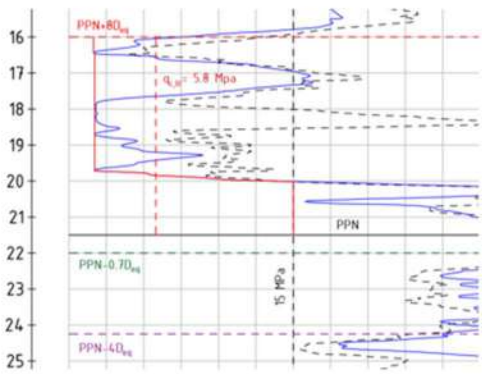
<u>Load capacity pile:</u> $= R_b + R_s - F_{nk}$

whereby
- R_b = Point bearing capacity;
- R_s = Shaft bearing capacity;
- F_{nk} = Negative adhesive.

Before the point bearing capacity can be determined, the maximum point resistance must first be calculated. The maximum point resistance is calculated as follows:

$q_{b;max;i} = \alpha_p * \beta * s * 0.5 * (\; + q_{cIII})$

In order to calculate the maximum point resistance, three trajectories must be determined. These ranges are determined based on the equivalent diameter. This is calculated using the formula below:



Bepalen trajecten qc,I - qc,II - qc,III

$D_{eq} = 1.13 * a *$ -> $1.13 * 0.61 * = 0.69$ m

Plotting the trajectories with respect to pile tip level yields the following mean cone resistances:

q_{cI} = 15 MPa
q_{cII} = 15 MPa
q_{cIII} = 5.8 MPa

The pile type determines the pile class factor αp, the form factor β and factor for the pile base shape.
Reductions are charged for the chosen pile type, partly due to the presence of a pile foot.

Filling in yields:

$q_{b;max;I} = 0.7 * 0.6 * 1 * 0.5 *(\; + 5.8) = 4.37$ MPa

The point bearing capacity is obtained by multiplying The maximum point resistance by the area of the pile tip/foot. In formula form:

$R_{b;cal;i} = A_{paalvoet} * q_{b;max;i}$ à $R_{b;cal;i} = 0.61*0.61*4.37 = 1625$ kN

Calculating shaft load capacity

The pile shaft provides a bearing capacity over a defined area, namely the contiguous area where the cone resistance is greater than 2 MPa up to and including the pile tip level (L_{pk}). The shaft resistance is calculated in the following way:

$R_{s;cal;i} = O_{s;gem} * \alpha_s * q_{c;gem} * L_{pk}$

In order to be able to calculate the shaft load capacity, the average shaft resistance must be determined over the length of the positive adhesive zone. The chosen pile/pile type determines the pile circumference and pile shaft class factor.

Filling in yields:

$R_{s;cal;i} = (4*0.4) * 0.012 * 8.3 * 7 = 1116$ kN

The combined bearing capacity (without negative adhesive) is determined as follows:

$R_{c;cal;i} = R_{b;cal;max} + R_{s;cal;i}$ -> $R_{c;cal;i} = 1625 + 1116 = 2741$ kN

To convert this value to the SLS, a safety factor must be applied. This safety factor is 1.26, since a rigid structure is assumed, for which one CPT has been applied. Negative adhesive does not apply.

The pile bearing capacity in the SLS is: **$R_{c;k}$ = 2741/1.26 = 2175 kN**

To convert the pile bearing capacity from the BGT to the UGT, a safety factor of 1.2 must be applied. The pile bearing capacity should be reduced by this factor.

The pile carrying capacity in the ULS is: **$R_{c;d}$ = 2175/1.2 = 1813 kN**

4.4 Results

In this part, the most important profiles of the structure are checked. First, we look into the deflection of the main beam and the cross beams. Furthermore, we will look into the moments of the structure and test whether these profiles can absorb the forces. Furthermore, we look into the support reactions to check whether the calculated pile carrying capacity is large enough.

4.4.1 Steel construction

The following assumptions are used to check the deflection:

- The maximum global deflection is 1/250th of the span.
- The maximum local deflection is 1/250th of the mutual distance between two support points.
- Maximum deflection section 65 meter: **260 mm**
- Maximum deflection section 60 meter: **240 mm**
- Maximum deflection cross beam: **28 mm**

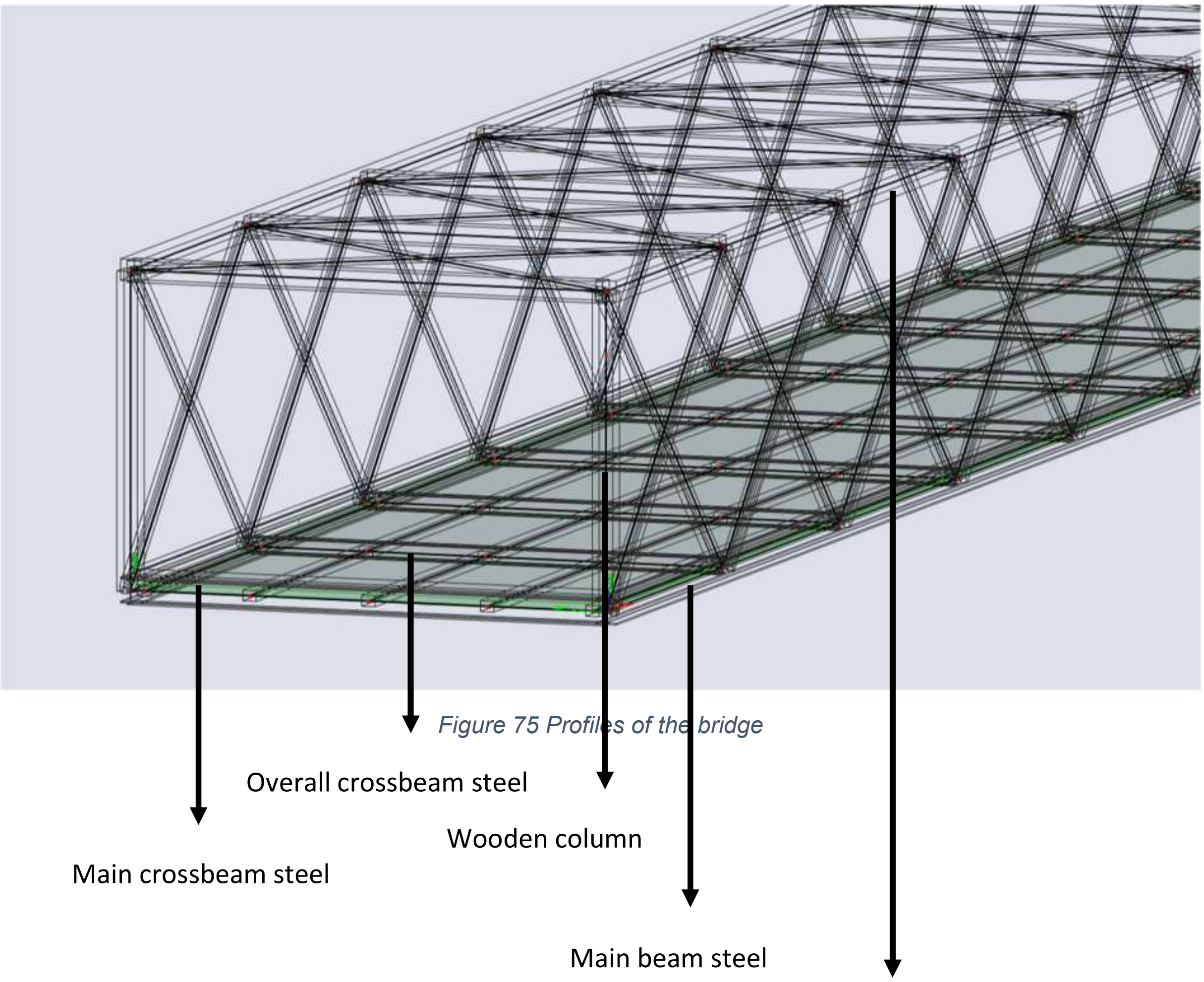


Figure 75 Profiles of the bridge

Deflection main beam:
The structure consists of eight main beams which are located above the bridge support points. The chosen profile is a HEB360 with a length of 4 times 65 meters and 4 times 60 meters with steel quality S355.

Span 65 meter

It is checked whether the global deflection of the construction meets the requirement of 1/250th of the span. For the main profile, this gives a maximum global deflection of 260 mm. The occurring deflection in the normative combination is 208.9 mm.

208.9 mm < 260 mm, satisfies!

Figure 76 Deflection span 65 meter

Span 60 meter

It is checked whether the global deflection of the construction meets the requirement of 1/250th of the span. For the main profile ,this gives a maximum global deflection of 240 mm. The occurring deflection in the normative combination is 118.5 mm.

118.5 mm < 240 mm, satisfies!

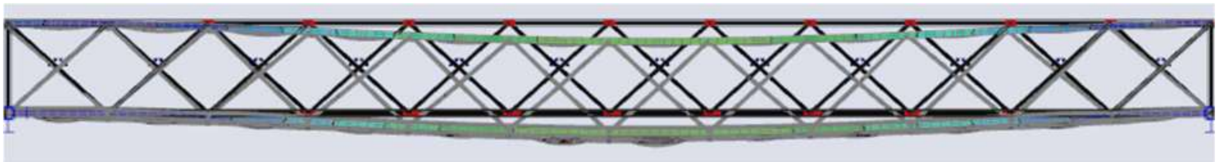


Figure 77 Deflection span 60 meter

Deflection cross beam:
The structure consists of 48 cross beams which are located above the bridge support points. The chosen profile is a HEA240 with a length of 7.0 meter with steel quality S355.

It is checked whether the global deflection of the construction meets the requirement of 1/250th of the span. For the main cross beam profile, this gives a maximum global deflection of 28 mm. The occurring deflection in the normative combination is 4.3 mm.

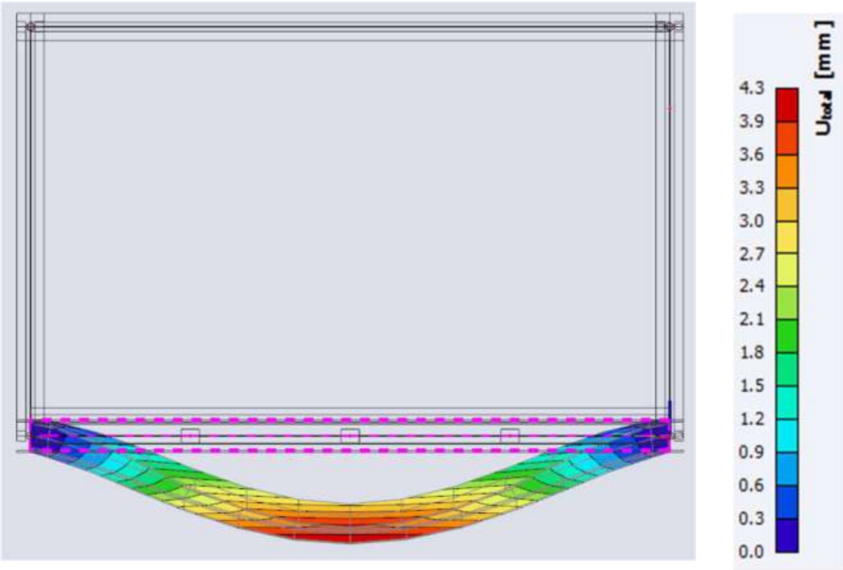


Figure 78 Deflection cross beam

4.3 mm < 28 mm, satisfies!

Deflection overall cross beam:
The structure consists of four cross beams which are located above the bridge supports points. The chosen profile is a HEB360 with a length of 7.0 meter with steel quality S355.

It is checked whether the global deflection of the construction meets the requirement of 1/250th of the span. For the overall cross beam profile, this gives a maximum global deflection of 28 mm. The occurring deflection in the normative combination is 22.2 mm.

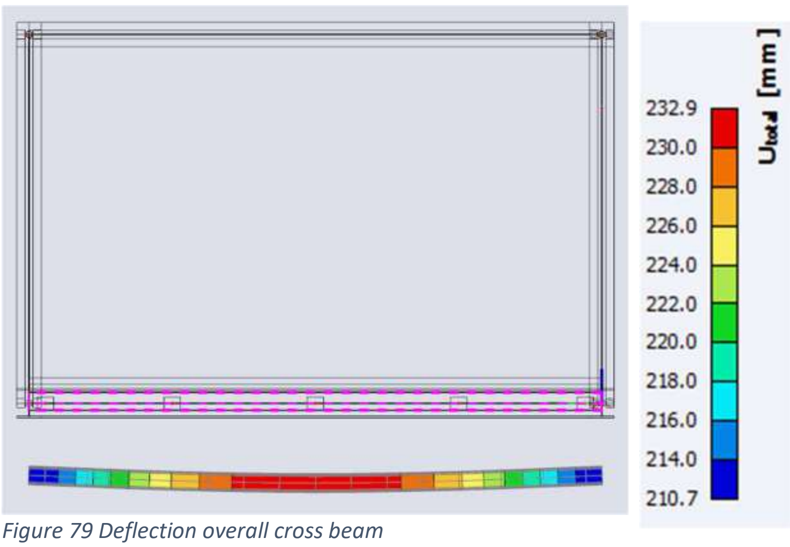


Figure 79 Deflection overall cross beam

22.2 mm < 28 mm, satisfies!

Maximum forces
Besides the deflection also the strength of the profiles has to be checked. The maximum forces in the main cross beam are displayed in the figures below. Figure 81 describes the maximum shear force, Figure 80 the maximum moment, and Figure 82 the maximum normal force.

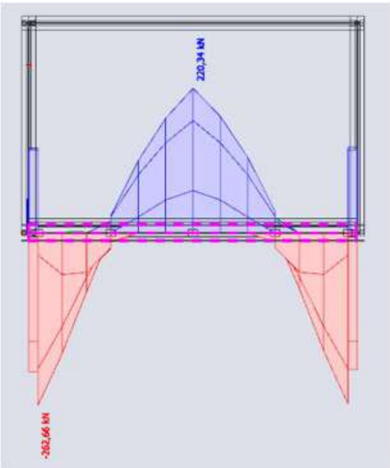


Figure 82 Normal force

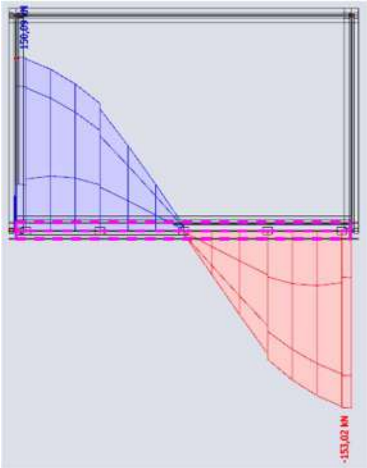


Figure 81 Shear force

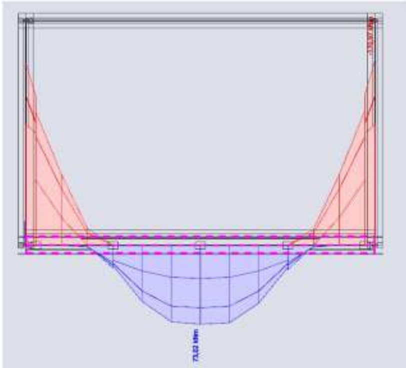


Figure 80 Moment

The main cross beam is a HEB360 profile. With the help of excel it is checked whether the profile can absorb the occurring forces. The results are shown in *Figure 83*. The unity check is smaller than 1, so the profile satisfies.

Hoofddwarsdrager										
Me;d;druk	73	kNm								
Me;d;trek	180,00	kNm								
					Ligger					
staal				*Toetsing veld druk*				*Toetsing veld trek*		
Fy;d	355	N/mm2		Med	180	kNm		Med	73	kNm
e	180	mm		Qstaal	75	N/mm2		Qstaal	30	N/mm2
IY-Y	4,32E+08	mm4		Toetsing	Voldoet	0,21		Toetsing	Voldoet	0,09
IX-X	1,01E+08	mm4								

Figure 83 Check main crossbeam

Checking overall cross beam

The overall cross beam is a HEA240 profile. The course of the forces is the same as in the main crossbeam. With the help of excel, it is checked whether the profile can absorb the occurring forces. The results are shown in *Figure 84*. The unity check is smaller than 1, so the profile satisfies.

Overall dwarsdrager										
Me;d;druk	122	kNm								
Me;d;trek	64,00	kNm								
					Ligger					
staal				*Toetsing veld druk*				*Toetsing veld trek*		
Fy;d	355	N/mm2		Med	64	kNm		Med	122	kNm
e	115	mm		Qstaal	95	N/mm2		Qstaal	181	N/mm2
IY-Y	7,76E+07	mm4		Toetsing	Voldoet	0,27		Toetsing	Voldoet	0,51
IX-X	2,77E+07	mm4								

Figure 84 Check overall cross beam

Checking main beam

The maximum field moment is 150 kNM and the maximum support moment is 840 kNm.

Hoofdligger										
Me;d;trek	150	kNm								
Me;d;druk	840,00	kNm								
Ligger										
staal				***Toetsing veld druk***				***Toetsing veld trek***		
Fy;d	355	N/mm2		Med	840	kNm		Med	150	kNm
e	180	mm		Qstaal	350	N/mm2		Qstaal	63	N/mm2
IY-Y	4,32E+08	mm4		Toetsing	Voldoet	0,99		Toetsing	Voldoet	0,18
IX-X	1,01E+08	mm4								

Figure 85 Check main beam

4.4.2 Wooden construction

In addition to the main steel parts, there are also wooden parts present in the construction. With the help of Excel the profiles are checked. First we look at the forces that occur in the wooden main beam at the top. Chosen is to work with wood D50.

Main beam

The mean beam is a wooden 300 x 300 mm beam. In figure X the maximum tensile and pressure forces are displayed. The maximum tensile force is 1811 kN and the maximum pressure force is 1760 kN. In Figure 86 the maximum field and support moments are displayed. The maximum field moment is 6.56 kNm and the maximum support moment is 18 kNm.

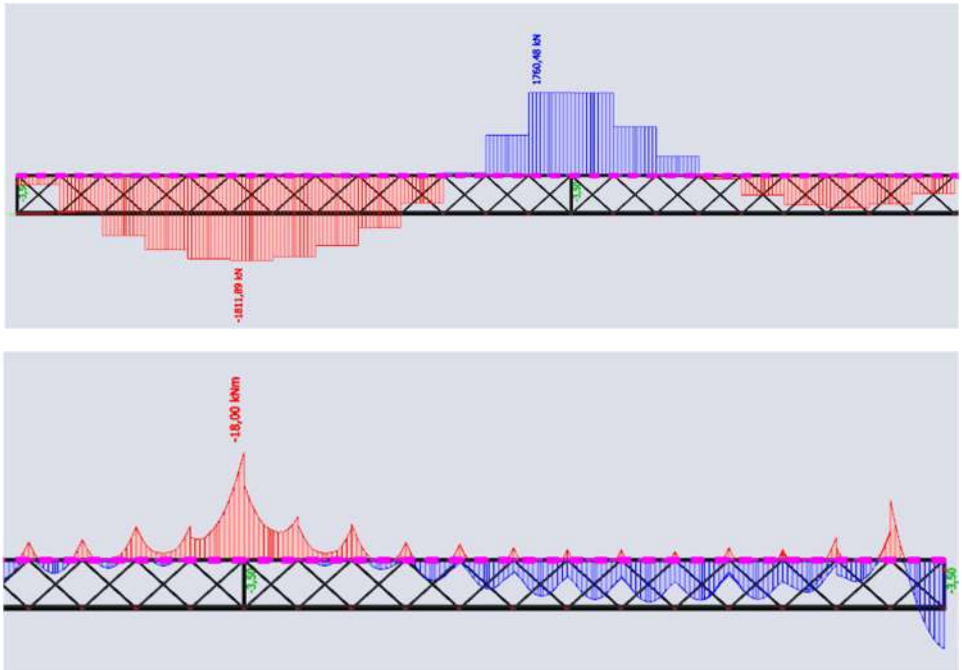


Figure 86 Maximum forces

The maximum forces are summed together in *Table 16*. The Unity check was determined on the basis of the maximum acting forces and the maximum absorbable forces. By working with the truss principle, the occurring moments are so low that they are sufficient

Table 16 Check main beam

Force #		**Unity Check**
Field moment	18 kNm	**Satisfies**
Support moment	6.56 kNm	**Satisfies**
Tensile force	1811 kN	**0.89**
Pressure force	1760 kN	**0.65**

Column
The bridge consists of 8 wooden columns with a dimension of 300 x 300 mm. In *Figure 87* the maximum pressure force is displayed.

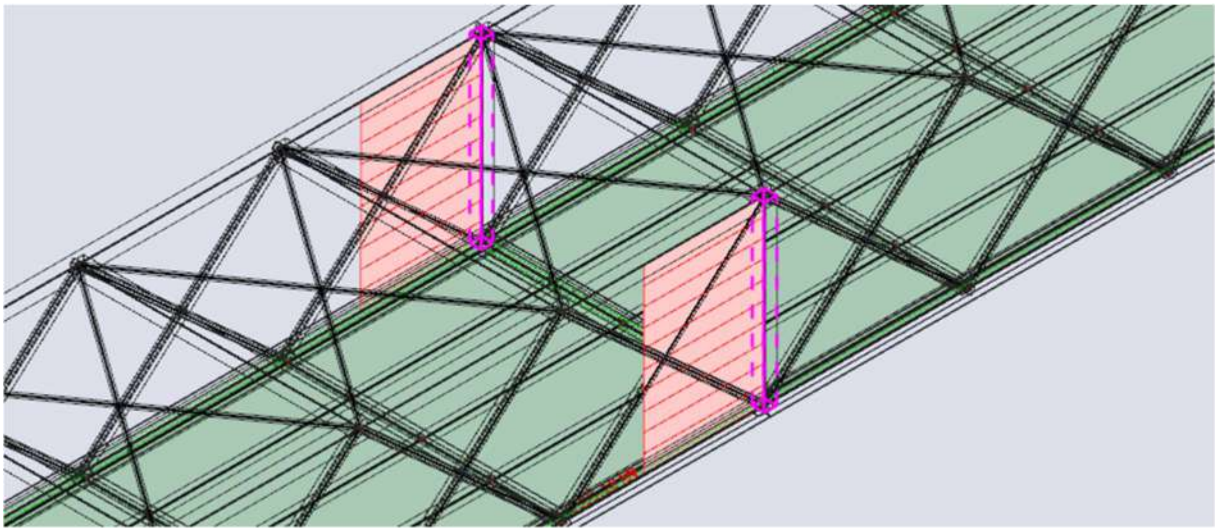


Figure 87 Maximum pressure force

Table 17 Check column

Force #		**Unity Check**
Pressure force	1395 kN	**0.69**

Diagonal
In order to absorb the forces generated by the loads, wooden trusses are modelled every 5 meters. In order not to make the dimensions of the wooden profiles too large, steel tension bars have been used between these crosses. However, not all tensile force will pass through these rods. The tensile force occurring in the wooden profile must therefore also be tested. The wooden profiles have a dimension of 100 x 150 mm. In Figure 88 the maximum force is displayed

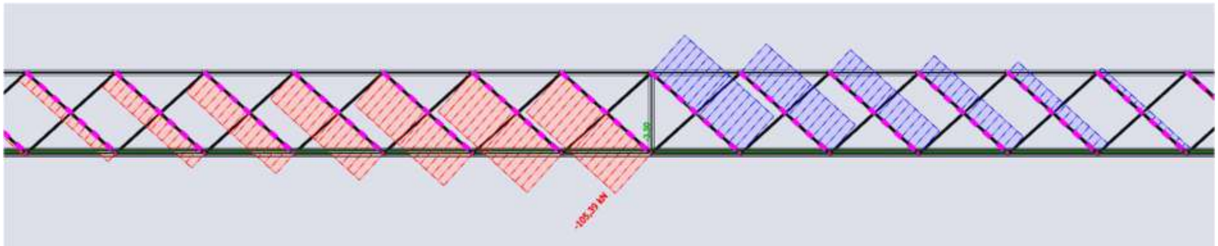


Figure 88 Maximum force diagonal

In Table 18 it is tested whether the profile can absorb the force.

Table 18 Check diagonal

Force #		**Unity Check**
Tensile force	105 kN	**0.23**

4.4.3 Support reactions

The support reactions in Y and Z direction are shown in *Table 19*.

Table 19 Check reaction forces

Support point #	**Force in Z-direction**	**Force in Y-direction**	**Unity Check**
Support 1/2	1075 kN each	129 kN each	**0.59**
Support 3/4	2837 kN each	200 kN each	**1.56**
Support 5/6	2252 kN each	185 kN each	**1.24**
Support 7/8	2923 kN each	235 kN each	**1.61**
Support 9/10	1085 kN each	133 kN each	**0.60**

In chapter 4.3 the pile carrying capacity in the ULS and SLS state is calculated. The calculated pile carrying capacity in the SLS for 1 pile is 1813 kN. The main plan was to place each section directly on two piles. The total carrying capacity is than 3626 kN. From table X we can conclude that for support points 3,4,5,6,7 and 8 two piles are not enough to carry the bridge. Therefore the bridge will be placed on two columns which will rest on the concrete base which is found on four piles. The maximum carrying capacity is then 7252 kN. This will give the following UC values:

Table 20 Check reaction forces 2.0

Support point #	**Force in Z-direction**	**Force in Y-direction**	**Unity Check**
Support 1/2	1075 kN each	129 kN each	**0.30**
Support 3/4	2837 kN each	200 kN each	**0.78**
Support 5/6	2252 kN each	185 kN each	**0.62**
Support 7/8	2923 kN each	235 kN each	**0.81**
Support 9/10	1085 kN each	133 kN each	**0.30**

5. Parking garage (Martijn Stok)

In this chapter the design of the parking garage at metro station Isolatorweg is explained.

5.1 Design

The last structure that will be made for the metro is a parking garage. The height of the metro station is 5.85 metres above NAP. The height of the surroundings is 0.34 metre above NAP. This means the total height of the station is 5.41 metre (Algemeen Hoogtebestand Nederland, n.d.). This is shown in Figure 89.

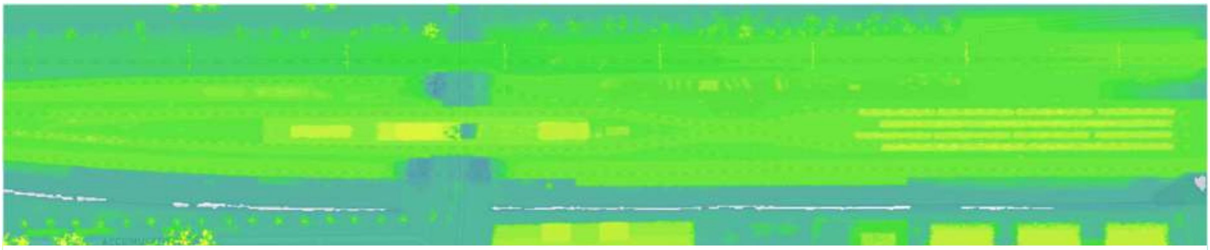


Figure 89 AHN (n.d.)

The height of a layer of the parking garage has a minimum of 2.30 metres (NEN, 2013). This does not include installations and the thickness of the floor that will be placed. This means that the parking garage can have only one layer under the current depot.

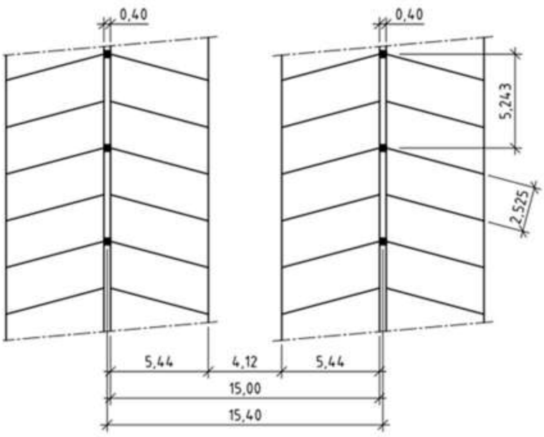


Figure 91 Parking spots long side parking garage

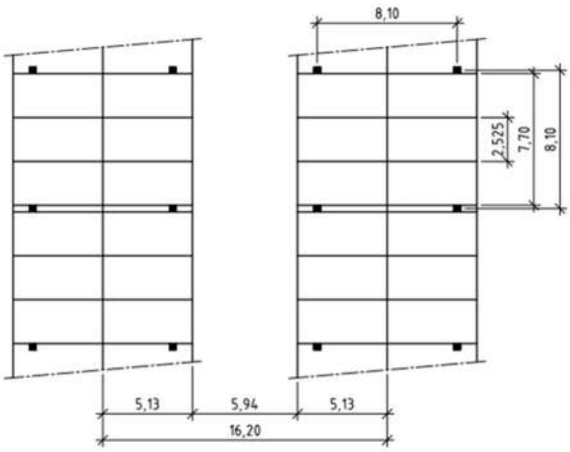


Figure 90 Parking spots short side parking garage

The length and width of the depot are approximately 240 and 27 metres (Afstandmeten, n.d.) and can be seen in figure 4. The parking garage under the depot will only be used for cars because the location of the station is very inconvenient for cyclists to come. The type of parking spots is shown in the left figure below (NEN, 2013) (Figure 90). For the sides (of 27 metres) the type of parking spots shown in the right picture is used (Figure 91).

With the dimensions in these figures the total dimensions of the depot can be calculated. In the width 3 rows of 5,44 metre plus 0.20 metre of the pole and 2 rows of 4,12 metre of the road in between. In total this leads to a width of 25,16 metres. For the sides the dimensions of the second figure are used. In the width this means 3 times 8,1 metre for 3 parking spots. This gives a total width of 24,3 metres. In the length the sides add a total of 5,13 plus 5,94 times 2 giving 22,14 metres. In the remaining length a total of 41 times two parking spots are built. Every two parking spots are 5,243 metres in total 5,243 metre. This leads to a total length of 215 metres and an additional 2,525 metre needs to be implemented because of the angle the parking spots have to the side profile. This is a total length of 239,665 metres. To this the widths of the walls needs to be added leading to a profile that comes close to the 27 and 40 metres of the depot. A sketch of the parking spots based on this data is shown in Figure 93.

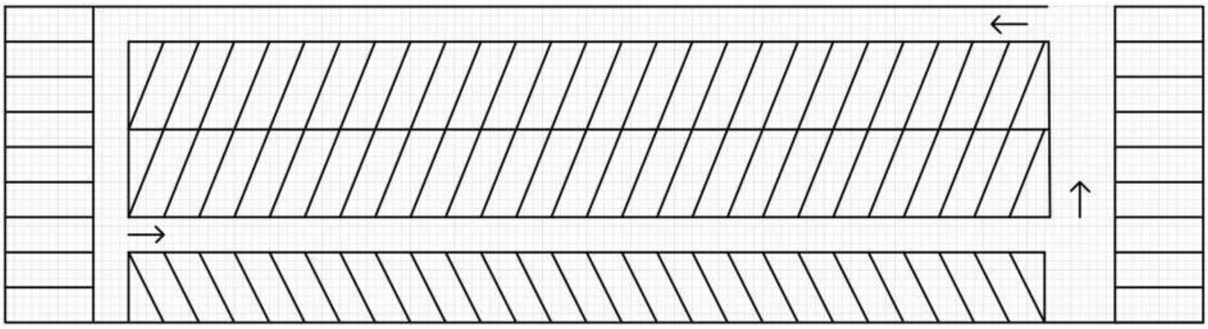


Figure 93 Parking spots

The location of the depot is shown in Figure 92 below. This is directly to the east of the metro station. The height of the parking garage is 5,85 metres as already explained at the beginning of this section.

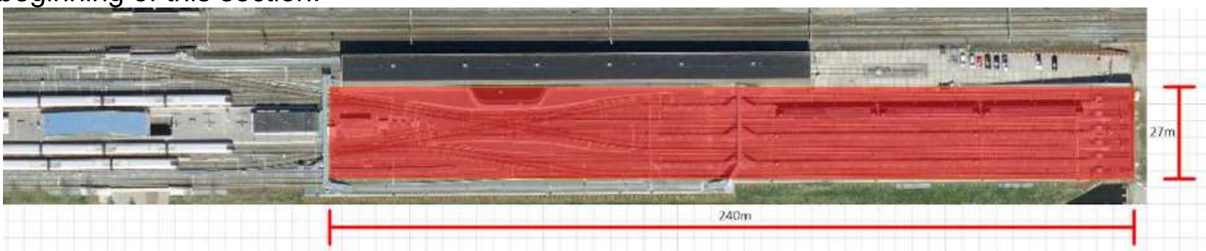


Figure 92 Location metro depot Isolatorweg

Figure 93 shows the illustration of the division of the parking garage. This illustration is not used for the exact number of parking spots with the correct dimensions of the separate parking spots.

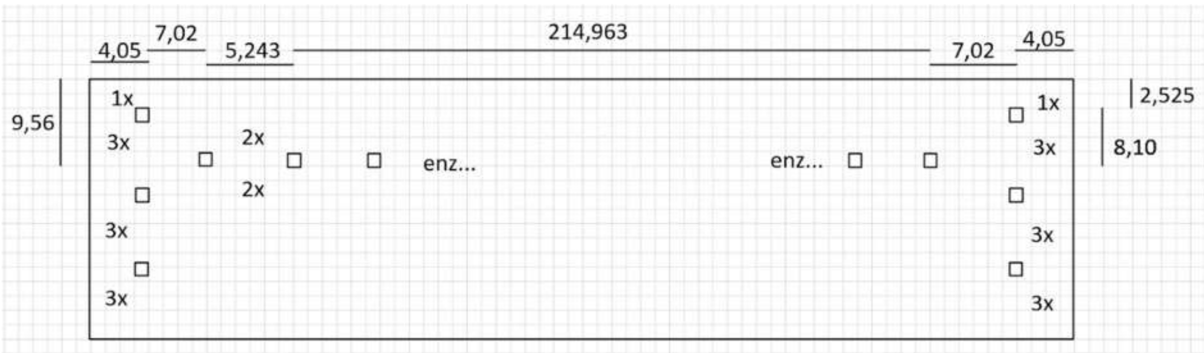


Figure 94 Sketch of locations for the columns

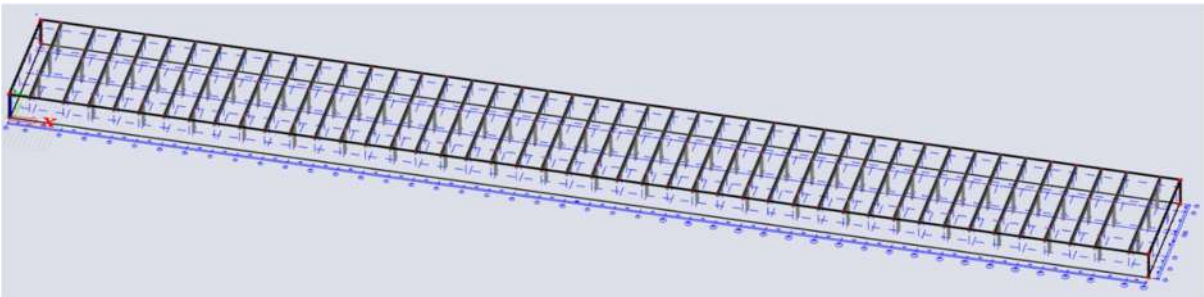


Figure 95 Structure metro depot without floor and roof

The two figures with the types of parking spots show where the columns need to be placed. The exact locations of the columns are in the figure from SCIA.

In the Figure 95 the structure is shown in SCIA but then without the ground floor and the roof. There is one main row of columns in order to have as much as possible space for car parking. At the sides there are more columns because the distance between the columns is higher there. There is also an extra row of columns in the south side of the figure. This slightly reduces the number of parking spots in the southern stripe. It is sufficient to have only half of the columns of the main row. This row of columns is added later after the sketch of the locations for the columns was made, based on the ultimate limit state with regard to deformations.

5.2 Loads

The loads for the self-weight are calculated via the SCIA model and are all shown table 21. The weight of a metro track is 55 kg/m, which is approximately 0,55 kN/m. In total there is 1350 metre of metro track and the total area is 27 times 240 is 6480 metre square. The load of the tracks is therefore 0,11 kN/m^2 (ProRail, 2013). The weight of a metro is 86.000 kg which is 860 kN (Treinreiziger, 2010). This is based on a different metro that is used in Amsterdam and therefore a higher weight is used. Another reason the weight is height is that the weight of a full metro is used. This is because the metro track that runs towards Amsterdam Central Station goes over the depot. The load of 860 kN is divided by the area of the metro which is 42 times 2,664 equals 7,7 kN/m^2. The load of the installations in the parking garage is estimated to be slightly higher than the load of the tracks of the depot. The loads for snow and wind are taken from the Quick Reference (TU Delft, 2016). The last is the load for the ground floor for the car parking based on the BS EN 1991-1-4:2005+A1:2010 of the Eurocode (NEN, 2013).

Table 21 Load cases

Description	Category	Magnitude
Roof	-	-
Self-weight	Permanent	From SCIA
Tracks of depot	Permanent	0,11 kN/m^2
Metro’s from depot	Variable	7,7 kN/m^2
Installations Parking Garage	Permanent	0,2 kN/m^2
Snow	Variable	0.7 kN/m^2
Ground floor	-	-
Self-weight	Permanent	From SCIA
Car parking	Variable	2,5 kN/m^2
Wind	Variable	0.69 kN/m^2

In the two figures below (Figure 97 and Figure 96) the ground profiles are shown which can determine the ground layers of the area. The two areas are very close to each other, so the ground profiles are very similar. The right profile is made smaller so it can be better compared with the profile on the left so that the depths of the data are on the same vertical spot. From 20 metres below the start of the measurement, which is at 0.850 metres above NAP. The total depth of the pile must be at least 21 metres below ground level.

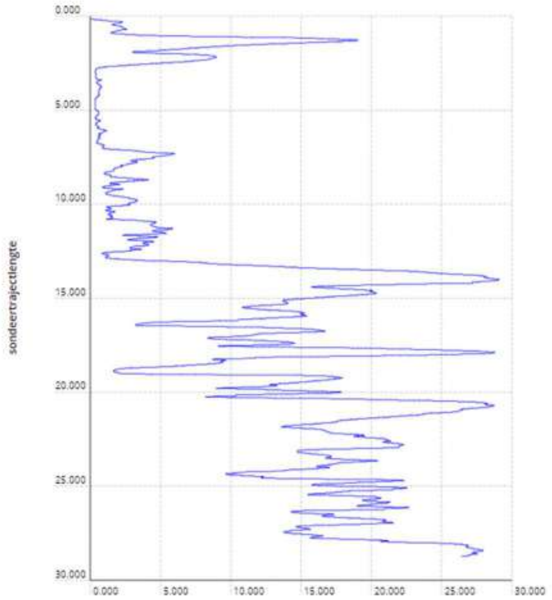


Figure 97 Ground profile 1

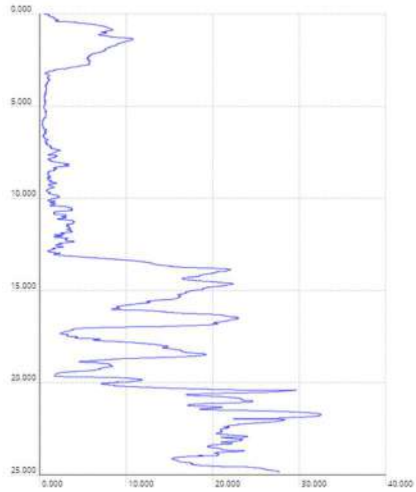


Figure 96 Ground profile 2

Based on the results of these figures the q_c values are determined. This is done in the next section.

5.3. Structure

The structure dimensions are based on the deflections in the structure. These are found in this section. Also the foundation pile dimensions are calculated in this section.

5.3.1 Deflections

The deflections that are most critical are over 12,15 metres (8,1 + 4,05) and there is a possible deflection of 0,004 times this is 48,6 mm (TU Delft, 2016). In the table 2 below the two load combinations are given and Figure 98 and Figure 99 show the results of the deformations in both combinations on the structure.

Table 22 Normative ULS and SLS combinations

	Normative combination
ULS	1.35*BG1 + 1.35*BG2 + 1.5*BG3 +1.5*BG4 + 1.5*BG5
SLS	1*BG1 + 1*BG2 + 1*BG3 + 1*BG4 + 1*BG5

For the ultimate limit state (see Table 22) the maximum deformation is 40,9 mm (Figure 98) while in the serviceability limit state gives a deformation of 28,7 mm (Figure 99). For the horizontal wind load a maximum deformation is 9 mm in the USL. The height there is 5,858 metre meaning that the maximum deformation could be 23,432 mm. This is not reached here as well with this construction.

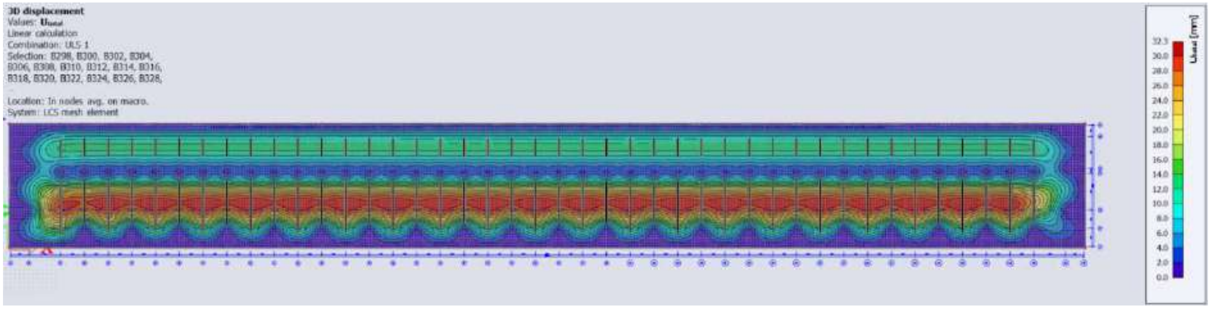


Figure 98 Deformations Ultimate Limit State (ULS)

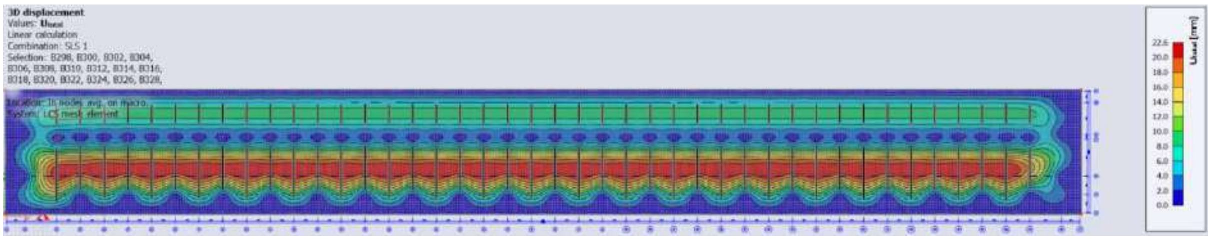


Figure 99 Deformation Serviceability Limit State (SLS)

In these two figures the dimensions of the beams are 500 x 800 millimetres and the dimensions of the columns are 500 x 500 millimetres. The walls have a thickness of 300 millimetres. The columns, beams and walls are all made with C30/37 concrete as it said earlier. Furthermore there is both a roof on top of the beams and a floor at the bottom both 300 millimetre thick and made of C30/37.

5.3.2. Foundation

The piles for the foundation are calculated with the point (R_b) and shaft (R_s) bearing capacity summed up. First the point bearing capacity is calculated. A diameter of 0,6 by 0,6 is used in the calculation. This gives a diameter of D_{eq} = 1.13 * a = 1.13 * 0.6 = 0.678. Then the following data is needed: q_{cI} = 16 MPa, q_{cII} = 13 MPa, q_{cIII} = 5,6 MPa, α_p = 0.7, β = 1, s = 1.0. The PBC is now $q_{b;max;i}$ = α_p * β * s * 0.5 * ((q_{cI} + q_{cII}) / 2 + q_{cIII}), with α_p = 0.7, β = 1, s = 1.0 per square metre and total R_b = A * $q_{b;max;i}$ = (0.7 * 1.0 * 1.0 * 0.5 * ((16 + 13) / 2 + 5,6)) *0.6 * 0.6 = 2583 kN.

The SBC is calculated with $R_{s;cal;i}$ = $O_{s;gem}$ * α_s * $q_{c;gem}$ * L_p and is $R_{s;cal;i}$ = (4*0.6) * 0.01 * 11,53 * 8 = 6030 kN. This is then divided by a safety factor for the serviceability limit state of 1,26 and that gives 4786 kN.

5.4. Results

Table 23 Required reinforcement beams and columns

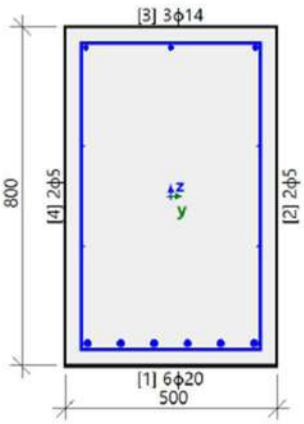
	Asz,max+ (mm^2)	Asz,max- (mm^2)	Asy,max+ (mm^2)	Asy,max- (mm^2)
Beam	424	1860	13	13
Column	6	0	0	528

With the data from this table the number of bars and the diameter of these bars are calculated. The results of reinforcement of the beams are shown below. In the results it is also shown whether the reinforcement is smaller than the maximum reinforcement. This is shown in Figure 101, Figure 100 and Figure 102.

Beam B326 — Rectangle (800; 500)

EC EN 1992-1-1:2004/AC:2008 — Section 8 [dx = 7.62 m]

Member length: L = 16.2 m
Buckling y-y: L_y = 16.2 m (sway)
Buckling z-z: L_z = 16.2 m (sway)



Concrete: C30/37
Bi-linear stress-strain diagram
Exposure class: XC3

Longitudinal reinforcement: B 500B
Bi-linear with an inclined top branch
6ϕ20+3ϕ14+4ϕ5 (2425 mm^2)
ρ_l = 0,606 % (19 kg/m)

Shear reinforcement: B 500B
Bi-linear with an inclined top branch
2L ϕ8/200 (101 mm^2)
ρ_w = 0,101 % (3.95 kg/m)

Cover (stirrup)
Top: 35 mm
Bottom: 35 mm
Sides: 35 mm

Figure 101 Reinforcement beam

Longitudinal reinforcement

	Basic	Additional	d_1 [mm]	$A_{s,ult}$ [mm^2]	$A_{s,min}$ [mm^2]	$A_{s,req}$ [mm^2]	$A_{s,prov}$ [mm^2]	s_{min} [mm]	s_{max} [mm]	Status
[1]	6ϕ20	---	53	1860	553	1860	1885	59	79	OK
								≥37	≤350	
[2]	2ϕ5	---	46	13	-	13	39	216	236	OK
								≥37	≤350	
[3]	3ϕ14	---	50	13	-	13	462	186	200	OK
								≥37	≤350	
[4]	2ϕ5	---	46	13	-	13	39	216	236	OK
								≥37	≤350	
ΣY	4ϕ5	---				26	79			
ΣZ	3ϕ14+6ϕ20	---				1873	2347			
Σ	4ϕ5+3ϕ14+6ϕ	---		$A_{s,min}$=553 mm^2≤		1899	2425	≤$A_{s,max}$=16000 mm^2		OK

Figure 100 Longitudinal reinforcement beam

Shear reinforcement

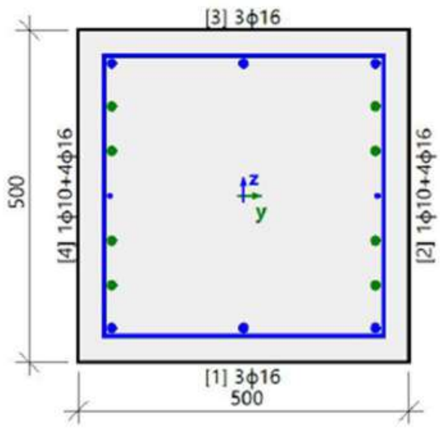
Stirrups	$A_{swm,req}$ [mm^2/m]	$A_{swm,prov}$ [mm^2/m]	$A_{swm,max}$ [mm^2/m]	Status
ϕ8/200mm, (ns=2)	438	503	6072	OK

Figure 102 Shear reinforcement beam

Then the results of the column are shown in Figure 103, Figure 105 and Figure 104.

Column B404	**Rectangle (500; 500)**
EC EN 1992-1-1:2004/AC:2008	Section 0 [dx = 0 m]

Member length: L = 5.86 m
Buckling y-y⊥ L_y = 6.76 m (sway)
Buckling z-z⊥ L_z = 6.06 m (sway)



Concrete: C30/37
Bi-linear stress-strain diagram
Exposure class: XC3

Longitudinal reinforcement: B 500B
Bi-linear with an inclined top branch
14ϕ16+2ϕ10 (2972 mm^2)
ρ_l = 1,189 % (23.3 kg/m)

Shear reinforcement: B 500B
Bi-linear with an inclined top branch
2L ϕ8/150 (101 mm^2)
ρ_w = 0,134 % (5.26 kg/m)

Cover (stirrup)
Main: 35 mm

Figure 103 Reinforcement column

Longitudinal reinforcement

	Basic	Additional	d_1 [mm]	$A_{s,ult}$ [mm^2]	$A_{s,min}$ [mm^2]	$A_{s,req}$ [mm^2]	$A_{s,prov}$ [mm^2]	s_{min} [mm]	s_{max} [mm]	Status
[1]	3ϕ16	---	51	3	-	3	603	183	199	OK
								≥37	≤350	
[2]	1ϕ10	4ϕ16	51	28	-	28	883	48	67	OK
								≥37	≤350	
[3]	3ϕ16	---	51	3	-	3	603	183	199	OK
								≥37	≤350	
[4]	1ϕ10	4ϕ16	51	500	500	500	883	48	67	OK
								≥37	≤350	
ΣY	6ϕ16	---				6	1206			
ΣZ	2ϕ10	8ϕ16				528	1766			
Σ	2ϕ10+6ϕ16	8ϕ16		$A_{s,min}$=500 mm^2≤		534	2972	≤$A_{s,max}$=10000 mm^2		OK

Figure 105 Longitudinal reinforcement column

Shear reinforcement

Stirrups	$A_{swm,req}$ [mm^2/m]	$A_{swm,prov}$ [mm^2/m]	$A_{swm,max}$ [mm^2/m]	Status
ϕ8/150mm, (ns=2)	503	670	6072	OK

Figure 104 Longitudinal reinforcement column

With Table 24 the dimensions of the concrete foundation piles can be determined. In the previous section the capacity of a 0,7 by 0,7 metre pile is calculated (4786 kN). This is higher than the maximum force of the columns in the south of the depot. These columns can be used for the foundations here. For the north wall with the piles of this dimension 16 piles are needed. For the south wall this number is just above 10 and therefore 11 piles is over dimensioned. If the same calculation is done but then for 0,6 by 0,6 columns a capacity of 3767 kN is found. For the south wall this means 13 piles give enough capacity. These piles can also be used for the columns in the middle. For the columns at the sides 0,5 by 0,5 is sufficient as these piles have a capacity of 2860 kN.

Table 24 Results maximum foundation forces

	Force (min)	Force (plus)	Force (middle / total)	Pile dimensions
North wall	-	-	76407	0,7*0,7 (16 piles)
South wall	-	-	48170	0,6*0,6 (13 piles)
Columns middle	3250	3736	-	0,6*0,6
Colomns sides	1286	2560	2286	0,5*0,5
Columns south	3780	4140	-	0,7*0,7

6. Bridge Isolatorweg

In this chapter, the design of the bridge next to the Isolatorweg-station will be elaborated. The responsible person of the structural engineering group for the bridge is Tjeerd Thuss. Firstly, the design will be explained. In the second paragraph will the loads be described and in the last two paragraphs will the structure itself and the foundation be elaborated.

6.1. Design

After the metro-station at the Isolatorweg in the direction of the central station of Amsterdam, the metro-line will go underground. However, according to the planned alignment for the new metro track, this will happen after 350 metres from the Isolatorweg-station.
The existing station at the Isolatorweg satisfies all the desired wishes of a metro station. The station is just slightly more than twenty years old, so a new station is not needed. The same holds for the depot next to the Isolatorweg (see: Figure 1). When this depot will be kept, the distance to cover above ground level is just 45 metres.

Figure 106: area of Isolatorweg-station and Contactweg-road

However, in the area of this distance, the road “Contactweg” and a small ditch cross the new metro track (see figure 106), so the track has to go over a bridge. In cooperation with the hydraulic engineering group, it is made clear that the part of the track when it moves underground belongs to their group and the other part above ground level to the structural engineering group, so the focus of this part will be only on the bridge *before it descends.*

The design of the bridge will be based on the bridge next to it for the train. The part of the bridge which spans the road will be supported by three walls at both sides and the part of the bridge which spans the ditch and before the bridge descends will be supported by columns. (see figure 107) The track for the metro will be a slab track. The deck itself will be 600 mm thick and 10 meters wide. On top of the bridge are walls of one meter wide and 600 mm high. The bearing walls at both sides of the road are each three meters wide, 3.75 meters high and 500 mm thick. The columns are one meter larger, as they are standing in the ditch and they have a diameter of one meter. The structure is modelled in a longer way than it actually is by 15 meters to the east side, to compensate for non-symmetrical loads on the columns. The total of bridge deck thickness, slab track thickness and walls/columns height is exactly enough to be in the correct alignment with the metro depot (AHN, z.d.)

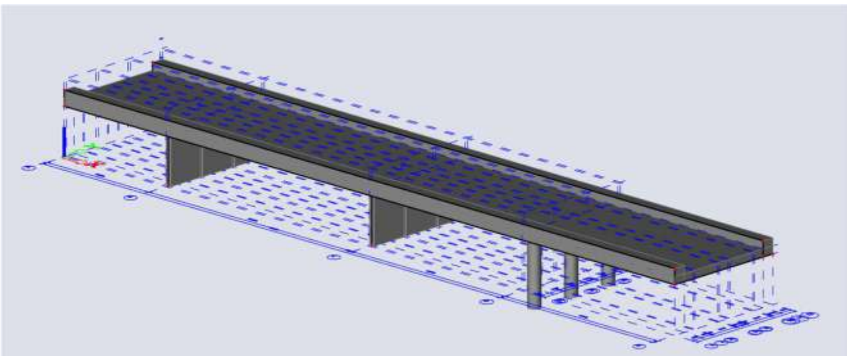


Figure 107: design of Isolatorweg-bridge

6.2. Loads

There aren't a lot of loads working on the bridge: only its own self weight and the loads of the passing metro's. The self-weight of the structure will be calculated with use of SCIA. However, the slab track will not be modelled in SCIA, so this permanent weight has to be calculated. All permanent and variable loads are summarised in table 25.

Table 25: loads on the bridge

Description	Category	Magnitude
Self weight	Permanent	Determined by SCIA
Slab track	Permanent	4.25 kN/m^2
Metro	Variable	5.8 kN/m^2
Other objects	Permanent	0.35 kN/m^2
Snow	Variable	0.70 kN/m^2
Wind	Variable	0.69 kN/m^2

Now, an elaboration for each load will be given:

Self-weight

The self-weight of the bridge is automatically calculated by SCIA.

Slab tracks

The tracks on top of the bridge will be slab tracks. For both directions there will be one slab track, so in total two slab tracks on the bridge. According to Esveld (2013), the weight of a specific new kind of slab track (the Japanese Shinkansen slab track) is approximately five tonnes for a slab with the sizes 4.93 x 2.34 x 0.19, so the specific weight would be 4.25 kN/m^2. Shinkansen slab tracks are mostly used in Japan for high speed trains, but will also suffice for these metro tracks. The load will be distributed over the 2.34 width.

Metro

The variable load of a passing metro is calculated as follows: for every current metro which follows one of the lines from Isolatorweg, the total weight of the vehicle is divided by its width and length. According to this strategy, the "series M4" has the highest distributed load: (weight of 48 t / length of 30.9 m / width of 2.65 m =) 5.8 kN/m^2. The load will be distributed over the width of a metro (2.65 m)

Other objects

On both sides of the bridge is a load of 0.35 kN/m^2 added. This load will be distributed on the complete width of the side walls, which have a width of 1 mete.

Snow

According to the Eurocode, the variable load of snow for The Netherlands has a value of 0.7 kN/m^2 (TU Delft, 2016).

Wind

For the wind load, a value of 0.69 kN/m^2 is used, just as for the other bridge structures.

All these loads have to be calculated in certain combinations for the Ultimate Limit State (ULS) and Serviceability Limit State (SLS). The normative combinations are the following two shown in 27.

Table 26: normative load combinations

	Normative combination
ULS	1.35*BG1 + 1.35*BG2 + 1.5*BG3 +1.5*BG4 + 1.5*BG5
SLS	1*BG1 + 1*BG2 + 1*BG3 + 1*BG4 + 1*BG5

Foundation

For the useful values for the foundation, the following soil types (see figure 107) are found with the use of DINOloket (n.d.).

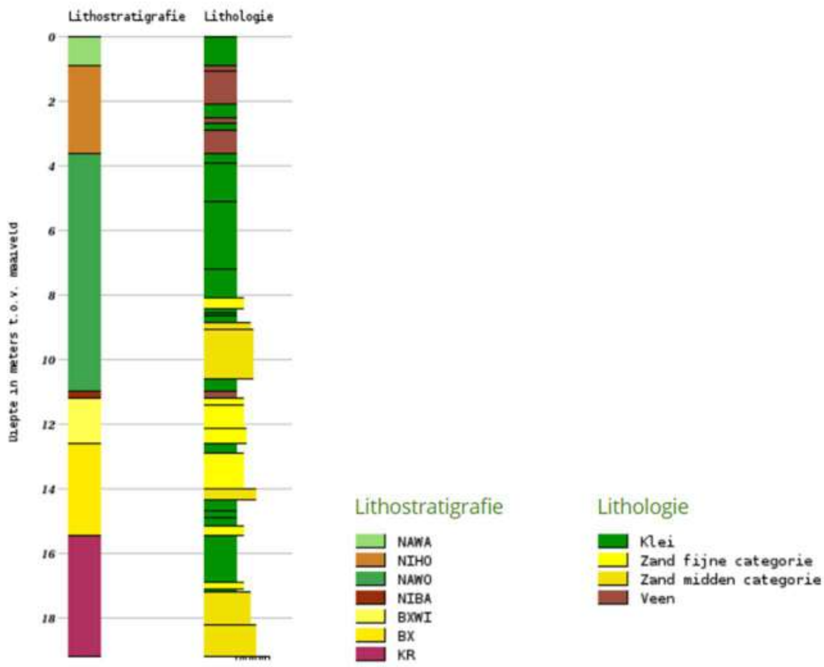


Figure 108: types of soil around the Isolatorweg

6.3. Structure

Deflections

First of all, the deflections of the structure are being analysed with the SCIA model. For the deflections, the SLS-combination has to be used. A floor should have a maximum deflection of 1/250 * L. The bridge part which spans 20 meters is the most nominative, as the maximum deflection will be 80 mm for this case. The occurring vertical deflections are shown in figure 109.

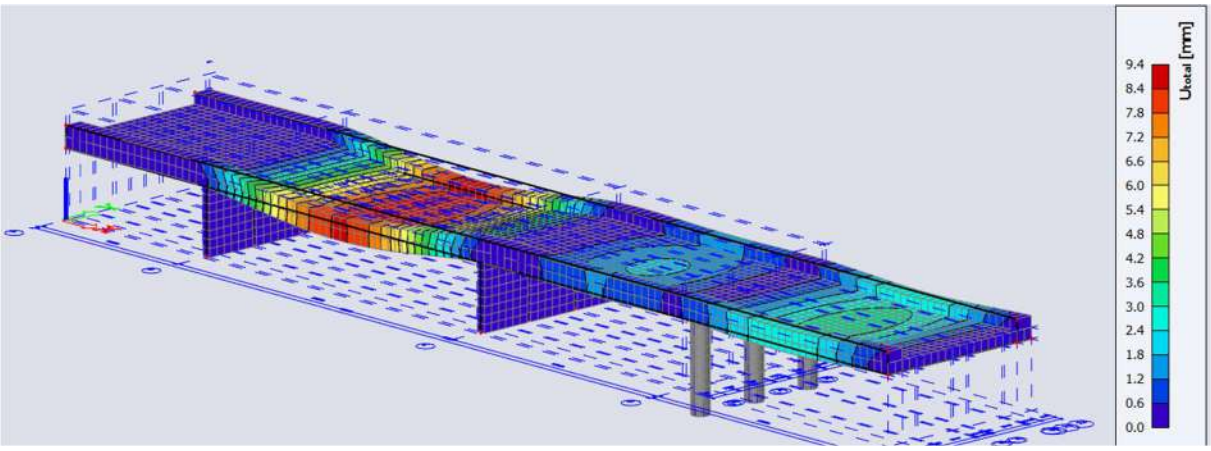


Figure 109: deflections of the bridge

As the figure shows, the maximum deflection will be in the part of the biggest span and will be 9.4 mm at maximum. This is approximately 8 times as small as the maximum allowed deflection (UC = 0.12), so the deflection of the structure is sufficient.

Strength

As the whole structure is made of a concrete with strength C30/37, the stresses in the structure are not allowed to be more than 30/1.5 = 20 N/mm^2. For the strength of a structure, the nominative ULS-combination has to be used. The results of the calculation of the SCIA model are shown in figure 110.

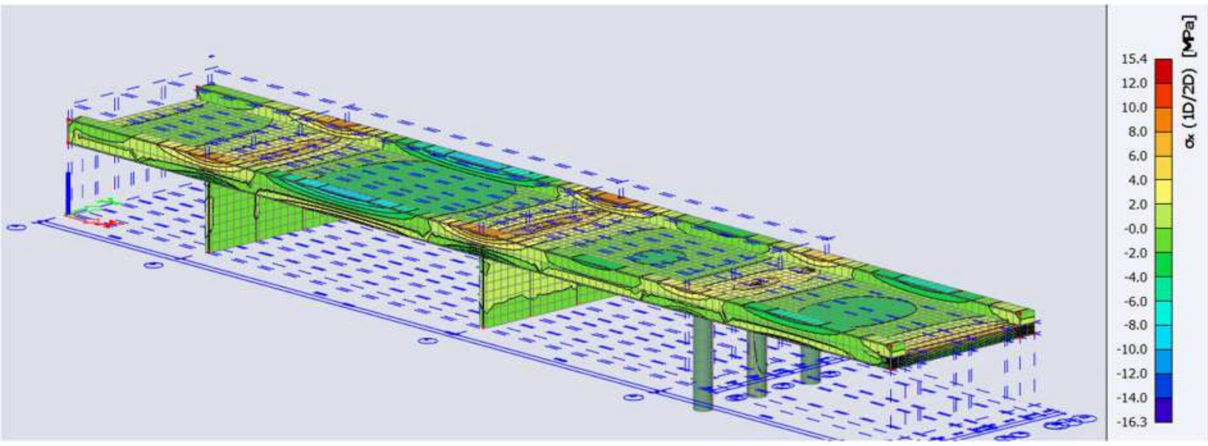


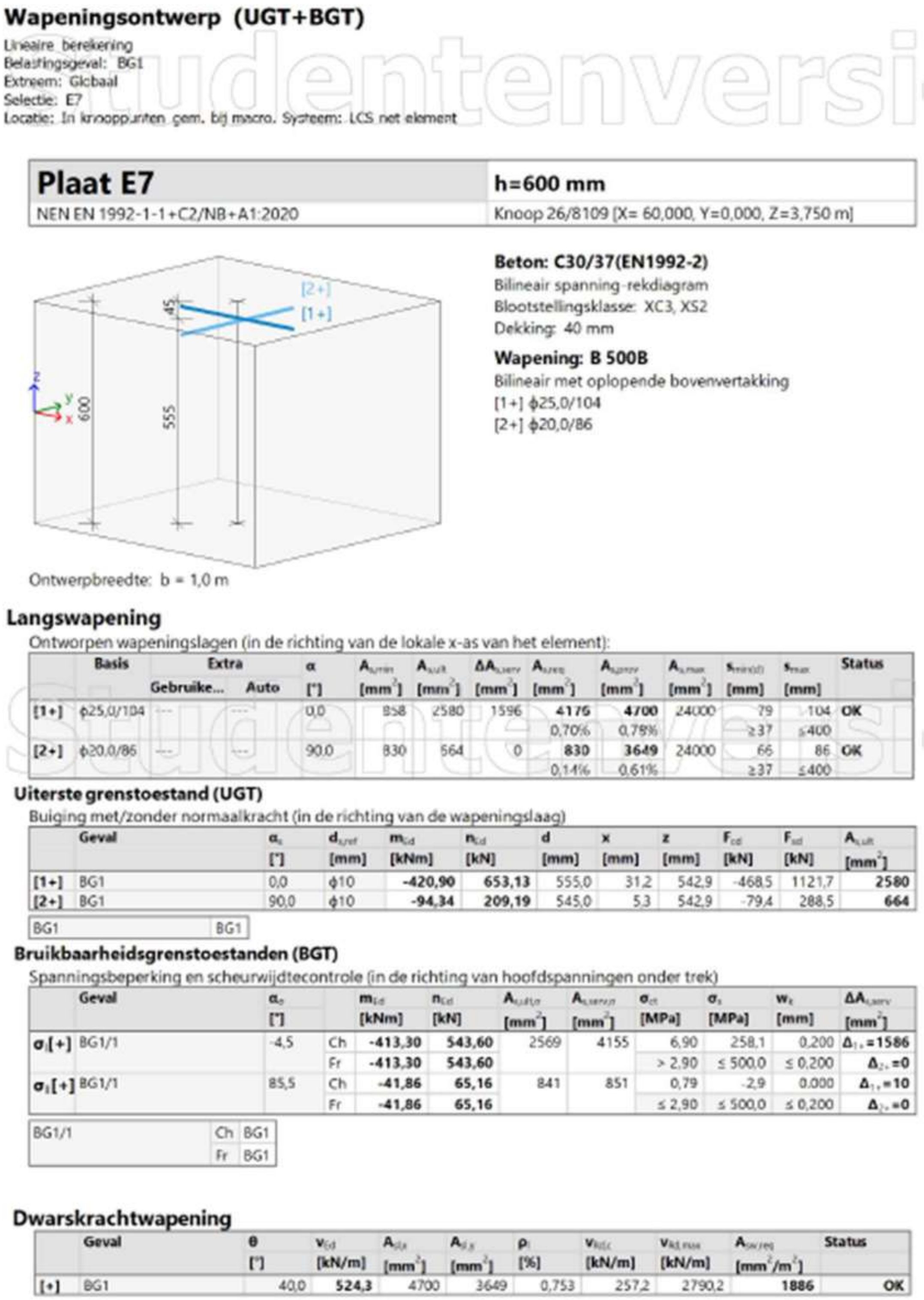
Figure 110: stresses in the bridge

Nowhere in the whole structure are the stresses more than the limit value. The maximum unity check of the structure for the strength will be 15.4/20 = 0.77. This is very sufficient.

Reinforcement

For the whole structure, reinforcement is needed. For each element (bridge deck, walls, columns), the reinforcement will be shown.

Bridge deck



Wapeningsontwerp (UGT+BGT)

Lineaire berekening
Belastingsgeval: BG1
Extreem: Globaal
Selectie: E7
Locatie: In knooppunten gem. bij macro. Systeem: LCS net element

Plaat E7	**h=600 mm**
NEN EN 1992-1-1+C2/NB+A1:2020	Knoop 26/8109 [X= 60,000, Y=0,000, Z=3,750 m]

[2+]
[1+]
45
600
555
z
y
x

Beton: C30/37(EN1992-2)
Bilineair spanning-rekdiagram
Blootstellingsklasse: XC3, XS2
Dekking: 40 mm

Wapening: B 500B
Bilineair met oplopende bovenvertakking
[1+] ϕ25,0/104
[2+] ϕ20,0/86

Ontwerpbreedte: b = 1,0 m

Langswapening

Ontworpen wapeningslagen (in de richting van de lokale x-as van het element):

	Basis	Extra		α	$A_{s,min}$	$A_{s,ult}$	$\Delta A_{s,serv}$	$A_{s,req}$	$A_{s,prov}$	$A_{s,max}$	$s_{min(d)}$	s_{max}	Status
		Gebruike...	Auto	[°]	[mm²]	[mm²]	[mm²]	[mm²]	[mm²]	[mm²]	[mm]	[mm]	
[1+]	ϕ25,0/104	---	---	0,0	858	2580	1596	**4176**	**4700**	24000	79	104	**OK**
								0,70%	0,78%		≥37	≤400	
[2+]	ϕ20,0/86	---	---	90,0	830	564	0	**830**	**3649**	24000	66	86	**OK**
								0,14%	0,61%		≥37	≤400	

Uiterste grenstoestand (UGT)

Buiging met/zonder normaalkracht (in de richting van de wapeningslaag)

	Geval	α_s	$d_{s,ref}$	m_{Ed}	n_{Ed}	d	x	z	F_{cd}	F_{sd}	$A_{s,ult}$
		[°]	[mm]	[kNm]	[kN]	[mm]	[mm]	[mm]	[kN]	[kN]	[mm²]
[1+]	BG1	0,0	ϕ10	**-420,90**	**653,13**	555,0	31,2	542,9	-468,5	1121,7	**2580**
[2+]	BG1	90,0	ϕ10	**-94,34**	**209,19**	545,0	5,3	542,9	-79,4	288,5	**664**

BG1	BG1

Bruikbaarheidsgrenstoestanden (BGT)

Spanningsbeperking en scheurwijdtecontrole (in de richting van hoofdspanningen onder trek)

	Geval	α_σ		m_{Ed}	n_{Ed}	$A_{s,ult,cr}$	$A_{s,serv,cr}$	σ_{ct}	σ_s	w_k	$\Delta A_{s,serv}$
		[°]		[kNm]	[kN]	[mm²]	[mm²]	[MPa]	[MPa]	[mm]	[mm²]
σ_I[+]	BG1/1	-4,5	Ch	**-413,30**	**543,60**	2569	4155	6,90	258,1	0,200	**Δ_{1+}=1586**
			Fr	**-413,30**	**543,60**			> 2,90	≤ 500,0	≤ 0,200	**Δ_{2+}=0**
σ_{II}[+]	BG1/1	85,5	Ch	**-41,86**	**65,16**	841	851	0,79	-2,9	0,000	**Δ_{1+}=10**
			Fr	**-41,86**	**65,16**			≤ 2,90	≤ 500,0	≤ 0,200	**Δ_{2+}=0**

BG1/1	Ch	BG1
	Fr	BG1

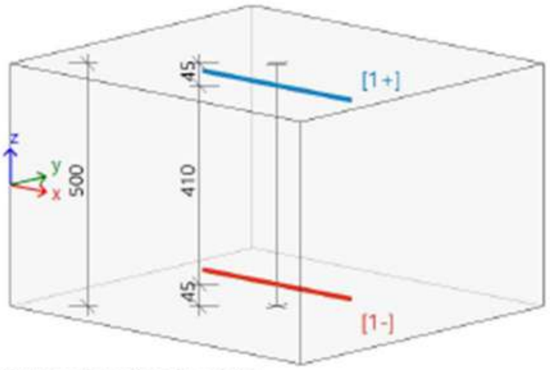
Dwarskrachtwapening

	Geval	θ	v_{Ed}	$A_{sl,x}$	$A_{sl,y}$	ρ_l	$v_{Rd,c}$	$v_{Rd,max}$	$A_{sw,req}$	Status
		[°]	[kN/m]	[mm²]	[mm²]	[%]	[kN/m]	[kN/m]	[mm²/m²]	
[+]	BG1	40,0	**524,3**	4700	3649	0,753	257,2	2790,2	**1886**	**OK**

Figure 111: reinforcement of the bridge deck

Wall

Wand E6	h=500 mm
NEN EN 1992-1-1+C2/NB+A1:2020	Knoop 377/186 [X= 30,000, Y=9,375, Z=3,750 m]



Ontwerpbreedte: b = 1,0 m

Beton: C30/37(EN1992-2)
Bilineair spanning-rekdiagram
Blootstellingsklasse: XC3, XS2
Dekking: 40 mm

Wapening: B 500B
Bilineair met oplopende bovenvertakking
[1+] ϕ10,0/150
[1-] ϕ10,0/150

Langswapening

Ontworpen wapeningslagen (in de richting van de lokale x-as van het element):

	Basis	Extra Gebruike...	Extra Auto	α [°]	$A_{s,min}$ [mm²]	$A_{s,ult}$ [mm²]	$\Delta A_{s,serv}$ [mm²]	$A_{s,req}$ [mm²]	$A_{s,prov}$ [mm²]	$A_{s,max}$ [mm²]	$s_{min(c)}$ [mm]	s_{max} [mm]	Status
[1+]	ϕ10,0/150	---	---	0,0	---	496	0	**496**	**524**	---	140	150	**OK**
								0,10%	0,10%		≥37	≤400	
[1-]	ϕ10,0/150	---	---	0,0	---	338	0	**338**	**524**	---	140	150	**OK**
								0,07%	0,10%		≥37	≤400	

Uiterste grenstoestand (UGT)

Buiging met/zonder normaalkracht (in de richting van de wapeningslaag)

	Geval	α_s [°]	$d_{s,ref}$ [mm]	m_{Ed} [kNm]	n_{Ed} [kN]	d [mm]	x [mm]	z [mm]	F_{cd} [kN]	F_{sd} [kN]	$A_{s,ult}$ [mm²]
[1+]	BG1	0,0	ϕ10	**-14,08**	**362,21**	455,0	0,0	409,5	-10000,0	-135,2	**496**
[1-]	BG1	0,0	ϕ10	**-14,08**	**362,21**	455,0	0,0	409,5	-10000,0	-146,8	**338**

BG1	BG1

Bruikbaarheidsgrenstoestanden (BGT)

Spanningsbeperking en scheurwijdtecontrole (in de richting van hoofdspanningen onder trek)

	Geval	α_σ [°]		m_{Ed} [kNm]	n_{Ed} [kN]	$A_{s,ult,\sigma}$ [mm²]	$A_{s,serv,e}$ [mm²]	σ_{ct} [MPa]	σ_s [MPa]	w_k [mm]	$\Delta A_{s,serv}$ [mm²]
$\sigma_I[+]$	BG1/1	33,3	Ch	**-43,69**	**28,33**	347	347	1,09	-4,8	0.000	$\Delta_{1+}=0$
			Fr	**-43,69**	**28,33**			≤ 2,90	≤ 500,0	≤ 0,200	$\Delta_{2+}=0$
$\sigma_{II}[+]$	BG1/1	123,3	Ch	**-65,89**	**-578,81**	149	149	0,42	-14,9	0.000	$\Delta_{1+}=0$
			Fr	**-65,89**	**-578,81**			≤ 2,90	≤ 500,0	≤ 0,200	$\Delta_{2+}=0$
$\sigma_I[-]$	BG1/1	1,0	Ch	**-15,48**	**269,63**	338	338	0,17	1,4	0.000	$\Delta_{1-}=0$
			Fr	**-15,48**	**269,63**			≤ 2,90	≤ 500,0	≤ 0,200	$\Delta_{2-}=0$

BG1/1	Ch	BG1
	Fr	BG1

Dwarskrachtwapening

	Geval	θ [°]	v_{Ed} [kN/m]	$A_{sl,x}$ [mm²]	$A_{sl,y}$ [mm²]	ρ_l [%]	$v_{Rd,c}$ [kN/m]	$v_{Rd,max}$ [kN/m]	$A_{sw,req}$ [mm²/m²]	Status
[+]	BG1	40,0	**57,7**	524	0	0,116	222,8	2259,8	---	**OK**

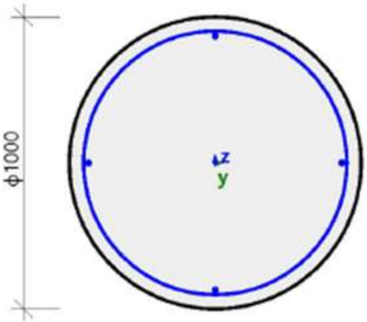
Figure 112: reinforcement of the walls

Column

For the columns has to be noticed that the cover of the reinforcement had to be increased, due to the fact that the columns are standing in the ditch.

Kolom S4	**Cirkel (1000)**
NEN EN 1992-1-1+C2/NB+A1:2020	Doorsnede 11 [dx = 5.25 m]

Staaflengte: L = 5.25 m
"Knik y-y⊥ L_y = 17.6 m (zijdelings flexibel)
Knik z-z⊥ L_z = 16.2 m (zijdelings flexibel)



Beton: C30/37
Bilineair spanning-rekdiagram
Milieuklasse: XC3, XS2

Langswapening: B 500B
Bilineair met oplopende bovenvertakking
4ϕ25 (1963 mm^2)
4ϕ10* (314 mm^2) (detaillering)
ρ_l = 0,290 % (17.9 kg/m)

Dwarskrachtwapening: B 500B
Bilineair met oplopende bovenvertakking
2L ϕ8/200 (101 mm^2)
ρ_w = 0,084 % (3.95 kg/m)

Dekking (beugel)
Hoofd: 45 mm

Ontwerp krachten

Geval	N_{Ed} [kN]	V_{Edy} [kN]	V_{Edz} [kN]	T_{Ed} [kNm]	M_{Edy} [kNm]	M_{Edz} [kNm]	λ/λ_{lim} y-y⊥		λ/λ_{lim} z-z⊥	
UGT-Set B (automatisch)4/1	-1684,4	-15,2	-15,6	0,0	-455,3	-421,0	2,12	2nd	1,96	2nd
UGT-Set B (automatisch)4/2	-1842,5	-13,2	-17,4	0,0	-500,0	-442,4	2,22	2nd	2,05	2nd
UGT-Set B (automatisch)4/3	-1816,5	-13,4	-17,1	0,0	-492,7	-438,2	2,20	2nd	2,03	2nd
UGT-Set B (automatisch)4/4	-1710,4	-15,1	-15,8	0,0	-462,6	-425,2	2,14	2nd	1,97	2nd

UGT-Set B (automatisch)4/1	1.35*BG2+1.35*BG1+1.35*BG4
UGT-Set B (automatisch)4/2	1.35*BG2+1.35*BG1+1.05*BG3+1.35*BG4+1.05*BG5
UGT-Set B (automatisch)4/3	1.35*BG2+1.35*BG1+1.05*BG3+1.35*BG4
UGT-Set B (automatisch)4/4	1.35*BG2+1.35*BG1+1.35*BG4+1.05*BG5

Dwarskrachtwapening

Beugels	$A_{swm,req}$ [mm^2/m]	$A_{swm,prov}$ [mm^2/m]	$A_{swm,max}$ [mm^2/m]	Status
ϕ8/200mm, (ns=2)	503	503	9558	OK

Figure 113: reinforcement of the columns

Foundation

The biggest foundation load of the structure will be under the centre walls with a total of 1934.82 kN for the most loaded wall. These walls will be placed on a stroke foundation which will be supported by piles, so the total load will become 5804.76 kN. As the structure is placed in the same region as the parking garage, the same values hold for q_{cI}, q_{cII} and q_{cIII}, namely q_{cI} = 16 MPa, q_{cII} = 13 MPa and q_{cIII} = 5,6 MPa. The diameter of these piles will be 0. Meter, so D_{eq} = 1.13 * a = 1.13 * 0.3 = 0.339 m. The coefficients will be α_p = 0.7, β = 1, s = 1.0 as well. With the same method of Koppejan, the value of R_b will become A * $q_{b;max;i}$ = (0.7 * 1.0 * 1.0 * 0.5 * ((16 *10^3+ 13*10^3) / 2 + 5,6*10^3)) *0.3 * 0.3 = 633.15 kN.

With two piles of eight meters long, the shaft bearing capacity (R_s) will become: $R_{s;cal;i} = O_{s;gem} * \alpha_s * q_{c;gem} * L_p$ = (4*0.3) * 0.01 * 11,53 *10^3* 8 = 1106 kN, and with a safety factor of 1.28 this value will become 864.75 kN which makes a total of 633.15 + 1106 = 1497.9 kN. Four piles, two at the sides of the most outer walls and two between two walls, will have the capacity to carry 4*147.9 = 5991.6 kN. This will be sufficient.

7. Discussion

Even though the calculations show promising results, there were some caveats in the process. Because integrality is a key item in the project the initial start was very slow for the Structural discipline. Changes in structure or adjustments during the course of time meant that the progress was delayed even more. The software SCIA Engineer was also relatively new for most, so inaccuracies in the modelling can be found as result.

For the modelling of the reinforcement in concrete SCIA showed two different values as required reinforcement area. As previously named in the report one value was calculated using the “UGT en BGT 2D - wapeningsontwerp” whilst the other was calculated automatically by SCIA. Usually the “UGT en BGT 2D - wapeningsontwerp” showed that larger values were needed. This can be seen in some unity check calculations where it looks like the used amount of reinforcement is larger than needed. However this amount was correct using the “UGT en BGT 2D - wapeningsontwerp” method.

8. Conclusion

Havenstad is a neighbourhood in Amsterdam which is relatively unused. With the increasing population of Amsterdam and the great urgency for more housing, this neighbourhood is redesigned. To accompany the redesign of Havenstad in Amsterdam multiple constructions were designed. Closing the metro ring caused the need for new metro stations, one of which was placed at Nassauplein. Also construction of a bridge at Isolatorweg was needed to allocate the metro track. For better connectivity in the area itself a bridge crossing the train and metro track was constructed.

However, before these constructions can be placed, all the dimensions are needed and safety of the construction needs to be guaranteed. All the constructions were modelled and calculated using SCIA Engineer. This software allowed for difficult calculations to be executed relatively simply. All the constructions were tested on displacement, foundation, required reinforcement, yield strengths and other Unity Checks.

The HUB is founded on a combination of 200x200mm^2 and 300x300mm^2 stripped pile foundations. The floor is 300*mm* thick with reinforcement bars in both directions. The 200*mm* thick roof is supported by a mesh of steel beams, using IPE300, IPE240 and IPE160 profiles. Upholding this construction are 300x300mm^2 concrete reinforced columns.

The underground station at Nassauplein satisfies the environmental loads given the situation at the location. Despite the safe results of the reinforcements, which are mainly Ø12 and Ø14 for the basis and Ø10 and Ø12 for the longitudinal. Related to the applied dimensions of the tunnel, which are 1 meter for the floors and 0,75 meter for the walls. This can be optimized for further investigation of the tunnel using a handy tool such as Python or MatLab.

The bridge between Westerpark and Havenstad consists of four elements, two elements with a length of 65 metres and 2 elements with a length of 60 meter. The bridge has a steel-wood structure combination and will only be accessible by cyclists and pedestrians. Each section is founded on four piles. The bridge section itself build from HEB360 and HEA340 profiles in combination with wooden columns of 300 x 300 mm

The parking garage is under metro depot Isolatorweg and in the parking garage as less as possible piles are used in order to maximise the number of parking spaces. There are two rows of piles with a 0,5 x 0,5 metres dimensions where the main row in the middle has twice as many piles as the row that supports the longest span. The foundation is piles with 0,7 by 0,7 to 0,5 by 0,5 metres depending on where the highest reaction forces are.

The reinforced concrete bridge next to the Isolatorweg-station consist of a main bridge-deck, with three load-bearing wall supports at both sides of the Contactweg to look the same as the nearby bridge for the train. The bridge will also be supported by columns, which are standing in a little ditch next to the contactweg. The bridge dek will be 0.6 meter thick, the walls 0.5 meter and the columns one meter.

Bibliography

Afstandmeten (n.d.). *Afstandmeten Satelliet*. https://www.afstandmeten.nl/

Algemeen Hoogtebestand Nederland (n.d.). *AHN Viewer*. https://www.ahn.nl/ahn-viewer

Grondverzet. (n.d.). *Soortelijk gewicht zand overzicht*. Grondverzet.nu. Retrieved 27 May 2022, from https://grondverzet.nu/soortelijk-gewicht-zand/

De Vree, J. (z.d.). *grondspanning, waterspanning, korrelspanning*. joostdevree.nl. Geraadpleegd op 21 juni 2022, van https://www.joostdevree.nl/shtmls/grondspanning.shtml

NEN (2013). *Parkeren en stallen van personenauto's op terreinen en in garages*. NEN 2443

https://www.dinoloket.nl/ondergrondgegevens

Singleply. (n.d.). *How much will a Green Roof Weigh? A guide to your options*. SIG Design & Technology. Retrieved 27 May 2022, from https://www.singleply.co.uk/how-much-will-a-green-roof-weigh-a-guide-to-your-options/

Solar Bay. (2020, October 12). *Installing Solar Panels: The Importance of Site Conditions*. Retrieved 15 June 2022, from https://solarbay.com.au/newsroom/installing-solar-panels-the-importance-of-site-conditions/#:%7E:text=Considering%20their%20average%20areas%20of,to%2020%20kg%20per%20m2.

TU Delft. (2016). *Quick Reference* (Vol. 2014). TU Delft. https://esveld.com/Download/TUD/ERR_Slabtrack.pdf

Appendix E: Transport & Planning

Group Members

Mart de Groote	5016371
Merel Krämer	4958446
Jorn van Steen	5152771
Pelle Limburg	5652529
Amy Zijlmans	4556526

Date: 22-6-2022
Place: Delft

Prologue

This report has been written in response to the assignment of the course CTB3420: Integral Design of Infrastructure. This course is a part of the Bachelor Civil Engineering at TU Delft. The main purpose of the Transport and Planning part is to develop the area of Havenstad. A vision of Havenstad will be created which will help with the development of the area. This will also make sure the integrality within the complete group will be retained.

Specialists who are interested in the area analysis of Havenstad can consult Chapter 2. Specialists who are interested in the development of Havenstad can consult Chapter 3, this includes the vision of Havenstad with guiding principles and a visualisation of the area. Specialists who are interested in Transit Oriented Design can consult Chapter 4. For Subway Transit Flows, Chapter 5 can be consulted. The transport infrastructure can be found in Chapter 5.

As the Transport & Planning discipline we want to thank Dr. Erik-Jan Houwing for his feedback and presence during the A2 group meetings. We also want to thank Dr. Ir. Wouter Schakel for answering our questions during the discipline meetings and providing feedback for our products.

Transport & Planning discipline of group A2
Delft, June 2022

Summary

Amsterdam has the ambition to gain over 300 thousand new housing spaces and over 250 thousand new jobs in the next 30 years. One of the area's contributing to this increase is the Havenstad in the west of Amsterdam, between the stations Sloterdijk and Amsterdam Central. The substantial increase in functions in the area is putting pressure on the current infrastructure and is offering an opportunity to expand the metro-ring in Amsterdam in the north-west corner. The focus in this appendix is on the Havenstad vision and the transportation in and around Havenstad. These transportation flows and design of Havenstad itself is based on the new location of the metroline, with the chosen track 4a, on transport oriented development (TOD), on the guiding principles and on the spatial concepts.

To be able to construct a good vision, it is necessary to look at the current situation. This is done in a spatial analysis and stakeholder analysis. In the spatial analysis, current infrastructure, greenery and important buildings/areas are identified. It is seen that in the vicinity of the Houthavens there is good connecting infrastructure in the forms of roads, bike lanes and public transport. In the stakeholder analysis, the primary and secondary stakeholders are analysed. From this, the power and interests from the different stakeholders are identified. From these analysis, the vision is made.
The guiding principles used for the vision are green inclusiveness and social cohesion. The main spatial concepts are urban green network combined with energy scape, room for water and transit oriented development. All these ideas are combined and visualised in a vision map of the area, combining urban life and nature. A significant part of the area is designated as an urban park which acts as a green corridor throughout the neighbourhood surrounded with residentials. These residentials in the centre part of Havenstad are connected with "bike orientated streets", where bikes have priority on those roads. The other parts of this area are connected with regular 30 km/h roads.

The main square in the form of a triangle is close to the metro-station and has high rise buildings with offices and apartments. This is aimed to be the Core or centre of Havenstad. This triangular area is designed with the basis TOD and is designed with mixed-use areas, good walkability, sufficient accessibility to building and the metro station, mobility with Park and Ride options and lastly green inclusiveness around the pedestrian and cyclist paths such as the earlier mentioned green corridor. There is also room for bike parking near the station for up to 4000 bikes to offer possibilities for Havenstad to travel by bike to the station instead of by car or public transit. The connectivity in Havenstad and from the station to Havenstad is increased by adding a bus line through the area. Despite the increase of metro users from Havenstad, the metro should still be able to offer enough capacity if the frequency stays one metro per 5 minutes (12 per hour) in both directions. To compensate for the increase of metro tracks (closing the ring) and to maintain the frequency, there should be more metro vehicles on the track than before the closure of the ring.

E1. Introduction

The city of Amsterdam is looking to redevelop the neighbourhoods of Havenstad and Houthavens. There is a demand for residential developments and office space. These two neighbourhoods are the perfect fit as they are close to the city centre. To make sure these neighbourhoods have a great connection to other parts of Amsterdam, a new metro line will be constructed. This line connects to the already existing metro lines and also the train stations of Sloterdijk and Amsterdam Centraal. It completes the metro ring around the city centre, enabling great connectivity to the whole of Amsterdam.

This report is part of a bigger project report, with several different disciplines. This report consists of several different sections: a stakeholder analysis, a spatial analysis, a vision, estimation of metro line usage and description of transport infrastructure in the project area. The goal of this report is to construct a clear and well-structured vision map to indicate where which kind of development should be located. This includes a detailed description of several aspects of the vision map and transit usage.

The vision is the guideline for other disciplines during this integral project. This vision is constructed in several steps. First a spatial analysis is conducted. This is important to get a good understanding of different current relations with the Havenstad en Houthavens neighbourhoods. Following this, a stakeholder analysis is done. This gives insight in which stakeholders have which interests. With this information, the vision of Havenstad is constructed. The area which the vision is focused on is bordered by the proposed metro line from Isolatorweg to central station and the river 'het IJ'. After first formulating the guiding principles and spatial concepts of the vision, a vision map was made. After this, the transit oriented development near the proposed metro station is elaborated in detail. Subsequently, the transit flows from and to the metro stations were calculated. Finally, the different transport infrastructure is elaborated in detail.

In chapter 2, the area around the closed ring will be analysed and stakeholders will be inventoried. In chapter 3, the vision of Havenstad will be given based on the guiding principles and spatial concepts, followed by a map with explanatory figures for different parts of the area. Chapter 4 will dive deeper into the concept of transit oriented development, Chapter 5 will cover the usage rates of different stations by inhabitants of the neighbourhoods and Chapter 6 will evaluate the different transportation routes and flows in Havenstad and Houthavens. To finalise this appendix, Chapter 7 draws conclusions and discusses the process and the findings and in Chapter 8, a reflection is drawn in combination with the risk management within the Transport and Planning discipline. Chapter 10 covers the responsibilities for each chapter in this appendix.

E2. Spatial analysis

In this chapter the project area will be analysed in terms of scope, neighbourhoods and stakeholder analysis. This gives a better understanding of which neighbourhoods are surrounding the project area and which type of infrastructure is already present. This is important for the development of a vision for the project area as it should fit in in the surrounding area.

E2.1 Analysis of the physical space

The analysis of the physical space results in a good understanding of the area with its different buildings and structures and the cohesion between these. This is an essential part to determine the location of the stations.

Current infrastructure

The sections analyses the different types of infrastructure that's currently present in the project area and its surroundings. These include the public transit network like buslines, metro lines and shared mobility, the road network, bicycle and walkability.

- Public transit network

The public transit network in the surrounding neighbourhoods mainly consists of bus lines, tram lines and railway lines. The different modes of public transit are shown in figure E2.1.1 (GVB, 2021). It shows that bus line 48 runs from central station to Houthavens. This is the only existing connection to the project area as there are currently no tram lines in Houthavens or Havenstad.

Figure E2.1.1: Public transit map (GVB, 2021)

- Main road network

The main highway is the Ring A10 west. The exit of the highway to Havenstad is the exit 2 to the S102. Furthermore the Transformatorweg from east to west and the Nieuwe Hemweg from northwest to southeast is connected to the Spaarndammerdijk. When continuing on this road to the central station this road changes into Haarlemmerdijk. It can be seen that the neighbourhood has a great connection to the road network of Amsterdam and the rest of the country. This can be seen in figure E2.1.2 (Openstreetmap, 2022).

Figure E2.1.2: Road network (Openstreetmap, 2022)

- Bike network

The bicycle network runs from the central station from Haarlemmerdijk and the Spaarndammerdijk to Transformatorweg to the west. It is part of the larger bicycle network of Amsterdam and the region. This can be seen in Figure E2.1.3 (Gemeente Amsterdam, 2022)

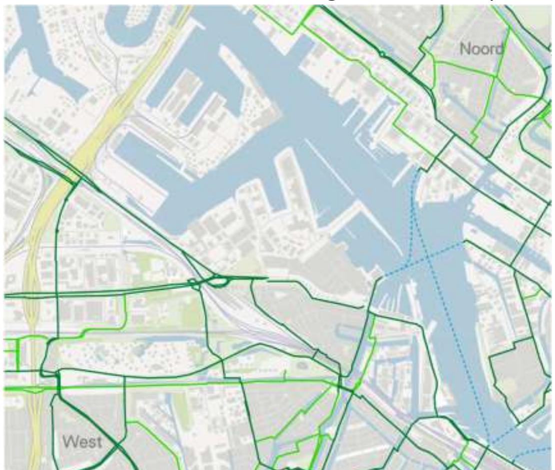


Figure E2.1.3: (Gemeente Amsterdam, 2022)

Other services

In this case services refer to other areas and buildings servicing the people or community in the neighbourhoods.

- Green areas

Green areas are important for the health and mental well-being of the citizens. The neighbourhoods surrounding the project area are shown in Figure E2.1.4. Here the green areas are shown. As for the current green infrastructure in Houthaven, there is one city park. Other than that, there is no greenery. In the surrounding neighbourhoods there is more significant greenery, with community gardens and bigger urban parks like Westerpark.

Figure E2.1.4: Main green structures Amsterdam Municipality (Gemeente Amsterdam, 2022)

- Education

Education is also an important facility. The existing educational institutes are the secondary school “Het 4e gymnasium” and two primary schools “Onze Amsterdamse School” & “Dalton School”. These can be seen in figure E2.1.5 (Google Maps, 2022)

- Sport facilities

Access to sporting facilities is important for the physical and mental well-being of the citizens. As shown in figure E2.1.5, there are a few sporting facilities in the surrounding neighbourhoods. Aside from a soccer court and one sporting complex, there are nog a lot of sports facilities.

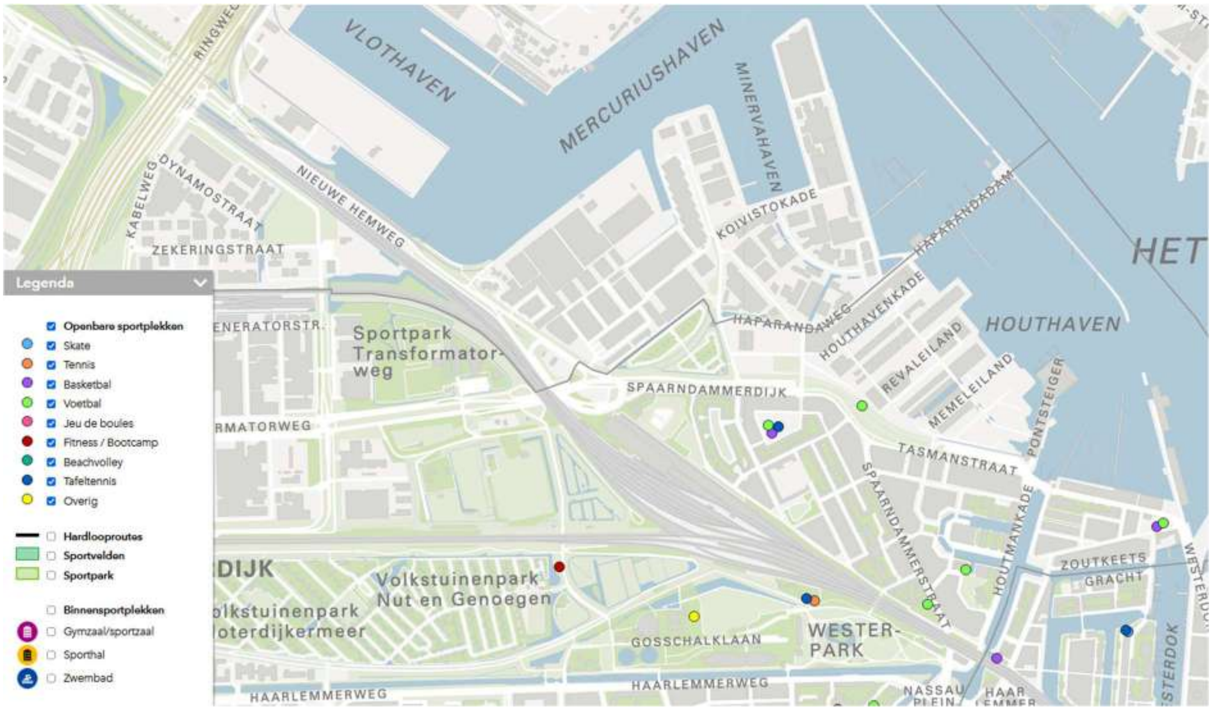


Figure E2.1.5: Sporting facilities (Gemeente Amsterdam, 2022)

- Playgrounds and play areas

Playgrounds and play areas are important for the development of children in many different aspects, mainly social and fine motor skills. In figure E2.1.6 the current playgrounds and play areas are shown. As it can be seen there are several playgrounds in the newly developed Houthavens neighbourhood. There are also a significant number of playgrounds in the Spaardammerbuurt neighbourhood.

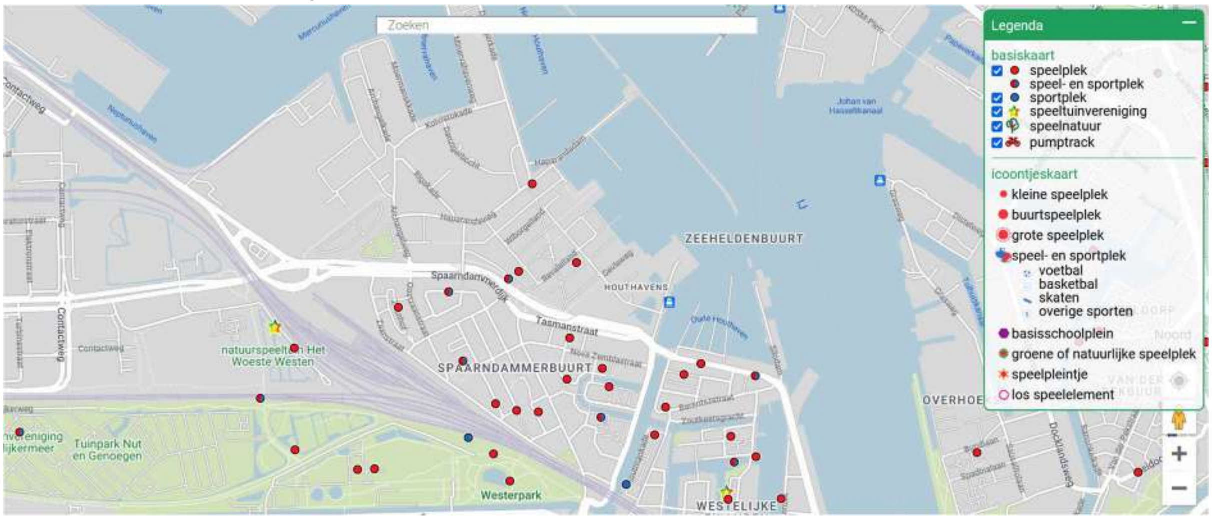


Figure E2.1.6: Playgrounds and play areas (Gemeente Amsterdam, 2022)

E2.2 Neighbourhoods

Around the metroline, there are a few different neighbourhoods, beginning with Houthavens. Houthavens is a small and new neighbourhood just above the Transformatorweg next to the location of the new neighbourhood Havenstad. Houthavens contains the most owner-occupied houses with the highest rate of highly educated people (in comparison to the other surrounding neighbourhoods.

The next neighbourhood is Spaarndammerbuurt, A neighbourhood just below Houthavens and next to the location of the new metroline. Spaarndammerbuurt is an average neighbourhood in Amsterdam, containing mostly old houses for the workers that used to work down in the harbour of Amsterdam. Spaarndammerbuurt also contains the least amount of owner-occupied houses, compared to the other 3 neighbourhoods around the new route of the metro.

Next is Haarlemmerbuurt, a neighbourhood that borders the city centre of Amsterdam and “Het IJ”. Haarlemmerbuurt is also a pretty average neighbourhood in Amsterdam, with average income per resident and just above 60% high educated inhabitants.

The final neighbourhood that shares a connection with the metroline is Staatsliedenbuurt, also the neighbourhood with the most residents. Also this neighbourhood contains old residentialials for the workers of the harbour and is with education and income a pretty average neighbourhood for Amsterdam. An overview of these neighbourhoods and its spatial layout is given in figure 2.2.1 and a short summary of the main characteristics of the neighbourhoods is given in table 2.2.1 below.

Table E2.2.1: Main characteristics of neighbourhoods (AlleCijfers, 2022)

Wijk	Inwoners	Inkomen (€)	Koopwoningen (%)	Auto's (per km2)	Hoog opgeleid (%)
Houthavens	3685	53600	54	2603	76,2
Spaardammerbuurt	10655	29300	23	1706	46,8
Haarlemmerbuurt	9170	38000	30	8153	61,3
Staatsliedenbuurt	12905	33300	29	5407	59,4

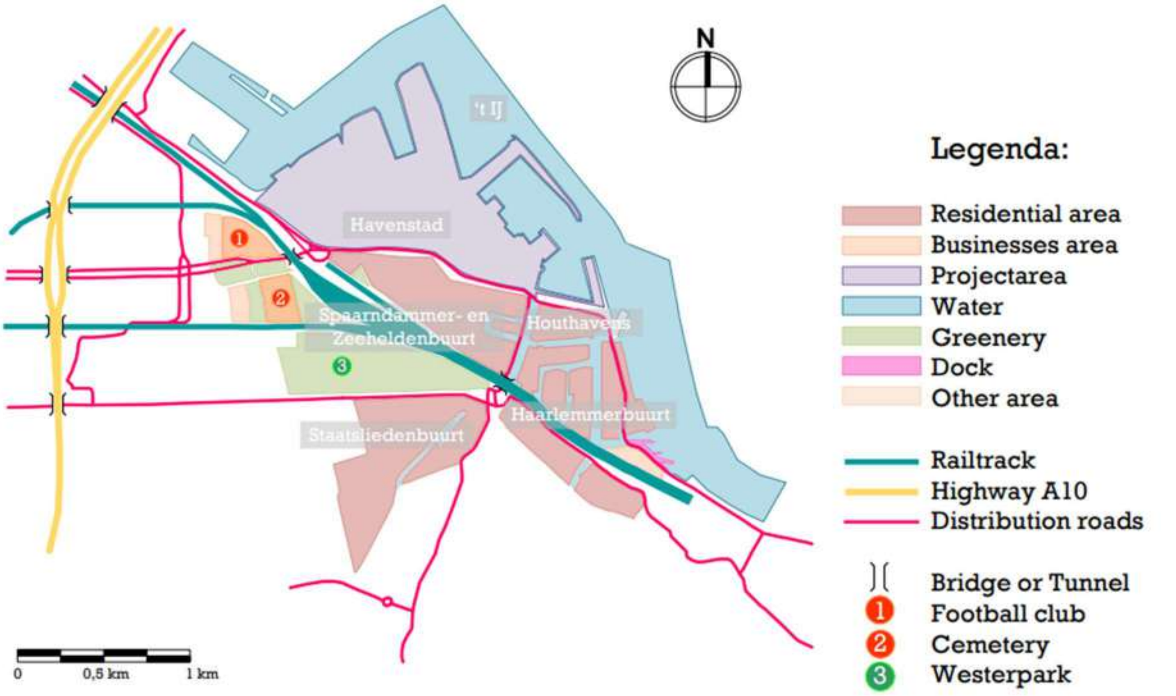


Figure 2.2.1: Overview Neighbourhoods and spatial layout of surrounding area (Transport and planning discipline)

E2.3 Stakeholders analysis

In this section a stakeholder analysis will be performed for the new metro line expansion and the project area. The stakeholder analysis provides an overview on the interest and influence of different Stakeholders. The stakeholders in this project are every party that has influence or is influenced by the actions, the behaviour and/or the policies of the new metro line expansion.The Stakeholder analysis is performed by describing for each party its role and its interests in the project. The outcome of the stakeholder analysis will be visualised by the power-interest matrix.

E2.3.1 Stakeholders

A - Municipality Amsterdam

As Municipality it is the responsibility of Amsterdam to keep the city well accessible, to improve or keep the attractiveness of the city, providing job opportunities and tourism. Amsterdam has a lot of influence on the new area called Haven-Stad and fulfils an important role in decision-making, because this new neighbourhood is in their Municipality. They do not only have influence, they also benefit the new neighbourhood. This benefit will be new houses and more job opportunities in Haven Stad, and therefore also for the municipality of Amsterdam. The vision of Amsterdam is to realise at least 325.000 new houses and 270.000 new jobs Haven stad plays a part to these numbers. Also the new metro line is very interesting for the municipality of Amsterdam, because it will not only influence the accessibility of Haven stad but also of the rest of Amsterdam.

B - Province Noord-Holland
The province Noord-Holland should facilitate a well-functioning infrastructure network for residents and businesses. That is why it is important that the capacity of the roads near this new neighbourhood remains sufficient in the future. The province has less interest in this particular project than the municipality and as a province it also has less influence on decisions. However, it still has a relatively large influence on decision-making.

C - GVB (Gemeentevervoerbedrijf, metro)
The new metro line connects the surrounding neighbourhoods and together with the buses they are the foundation of the public transport of the area. For GVB it is important that the metro line has enough interface, but also the integration of the metroline in the current network is very important.

D - Residents Havenstad
For the future residents in Havenstad it is important that for example the neighbourhood is safe, that there are enough facilities and that there is social cohesion in the neighbourhood. The new residents do not have a lot of influence on the project process itself, but if the neighbourhood does not meet their expectations, they are not going to live there.

E - Residents Nassauplein (Jordaan)
The new metro station will be implemented in Nassauplein. It is important for the residents that the metro station is easily accessible and there is enough space to park the car or the bike. It is also important that the metro arrives at the station at high frequency, so whenever you want to take the metro you wouldn't have to wait very long. For the local residents it is important that the building process wouldn't cause any nuisance.

F - Rijkswaterstaat
Rijkswaterstaat is responsible for managing and developing the main roads, the main waterways and main water systems. With the main task to work on a smooth and safe flow of traffic, the maintenance and improvement of the waterway system and flood protection. The implementation of these principles in the project is also very important and needs to meet the requirements set by Rijkswaterstaat. The vision of Rijkswaterstaat is working on making The Netherlands a safe, liveable and accessible country (Ministerie van Infrastructuur en Waterstaat, 2022)

G - Travellers
For the travellers of the new metroline, it is important that the transportation is fast and frequent. It is also important that the metro stations are easily accessible. For the less agile it is of interest that they can also easily acces the metro stations.

H - Environmental organisations
For environmental organisations it is very important that the new neighbourhood pays enough attention to nature and sustainability. Neighbourhoods are made of a lot of stone material that heats up quickly in the sun and cools down slowly. This means that the area heats up. With

enough nature in the neighbourhood the rise of the temperature will be less. Which is important because of the changing climate with rising temperature (Staal, 2019)

I - Contractors and civil engineering firm
The contractors and the civil engineering firm of the construction process must be clear to know what will be expected of them. The building plans must be thorough and detailed so that the construction process can proceed without any obstacles or delay. They are involved in the project
but have no significant interests in the project itself.

J - Cyclists and pedestrians
The interest for cyclists and pedestrians is that the transport is fast and safe. Also the quality of the transportation network is very important for both, just as the cohesion, directness, comfort and the attractiveness of the network. It is also very important for the cyclists that there is enough space to park their bikes.

K - Established companies
For the companies in Havenstad, it is important that they are able to perform their necessary tasks. It is also of interest that there is a proper accessibility to their location. Proper accessibility is important for goods transportation for example goods and for a fast travel time to work, which is very important for future employees.

L - Emergency services
The emergency services need to have easy and fast access to and from the area. For the fire brigade it is also important that there are enough water taps in the area to extinguish fire.

E2.3.2 Power/interest matrix

This section of the report will discuss the power/interest matrix made for this project. The power/interest matrix can be found in figure xx. The overview of the letters hereby is found in figure yy. The goal of making a power/interest matrix is to prioritise the Stakeholders. The Stakeholders for the covered walkway aren't all very interested in the new metroline and have little or high influence on the project. That is why the power/interest matrix is a powerful tool to understand how the Stakeholders should be informed about the progress and what power they have over the project. This power-interest matrix also displays the best manner of communication with the stakeholders. In this way the stakeholders should keep being satisfied.

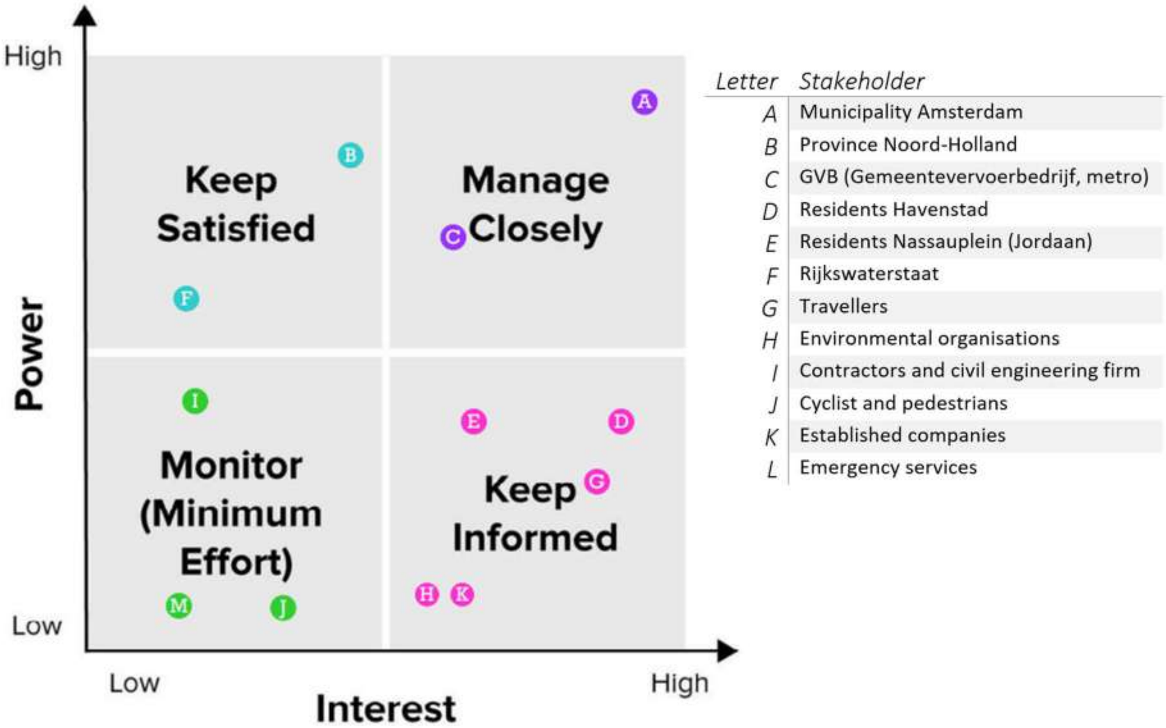


Figure E2.3.1: Conclusion Stakeholder analysis

E2.3.3 Informing the stakeholders

The Stakeholder power/interest matrix is divided in four sections. The Stakeholders are each classified in a certain section. For every section there is a different approach to inform them about the project. The Stakeholders in these different sections each need a different way of informing about the project, for example the municipality of Amsterdam who has a high interest and power in the project wants a different way of informing and has other influence than the environmental organisations. By dividing these stakeholders, each party is informed in their preferred way, and hereby misconceptions and exclusion are prevented.

E3. Vision havenstad

This vision is focused on the Havenstad neighbourhood. The goal is to connect human urban life and nature.This vision contains different sections, starting with the guiding principles. These principles can be categorised under a few different main themes: social, environmental, accessible and climate resilience. After this the spatial concepts used in the vision will be elaborated, these contain different concepts that have interfaces with the different disciplines in the project. Following this, the future key activities will be listed and explained. The combination of these different aspects are used in the vision.

E3.1 Guiding principles

The definition of a guiding principle is the leading thread for the vision. So in other words, which principles will be taken into account and therefore form the basis for the future vision of Havenstad. The guiding principles are green inclusiveness and social cohesion within the neighbourhood. Green inclusiveness means that Havenstad will contain enough green spaces to sustain the bio-environment in that area. The green inclusiveness principle also means that everybody has equal access to the greenery present in the neighbourhood. The second guiding principle is social cohesion. This means that the different people, with different backgrounds and income, live together in harmony. An example of social cohesion improvement are allotments, where people of all different backgrounds get in contact with each other. Now the spatial concepts following these guiding principles will be elaborated.

E3.2 Spatial concepts and reference

The spatial concepts show how the space should be structured in the neighbourhood Havenstad. The spatial concepts complement the guiding principles in defining the final vision. The spatial concepts that are important in this vision and that will be elaborated below are the urban green network, room for water and transit oriented development.

E3.2.1 Urban green network and energy scape

The urban green network and energy scape are combined in this case as they both have interfaces with sustainability. The urban green network is a spatial concept where the greenery in the neighbourhood is all connected via green corridors. The goal of the urban green network is an equal distribution of greenspaces in the neighbourhood. The green network also has other benefits such as improved conditions for the ecosystem, urban heat and improving the quality of life in the neighbourhood.

The energy scape is the concept that contains all the energy related assets in the neighbourhood. The focus is on renewable energy produced by solar panels, urban wind turbines and geothermal energy. This is visualised in the vision by selecting suitable areas in the neighbourhood where the implementation of these technologies is possible.

E3.2.2 Room for water

For a city like Amsterdam, surrounded by water, the discharge of water from heavy rainfall is an important concern in new areas. The room for water concept focuses on this. It prevents future flooding by creating areas for the water to go to, and be stored temporarily. A great example of this are Wadi’s where excess water can be stored to make sure the sewers don’t overflow.

E3.2.3 Transit oriented development

The third and final spatial concept is transit oriented development. Transit Oriented Development (TOD) means that new areas surrounding mass transit facilities are developed into lively and busy places. This mostly happens near public transit stations or mobility hubs. In this vision, TOD is used to develop the areas near the metro station of Havenstad

E3.3 Vision map

A vision follows from the earlier mentioned principles and concepts. The existing newly built housing in the Havenstad area will remain. The older houses present in the area will be demolished. Furthermore, the neighbourhood will contain many different kinds of buildings, such as commercial, residential and offices. The older industrial complexes will be demolished. The already present and relatively new offices will not be demolished. If they are not used anymore, they will be converted to residential buildings. The map and the legend of this vision are given below. Furthermore, the different elements that are in the vision will be better explained and linked to different concepts and principles of the vision.

Figure E3.3.1: Vision map of Havenstad en Houthavens

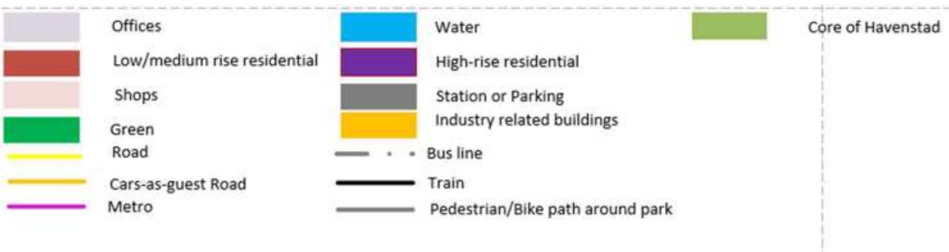


Figure E3.3.2: Legend of vision map

E3.3.1 Houthavens

The neighbourhood houthavens is part of the vision but although already a completed new area. Houthavens will be a guiding neighbourhood for the other residential areas in Havenstad. In the pictures below, the current situation in Havenstad will be illustrated to clarify what exactly is the inspiration for other residential areas in Havenstad. These illustrations are generated from field research in the project area.

Figures E3.3.3 and E3.3.4: Housing in Houthavens.

Havenstad also provides a non-space consuming way for car parking to minimise cars to park on the street itself. This principle is going to be used in the car-friendly streets and the residential of Havenstad.

Figure E3.3.5: Underground car parking in Houthavens.

The final element of Houthavens that will form a basis for Havenstad is the green corridor that already exists between Houthavens and the Tasmanstraat/Spaarndammerstraat. This corridor will continue into Havenstad and form the green core of the total Havenstad project area.

E3.3.2 Residentials Havenstad-North

This paragraph covers the residential area in the northern part of Havenstad, as visible in Figure E3.3.6:

Figure E3.3.6: Residential area in Havenstad-North.

In this neighbourhood, the same style is used as the style in Havenstad, so most of the buildings will be mid-rise residential like the ones visible in Figure E3.3.3 and Figure E3.3.4. To increase the number of housing in that neighbourhood (since the demand for new residential in Havenstad was estimated at 20.000 new residents) those mid-rise buildings could be split up in an up- and downstairs apartment. This will not only double the capacity of that residential block, it also makes sure that not only the rich people could afford such housing (Up- and Downstairs apartments are generally cheaper than mid-rise row houses that are double the size). This can improve social cohesion because multiple groups, so not only the rich, could live in Havenstad.

The difference between Houthavens and this neighbourhood is that this neighbourhood will have its waterways on the back instead of in the front of the housing, this means that the design will be based on a neighbourhood in Rotterdam with backyards on the waterside. This concept is illustrated in Figure E3.3.7

Figure E3.3.7: Neighbourhood built around water (Rotterdam Nesselande) (Van Omme & De Groot, 2022)

This concept also improves the execution of the concept: “room for water”, since water will become the main element on which the design of the neighbourhood is based.

In all the residential areas, some basic elements such as grocery stores and schools. An elementary school is needed in this residential neighbourhood since in The Netherlands, the

average distance between residential and elementary school is 600 metres (Stadszaken, 2020). At the moment only in Houthavens, an elementary school already exists and this location is more than 1 km from the furthest located residential plans.
The spatial analysis showed that this part of Havenstad lacks of sporting facilities and playgrounds too, because this northern area used to be more industrial. Therefore, in the neighbourhood, one sporting facility and some small playgrounds will be placed. This will also attract more families with children in this neighbourhood.

E3.3.3 Green corridor and surrounding housing/shops

In this paragraph, the green corridor through Havenstad and its surrounding infrastructure will be discussed. This green corridor is in line with the guiding principle of green inclusiveness, one of the principles used for the Havenstad vision. In the figure below, a zoomed-in map will be provided for clarification of what area will be described:

Figure E3.3.8: Map of the green corridor and the surrounding infrastructure

The housing around the green corridor are going to be low/mid-rise buildings (except for the purple square in the bottom left and centre right, these are high rise residentials). Furthermore, all the streets in this neighbourhood will be a “Car as guest” zone in combination with underground parking places as implemented in Houthavens and visible in Figure E3.3.5.
Figure E3.3.9 gives an impression on how this corridor will look like, based on a project proposal in Birmingham, United Kingdom. In this figure, it is clearly visible that a green area merges through the city core with housing on the sides.

Figure E3.3.9: Reference project for green corridor in Havenstad (Birmingham What's On, 2019)

The green corridor branches off towards the west into a shopping core of Havenstad (Pink strips around the green branch in Figure E3.3.3.1). In this area, some shopping facilities, cafés, restaurants and other facilities for leisure will be built for the residents of Havenstad and the neighbourhoods around Havenstad. This can also lead to an increase of the social cohesion in Havenstad, because there is a place where people can meet each other and spend some of their free time with each other.

E3.3.4 Office area and highrise

The last part of the vision, the office block and the highrise buildings in the northeast part will be discussed. In Figure E3.3.10, this area is indicated:

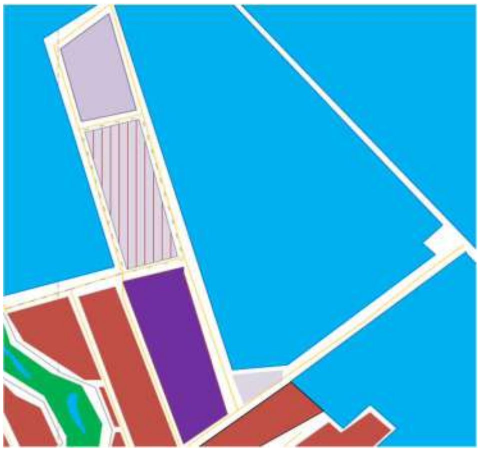


Figure E3.3.10: Vision map office area

Parts of the office area are already built (northern most part). The vision for this area is that this area will be expanded towards the south and slowly merges into high rise residential areas. The middle block in Figure E3.3.10 is already planned to be a combination of offices and high rise residential and the lowest block (dark purple) is planned to be fully designated to a living function. To give an impression of what this area will look like, the current offices in that location will be illustrated in Figure E3.3.11. As visible, these offices will have a modern character, and that is also the style that will be used for the rest of the office/highrise vision.

Figure E3.3.11: Offices in Havenstad Northeast (Architectenweb, 2019)

To reach this office area even more easily, the bus network that already existed will continue to the furthest possible place in this area. This will increase the accessibility towards the offices from Central Station but also from subway station Havenstad.

In Chapter 4, transit oriented design and the urban core of havenstad will be explained (urban core = green triangle in the vision map).

E4. Core of the vision in detail

The triangular area near the subway station where transit oriented development will be located, is elaborated in detail in this section. It goes into detail about the different land use and density in the area, the walkability and accessibility and multi modal transport options, mobility as a service and park & ride options (P+R).

Figure E4.1: Illustration of TOD (Institute for Transportation and Development Policy, 2019)

Transit Oriented Development is defined by the Institute for Transportation and Development Policy (Institute for Transportation and Development Policy, 2019) as “TOD, or transit-oriented development, means integrated urban places designed to bring people, activities, buildings, and public space together, with easy walking and cycling connection between them and near-excellent transit service to the rest of the city.”.

E4.1 Mixed use areas and density

The area is characterised by the design of mixed use areas. These contain different developments into one building, for example residential and commercial. This reduces the distance that needs to be travelled to reach this kind of development. In the transit oriented developed area in the vision the area contains residential, commercial, office, cultural and leisure developments. The area is envisioned to be an active place where different activities take place such as conventions and social events like concerts. The area is also designed to be a local gathering place as the different developments encourage this. The result of this is also improved social cohesion.

E4.2 Walkability and accessibility

The walkability and accessibility are also important factors in the design of the area. It is important, also for the social cohesion, that the area is accessible by everyone and also for people with disabilities. The walkability of the area can be ensured by providing direct walkways to all the buildings and making it easy to walk between these. Discouraging the use of other modes of transport within the area.

E4.3 Mobility

Mobility contains many different aspects. Mobility as a service and shared mobility, sustainable mobility, P+R. In the area close to the metro station there will be different modes of micro mobility available, OV-fietsen and shared mobility modes like electric mopeds and cars. There will also be an underground parking garage to facilitate users of the metro line who want to use their car to get to the station. As defined earlier, TOD gives access to different transit options. Therefore there will also be a bus line connecting the station to other neighbourhoods.

E4.4 Green inclusiveness

Green inclusiveness, one of the guiding principles as defined by the vision, is also important in the design of this area. By providing accessible greenery in the area such as on the rooftops of residential buildings and also on the streets in combination with pedestrian and cyclist paths, everyone in the area has access to greenery. This has several positive impacts on mental and physical well-being (Tarantino, 2017).

E4.5 Visualisation of the design

The central triangle is about 50.000 square metres. This area becomes the core of the project area and the gathering point of the neighbourhood. The idea is to use multiple vertical forest towers with each having multi-functional purposes. These purposes are social gathering, shops, restaurants, workplaces, housing and more. For the social cohesion there is a green plaza in between the towers, where among other things social gathering takes place, the same applies to the public places in the towers. There is the possibility to park your car and/or bike underground to prevent cars from being used in the triangle. These towers provide a lot of space for greenery which is good for the environment and is a good fit for the vision on green inclusiveness. For an idea of how the area is going to look, see figure 4.5.1.

F*igure 4.5.1: Forest Tower. (Straver, 2017)*

E4.6 Bike parking facility in the core

In the core of Havenstad, near to the subway station, a bike parking facility will be placed containing 4000 places for bikes and possibilities to rent bikes in the form of “OV-Bikes”. The clarification of the number of bike parking places can be found in Section E6.3

E5. Subway transit flows

In this chapter, the origin-destination matrix for the different subway stations will be set up. The results that this matrix will show is the expected flow that will go to each station, so the value for one specific station indicates the total number of people travelling from the neighbouring neighbourhoods to the station. This chapter also covers an evaluation on the necessity of extra metro vehicles when the new line is emplaced.

E5.1 Origin-destination matrix towards stations

In the first table of this chapter, the average distances are measured between the three main stations in the area and the different neighbourhoods that are closest to these stations and part of the project area.

Table E5.1.1: Distances from neighbourhood to station

	Houthavens	Spaarndammer-buurt	Haarlemmerbuurt	Staatsliedenbuurt	Havenstad
Isolatorweg	2.2	1.81	3	2.25	1.7
Havenstad	0.88	0.3	1.47	1.27	0.4
Nassauplein	0.9	1.04	0.15	0.88	1.55

To use this distances for the estimation of the transit flows to the different stations: the following formula is used:

travel ratio = $\frac{1}{{d_{ij}}^2}$

with d_{ij} the distance between station i and neighbourhood j

To distribute the total number of people over the stations, a normalised factor is used. In formula form, this normalised factor looks like the following equation:

normalised travel ration = $\frac{1}{{d_{ij}}^2} / \Sigma \frac{1}{{d_{ij}}^2}$

with $\Sigma \frac{1}{{d_{ij}}^2}$ the sum of all the travel ratios for all the stations.

These normalised factors are given in the table below:

Table E5.1.2: Reduction factors for the subway transit flows

	Houthavens	*Spaarndammer-buurt*	*Haarlemmerbuurt*	*Staadslieden-buurt*	*Havenstad*
Isolatorweg	*0.076*	*0.025*	*0.002*	*0.094*	*0.049*
Havenstad	*0.473*	*0.900*	*0.010*	*0.294*	*0.891*
Nassauplein	*0.452*	*0.075*	*0.987*	*0.612*	*0.059*
total	*1.000*	*1.000*	*1.000*	*1.000*	*1.000*

To finalise the calculation and obtain the total transit flow towards the different stations in the project area, the normalised travel ratio is multiplied by the factor 0.37 and the total inhabitants of the neighbourhoods. This value of 0.37 is based on the amount of metro trips per day per inhabitant in Amsterdam in 2020 (Gemeente Amsterdam, 2020). In the table below, the number of inhabitants per neighbourhood is given. The neighbourhood Havenstad is estimated to obtain a total number of 20.000 extra residents, so this value is used for the model.

Table E5.1.3: Inhabitants in the different Neighbourhoods

Wijk	*Inwoners*
Houthavens	*3685*
Spaarndammerbuurt	*10655*
Haarlemmerbuurt	*9170*
Staatsliedenbuurt	*12905*
Havenstad	*20000*

When the multiplication step as mentioned in the last paragraph is executed, the following values for the daily and yearly travel rates towards the subway stations:

Table E5.1.4: Number of flows from neighbourhood to station

	Hout-havens	*Spaarndammer-buurt*	*Haarlemmer-buurt*	*Staadslieden-buurt*	*Haven-stad*	*Daily*	*Yearly*
Isolator-weg	*103*	*98*	*257*	*361*	*365*	*1183*	*431920*
Haven-stad	*644*	*3549*	*1603*	*2256*	*6596*	*14649*	*5347004*
Nassau-plein	*616*	*295*	*1533*	*2157*	*439*	*5041*	*1839921*
tot	*1363*	*3942*	*3393*	*4775*	*7400*	*20874*	*7618846*

E5.2 Extra vehicles

Based on the latest data from the GVB (2022), the M5 vehicle has room for 960 people (seats and standing places). For the station's new line segment, an additional 7400 passengers will make use of the station (the new people that will live in Havenstad). The other around 13000 new users of this station will not be contributing in checking the necessity for new vehicles or more frequent metro's, because those passengers already used other stations that were part of the old, non-closed ring. The peak hour factor (PHF) that was used was based on a research of Weijermars (2007) and was estimated on around 10% of the total daily usage, which is 740 extra passengers in peak hour,
The current metros at the track between “Amsterdam Zuid " and “Isolatorweg” have a frequency of 12 per hour in both directions. This indicates that an additional 31 passengers must fit in the metro (assuming that people distribute equally in both directions of the metro line). GVB (2022) indicates that with the usage of more double vehicles and more frequent metros, the metros are not completely full during rush-hour. Therefore, it will not be necessary to increase the number of metro's per hour on this ringline. Although, to maintain this frequency, more metros should be implemented on that line, because there is now more distance to cover per metro.

If the metros are completely filled during rush-hour, a metro every 4 minutes (15 per hour) is already more than enough, because then you can cover for 960 * 4 * 2 = 7680 hourly passengers. So if necessary, one additional metro in rush hour can be used to cover for the 740 passengers (370 per direction). Although, the expectations are that with the current frequency, the extra metro users could be taken in easily.

E6. Transport infrastructure

In this chapter, the infrastructure within Havenstad is explained. Section E6.1 covers the different road types in Havenstad, Section E6.2 covers the design of the public transport in Havenstad and Houthavens and Section E6.3 covers the design of the bike parking facility close to subway station Havenstad.

E6.1 Roads

In this chapter, the infrastructure around transportation will be explained for the vision. In Figure E6.1, a map is visible for the different roads in the area. The yellow roads indicate normal streets, in which all the in city roads are designed at 30 km/h and the main road at 50 km/h (The road beneath the neighbourhood Havenstad).. All the red roads are the “fietsstraten” or bike-friendly roads. These streets prevent heavy car traffic since bikes have priority on that road. In Figure E6.2, an example of a “fietsstraat” is given.

Figure E6.1.1: Roads in Havenstad and Houthavens
Figure E6.1.2: “Fietsstraat” or bike-friendly road (Dura Vermeer, 2015)

In the pictures below, a clarification through figures is given on what kinds of road the non “fietsstraat” roads will be. In Figure E6.1.3, the 30 km/h roads through the northern residential part of Havenstad and in Figure E6.1.4, the design of the central road through the city centre (yellow line from the main road towards the northeast point, in which the offices are established).

Figure E6.1.3: Indication of the road lay-out in North Havenstad (Google Maps, 2022).
Figure E6.1.4: Indication of the main road lay-out through the centre of Havenstad (Google Maps, 2022).

E6.2 Public transport

In this section, the public transport (the subway excluded) will be drawn and explained.

Figure E6.2.1: Bus network in Havenstad

Chosen is to maintain the buslines 48 and 20 from Amsterdam central station to Houthavens and Sloterdijk respectively. The only adjustment that was made on the existing lines, is some extension in the northern part towards the offices. A turning loop was added with a new stop in this area to make the connection between the city and the offices a bit better transportation wise.

It is found that the optimal distance between bus stop and the destination/origin of the travellers in Amsterdam is 250 metre (Rijnmond, 2018) and therefore some new residentials

were not connected enough to the network. Also, there was no direct line from the station of Havenstad and the offices/residents, as also concluded from the spatial analysis. Based on those shortcomings, a new line (line 23) was set up and is indicated in light blue in Figure E6.2.1.
In Figure E6.2.2, the map is indicated with the area that is covered by the bus lines (based on 250 m radius). The red circle is the area that is covered extra due to the new bus line.

As visible, the whole new residential area is within the radius that is wished and only parts of Houthavens are not in the 250 m radius area, but this part of Houthavens is not too far from the closest bus station. Rijnmond (2018) found out that a radius of 400 to 500 metres is averaged in The Netherlands as an influence radius for bus stations. With this criterium, all the parts of Havenstad are definitely covered and therefore covering the small parts of Houthavens and Havenstad that have to walk slightly more than 250 metres is not really necessary.

Figure E6.2.2: Coverage of bus stations

E6.3 Bike parking facility in the core

In this section, the design of the bike parking facility close to station Havenstad is explained. According to the Government of The Netherlands (n.d.), 27% of the total amount of journeys were made by bike.
By assuming this value for the transportation towards the station Havenstad, the total number of bike trips towards that station can be estimated on: 0.27 * 14649 = 3955 total trips. Most of Havenstad is designed as residential and also the surrounding neighbourhoods that use Havenstad station contain mostly housing. Therefore, it is expected that most of the bike movements towards the station are work related. The users will therefore use the facility the entire day (9 to 5) and they will occupy parking slots for the entire time in between.

A facility of around 4000 parking slots is therefore necessary to maintain the availability of free slots throughout the day. Taking this large amount of free spots also encourages bike usage throughout the city and especially in Havenstad.
For travellers who arrive at Havenstad station and want to travel to the core of Havenstad or the offices by bike, some OV-bikes are available at this facility to provide easy options for travelling by bike. In Figure E6.3.1, an OV-bike station is illustrated to give an indication about what is meant with this concept.

Figure E6.3.1: OV-bike (Algemeen Dagblad, 2022).

E7. Conclusion & Discussion

E7.1 Conclusion

Amsterdam has an ambition to create housing spaces. The substantial increase in functions in the area is putting pressure on the current infrastructure and is offering an opportunity to expand the metro-ring in Amsterdam in the north-west corner.

The Vision for Havenstad is based on the leading threads, which are guiding principles and spatial concepts. The guiding principles for the vision are green inclusiveness and social cohesion. The main spatial concepts are urban green network combined with energy scape, room for water and transit oriented development, All these ideas are combined and visualised in a vision map of the area, combining urban life and nature. The green corridor running from the main square to the water ‘t IJ’ is one of the most important design conclusions. The main square in the form of a triangle is close to the metro-station and has high rise buildings with offices and apartments. This is aimed to be the Core or centre of Havenstad. Results of the calculations were that there are an expected number of daily travellers from all the neighbourhoods of 1100, 14700 and 5000 travellers for respectively metro station Isolatorweg, Havenstad and Nassauplein.
The transport infrastructure in Havenstad will contain of a combination of “fietsstraten” or bike friendly roads and standard 30 km/h roads. To increase the mobility in Havenstad, an extra bus-line will be added that flows along the subway station and ends at the office district.

E7.2 Discussion

The findings of this study have some limitations. The first limitation for the research was the ten week time limit. Focused on transport and planning. Furthermore the costs for the project were a limitation for the amount of ideas that could be implemented. The research is mostly made with public data as some data was not available. Maybe one of the most important ones was the availability of space. Lastly, the assignment from the municipality gave some restrictions and expectations.

One of our recommendations for all future work would be to make a visit to the project location. This helps with getting a clearer image of the area. More project specific the triangle shaped area around metro station Havenstad can be worked out in more detail.

E8. Reflection

In the next chapter there will be reflected on the project regarding integrality and risk management within the Transport and Planning discipline.

E8.1 Integrality

To maintain the integrality in the project we worked closely with other disciplines. For example with the Sustainability discipline we managed to get as much green as we could in houthavens. Solar panels are used on the roofs of windows and flats. Another example are the wadi's, we worked closely with the Water Management discipline to realise them.

E8.2 Risk management

As Transport and Planning we made sure to communicate all our risks with the other disciplines and worked together closely to prevent any unnecessary risks from happening. Regarding the internal risks we made agreements to cover people's work if they got sick or when there is a case of force majeure. One of the main ways to make sure people aren't 'Free-Riding' is to make use of the Timesheet to see when people work on the report and what they do exactly.

E8.3 Internal reflection within the group

The communication within our discipline went mostly through Whatsapp and the working area of Google Drive. We kept each other posted on our activities and our to do's. With internal deadlines within Transport and Planning we made sure we stayed on track, not influencing the big picture. If something had delayed with reason we helped each other where needed. We went to the project area near Amsterdam to get a feeling of what we were working on. It also counted as a team building experience, which made us work closer together near the end of the project.

E9. Reference list transport and planning

Algemeen Dagblad. (2022, 5 30). *OV-fiets binnenkort ook elektrisch: NS start proef met e-bikes*. Algemeen Dagblad. Retrieved June 17, 2022, from https://www.ad.nl/binnenland/ov-fiets-binnenkort-ook-elektrisch-ns-start-proef-met-e-bikes~a154e551/?referrer=https%3A%2F%2Fwww.google.com%2F

AlleCijfers. (2022). *Héél véél informatie over Amsterdam (update 2022!)*. AlleCijfers.nl. Retrieved June 10, 2022, from https://allecijfers.nl/gemeente/amsterdam/

Architectenweb. (2019, 21 juni). PVH Campus. Geraadpleegd op 22 juni 2022, van https://architectenweb.nl/projecten/project.aspx?ID=38355

Birmingham What's On. (2019, July 12). *Last chance to have your say on Birmingham's 'green corridor' plans*. Birmingham What's On. Retrieved June 8, 2022, from https://www.whatsonlive.co.uk/birmingham/news/last-chance-to-have-your-say-on-birminghams-green-corridor-plans/44779

Dura Vermeer. (2015). *Veiliger fietsen op Gorinchemgracht*. Dura Vermeer. Retrieved June 10, 2022, from https://www.duravermeer.nl/projecten/fietsstraat-gorinchemgracht/

Gemeente Amsterdam. (2020, 9 november). Dataset: Mobiliteit in Amsterdam | Website Onderzoek en Statistiek. Dataset mobiliteit in Amsterdam. Geraadpleegd op 31 mei 2022, van https://onderzoek.amsterdam.nl/dataset/mobiliteit-in-amsterdam

Gemeente Amsterdam. (2022). *Plusnetten en hoofdnetten infrastructuur*. Maps Amsterdam. Retrieved June 8, 2022, from https://maps.amsterdam.nl/plushoofdnetten/

Google Maps. (2022)

Government of The Netherlands. (n.d.). *Ways of encouraging bicycle use | Bicycles*. Government.nl. Retrieved June 17, 2022, from https://www.government.nl/topics/bicycles/bicycle-policy-in-the-netherlands

GVB. (2021). *Daglijnenkaart 2022*.

GVB. (2022, June 17). Onze metro’s. Retrieved 20 June 2022, from https://over.gvb.nl/ov-in-amsterdam/voer-en-vaartuigen/metro-in-cijfers/

GVB. (n.d.). Heeft GVB wel voldoende metrostellen voor alle lijnen nu de Noord/Zuidlijn ook rijdt? | GVB. Retrieved 20 June 2022, from https://www.gvb.nl/klantenservice/veelgestelde-vragen/heeft-gvb-wel-voldoende-metrostellen-voor-alle-lijnen-nu-de

Institute for Transportation and Development Policy. (2019, July 16). *What is TOD?* Retrieved June 1, 2022, from https://www.itdp.org/library/standards-and-guides/tod3-0/what-is-tod/

Ministerie van Infrastructuur en Waterstaat. (2022, June 17). Zakendoen met. Retrieved 20 June 2022, from https://www.rijkswaterstaat.nl/zakelijk/zakendoen-met-rijkswaterstaat#inkoopplanning-marktconsultaties-en-marktdagen

Openstreetmap. (2022)

Rijnmond. (2018, 2 17). *Wie bepaalt de locaties van tram- en bushaltes?* Rijnmond. Retrieved June 16, 2022, from https://www.rijnmond.nl/nieuws/165016/wie-bepaalt-de-locaties-van-tram-en-bushaltes

Staal, M. (2019, June 25). Hoe belangrijk is natuur in de stad? Retrieved 20 June 2022, from https://natuurwijzer.naturalis.nl/leerobjecten/hoe-belangrijk-is-natuur-in-de-stad#:%7E:text=Natuur%20is%20ook%20belangrijk%20voor,die%20de%20grond%20vruchtbaar%20maken.%E2%80%9D

Stadszaken. (2020, August 17). *Hoe dichtbij is het onderwijs in Nederland?* Stadszaken.nl. Retrieved June 9, 2022, from https://stadszaken.nl/artikel/2928/hoe-dichtbij-is-het-onderwijs-in-nederland

Straver, F. (2017). *Het verticale woonbos in Utrecht: 360 bomen, 9640 stuiken en heesters.* Retrieved June 9, 2022, from https://www.trouw.nl/duurzaamheid-natuur/het-verticale-woonbos-in-utrecht-360-bomen-9640-stuiken-en-heesters~bc1c7be5/?referrer=https%3A%2F%2Fwww.google.com%2F

Tarantino, J. (2017, August 25). *Benefits of Green Spaces in Urban Areas - The Environmental Blog*. The Environmental Blog -. Retrieved June 9, 2022, from https://www.theenvironmentalblog.org/2017/08/benefits-of-green-spaces-in-urban-areas/

Van Omme & De Groot. (2022). *Waterwijk RIVA2*. Van Omme & De Groot. Retrieved June 8, 2022, from https://www.vanomme-degroot.nl/projecten/waterwijk-riva2/

Weijermars, W. (2007). Analysis of urban traffic patterns using clustering. Retrieved from https://ris.utwente.nl/ws/portalfiles/portal/6069766/thesis_Weijermars.pdf

E10. Overview of responsibility

In this chapter an overview will be given regarding who wrote what.

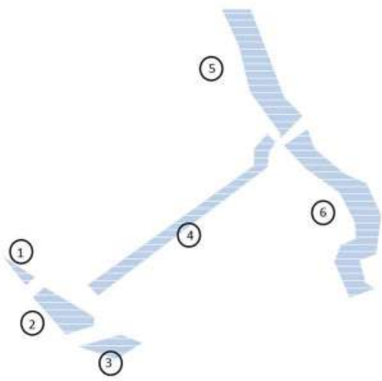
Tabel E10.1: Overview of responsibility

Chapter	Draft	Edit
Prologue	Pelle Limburg	Amy Zijlmans
Summary	Pelle Limburg	Amy Zijlmans
Introduction	Pelle Limburg	Mart de Groote & Amy Zijlmans & Jorn van Steen
Spatial analysis	Pelle Limburg & Mart de Groote & Jorn van Steen	Mart de Groote
Stakeholder analysis	Merel Krämer & Amy Zijlmans	Amy Zijlmans
Vision havenstad	Mart de Groote & Jorn van Steen	Jorn van Steen
Vision map and details	Jorn van Steen	Mart de Groote
Core of the vision in details	Mart de Groote	Merel Krämer & Amy Zijlmans
Visualisation of the design	Amy Zijlmans & Merel Krämer	Mart de Groote
Subway transit flows	Jorn van Steen	Merel Krämer
Transport infrastructure	Jorn van Steen	Merel Krämer
Conclusion and discussion	Pelle Limburg	Jorn van Steen
Reflection	Amy Zijlmans	Pelle Limburg
Overview	Amy Zijlmans	
Samenvoegen final report	Mart de Groote, Merel Krämer & Jorn van Steen	
Visios in Appendix E	Jorn van Steen & Merel Krämer	

Appendix F: Water Management

The representative areas of the figure above are given in table F1. The area which is green on the original map will be determined as an unpaved area, Everything else will be a paved area, including the bigger roads and the roofs of other residentials. Now the number of square metres can be determined by corresponding to the scale which is from 0-100-200-300 metres. These surfaces are estimated values and not precise.

Table F1: Surface per type of area

Type of area	**Amount of m^2**
Paved	Total area: 752000 m^2 paved will be total - all the others: 752000 - (109700 + 18300 + 83200 + 84635) = 456165 m^2
Unpaved	109700 + 50781(60% of wadi's) = 160481 m^2
Permeable pavement	Parking spot: (50 * 120) Parking area residential area: (35 * 120) + (20 * 75) Roads: all roads in the residential area have a width of 5 meters. (1320 m * 5) total: 6000 + 5700 + 6600 = 18300 m^2
Green roofs	From top roofs to bottom: (17000) + (30000) + (31500) + (4700) = 83200 m^2
Wadi's	The wadi's are numbered and their corresponding surface is given:  $(1125)_1 + (9800)_2 + (4250)_3 + (20300)_4 + (21680)_5 + (27480)_6$ = 84635 m^2. The total flow area was 20% so: 16927 m^2

From a report from Jesse Swagemakers (2020) the storage of permeable pavement and green roofs can be determined. A green roof, so called 'Polderdak', has a water buffer of 135 mm per m^2 (Swagemakers, 2020). The permeable pavement has a buffer of 5,5 mm per m^2 (Swagemakers, 2020). This is caused by the capillary characteristic of the pavement.

A model of the new water management system of Havenstad will be realized. A few assumptions will be made according to Jesse Swagemakers' report. These assumptions will be used to determine certain values of storage and irrigation.

- The sewerage will have no storage of water
- The storage of water on unpaved surfaces equals 5 mm/m^2 (Swagemakers, 2020).
- The storage of water on paved surfaces equals 2 mm/m^2 (Swagemakers, 2020).
- Storage for permeable pavement and green roofs are respectively 5,5 mm/m^2 and 135 mm/m^2.
- Storage of ‘t IJ is not limited.
- The storage of Wadi’s will be equal to the surface times the depth. All the water inside a Wadi will be stored in the reservoir or infiltrated into the groundwater. This is because the wadis will be designed to be dry within 24 hours and the permeability of the wadi is at least 0,5 m/day (Kennisbank GroenBlauw (2021)). The design is based on rainfall of 8 hours.
- The Groundwater Table lies at 0,75 m below ground level (see figure F2). The ground has a porosity of 0,05 (assumption, normal for Dutch soil).
- 8 hours of rainfall is normative, 103,5 mm for reassurance time T of 100 years.
- As already mentioned a total of 20% of the surface of the wadi will actually collect the water, the rest of the water will flow in the unpaved area surrounding the wadi or will evaporate.
- The average groundwater NAP is +0.2m, street level is +0.95 NAP.

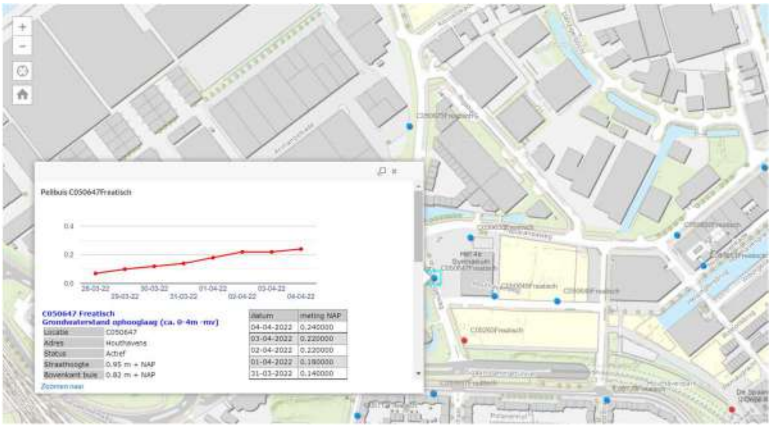


Figure F2: Map of groundwater level Havenstad (Waternet, 2022)

The water balances for the system are shown in the following tables.

Table F2: Calculations used for determining tables storage and surfaces

Calculations	
Total precipitation	Surface * precipitation (103,5 mm)
Total after storage	Max(0; total precipitation - storage), if storage is bigger than precipitation all the water will be stored and there is no water flow left.
Total drainage	Total after storage / time (8 hours)
Storage	Total surface * storage (mm/m^2 / depth(m)) for the groundwater: unpaved surface * porosity * depth of groundwater table.

Table F2: Surfaces and storages with innovations

Area	Surface (m^2)	Percentage (%)	Storage (m^3)
Paved	456165	60,7	912,33
Unpaved	160481	14,6	802,41
Permeable pavement	18300	2,4	100,65
Green roofs	83200	11,1	11232
Wadi	33854	11,2	27083,2
Groundwater	-	-	6018,04
Open water ('t IJ)	-	-	∞

Table F3: Surfaces and storages without innovations

Area	Surface (m^2)	Percentage (%)	Storage (m^3)
Paved	456165 + 18300 + 83200 = 557665 (paved + permeable pavement + green roofs)	74,2%	1115,33
Unpaved	160481 + 33854 = 194335 (unpaved + wadi's)	25,8%	971,68
Groundwater	-	-	7287,56
Open water ('t IJ)	-	-	∞

Table F4: Total drainage with innovations

Area	Precipitation (m^3)	Water after storage (m^3)	Drainage (m^3/ minute)
Paved	47213,08	46300,75	9,65
Unpaved	16609,78	15807,37	3,29
Permeable pavement	1894,05	1793,4	0,37
Green roofs	8611,2	0	0
Wadi	3503,89	0	0
Total	77832	63901,52	13,31

Table F5: Total drainage without innovations

Area	**Precipitation (m³)**	**Water after storage (m³)**	**Drainage (m³/minute)**
Paved	57718,33	56603	11,79
Unpaved	20113,67	19141,99	3,99
Total	77832	75717,99	15,78

Looking at tables 2 to 4, already can be concluded that with the innovations there is much less water flow per minute. Therefore less water is lost in the system and dumped in ‘t IJ. This is promising for a climate-proof city because there are 2,47 m^3 of water per minute less spilt and so possible for other purposes. In figure 3 a total overview of the water system in the new Haven Stad is shown compared to a system without innovations.

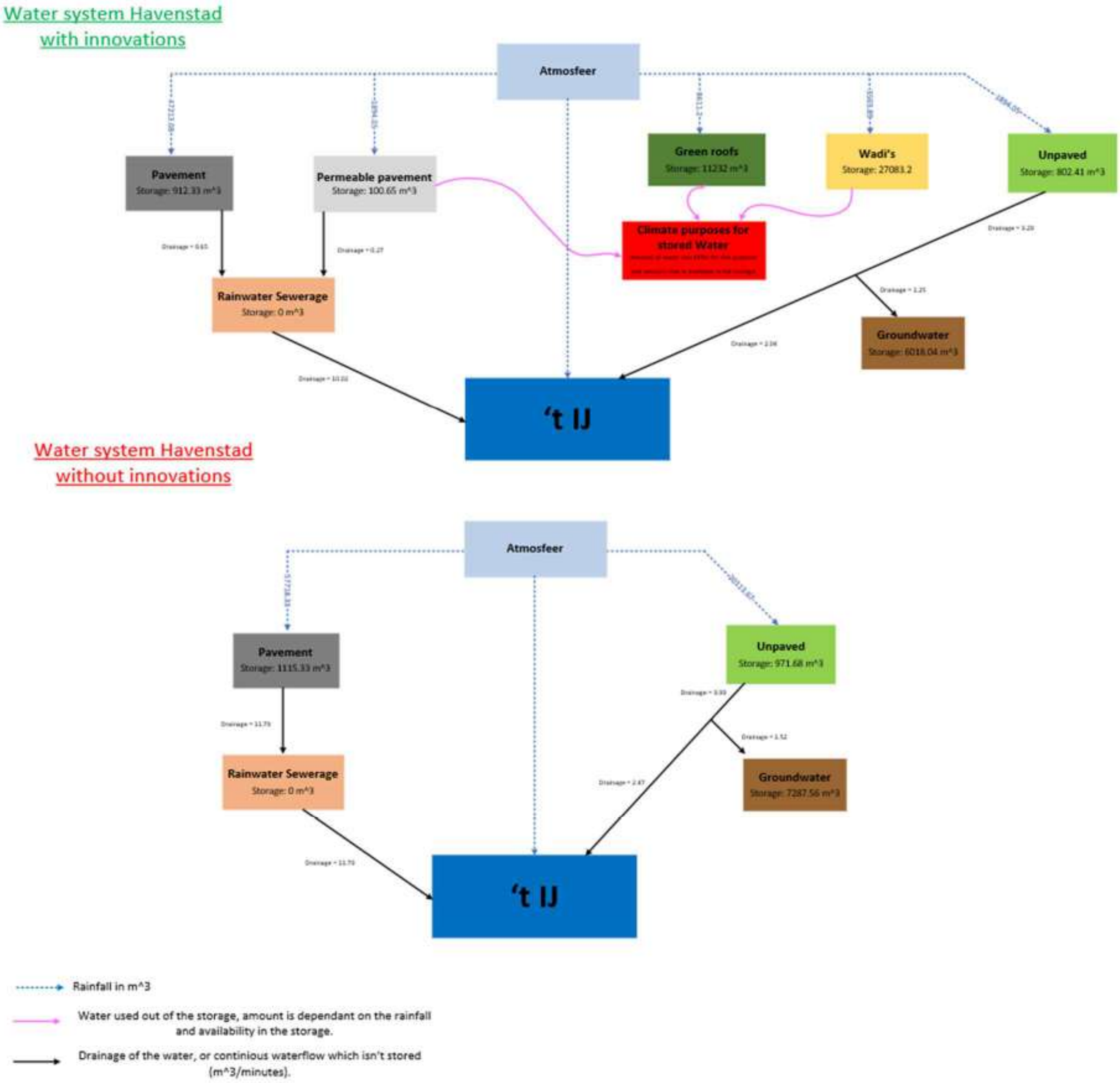


Figure F3: The water systems in Havenstad

When implementing innovations in Havenstad the region will be more climate-proof. There is less water lost in the ground and ‘t IJ so a water shortage will become less likely. The water is stored in the green roofs and Wadi's, because the water is now stored it can gain a new purpose. A new purpose for the water can be linked to the Climate, it can provide water during droughts or cool down the surface of the city. The urban heat island problem is now partly solved because the water cools. Another problem with Climate Change would be the heavy rain showers that can occur in the future. The storage of the Wadi's and Green roofs isn't fully used, so when a heavier rainfall occurs than expected this water can still be stored. There is right now in the figure no drainage from Green roofs and Wadi's to the groundwater or 't IJ, because everything is stored. When the storage is fully used there will be some drainage to groundwater and/or 't IJ through sewerage or the soil. If this happens there is still a possibility to repurpose the stored water in Green roofs and Wadis for Climate problems.

Overview and Responsibility

Chapter	**Draft**
Midterm-report compose	Michel van der Plas & Timo van Dieren
Choice track alignment	Eva Brouwer & Stijn van Leeuwen
Havenstad Environment	Eva Brouwer & Stijn van Leeuwen & Michel van der Plas & Timo van Dieren
Appendix F	Eva Brouwer & Stijn van Leeuwen & Michel van der Plas & Timo van Dieren

Appendix G: Sustainability

In this section, the contribution from Sustainability Sub-Group is explained and discussed such that it corresponds with the vision of the project as stated in the main document above.

The team consists of 5 members. Contribution was done in sections and also collaboration on all aspects including the main report for integrality.

Contribution of each group member (member listed alphabetically):

- Renewable Energy – Amine
- R’s Strategies– Oualid, Oussama
- Sustainable Development Goals (SDG’s) – Pyly
- Materials – Zakariya

In chapter 3.7.1 we expound on three(3) Sustainability Development Goals (SDG’s) that were considered and incorporated in the designs. A tabulated format of the SDG Goals as incorporated in the project is provided in Appendix G_4. SDGs key indicators are not fully developed within the Goals but institutions like UN Habitat have developed some key indicators e.g. on travel time, transport modes and planning. An example is provided in Appendix G_5.

In G_2 the Renewable energy is explained and discussed.

Thereafter, four(4) chosen R-strategies are elaborated. The full list is available in Appendix G_6.

The three chosen three(3) Guiding Principles for infrastructure planning and development, number 4, 5 and 7 and their consideration in this project are explained further in Appendix G_3.

Following this, the use of materials which is an important aspect of infrastructure projects is discussed and explained. Further information on the Material ranking is provided in Appendix G_1. CO2-emissions of different materials are also incorporated in the report in Appendix G_2.

Last but not least some of the ideas that were explored but eventually shelved for various reasons are tabulated in Appendix G_7.

G1. Sustainable Development Goals (SDG’s)

Sustainable Development Goals (SDG’s) for the Metro project that is also linked to several new high density housing developments along the line are provided below. Three of these goals are given a higher priority for this specific project.

Goal 6: Water: Ensure availability and sustainable management of water for all

6.4: By 2030, substantially increase water-use efficiency across all sectors.

- ❖ The wadis will collect fresh water runoff which helps in increasing water storage and hence water-use efficiency (the wadis also help in flood risk management).
- ❖ Water from the wadis is piped to the underground farming in the metro station (hydroponics) and excess pumped out to the water body, ‘t IJ.
- ❖ We have incorporated underground farming in the project. These farms are a relatively good choice where the space above the tunnels has another purpose. The farms use upto 70% less water and groundwater will be subtracted and used by the farm. The underground farming is expected to use between 0.4 to 0.6 litres of water in comparison to normal farming that consumes 1.5 to 2 litres of water for a normal greenhouse (450L - 600L per year per m2) and this reduction links to Goal 6 on water sustainability.

Goal 7: Sustainable & Modern Energy: Ensure access to sustainable energy for all.

7.2: By 2030, increase substantially the share of renewable and sustainable energy globally.

- ❖ The use of solar panels for energy on the bicycle parking and on the residential blocks and office buildings as a source of renewable energy.
- ❖ The installation of wind turbines in Houthaven metro tunnel as a sustainable option that also increases the global ratio of renewable energy.

7.3: By 2030, double the global rate of improvement in energy efficiency.

- ❖ The details are covered in this report in a broader sense in the chapter on Energy. This includes Renewable energy and wind turbines in the Tunnels that use the power of wind as the metro's pass by.
- ❖ Other plans are having solar panels installed to generate power to run the metro rails. Some examples have been implemented and tested in countries e.g. The Riding Sunbeam project (Saraogi, 2019) in the United Kingdom and India (Goyal, 2019). The photovoltaic panels will be placed above ground since we have dual usage with the metro below ground. The project in India is already meeting 60% of its metros are powered from solar energy reducing reliance on coal. This is also saving India as a country 13% of the government's entire transport budget in a year (Goyal, 2019). Solar Energy is a widely used method to create sustainable energy. This is further explored in the section 3.7.2 on Energy and fits into Goal 7.

Goal 11: Inclusive, Safe, Resilient & Sustainable Cities & Human Settlements: Make cities and human settlements inclusive, safe, resilient and sustainable.

11.2: By 2030, provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport.

1. The metro line with connections to main hubs reduces the need for cars hence improving road safety.

11.6: By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and waste management

1. The green roofs and vertical gardens will help in the improvement of air quality.

2. We explored possible waste management but it was eventually out of the scope of the project and due to time constraints this was not explored further.
3. Use of well designed concrete tunnel structures to reduce the amount of concrete needed.
4. Using sustainably sourced FSC-certified wood for the walking / cycling bridge.
5. Use of porous paving at residential pavements and walkways to reduce impact of flooding.

11.7: By 2030, provide universal access to accessible, green and public spaces.

1. The green spaces for example the existing park will be connected with the neighbourhood by a walking and cycling bridge. These green spaces are important for mental health. (Kate Douglas &Joe Douglas (2021, 24 March)

11.b: By 2020, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards resource efficiency, mitigation and adaptation to climate change and resilience to disasters.

1. Resilience in terms of water management links back to implementation of the targets in goal 6. An example is water from the wadi used to supplement water resources in its use for underground farming.
2. With the metro services underground and less people commuting by car, there would be reliable safe, affordable transport and it also reduces the number of road accidents hence improving road safety. This is part of target 11.2.

Itemised details of how the Metro Project has fitted the design to the Sustainable development goals are tabulated and attached in Appendix G_4.

G2. Renewable Energy

Almost everything around us uses energy to operate or be made. The current energy sources are exhaustible and are a harm to the environment. A booming topic therefore is renewable energy, or so called clean energy. This is linked with goal 7 of the SDG's.

In and around the tunnel there are plenty of options to re-use energy. For example in the tunnel we are placing wind turbines that use the turbulence caused by the metro when passing by. Tesup has various wind turbines which can be installed to generate energy. This generated energy can be used to light up the station. (ATLASX Windturbine (Gemaakt in Europa), z.d.)

Across the track, bridges are also a source of energy. On top of the bicycle parking (an area of 45 x 45m which is roughly 2000m2) solar panels will be placed. The solar panels on the bicycle parking with a capacity of 164kWh per m2 will provide approximately 328,000 kWh per year.

G3. R-strategies

In this project, four (4) R-strategies will be used: recycle, rethink, reduce and repair.

In this project we implement the strategy Reduce to achieve the chosen sustainability goals. The use of materials is an important aspect in this project, so this strategy will highlight this subject more. The first step is to use less materials in general, only the amount that is

necessary and not more. The materials used are to be prepared in a sustainable manner to reduce CO2 emissions and other negative effects on the environment. It is a requirement that the materials meet the quality criteria to prevent the amount of costs and waste.
The R-4a track provides possibilities for sustainable innovations as do all the others. But underground metrorail and making use of the existing tram-line in R-4a is efficient with land-use and is also a reduce and reuse strategy.

Recycling is one of the strategies to meet the sustainability goals for this report. The ballast can be obtained by recycling the bricks from the demolition or renovation of old buildings in the surrounding. Also, the material of the rail itself can be recycled from old rails or renovated rails. During the output phase, when the lifecycle of the tram is at the end, the ballast and the rails can be recycled for other trams or also used for other purposes. The ballast can be turned into valuable recycled products by an effective washing and screening process. The rail steel can be transported to a factory and can go into a furnace where it is heated. This steel can be shaped into different products for different purposes. More information about this is explained in the following section on the research for *Material use.*

The strategy Repair will be implemented in this project by recovering the sustainable materials that have been damaged by corrosion or other causes. Also the strategy rethink will be implemented to attain the sustainability goals of the project group.

Material use

Designing in a sustainable way means knowing which materials should be used and which ones are sustainable. This is to suit goal number 7, how to be most sustainable. A couple of things are worth thinking about: the CO2 emission, recyclability, the origin of production, whether it is fair trade, and the harmfulness to the environment. Searching for the right balance is crucial.

The article of irbnet.de made a list where they ranked the material by usage and sustainability. This was based on several criteria's (Illankoon, 2013). Every criterion has its own contribution factor. This total sum of values is called the Relative Important Index (RII) value. So, with a formula the RII value is determined to illustrate which material is most sustainable. The table can be seen in Appendix G_1. So timber is more sustainable than concrete, but metal and bricks are more sustainable than timber. So in this project we will use timber, where possible. The bridge will partly be made from timber.

Aluminium is a material that is not in the list. It is an upcoming material in the construction world (Moulin, 2021). Aluminium is a light material with a low CO2 emission. It is also a material that is recyclable and can be re-used multiple times. It has a centred cubic crystal structure and has no allotropes. This is also the reason the properties stay constant. Unfortunately, it is very energy intensive the first time it is produced, but this is compensated by the lifespan. In Appendix G_2 below you can see the CO2 emissions of different materials per kg CO2eq per unit (Winnipeg, 2012). For these reasons aluminium is going to be used for the body of the metros (Djukanovic, 2017).

Already existing rail tracks and ballasts are going to be used in this projection. This can be acquired from ProRail. Concrete cannot be avoided in this construction (also mostly reused and reduced by having designs with need for less concrete). Also, the use of circular concrete is recommended that uses blast furnace slag as an ingredient for the binder, which is typically in the production of the Netherlands (TNO, 2021).

CFC® Certified timbers can be found via the site from van den Berg Hardhout

(VandenBergHardhout, 2020).There are two types of timber that are very sustainable to use for the bridge (Red Angelime and Cumaru). Both with different hardness and strength.

Appendix G1. Material ranking

Here can be seen what the ranks are for different materials. Metal, timber and bricks have a low ranking. Cement on the contrary has a high ranking, this means that it is not so sustainable but is ranked number one for usage (this is why it is important to reuse cement).

Material	RII As per the sustainability	Rank as per the sustainability	RII As per the usage	Rank as per the usage
Clay tiles	0.608	1	0.232	13
Straw	0.528	2	0.200	15
Ply wood	0.488	3	0.272	11
Metal	0.472	4	0.472	4
Bricks	0.448	5	0.448	6
Sand	0.392	6	0.736	2
Timber	0.368	7	0.360	9
Carpet	0.336	8	0.200	15
Glass	0.288	9	0.432	7
Rubble	0.264	10	0.296	10
Cement	0.256	11	0.816	1
Blocks	0.248	12	0.472	4
Aggregates	0.240	13	0.384	8
Reinforcement	0.240	13	0.592	3
Asbestos	0.240	13	0.256	12
Plastics	0.200	16	0.200	15

Figure G1.1: Material ranking

Appendix G2. The CO2 emissions of different materials

The CO2 emissions of different materials per kg CO2eq per unit (Winnipeg, 2012)

Cement has a lower emission factor than aluminium. In this table the team used the emission factor of different materials like metal, aluminium and cement, to determine how to be most sustainable.

Emission factors in kg CO2-equivalent per unit						
Categories			Label		Default value	
Category 1	Category 2	Category 3	Title	Unit	Emission factor (kg CO2eq per unit)	Uncertainty
Material	Construction material	Cement	Cement	kg	0.89	20%
Material	Construction material	Concrete	Concrete (kg)	kg	0.15	20%
Material	Construction material	Concrete	Concrete (m3)	m3	263.00	
Material	Construction material	Concrete	Reinforced concrete	kg	0.36	20%
Material	Construction material	Fibre	Fibreglass	kg	2.60	20%
Material	Construction material	Gravel	Gravel	ton	4.32	
Material	Construction material	Lime	Lime	kg	0.74	
Material	Construction material	Other	Anthracite	kg	0.53	10%
Material	Construction material	Other	Other	kg	3.00	80%
Material	Construction material	Sand	Sand	kg	0.01	
Material	Iron metal	Iron	Cast iron	kg	1.51	
Material	Iron metal	Iron	Iron	kg	1.91	
Material	Iron metal	Steel	Reinforced steel	kg	1.49	
Material	Iron metal	Steel	Stainless steel	kg	6.15	
Material	Iron metal	Steel	Steel	kg	1.77	
Material	Iron metal	Steel	Steel r.	kg	0.88	10%
Material	Iron metal	Steel	Steel v.	kg	3.29	10%
Material	Non Iron metal	Aluminium	Aluminium	kg	8.14	
Material	Non Iron metal	Aluminium	Aluminium r.	kg	2.01	30%
Material	Non Iron metal	Aluminium	Aluminium v.	kg	11.89	30%
Material	Non Iron metal	Copper	Copper	kg	2.77	50%
Material	Non Iron metal	Copper	Copper v.	kg	3.83	
Material	Non Iron metal	Glass	Glass	kg	0.85	
Material	Non Iron metal	Glass	Glass r.	kg	0.73	20%
Material	Non Iron metal	Glass	Glass v.	kg	4.40	20%
Material	Non Iron metal	Lead	Lead	kg	1.64	30%
Material	Non Iron metal	Lead	Lead r.	kg	0.53	
Material	Non Iron metal	Lead	Lead v.	kg	2.61	
Material	Non Iron metal	Nickel	Nickel	kg	11.53	30%
Material	Non Iron metal	Other	Other metal	kg	4.40	80%
Material	Non Iron metal	Zinc	Zinc	kg	3.41	20%
Material	Other	Paper	Paper	kg	2.42	20%
Material	Other	Waste	Waste	ton	14.67	50%
Material	Other	Waste	Waste plastics	ton	1,739.67	20%
Material	Plastic	Fibre	GRP	kg	8.10	
Material	Plastic	Other	Other plastic	kg	2.70	20%
Material	Plastic	Rubber	Rubber	kg	3.18	
Material	Plastic	Rubber	Rubber latex	kg	1.63	
Material	Plastic	Rubber	Rubber synt.	kg	4.02	
Material	Plastic	Thermodurcible	Polyurethane flex.	kg	4.99	40%
Material	Plastic	Thermodurcible	Polyurethane rig.	kg	3.61	
Material	Plastic	Thermoplastic	ABS	kg	3.46	
Material	Plastic	Thermoplastic	EVAC	kg	2.11	
Material	Plastic	Thermoplastic	HDPE r.	kg	1.10	20%
Material	Plastic	Thermoplastic	HDPE v.	kg	1.90	20%
Material	Plastic	Thermoplastic	LDPE r.	kg	1.01	20%
Material	Plastic	Thermoplastic	LDPE v.	kg	2.06	20%
Material	Plastic	Thermoplastic	Nylon	kg	7.90	
Material	Plastic	Thermoplastic	PE	kg	2.40	
Material	Plastic	Thermoplastic	PET r.	kg	1.76	20%
Material	Plastic	Thermoplastic	PET v.	kg	5.44	20%
Material	Plastic	Thermoplastic	Polystyrene	kg	3.07	
Material	Plastic	Thermoplastic	PP gra.	kg	1.95	
Material	Plastic	Thermoplastic	PVC r.	kg	0.48	20%
Material	Plastic	Thermoplastic	PVC v.	kg	2.22	20%
Material	Plastic	Thermoplastic	SAN	kg	3.46	
Reagent	Other	CaCO3	Lime stone	kg	0.01	0%
Reagent	Other	CaO	Lime CaO	kg	0.15	50%
Transport	Freight	Rail	Rail freight	t.km	0.03	
Transport	Freight	Rail	Train EU	t.km	0.02	50%

Appendix G3. Guiding principles for infrastructure planning and development

Table G3.1: Principles and solutions

NO.	**THREE OF THE TEN GUIDING PRINCIPLES FOR INFRASTRUCTURE PLANNING AND DEVELOPMENT:**	**SOLUTIONS IN PROJECT OUTLINING HOW AND WHY:**
Principle 4	AVOIDING ENVIRONMENTAL IMPACTS of infrastructure systems and investing in natural infrastructure to make use of nature's ability to provide essential, cost-effective infrastructure services and provide multiple co-benefits for people and the planet.	- Green corridor - Connecting existing park by building a cycling and walking bridge - Constructing the metro line underground, allows for nature above ground - Incorporating Wadi for groundwater ecosystem services - Green roofs and vertical gardens helps to reduce CO2 emissions - Permeable pavements, assists in water management and prevents flooding - Underground farming using less water than standard farming methods (approximately 70%).

Principle 5	. 3. 7. 2. 10. These ten principles can be used to support integrated, systems-level approach that can increase governments' abilities to meet a given level of service needs with less infrastructure that is more resource efficient, pollutes less, is more resilient, more cost effective and has fewer risks than "business-as-usual" approaches. 6. 4. 8. RESPONSIVE, RESILIENT, AND FLEXIBLE SERVICE PROVISION to meet actual infrastructure needs, allow for changes and uncertainties over time, and promote synergies between infrastructure projects and systems. COMPREHENSIVE LIFECYCLE ASSESSMENT OF SUSTAINABILITY, including the cumulative impacts of multiple infrastructure systems on ecosystems and communities over their entire lifespans, to avoid "locking in" infrastructure projects and systems with various adverse effects. AVOIDING ENVIRONMENTAL IMPACTS of infrastructure systems and investing in natural infrastructure to make use of nature's ability to provide essential, cost-effective infrastructure services and provide multiple co-benefits for people and the planet. RESOURCE EFFICIENCY AND CIRCULARITY to minimise infrastructure's natural resource footprint, reduce emissions, waste and other pollutants, and increase the efficiency and affordability of services.	- Renewable Energy: wind, solar panels (future proof) - Recycling and reuse (R strategies) - Sustainable materials: wood, aluminium and concrete
Principle 7	ENHANCING ECONOMIC BENEFITS through employment generation and support for the local economy.	- Underground farming - Green roofs and vertical gardens helps to reduce CO2 emissions - Hubs, enhancing the local economy

Appendix G4. Sustainable Development Goals (SDG's)

DESIGN	SOLUTION	SDG GOAL	
Wadi's • Wadi's above ground at Westerpark and Havenstad station Water Reservoirs • Water storage under wadi's linked with pipes to underground farming	Wadi's - Fresh water collection (rain runoff) Wadi's - Water storage Wadi's - Reducing flooding Water reservoir - Storage structures under wadis to assist in flood control and water management. Important as it links to underground farming (hydroponics).		***6.4*** ***By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity*** ***6.6*** ***By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes*** ***13.1*** ***Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries***

Green walls & Vertical gardens on residential and office blocks Green roofs on high-rise housing developments, shopping malls and offices. Green spaces at existing park	Green walls & Vertical gardens - on high-rise housing developments, shopping malls and offices. Green roofs - Reducing CO2 greenhouse gases and alleviating climate change. Green spaces - parks to improve mental health.		***13.1*** ***Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries*** - ***Promote healthy living and improve mental health by creating green spaces.***
Metro rail (sluiten van de ring)	Metro rail - Efficient rail system for the existing and new micro-neighbourhoods. Metro rail - Efficient rail system inclusive for all persons. Metro rail - Fast services with ideal travel times for all. Metro rail - Less greenhouse gas emitting cars, more shared transport for high density areas.		***11.a*** ***Support positive economic, social and environmental links between urban, peri-urban and rural areas by strengthening national and regional development planning*** ***11.2*** ***By 2030, provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport.***

Bridge (Westerpark-Havenstad) • Pedestrian • Cycling	Bridge (excluding cars) - Safe walking environment connecting people - Safe cycling Environment Connecting people and places - Encouraging walking and cycling which reduces use of cars and encourages healthy living.	11 SUSTAINABLE CITIES AND COMMUNITIES	***11.a*** ***Support positive economic, social and environmental links between urban, and peri-urban areas by strengthening national and regional development planning*** ***11.2*** ***By 2030, provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport.***
Mixed High-Density Housing Project • Use of space above ground for mixed high-density residential area	High-density residential area -High quality of amenities -High quality of low cost, middle and high income budgets -Availability of rail transport and multi-use areas in the zones	11 SUSTAINABLE CITIES AND COMMUNITIES	***11.1*** ***By 2030, ensure access for all to adequate, safe and affordable housing and basic services.***
Underground farming at Metro Station Havenstad	Underground farming -Reduction of CO_2 emissions (greenhouse gases). -Possibility for food production. - Uses less water.	13 CLIMATE ACTION	***13.1*** ***Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries***

Materials • Reduce - Design that less concrete is needed. • Recycled concrete for non-load bearing structures i.e. pavements. • Sustainably sourced, produced and certified(FSC) timber. • Sustainably sourced, produced steel	Sustainable materials -Sustainable sourcing i.e. companies integrating the following: • Recycling • Reduction • Reuse	11 SUSTAINABLE CITIES AND COMMUNITIES 13 CLIMATE ACTION	***11.6*** ***By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management*** ***13.2*** ***Integrate climate change measures into national policies, strategies and planning***
Energy • Solar panels at Nassauplein station bicycle parking. • Wind turbines in tunnels at Havenstad. • Escalators (energy efficient)	Green Energy - Solar panels at the hubs, metro station outlets and buildings, bicycle parking above ground. - Wind turbines in tunnels that are driven by the passing metros. - Choice of escalators that switch off to save energy when not in use. There is also the probability of adding interactive information panels to inform users how much energy they are	7 AFFORDABLE AND CLEAN ENERGY 13 CLIMATE ACTION	***7.2*** ***By 2030, increase substantially the share of renewable energy in the global energy mix*** ***7.3*** ***By 2030, double the global rate of improvement in energy efficiency*** ***13.1*** ***Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries*** ***7.3*** ***By 2030, double the global rate of improvement in energy efficiency***

	using when they get on.		
Aesthetics/ Art • Utility services as a work of art. • Ideal public spaces Maximum use of space.	Pleasant aesthetically pleasing living environment & Maximum use of space - Where necessary turn visible piping and cabling into a work of art – aesthetically pleasing.		***11.7*** ***By 2030, provide universal access to safe, inclusive and accessible, green and public spaces.***

Space utilisation ● Dual use of space above and below ground. ● Room for green spaces	Efficient use of space -Tunnel allows for dual use of space and saves existing buildings above ground including monuments. - Tunnel allows for room to create green social spaces above ground - Maintaining existing structures -Saving monuments	11 SUSTAINABLE CITIES AND COMMUNITIES	***11.b*** ***By 2020, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and develop and implement, in line with the Sendai Framework for Disaster Risk Reduction 2015-2030, holistic disaster risk management at all levels*** ***11.4*** ***Strengthen efforts to protect and safeguard the world's cultural and natural heritage*** ***11.7*** ***By 2030, provide universal access to safe, inclusive and accessible, green and public spaces.***

DETAILS ON THE PROJECT SOLUTIONS IN RELATION TO THE SDG'S

Wadi

A wadi is a green valley in an urban area, it stores and purifies rainwater after which the water infiltrates the ground. This way a wadi helps to prevent drought and flooding. Often structures under the wadi are placed to store and drain the water like infiltration crates, granulated granules and drainpipes. The wadi location as proposed by Water Management is shown in figure G_4.1a. An intersection of a wadi is shown in figure G_4.1b.

Figure G_4.1a: Intersection of a wadi (Team A2-Sustainability & Water Management Team, 2022).

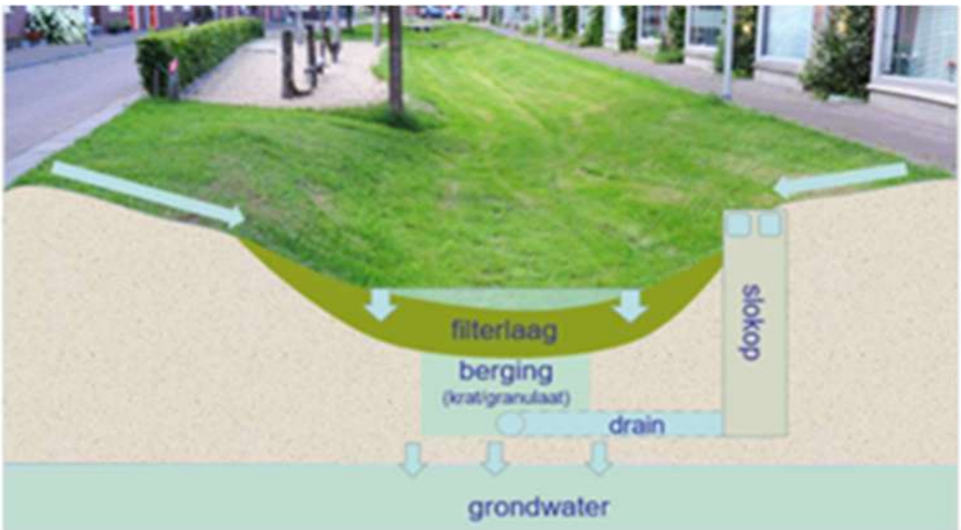


Figure G_4.1b: Intersection of a wadi (Kennisportaal klimaatadaptatie, 2020).

Permeable pavements

At and around the wadis, permeable paving is used. This assists in water management and prevents flooding. An example of porous paving for this project is shown below in figure 2b.

Figure G_4.2a: Porous paving for drainage ((de Groot, n.d.)*).*

Figure G_4.2b: Porous Aquastone

Green roofs and Vertical gardens and Green spaces

At the station Nassauplein, we have designed a green roof / water-draining roof. The combination of permeable pavement and green roofs will have a positive impact on the space to be developed. An example of a green roofs at a station in Lausanne, Switzerland is shown in figure G_4.3a and G_4.3b.

Figure G_4.3a: Green roofs – Living roof at metro station in Douglas *Lausanne, Switzerland (* (Crawford, n.d.)*).*

Figure G_4.3b: Green roofs: Urban-Greening– Kate &Joe Douglas (2021, 24 March).

Figure G_4.3c: Vertical green walls – Urban greening,).

Figure G_4.3d: Green spaces – Urban greening,).

Underground farming

Underground-Farms use 70% less water (hydroponics) and produce 10 times more harvests than regular farms. Therefore, a very sustainable way for growing foods. A sketch of the design by team is shown in figure G_4.4a and an example from London, UK is shown in figure G_4.4b.

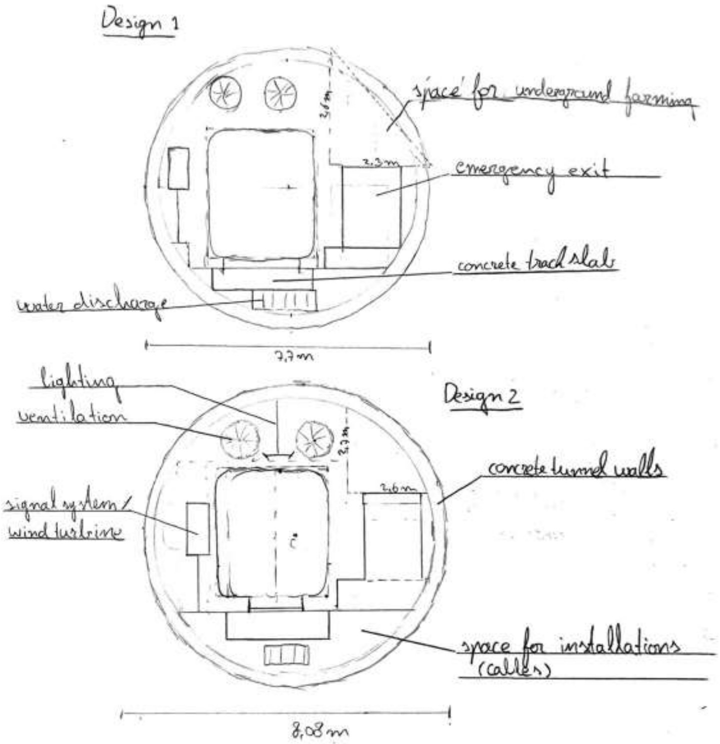


Figure G_4.4a: Sketch of Metro tunnel with proposed underground farming (Team A2-Sustainability & Hydraulics Team, 2022).

Figure G_4.4b: Existing underground farming, London, UK (Broom, Douglas. (2021, April 22))

Sustainable Energy

Sustainable energy has been provided by means of solar panels above the bicycle parking (see BIM 3D-model G_4.5.a below) and also by introducing wind turbines in the metro tunnels powered by the passing metros (see product from AtlasX in figure G_4.5.b. below).

Figure G_4.5a: Solar panels over the bicycle parking (Team A2 (2021, June))

Figure G_4.5a: Turbines (ATLASX Wind Turbine (Made in Europa). (z.d.)

Appendix G5. Sustainability: UN Habitat Indicators

FURTHER RECOMMENDED RESEARCH:

Many of the SDG indicators assess outcomes, rather than the comprehensive and integrated ‘upstream’ policies and interventions required to deliver outcomes on-the-ground. Conversely, the UN Habitat framework incorporates intervention indicators.

UN HABITAT

UN-HABITAT has adopted a more holistic approach by integrating the Habitat Agenda (HA) indicators in the overall MDG framework (Annex B. List of MDG and HA indicators). The Habitat Agenda indicators have been developed on the basis of the Habitat Agenda and on Resolutions 15/6 and 17/1 of the United Nations Commission on Human Settlements. They comprise of 20 key indicators, 8 check-lists and 16 extensive indicators which measure performances and trends in selected key areas of the Habitat Agenda (the list of indicators is provided in Table 1, Section 7). Together, they should provide a quantitative, comparative base for the condition of cities, and show progress towards achieving the Habitat Agenda.

CHAPTER 3: Environmental Management

key indicator 12: planned settlements
key indicator 13: price of water
extensive indicator 8: water consumption
key indicator 14: wastewater treated
key indicator 15: solid waste disposal
extensive indicator 9: regular solid waste collection
check-list 5: disaster prevention and mitigation instruments
extensive indicator 10: houses in hazardous locations
key indicator 16: travel time
extensive indicators 11: transport modes
check-list 6: local environmental plans

Indicator 16: Travel time

Habitat Agenda Goal: *Promote effective and environmentally sound transportation system*

Rationale:	Travel time is one of the key performance measures of transportation systems. Long transport time to work is an obvious sign of urban dysfunction, associated with severe traffic congestion, uncontrolled mixes of traffic types, poorly operating public transport networks, lack of adequate local traffic management, accidents and general dissatisfaction of the population who d aily commute to their workplace. Reducing travel time has become a real challenge for transport planners of fast growing megacities, where commuters spend sometimes more than one hour in average to reach their workplace.
Definition:	**Average time in minutes for a one -way work trip. This is an average over all modes of transport.**
Methodology:	This is an average over all modes used during a work trip. It may be necessary to estimate average times for each mode of transport and then, on the basis of an esti mate of the different modes of transport used for work trips(extensive indicator 12: transport modes), to obtain an overall weighted average. Train and bus times should include average walking and waiting times and car times should include parking or walking to the workplace. Transportation experts should be consulted, including city planners and city managers, selected key informants in slum and non-slum areas, etc. in order to provide an estimation. Specific recent transport studies may provide adequate information.
Gender:	Mobility is an essential part of daily life and it is the main means of access to city services and social opportunities. Mobility conditions access to employment as well as social integration, and it can become a factor for social discrimination and even exclusion. Women are less mobile: they are less likely than men to have a personal vehicle, public transport networks remain generally inadequate to respond to all men and women and insecurity prevail in certain areas. Women spend generally more time in travel, and use cheaper and slower modes of transportation. It will be useful to obtain the travel time disaggregated by sex. The question will be: how much time do men and women spend for an average one-w ay trip to work ?
Comments and limitations	Given the fact that this indicator is based on average values, it will not inform about the range of travel times used by different type of commuters and work trips. This information may be useful to obtain for more in-dept assessment.
Level:	City

Extensive indicator 11: Transport modes

Habitat Agenda Goal: *Promote effective and environmentally sound transportation system*

Rationale:	Transport can play a determining role in the economy and quality of life of cities. Effective and environmentally friendly transportation systems are revealed through measures of the different travel modes used for work trips. Transportation system should be adequately balanced for the several uses required. While transport should be as efficient as possible to ensure the movement of goods and people, as a major consumer of non-renewable energy and a major contributor to pollution, congestion and accidents, an adequate mix of modes is necessary to ensure its sustainability and reduced impacts on the environment. While private motorized transport (cars, motorcycles) has become the major mode in cities at the end of this century, public transport and non-motorized modes of transport should be encouraged, since they are generally affordable, efficient and energy-saving.
Definition:	**Percentage of total work trips undertaken by: a) private car; b) train, tram or ferry; c) bus or minibus; d) motorcycle; e) bicycle; f) foot; g) other modes.**
Methodology:	When several modes of transport are used for a given trip, the following hierarchy should be employed to determine the principal mode: (1) train, tram or ferry; (2) bus or minibus; (4) private car or taxi; (5) motorcycle; (6) bicycle or other non-motorised modes. Data on transport modes are usually obtained through specific transport surveys. Transportation experts should be consulted, including city planners and city managers, selected key informants in slum and non-slum areas, etc. in order to provide an estimation.
Gender:	In many countries, women are generally less mobile than men and are less likely to have a personal vehicle. Public transport networks remain generally inadequate to respond to all men and women and insecurity prevails in certain areas. Studies show that, in many cities, women are more likely to use non-motorised modes, especially walking. It will be useful to obtain percentage of transport modes used disaggregated by sex.
Comments and limitations	These data may be difficult to obtain, especially disaggregated data. If data cannot be provided for the level of detail above, please provide data on : private motorised; train and tram; bus and minibus; non-motorised. If not available, this data may be integrated in future transport surveys.
Level:	City, national urban

Check-list 6: Local environmental plans

Habitat Agenda Goal: *Support mechanisms to prepare and implement local environmental plans and local Agenda 21 initiatives*

Rationale: Sustainable human settlements depend on the creation of a better environment, which will improve the living conditions of people. To achieve this, Governments should support mechanisms for consultation and partnership among interested parties, to prepare and implement local environmental plans and local Agenda 21 initiatives, as well as specific cross-sectoral environmental health programmes.

Definition: **Level of achievement and implementation of local environmental plans (questions below).**

1. Has the city established a long-term strategic plan for sustainable development?	1☐ yes, being implemented year of implementation: ……… 2☐ yes, being implemented partly 3☐ yes, not implemented 4☐ plan to be elaborated soon 5☐ no plan existing nor planned
2. Is the environmental plan accompanied with appropriate funding for implementation? 3. Has it involved representatives from the following?	1☐ yes, full funding available 2☐ yes, major part of the funds available 3☐ yes, some funds available 4☐ no funds 1☐ Non-governmental organisations 2☐ Community based organizations 3☐ women groups 4☐ the private sector 5☐ research institutions 6☐ universities 7☐ youth groups

Methodology: Local authorities and urban environment experts dealing with all stakeholders in the city should be consulted for this information.

Gender: When it comes to environmental planning at the national and local level, it is important to involve key partners, men and women in all the stages of decision-making. Both men and women should be involved on prioritisation, consensus, action plans and institutionalisation.

Comments and limitations In order to supplement this check-list, progress may be assessed over a given time frame, looking back at effective changes since the early 1990s and looking forward, by assessing future provisions and plans for the next 10 to 20 years.

Level: City

Appendix G6. R-Strategies

The R strategies

BEFORE THE LIFETIME BEGINS:

→ Design (ex. modular design, or accessible feature for easy repair)
→ Can we reduce inputs?
→ Can we have more recycled inputs?
→ Can we prolong the lifetime?
→ How much can we reuse at the end of the lifetime?
→ How much can we recycle at the end of the lifetime?

Smarter product use and manufacture	R0	Refuse	Make product redundant by abandoning its function or by offering the same function with a radically different product
	R1	Rethink	Make product use more intensive (e.g. through sharing products or by putting multi-functional products on market).
	R2	Reduce	Increase efficiency in product manufacture or use by consuming fewer natural resources
Extend lifespan of product and its parts	R3	Reuse	Re-use by another consumer of discarded product which is still in good condition and fulfils its original function
	R4	Repair	Repair and maintenance of defective product so it can be used with its original function
	R5	Refurbish	Restore an old product and bring it up to date
	R6	Remanufacture	Use parts of discarded product in a new product with the same function
	R7	Repurpose	Use discarded products or its part in a new product with a different function
Useful application of materials	R8	Recycle	Process materials to obtain the same (high grade) or lower (low grade) quality
	R9	Recovery	Incineration of material with energy recovery

Reference: Morseletto (2020)
https://doi.org/10.1016/j.resconrec.2019.104553

Appendix G.7: Sustainability: Extra ideas (not implemented)

Table G.7.1: Ideas that have not been implemented

IDEA	GOAL	COMMENTS
(6.b) ***Substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater.***		
Wastewater Management • Waste water recycling for flushing toilets and watering greenery.	***DATA:*** *In a specific study, the potential of vertical gardens) was explored as a viable greywater treatment system that can greatly minimise the treatment footprint and provide a series of benefits in the urban landscape such as greening, CO2 trapping, O2 production, microclimate effects, house insulation among other benefits and if the concept of recycling greywater at building or block level could be applied on a large scale in a city (e.g. our hubs), the approach could significantly reduce the dependence on very expensive infrastructures like sewer systems and large wastewater treatment plants, optimising the overall wastewater management.* *Masi, Fabio & Bresciani, Riccardo & Rizzo, Anacleto & Edathoot, Ajith & Patwardhan, Neha & Panse, Dayanand & Langergraber, Günter. (2016). Green walls for greywater treatment and recycling in dense urban areas: A case-study in Pune. Journal of Water, Sanitation and Hygiene for Development. 6. 10.2166/washdev.2016.019* Recycling the waste water from the residential areas and the facilities in the metro stations. This water could also be used for watering plants, cleaning public areas and/or creating water features at ground level. Signs at ground level encouraging users to use recycled water for plants instead of drinking water could be used. This links to 6.5 (integrated water resources), 6.b (improving water and waste management). Recycled Water for sustainable urban development (M. Tao). The city faced acute water shortages that had a negative effect on the development and the economy. Water recycling infrastructure was built and they produced more than enough as an alternative water source with environmental benefits e.g. an urban lake, biodiversity, aquatic life. ***STATUS:*** ***Idea shelved since it was not in the scope for Water management and Transport and Planning.***	
Water Reservoirs	***The idea was to incorporate storage reservoirs for water in the tunnel walls e.g. from the wadis. This could serve as a buffer for the high-***	

• Water reservoirs in the metro tunnel walls.	***density hubs. The water could also be used to cool down systems in the tunnel that may need cooling.*** ***STATUS:*** ***Idea was shelved as there was no space in the current design by Hydraulics and Structural to incorporate water reservoirs in the tunnels.***
7.2 ***By 2030, increase substantially the share of renewable energy***	
Kinetic energy in the metro tunnels	*In the bridge kinetic energy tiles are abn ideal option that can also be fun for the users. When pedestrians or bicycles move over them, kinetic energy is transformed into electric energy. A part of this energy could be used for the metro, another part for lights inside the bridge.* *A London company called Pavegen has developed them. The potential for using kinetic energy (a Rethink aspect and fits in with SDG goal 7).* ***STATUS:*** ***Ideas were not further defined due to time constraints for this project research work.***
Heat tunnels	Another Rethink idea was Heat tunnels, with enough heat to use to heat the high density homes above ground. ***STATUS:*** ***Idea was shelved since, with electrically-run metros, there will not be enough heat generated in the tunnels to heat the homes above.***
11.2 ***By 2030, provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons.***	

Metro rail (sluiten van de ring)	***Metro rail - Efficient rail system for the existing and new micro-neighbourhoods.*** ***Metro rail - Efficient rail system inclusive for all persons.*** ***Metro rail - Fast services with ideal travel times for all.*** ***Metro rail - Less greenhouse gas emitting cars, more shared transport for high density areas.*** ***STATUS:*** ***Ideas were not further defined due to time constraints for this project research work.***
Materials - Recycled concrete	***The idea was to incorporate recycled concrete for the structures to assist in reuse and recycling of materials for sustainability.*** ***STATUS:*** ***Ideas were not further worked out due lack of time and difficulty in finding the right materials that can be used safely from the metro tunnels without creating other risks i.e. the information was not readily available.***
Materials - Self healing concrete	***Long lasting concrete is also sustainable and provides resilience to the cities. Looking into self-healing concrete is also an option for resource efficiency and waste reduction. TU Delft has developed a recipe and there is more research going on (TU-Delft-OCT-07-054, Self healing concrete-materials that can repair itself, n.d.).This approach falls under goal 13 but also goal 11.*** ***STATUS:*** ***Ideas were not further worked out due lack of time to find a way to incorporate this into the project.***

13: Climate Change & its Impacts

INTERVIEW WITH INDUSTRY EXPERT FOR IDEAS:

The Metro project is linked to the new high density housing developments. Some of the goals could be implemented in the new metro project. Others were explored but not implemented for this project.

Below is an interview done on recycling and effects on climate change and ways we can improve:-

- Resilience in terms of water management links back to implementation of the targets in goal 6. There are different types of wastewater and the metro project combined with the new settlements around it need to integrate their designs and align their resources to ensure availability of clean water and management of wastewater. An excerpt of an interview conducted for this research with Jan-Peter Born, an industry expert (Mucuthi & Born, 2022) is given below:-

" *Waste water can be divided into inorganic waste water (heavy industry like WtE) and organic waste water (households and food industry). Treatment is totally different. Inorganic: depoisoning-neutralizing-dewatering; organic: digesting; dewatering; combustion of sludge.* "

Waste water was eventually not incorporated in the design due to time constraints.

- Use of sustainable materials also has an effect on the long term for CO2 emission reduction. Together with other Team there was the option to look into the use of sustainable materials. Use of new innovative concrete for example can reduce emissions by 44%. (Kruithof, 2021). Ash for concrete used in innovative concrete can for example be be sourced locally. There are however limitations when using ash in a steel reinforced concrete construction. See excerpt of interview conducted with an industry expert (Mucuthi & Born, 2022) below:-

" *The waste industry is basically a cherry picking(sic) chain. Everybody takes out what is useful or can be recycled easily. Over the last decades we have seen that more and more waste fractions has found reuse in many different forms, in all stages of the waste chain. As an effect the waste that is incinerated (the last step in the chain) is transforming itself into a residue of different waste sorting technologies. Nevertheless, by washing the ash we still succeed to turn this into a road building material. And we recover many metals that are still present in their metallic form.*
Many ashes from different origin have found their way in all sorts of concrete products. Some are even pozzolanic by itself (i.e. ash from coal fired plants) and add to the strength of the ash(sic). Others act as a filler to make concrete more dense. Others are just cheaper that sand or gravel. Ash from WtE normally contains considerable amounts of chloride which makes it less useful in steel(sic) reinforced concrete. "

Further research was not done on the use of ash for concrete as ash-based concrete was eventually not incorporated in this project.

- For incentives to reduce CO2 emissions, tax incentives are available. See excerpt of interview conducted with an industry expert (Mucuthi & Born, 2022) below:-

" *The European policy with respect to CO2 emissions is tax based…The emission of CO2 is expressed as a total weight per year per ton of input... For WtE the purpose is to convert waste into energy (end, hence, CO2). It makes no sense..to seek another fuel. Only avoidance of waste upstream in the waste chain is the solution.. Within one type of industry a benchmark of CO2 per ton of feedstock is established. The better (less CO2 per ton input) a particular factory operates, the lower the tax per ton of CO2. The actual measurement is the concentration in flue gas, multiplied by the amount of flue gas*. ".

This means that if the client would like to explore the idea of tax-based emissions and get tax incentives at a later stage for this project, the avenue is open for exploration, of course based on the emissions of CO_2 from the project.

Further research on this aspect was not done as we decided as a team not to delve into financial details at this stage of the project and due to time constraints.

We also decided as a team to shelve this goal and concentrate on the other 3 Goals elaborated in the report.

Appendix G.8: Consistency & Integrality

There are also important aspects of Sustainability that are important in projects and this include aspects about integrality and the treatment of others.
In this section, we explain how this project achieved these goals.

Achieving consistency and integrality
In this section the realisation of consistency in the project will be explained. Thereafter, the realisation of integrality will be discussed and explained.

G8.1 Consistency
There are many ways of ensuring consistency in projects. Below are four ways (Management-Training-Institute, 2020) that helps achieving consistency within the project and how this has been implemented in the projectteam:

G.8.1.1 Follow through with commitments:

1. We as a group set clear deadlines each monday at the weekly meetings and we made agreements to ensure these deadlines were met.
2. We organised meetings and made sure everyone was present, or absent with notice.
3. We shared commitments and shared data drives to ensure everyone was working towards the same goal.

G.8.1.2 Treat everyone equally:

1. We worked as a group and as a team and agreed to listen to each other's arguments.
2. Everyone was given the opportunity to share their ideas or issues in meetings.
3. Brainstorming sessions were held to encourage everyone to participate in the project and integrate what we come up with as a group and/or team.
4. Within the teams, there was collaboration on designs and information with the group and teams networking with online applications and meeting physically.

G.8.1.3 Focus on consistent communication:

1. We set goals at meetings, used the GANTT-chart and To-do-lists.
2. We delegated duties to ensure the work was executed by relevant teams and it was finished on time. This also includes having a Management Team and a BIM team to assist with planning and delegation.
3. Meetings had a rotating chairperson and secretary, teams had a fixed chairperson. Team chairpersons also sat in the management team to ensure consistency, continuity and ensure smooth and clear flow of information.

G.8.1.4 Consistently enforce professional rules:

1. We ensured punctuality for meetings by having a fixed date, time and location for meetings. Meetings were on Mondays every week.
2. We started meetings on time. It was, as with most meetings with large groups of people, still a challenge to finish on time. The use of an agenda, prepared in advance, assisted in keeping the meetings on point. We also implemented a new role of timekeeping to help with that.
3. We tried our best to minimise conflicts and ensure heated discussions did not go out of control. Engineers are not known for their social skills! It was a success!

G8.2 Integrality

As noted above in the section on consistency, the group achieves its goals, as set out in the assignment, by the application of several good practices. This ensured we used our skill sets and worked towards the goals in a collaborative way. Some of the activities mentioned above assisted in the implementation of this integrated project.

To achieve consistency and integrity, our team was made up of the following:

1. Group work (28 members)**:** A2
2. Team work (4 to 5 members)**:** BIM, Transport & Planning, Hydraulics, Structural, Water Management, Sustainability.
3. Management team: Representatives from the teams and the rotational weekly chairperson.

The following resources were used by the group and teams:

1. On campus physical meetings
2. Video calling & sharing
3. Messaging in app application
4. Scheduling app to synchronise calendars and plan meetings for management
5. General shared storage for all project documents, group work and team work.