Constructing The Green Connection with and without the use of an intermediate support

By

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- PRELIMINARY STUDY -

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Preface

This Preliminary Study is the first report in a series of two research reports which will be written in order to obtain the degree Master of Science at the Delft University of Technology.

This report is formulated to investigate several aspects in the design phase of a new to be constructed deck structure crossing an already existing motorway. This motorway is the A27 at the east side of the city Utrecht and this deck structure is called *"The Green Connection"*. It will cross this motorway with a span of about 75 meters. The feasibility in design phase will be investigated. This report is also meant to confine the project as much as possible, so it can form the basis of the subsequent report *"Master Thesis".*

First of all, I would like to thank the members of my graduation committee. I would like to thank Professor Dick Hordijk and associate Professor Cor van der Veen of the TU Delft for their guidance during the thesis. Furthermore, words of thanks to my company supervisor Rob Vergoossen. I appreciated the inspiring conversations and constructive feedback you gave. Your structural speciality was very useful during dimensioning the deck structure. Additionally, I would like to thank all other colleagues at Royal HaskoningDHV for their help and discussions. I would like to express my gratitude to the company Royal HaskoningDHV for providing me the opportunity to conduct this thesis and to graduate as a civil engineer. I look back to a pleasant period.

Niels van Bergenhenegouwen

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Summary

In the Netherlands a lot of traffic congestion occurs on motorways. This problem is most severe nearby larger cities. Utrecht is a city which is centrally located in the Netherlands and the surrounding road and motorway system suffer a lot from traffic jams. To improve the mobility and traffic flow in this area, the organization which is responsible for these roads and motorways, Rijkswaterstaat, came up with a huge masterplan named *"A27/A12 Ring Utrecht".*

This total masterplan consists 3 national motorways, local routes and about 100 engineering structures of all kind. However, only a small part of this plan is considered in this report. It consists of a part of the motorway the A27 between the traffic junctions Lunetten and Rijnsweerd. The existing motorway between these junctions is constructed below ground surface. The deepened section of the motorway consists of two parts. The one considered here is the part constructed as a U-shaped concrete structure. This structure is applied because it doesn't require a lot of space in width, which was a key point during construction since this U-shaped structure crosses the forest of Amelisweerd. Due to this structure, a lot of trees of this highly valued forest could be preserved.

Nowadays, the structure at Amelisweerd accommodates space for 10 driving lanes and the total internal width is 51.7 meters. According to the masterplan of Rijkswaterstaat the new situation must consists 14 driving lanes, which implies an extension of the motorway at both sides with 15 meters. The total internal width becomes 81.7 meters. Besides, on top of this extended U-shaped concrete structure a deck structure must be created. This deck structure is called "*The Green Connection*" which spans the width of the motorway and covers it with a length of 249 meters. On top of this deck structure a public garden must be created with a viaduct incorporated in the design. This thesis is related to the construction of this Green Connection.

In the original design of Rijkswaterstaat an intermediate support is used as a boundary condition. But, construction of this intermediate support must be executed in the middle of the A27. A new foundation must be applied, but in what way is still unknown. The structure lays about 7 meters below ground water table and drainage is prohibited due to the surrounding forest. The floor of the U-shaped structure has a thickness of almost 2 meters because the structure is dimensioned to counteract floating. And if some driving lanes must be blocked it will result in societal consequences and costs. A limitation of the number of driving lanes is only allowed in periods of less traffic intensity, such as nights and/or weekends.

Altogether, constructing this middle support is quite an extensive task. Therefore, in this Preliminary Study it's investigated if a deck structure can be designed without such a support. It resulted in the following research question:

> *How to construct The Green Connection as a concrete structure with and without the use of an intermediate support?*

In order to answer this question properly, this report will only highlight the main design criterion and confine the project as much as possible. This report will also consist a preliminary design and will form the basis of the next report, the Master Thesis. The above stated research question will be answered in the Master Thesis.

A lot of boundary conditions and confinements are discussed. Some important conditions are that the structural span becomes 75 meters and that the load resulting from the public garden on top is almost twice as high as the normal traffic load on a viaduct according to the Eurocode. This load resulting from the public garden is designed according to the ROK 1.4, which is a guideline of the organization Rijkswaterstaat.

Furthermore, The Green Connection is a deck structure which is going to be constructed between two structural walls and has quite some resemblances with the construction of a normal bridge/viaduct. The Green Connection

has a lot of similarities with the requirements concerning bridge structures in the ROK 1.4 and therefore this structure is appointed to be a bridge structure. That's the reason why the current state of the art in constructing bridges is discussed. The methods of execution in bridge construction are discussed as well as methods of construction which prevent traffic hindrance as much as possible. Also, the concrete deck structures are discussed such as the common in-situ cross sections and prefab structures which are commonly used. Both kind of structures are discussed with key figures such as slenderness and maximum span. In the end it turns out that in-situ construction is not applicable because it causes too much traffic hindrance. Prefab structures seem to be advantageous, but a prefab beam with these dimensions is never constructed before in the Netherlands. A custom made prefab design is required.

Transport of prefab elements is mostly the limited factor in the final structural design since the weight and dimensions of the elements is dominating. First the possible prefabrication company is discussed. The only company with a sufficient prefabrication yard is Haitsma Beton. This facility can hoist prefabricated elements of 280 tons and can construct beams with lengths up to about 70 meters. From here on, the transport of such elements by truck and trailer, by train and by ship and pontoon are discussed. It turns out that neither of the 3 possibilities seem to be an optimal solution, mainly due to the transport route of about 180 km and the necessity of temporary stock yards.

Therefore, the surrounding area is investigated. Two large areas are appointed by Rijkswaterstaat as construction sites. One of these areas is 2.8 hectares large and is almost adjacent to the final location of The Green Connection. Considering that the possible transport possibilities are not that optimal, and a lot of beams or sub parts must be constructed to cover the structure with global dimensions of 75 by 249 meters (so economies of scale is achievable), a construction site nearby seems to be the solution. From this point on, this construction site is used for the prefabrication of the elements as well as a stock yard since this area is large enough accommodate these aspects. Using this construction site incorporates more freedom in the design phase with respect to transport of these elements. If the prefab solution consists of prefab beams, a maximum weight of 280 tons each is taken as a boundary condition. This amount is the same as the facility at the company Haitsma Beton.

Since this structure is a unique one, a unique solution must be figured out. Therefore, three out-of-the-box ideas are designed. Idea one consists of a custom-made optimized pre-stressed prefab box beam. After hoisting these beams into final position an in-situ concrete topping is going to be constructed on top. After hardening, the beam will be post tensioned. Idea number two consists of a balanced cantilever method where at one side of the hammer head elements are produced. Global equilibrium is restored with anchorage and a vertical support. The third idea consists of a concrete deck structure which is prefabricated at the construction site with dimensions of about 75 meters by 12 meters. Such a structure will be constructed 20 times and will be transported individually with SPMTs.

In total six reference projects are discussed. Three of them consists of bridge structures and the other ones consists of tunnel structures with a public garden on top.

If it turns out that a single span isn't feasible, two alternatives are opted which include a support in their design. These alternatives seem to be advantageous in comparison with the original global design of Rijkswaterstaat.

To continue this research, the execution aspects are discussed when the original design of Rijkswaterstaat is going to be constructed. The aspects relate to the extended parts, the intermediate support and the deck structure itself. After that, two preliminary designs are going to be performed. After judging one of them as most beneficial, a structural design check will be performed, which will be a more thorough calculation. Furthermore, a chapter will be dedicated emphasizing the differences between the two designs, related to the execution aspects, feasibility and hindrance.

Contents

1. Introduction

1.1 Introduction

The Netherlands has a very dense infrastructural network, especially nearby the larger cities. Utrecht is one of these cities. This city is centrally located in the Netherlands. Although it has several advantages to be in the center of a country, like for instance accessibility, a disadvantage is the fact that a lot of traffic is present at the local road and motorway system. It not only means that the local traffic is present, but also traffic which uses the surrounding motorway system to drive by. All these vehicle movements around Utrecht result in traffic jams on a daily base. When considering the current economic growth, it's even getting busier and thus worse. Therefore, Rijkswaterstaat came up with a large improvement plan for the infrastructural system to reduce the traffic hindrance around Utrecht.

First of all, Rijkswaterstaat is the organization in the Netherlands which is responsible for the design, construction, management and maintenance of the motorway network. It came up with an improvement plan. This masterplan is called: *"A27/A12 Ring Utrecht"* [1]. Figure 1.1 shows the scope of this masterplan. As made visible in this figure, the scope of this plan is enormous. The project contains 3 busy motorways, the A12, the A27 and the A28 with several accesses and exit possibilities. It also contains 3 large traffic junctions and local roads. The project also contains 6 locations which are indicated as key-point traffic jams locations. These locations are listed in the top 50 of most occurring traffic jam locations in the Netherlands [2]. Therefore, the objective of this masterplan is to improve the traffic flow in the whole area while keeping the living environment at least in the same shape as nowadays and improve the environment if possible.

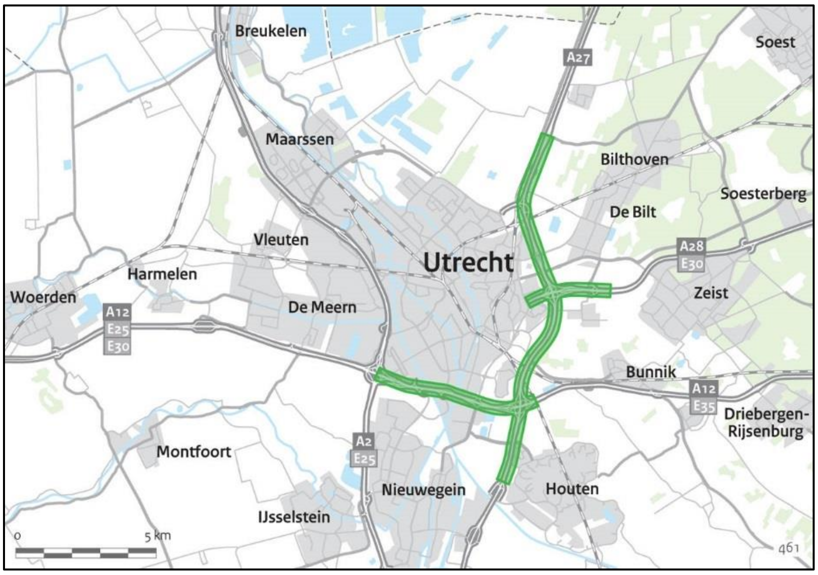

Figure 1.1: Scope of the masterplan of Rijkswaterstaat visualized in green [3].

To improve mobility in the current motorway system, several countermeasures should be taken to prevent a further increase of traffic congestion at Ring Utrecht. Extra traffic lanes are going to be constructed. But only extra asphalt won't succeed the masterplan. Rijkswaterstaat has also identified another event which caused traffic jams. Switching lanes during driving is also contributing to congestion. But switching lanes is necessary to reach the intended arrival. It can't be prohibited.

However, the problem can be minimized. Rijkswaterstaat uses "bypasses" in the new design. This means that drivers have to pre-sort at the beginning of Ring Utrecht, so the amount of switching movements decrease drastically at the ring itself. Then, the motorists can drive in a separate lane in the same direction as the main carriageway. Since traffic dynamics won't be considered in this report, this phenomenon will not be discussed anymore. But, the accompanying fact of applying bypasses in the new design plan results in the necessity of increasing the width of the motorways. Conflicts occur at various structures, like viaducts and traffic junctions. More space is required, and the current infrastructural structures must be improved, adapted or expanded.

The total masterplan of A27/A12 Ring Utrecht contains more than 100 engineering structures. These structures vary from simple structures like a culvert underneath the motorway up to structures which are more complex, like viaducts. One special structure within this masterplan is a U-shaped concrete structure at the motorway A27 at the estate of Amelisweerd. In the next section this construction will be discussed.

1.2 Introducing the U-shaped concrete structure at Amelisweerd

One part of the masterplan consists of the A27 between the two traffic junctions Lunetten and Rijnsweerd, showed in Figure 1.2. In between these junctions several engineering structures are located. One of them is the U-shaped concrete structure at the estate of Amelisweerd. This structure forms the basis of this report, is located in the A27 and is indicated with a green circle in the next figure.

Figure 1.2: The east part of Ring Utrecht; the A27 between traffic junction Lunetten and Rijnsweerd [1].

1.2.1 History

Before construction this part of the motorway, the estate Amelisweerd was surrounded by a beautiful forest. This forest entails a lot of cultural and environmental value. Due to the increasing number of motorists in the seventies, an improvement of the motorway system around Utrecht was necessary. First, the plan was to connect the 2 junctions Lunetten and Rijnsweerd directly in one straight line crossing the forest of Amelisweerd. This resulted in a lot of demonstrations in and around the city Utrecht. The community wasn't pleased about the progress of extending the new A27, which resulted in an adjustment of the intended plan. Some measurements had to be taken. The first part above traffic junction Lunetten is going to be realized several meters below surface level. The reason behind it was the fact that it reduces hindrance such as noise pollution to the surrounding area. But how can several kilometers of motorway be constructed and still make an economic solution?

The applied method was a well-known Dutch engineering solution; creating a polder and construct a motorway beneath ground surface. It was the best economical solution. One disadvantage of this method is that it takes a considerable amount of space in width, which is of great importance at the location of the forest of Amelisweerd. If this method was applied at the forest, too many trees had to be chopped down.

Keeping this in mind, the solution was constructing a U-shaped concrete structure, which is located deepened and below ground water table. It was made at the edge of the forest of Amelisweerd. Via this method, the amount of space which was necessary to construct the deepened motorway could be reduced. More area of forest could be preserved. To save the estate even more, the intended route of the A27 was reconsidered and shifted to the edge of the forest, so the renewed track affects the forest as less as possible.

Initially, the track is visualized in Figure 1.3 with yellow lines. With this option the forest is cut into two parts, which was not desirable and disapproved. Finally, the motorway was shifted more to the edge of the forest in the direction of the city Utrecht. The current location of the U-shaped concrete structure is visible in the same figure.

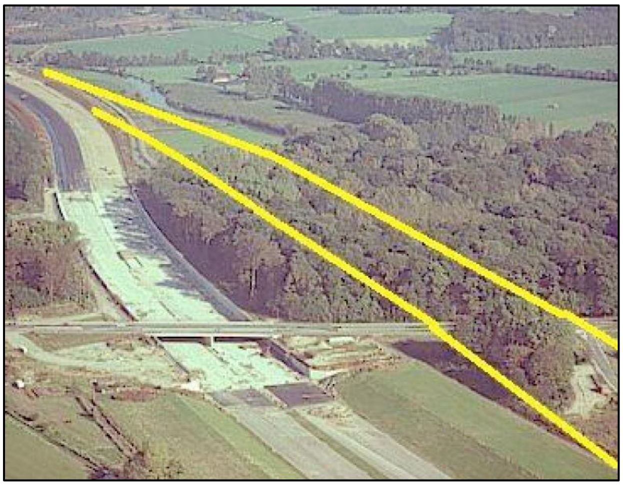

Figure 1.3: Final location of the structure of Amelisweerd and the initial intended location visualized with yellow lines [4].

1.2.2 Current structure

A global lay out of the current structure and situation is visible in Figure 1.4. This figure is a 3D render of Google maps. It is pretty well shown that the layout lies beneath ground surface. The same holds for the viaduct of the Koningsweg (which crosses the A27), the number of lanes in each direction at the A27 and the concrete walls of the U-shaped concrete structure.

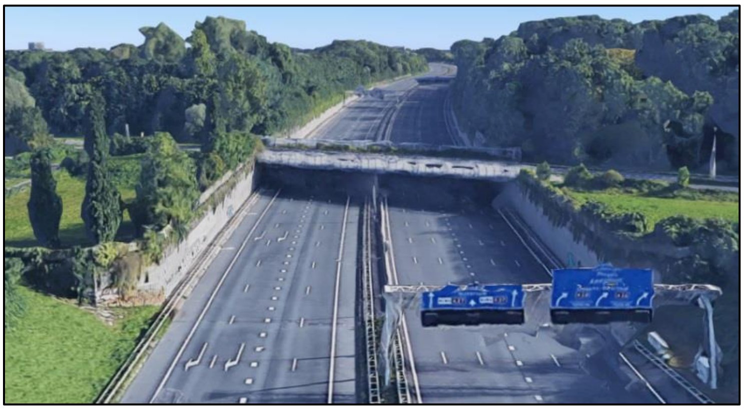

Figure 1.4: A 3D render of Google maps of the current situation of the U-shaped structure at Amelisweerd.

The method of construction will be briefly emphasized because possible future adaptions could be dependent upon this used method [5]. The construction of this concrete U-shaped structure started back in 1983. After applying a sheet pile wall with temporary inclined anchors in combination with wales, the anchors were tensioned, and the excavation of the pit started. Due to the high ground water table, the pit is excavated in wet conditions with a small dredging vessel. After the excavation, tension piles were installed with special equipment on a floating pontoon and afterwards from the same pontoon the sheet pile wall was constructed in cross direction. This sheet pile wall was constructed because of the opportunity of pouring the underwater concrete floor in several shifts, with less risk for water leakage. After pouring the whole underwater concrete floor the pit was pumped dry. Followed by a small layer of aggregate the structural floor was applied and later the construction of the concrete walls started which made the U-shaped concrete structure complete. A cross section of the current structure is shown in the next Figure 1.5.

The underwater concrete floor has a thickness of minimal 1 meter. In combination with the tension piles it ensured vertical equilibrium. The gravel layer on top is about 30 cm thick and the structural floor is about 0.7 – 1 m thick. The concrete walls of the U-shaped structure are maximal 0.7 meters in width.

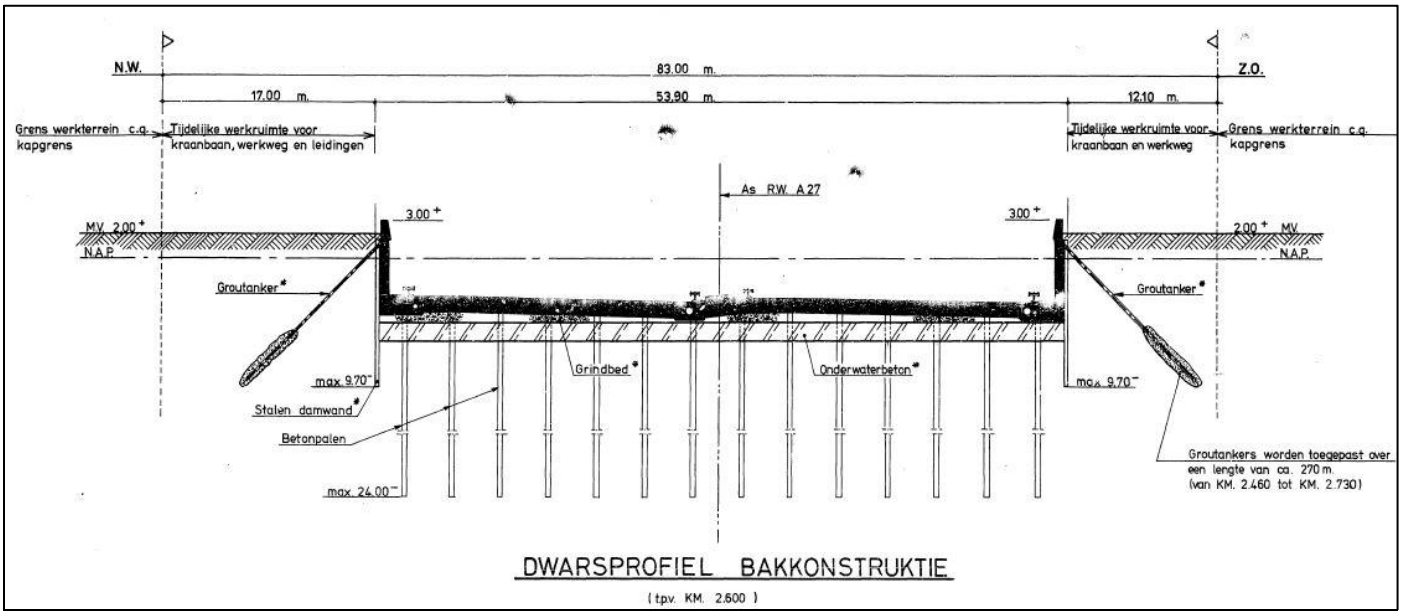

Figure 1.5: Cross section of the current structure at Amelisweerd [6].

As seen in Figure 1.5, anchors are shown. These anchors where only a temporary measure and were removed after sufficient height of the concrete walls. In this case global equilibrium of the pit was ensured and the anchors were pulled out. The sheet pile walls however are permanent. The external width of the structure is given in this figure as well and is about 53.90 meters.

According to the technical specifications [6], the internal width is about 51.70 meters. This width can be deduced from Figure 1.5. This document is provided by Rijkswaterstaat and used for the future tender phase of this project.

1.2.3 The *"Koningsweg"*

A provincial road crosses the A27 via a viaduct, as can be seen in Figure 1.4. This road is called the Koningsweg. Due to the enlarging of the A27 the span and structural design of this viaduct have to be adapted or reconstructed. The design of this viaduct must be integrated in the new design of The Green Connection.

1.3 Problem description

Traffic jams at the motorway system around Utrecht are present on a daily base. To reduce these jams, Rijkswaterstaat wants to improve the infrastructure in this area. The masterplan contains a lot of aspects, structures, situations and other adjustments in the infrastructural network around Utrecht, but the only one considered in this thesis is the situation around the structure of Amelisweerd. Here, the motorway A27 lays deepened in a U-shaped concrete structure. In the current situation, the motorway consists of 6 driving lanes in one direction and 4 lanes in the other direction. According to the new masterplan, both directions shall have 7 lanes. The current structure at Amelisweerd is not wide enough to accommodate 14 driving lanes and hard shoulders which are defined in the masterplan. Without an extending of the current structure in width, the structure becomes a bottleneck in the future masterplan. Therefore, the U-shaped concrete structure must widen maximal 15 meters at both sides.

Besides the widening of the motorway which is necessary to accommodate the extra lanes, another task must be completed. At the location of Amelisweerd, the U-shaped concrete structure has to be covered up over a length of 249 meters. This structure will literally connect the estate of Amelisweerd with the city Utrecht and it's a compensating measure for the living environment as well as for the ecological environment.

One key point in the masterplan implies that the quality of the living environment may not get worse and must be improved if possible [1]. Therefore, to counterbalance all construction activities, a decision is made to construct a public garden on top of this deck structure. Another reason is that it will improve the accessibility to the estate Amelisweerd from the city Utrecht. It adds value to the region and complies with the key points of the masterplan. Nevertheless, it's also a compensating measure to the chopped off trees which are necessary to realize the extending of the A27 at Amelisweerd. The current and the global future situation are visualized in Figure 1.6.

Figure 1.6: Current situation (left) and new intended situation (right) [7].

The covering up of the deepened U-shaped concrete structure is called "The Green Connection". From now on, this expression is used for the future roof connection on top of the concrete structure which lies within the A27 at Amelisweerd.

1.4 Research objective

Although Rijkswaterstaat made up an enormous masterplan, this thesis is limited to the motorway A27 which is situated beneath ground surface in a U-shaped concrete structure. On top of this structure a deck structure must be constructed, The Green Connection. In particular, this thesis is limited to the construction of this Green Connection. Figure 1.6 shows this new structure. A remarkable point is the fact that in this visual the deck structure is designed with the use of an intermediate support. This intermediate support is according the original design made by Rijkswaterstaat.

The reason to investigate this structure is that the construction of this intermediate support is quite an extensive task. The bottom of the current structure exists of about 2 meters of concrete as described in paragraph *1.2.2*. Due to the high loads resulting from the deck structure, a new support and foundation must be constructed in the middle of the U-shaped concrete structure in between the busy motorway. Besides, the structure is locally situated almost 7 meters below ground water table and drainage is prohibited due to the surrounding forest of Amelisweerd.

Altogether, it would be quite advantageous if this intermediate support could be omitted. Therefore, in this Preliminary Study it is investigated if The Green Connection can be constructed without the use of an intermediate support. A solution is sought in the feasibility of the construction of The Green Connection as a single span design, in contrast to the design of Rijkswaterstaat. One key point in this single span design is the deck structure itself. All kinds of important considerations related to constructing this deck structure of the relative large span will be discussed. In the subsequent report Master Thesis, it's going to be considered how to construct an intermediate support in such a way that a fair comparison can be made.

1.5 Research question

From the previous paragraphs the following research question is formulated:

> *How to construct The Green Connection as a concrete structure with and without the use of an intermediate support?*

In order to answer this question properly, this report (the Preliminary Study) will only highlight the main design criterion in constructing a deck structure and confine the project as much as possible. This report will form the basis of the next report, the Master Thesis, and it will also consist a preliminary design. The above stated research question will be answered in the Master Thesis.

2. Boundary conditions

A special chapter is dedicated to the boundary conditions. Since the masterplan is such a huge project, it's necessary to confine this Preliminary Study as much as possible and specify the research. The current structure is already emphasized in paragraph *1.2.2*. With this information kept in mind, the new intended structure opted by Rijkswaterstaat is discussed and reviewed with the help of some figures. A more detailed description of the road arrangement is specified in Appendix A. After that, some other boundary conditions are mentioned, and some further confinements are opted to specify the research as much as possible in a separate paragraph.

The ROK 1.4 is outlined. This document is a guideline especially for structures in the Netherlands. The manual of tunnel construction is also discussed. The last paragraph elaborates what kind of load is dominating upon the deck structure, since the structure has globally two functions, a viaduct and a public garden.

2.1 The new intended situation

In this paragraph the new intended situation is discussed. According to technical specifications document of Rijkswaterstaat [6], a situation of the newly intended cross section of the motorway is designed and schematized in Figure 2.1.

If this figure is compared to the Figure 1.5, the width of the structure in the new version is extended at both sides with 15 meters. Therefore, the total internal width between the two side walls becomes 81.7 meters. However, one remarkable difference in comparison with a starting point of this study is also shown in this figure. As visualized, an intermediate support is schematized.

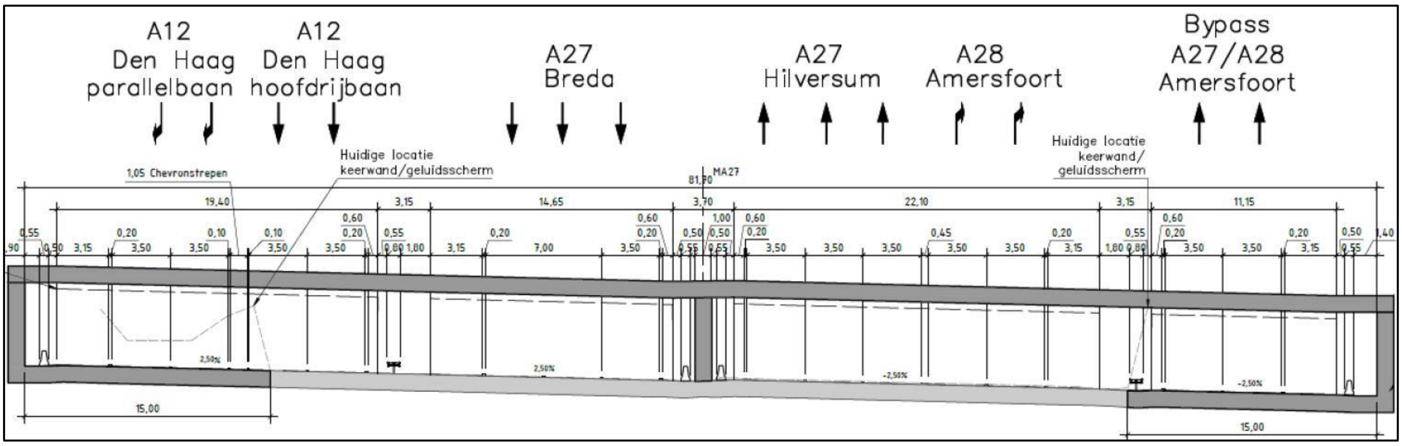

Figure 2.1: The new intended situation opted by Rijkswaterstaat with the use of an intermediate support [6].

To construct such a support some complicated measures must be taken. The underwater concrete floor is dimensioned to counteract floating and not upon bearing vertical (gravitational) loads. It is most likely that the foundation applied lacks resistance to bear the vertical forces of the concrete structure including the load of the on top to be created public garden. Conclusion: a new foundation must be constructed in the middle of one of the busiest motorways in the Netherlands. A vertical as well as a horizontal cross section of this opted new solution is visualized in the next figure to clarify the previous Figure 2.1. The original layout of the current U-shaped structure is drawn with a dashed grey line in the top of this figure. The small vertical red line is the middle axis of the motorway.

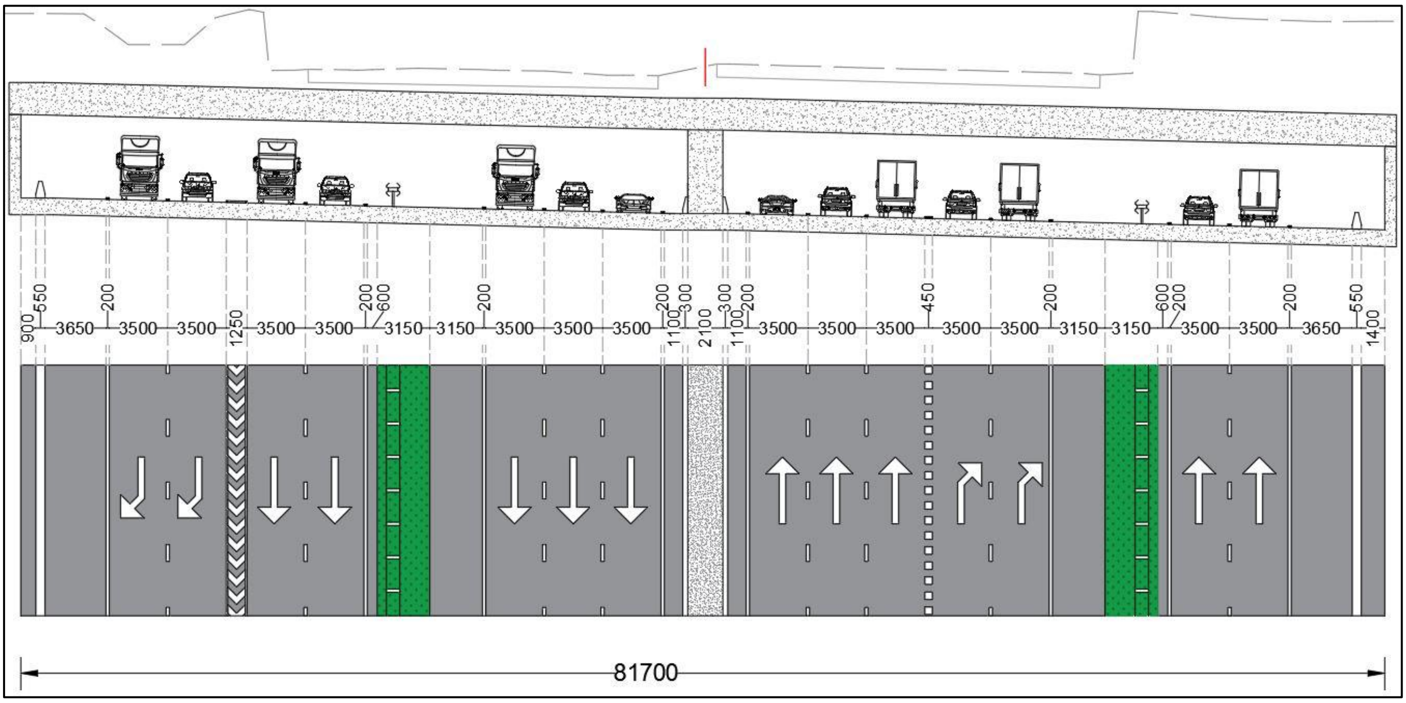

Figure 2.2: Digital version and clarification of Figure 2.1.

If an intermediate support is going to be constructed, it will become complex solution during construction. It was briefly outlined in paragraph *1.4* to emphasize the complexity of constructing this middle support. But, when the construction phases are considered in more detail, it becomes even more extensive.

Because of the 6.7 meters of water pressure in the middle of the motorway, the first problem started. The ground water table must be lowered with the help of a kind of drainage system to create a dry working space, while drainage is prohibited due to the surrounding forest of Amelisweerd. Probably, an exception must be made to locally lower the water head. After that, the structural floor must be partly removed followed by the underwater concrete floor. This is almost a layer of 2 meters of concrete!

Then, first the already existing tension piles have to be located followed by the construction of big foundation piles to resist the high loads. Large equipment will be necessary for construction due to the expected relatively high vertical forces. And it must be constructed in the middle of the busy motorway. A big temporary construction site must be constructed in the middle of the A27 with the accompanying temporary road alignment.

The result of all this will cause a lot of traffic hindrance. Nevertheless, it's also very time-consuming job and thus a costly one. It also consists a high-risk potential since the global equilibrium of the structure is not ensured anymore.

Therefore, constructing a middle support in the current structure is an unfavorable activity and it would be advantageous to leave this support behind. But what are feasible solutions in the situation where no intermediate support is present? Is it still feasible to construct The Green Connection? The challenge is to come up with an idea where such a support isn't necessary. Covering this structure with no intermediate support is one of the most severe and challenging boundary conditions. In contrast to the point of departure of the document of Rijkswaterstaat, the starting point of this preliminary design is constructing The Green Connection without an intermediate support.

If this support can be left out, the road arrangement of the new intended A27 could be changed a bit. Figure 2.3 shows a cross section of the intended structure covered up without the use of an intermediate support. The dimensions of the structural parts are schematized indicatively. Since this research wants to investigate the single span design, the starting point is not to use the middle support, which implies a new arrangement for the motorway. Again, the original layout of the current U-shaped structure is drawn with a dashed grey line in the top of this figure. The small vertical red line is the middle axis of the motorway.

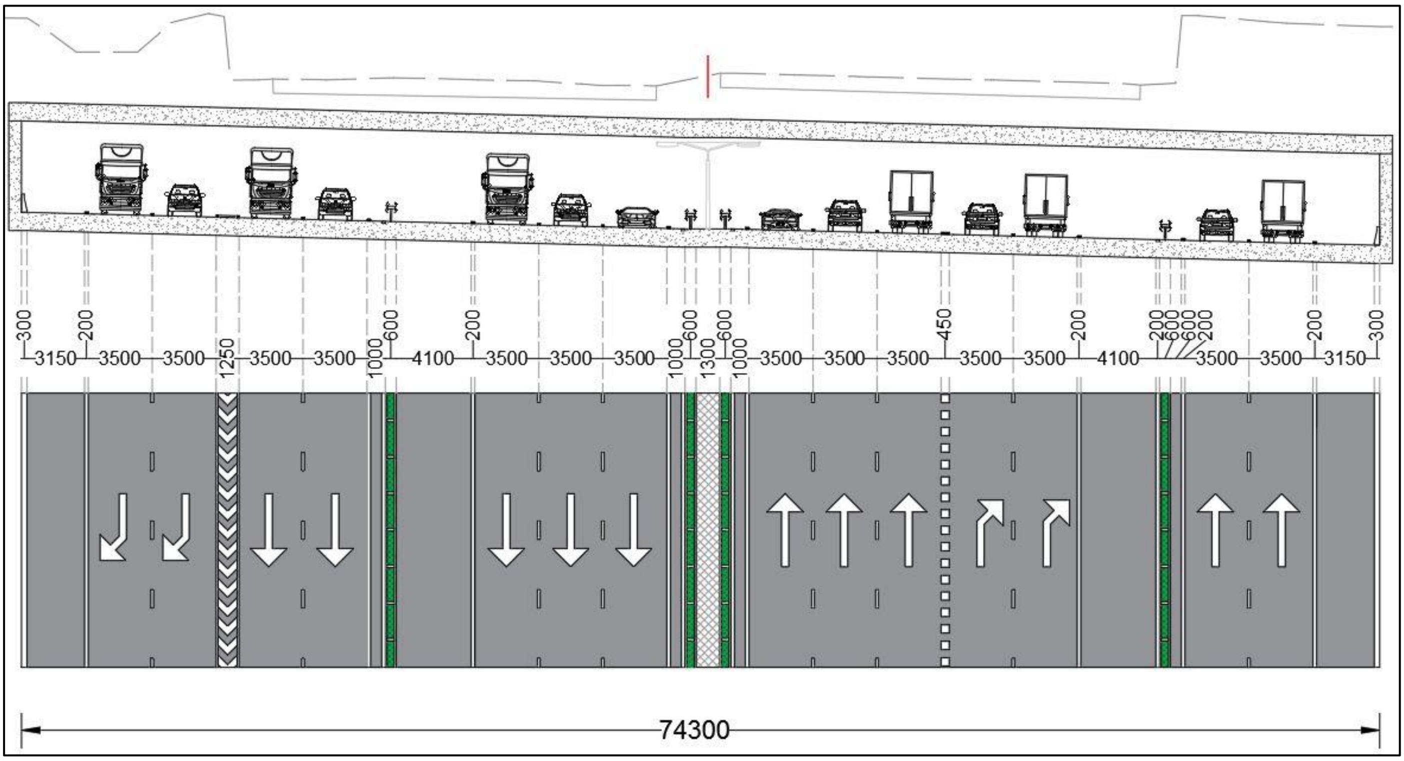

Figure 2.3: Renewed road arrangement.

In the Netherlands, a layout for a new motorway or a reconstruction of a motorway must be designed according to the Dutch ROA *Richtlijn Ontwerp Autosnelwegen 2017* [8]. It's like the national Eurocode for motorways and a guideline to take into account all the safety considerations in designing a proper layout for motorways. Based on this guideline a renewed layout of the A27 is designed. The main task of the new design was to reduce the width of the carriageway as much as possible and still get a save design. The span is a very important parameter in the distribution of forces and it's favorable to reduce the span as much as possible. The renewed design can be seen in Figure 2.3.

Since the 1970's, a trend in designing new motorway tracks is to consider the future purpose of the motorway itself. In some designs it's usual to let the motorway contain a hard shoulder with an extended width. Reason for that is the possibility to extend the motorway with an extra lane in the future. This concept is often applied in designing viaducts and other engineering structures within a new motorway track. The reason for that is the fact that constructing a wider viaduct is relatively cheaper than initially constructing a smaller viaduct and after a couple of years extending the same viaduct.

Keeping this in mind, research is done for the future purposes of extending the capacity of the A27 at Amelisweerd. Although it's a bit exaggerated or contradictory to consider another extending of the motorway while the intended extending hasn't taken place yet, one must consider this tendency. But, in the masterplan of Rijkswaterstaat [1] no further information or demands are stated about future widening of the A27 at Amelisweerd. However, some notes are written about the A27 above Rijnsweerd. This part of the motorway won't be considered in this thesis, but one remarkable note must be made; the masterplan points out 3 driving lanes in each direction and the possibility to have a 4th driving lane (future purpose). This thought is also considered in this new design, because the costs of a future extending of the U-shaped concrete structure will be enormous compared to the adaptions which can easily made initially. The final plan was already shown in Figure 2.3. This motorway plan is designed according the *Dutch ROA* [8] and still have the possibility to extend the A27 with another driving lane in both directions. The reasoning behind this new design is discussed in Appendix A.

From Figure 2.2 and Figure 2.3 can be deduced that the internal span can be reduced by almost seven and a half meters, which could be crucial in a later stage when considering the structural design. As said before, the span is an important parameter and these 7.4 meters could be essential. From now on, it is determined that the internal span is 74.3 meters. The structural span is determined to be 75 meters, taken into account the support distance.

2.2 Groundwater table

The motorway runs through the forest Amelisweerd. The ground water table is pretty high and may not be lowered due to the existing trees and other vegetation in the surrounding area. During construction, this demand was applied and therefore it's the main reason why an underwater concrete floor was used. It was prohibited to lower the groundwater table. At its deepest point, the water pressure could be 6.7 meters. The underwater concrete floor in combination with tension piles ensured vertical equilibrium, so the foundation is dimensioned on tensile forces to counteract floating.

2.3 Clearance

The clearance beneath The Green Connection should be at least 4.8 meter. This height is composed of 4 meters of vehicle height, like lorries, 0.3 meters for suspension differences and 0.2 meters left for safety. The last 0.3 meters could be useful for quick asphalt replacement. In this case the new layer is going to be constructed upon the other existing layer, which sums it up to a minimum of 4.8 meters clearance. In the design is 5 meters of clearance used, because of construction tolerances [9].

2.4 Traffic hindrance

The objective of an improvement of the infrastructure around Utrecht is to avoid the current hindrance what takes place nowadays such as traffic congestion. During construction, the national motorway A27 and the provincial road N411 (The Koningsweg viaduct) must be (partially) blocked as less as possible. Therefore, it's important to take into account the degree of hindrance in traffic what could suffer at the A27 during construction. A certain criterion is used by Rijkswaterstaat to globally measure this hindrance. In Dutch it's called "v*oertuigverliesuren*". The definition is the number of hours lost in travel time compared to an undisturbed travelling time [10]. This number of hours lost by a vehicle is calculated by the actual driven travel time over a period of a year compared to the travel time over the same track without any traffic hindrance, an undisturbed track. This value is multiplied by the number of vehicles driving in this track. For example; one lost hour of vehicle movement is the same as one vehicle which has one-hour delay over a certain track. Or 60 vehicles with a delay of 1 minute and so on.

Another criterion is the closure of a driving lane for a certain period of time. Because of possible reconstruction of the concrete structure, it could be possible that a driving lane must be blocked to provide extra working space. The unity of this measure could be the driving lane closure per hour, with an accompanying fine per hour.

These criteria have to be bore in mind while judging certain solutions concerning construction time. Later on, these criteria will be discussed. For now on, it's important to determine the fact that the amount of traffic hindrance is of great importance and it will be an influencing parameter in determining which kind of execution method is used.

2.5 Transportation

If the construction method consists of a prefab solution, it's important to consider whether it is a feasible one. Prefab solutions will be discussed in chapter *3*. Transportation of huge prefab concrete elements could be an impeding factor. For instance, the height of a concrete beam may not be a lot more than 4 meters including all auxiliary elements like the truck itself. This is due to the mean clearance of the viaducts.

Transportation of these huge elements could be done via several methods. As mentioned before, it can be transported via the motorway system. Another possibility is transportation via the main water roads by a vessel. Last option could be transportation via a train. The suitability should be determined after the final design is known. Although that takes a while, it's important to bear in mind that the matter of transportation is also a dominating factor in the final design. It should be considered in the designing phase.

For now on, the possibilities of transportation of such elements are considered. All 3 mentioned opportunities could be feasible, because of the presence of a motorway system, railway system and a waterway in the vicinity. In the possible solution the location of the factory must also be considered and whether these 3 opportunities are a suitable solution. These subjects are outlined in chapter *4*.

2.6 Further confinement

This Preliminary Study roughly discusses the main engineering challenges in constructing a structure above a motorway which must cover up 75 meters of span. The accompanying execution method is also of great importance since the design depends upon this method. Other engineering tasks are not discussed in detail. Examples are other tasks to accomplish this total project. These tasks are presumed that it will happen and won't result in any kind of problems during the construction of The Green Connection. Not all the subjects can't be described in detail, and some further confinements are made to ensure the focus is pointed on the execution method of The Green Connection as well as the deck structure itself. The following (provisional) confinements are made:

- *Steel, composite or FRP bridge decks*
  The deck of The Green Connections will be constructed in reinforced, most likely including pre and/or post tensioned concrete since the graduation subject must be related to concrete structures. Therefore, other possibilities like steel bridges, composite bridges or FRP bridges won't be considered.

- *The membrane structure*
  From junction Lunetten to the beginning of the U-shaped concrete structure at Amelisweerd a special "membrane construction" is applied during construction. This structure is mentioned before, but it won't be considered anymore in this thesis.

- *Widening of the main motorway*
  The current motorway must expand at both sides about 10-15 meters. This widening consists of several activities which have to be realized. Globally, it consists of the trees which must be chopped off, the sheet

piling to allow excavation and other activities which are necessary to construct the supports of The Green Connection.

- *Construction of tension piles in combination with an underwater concrete floor*
  Because the motorway lays below ground water table, the motorway will float due to the high-water pressure below if no countermeasures were taken. During construction of the A27, the use of an underwater concrete floor in combination with tension piles are used to resist this upwards water pressure. It is presumed that it must also be applied at the extending parts of the motorway and it won't be considered in this thesis in detail.

- *Drainage of the building pit*
  After the construction of the underwater concrete floor, the building pit will be pumped dry to construct the structural concrete floor for the intended widening of the motorway. What kind of drainage system will be applied is not considered here. It is presumed that a sufficient drainage system can pump dry the building pit.

- *Gravel layer and structural concrete floor*
  After drainage of the building pit, a gravel layer can be applied on top of the underwater concrete floor to set the structural floor. The thickness of this gravel layer, the amount and composition won't be considered. The structural concrete floor won't be considered as well. It is presumed that it's possible to construct such a floor and no attention will be paid to the composition of the concrete mixture and the amount of required reinforcement.

- *The supports*
  The supports which are also function as structural walls are not considered in detail this thesis. It is presumed that these supports are strong and stable enough to resist the final loads which results from calculations. If for what reason still a support has to be constructed in the middle of the motorway, it's again presumed that it is possible to construct such a support. In these cases, the amount of reinforcement and the composition of the concrete mix won't be considered.

- *The Koningsweg*
  This provincial road crosses the A27 via a viaduct. The design of this viaduct must be integrated in the total design of The Green Connection. The blocking of this road, the removing of the current viaduct and the esthetical incorporation into the total design won't be considered. The same holds for the traffic flow and/or traffic dynamics during construction or the temporary solution if closure of the viaduct is prohibited by the municipality.

2.7 ROK 1.4

The guideline ROK 1.4 is a abbreviation for *"Richtlijnen Ontwerp Kunstwerken 1.4"* and is a technical document of Rijkswaterstaat [11]. The document literally means a guideline for the design of engineering structures. The Eurocode and its national annexes contain guidelines for structural safety and durability. The Eurocode specifies three categories, which are buildings, bridges and "other structures". The ROK however specifies more categories and therefore it prescribes some additional requirements for these "other structures", such as hydraulic structures and tunnels. Nevertheless, if the requirements from the ROK contradicting the Eurocode norms, the ROK is the governing one.

Every new design in the Netherlands which is going to be constructed for Rijkswaterstaat must comply with the guideline ROK 1.4. The same holds for new parts or components at existing structures or extensions of existing structures. The new to be designed Green Connection is such a structure and therefore it's now elaborated which kind of restrictions and boundary conditions are prescribed by this document.

This information is outlined in Appendix B and summarized in paragraph *2.9.1*.

2.8 Manual of tunnel construction

According to the manual of tunnel construction [12], four types of load models are distinguished which could exert upon a tunnel:

1. A traffic load which will be discussed in paragraph *2.9.2* and Appendix C.
2. A uniformly distributed load if no further restrictions are mentioned. The amount of it is 20 kN/m^2.
3. Future prospects above the tunnel could be considered. In that case a variable load of 30 kN/m^2 is applied.
4. Special load model in case of a building is constructed upon the tunnel. In that case project specified information is provided.

In the case of The Green Connection one of these load models might be applicable, but possibly less severe since this new to be designed structure is not a tunnel. The total length of The Green Connection is only 249 meters, so in its way it's not a tunnel. It's just a kind of covering, a kind of roof and/or partly a viaduct.

2.9 Basic assumptions and governing equations

It is of great importance to know what kind of loading is exerted to the new to be designed structure; otherwise it's not possible to design The Green Connection in an efficient way. Therefore, in a preliminary design the self-weight of the materials as well as the loads exerting on the structure are determined. If this information is clear, some preliminary calculations could be made which provide a certain estimate of the dimensions of the intended structure. It will also give a global insight of the feasibility.

In a preliminary design, the self-weight of the materials and the external load are of great importance. The self-weight of normal reinforced concrete is 25 kN/m^3. This weight is based on reinforced concrete with maximum 200 kg/m^3 of steel. If heavily reinforced concrete is applied, a higher value than 25 kN/m^3 might be more suitable especially in combination with a high concrete strength and pre-stressing cables. A higher concrete strength class means more cement in the concrete mixture. Concludingly, the self-weight of the reinforced and prestressed concrete is taken as 26 kN/m^2.

Furthermore, on top of The Green Connection could be roughly two kinds of load models. The first one is a load model which represents the public garden. An assumption is made about the height of the loading by the municipality of Utrecht. This organization states a load of 30 kN/m^2 on top of The Green Connection [13]. It seems that the municipality easily took into account the load consideration of the manual of tunnel construction (3) since no further information about the load of the public garden is specified. This load could be used as a basic assumption in the report. But what are the regulations regarding a public garden on top of a structure? The only regulations for structures like this are specified in the ROK 1.4. This information is outlined in Appendix B.

The second load model represents the traffic load of a provincial road, the Koningsweg. This load on the structure must be applied according to the Eurocode and the National Annex ([14] & [15]). Both load combinations have to be calculated and the most governing one must be determined. These load models are applied to a structural span of 75 meters. This span is determined in paragraph 2.1 . First, the approach of how to determine the load is explained and afterwards the load due to the traffic model is calculated. The calculation will be attached in Appendix C. The objective of this annex is to get an estimation of the magnitude of the traffic load and compare it with the load model of the public garden. In this way the governing load model can be distinguished.

Furthermore, an assumption is made that the Koningsweg shall have a different surface level than the surrounded public garden. So, at the location of the Koningsweg, it will be either the traffic load model or the public garden load model and definitely not a combination of both!

2.9.1 The composition of the load resulting from the public garden

In Appendix B the load resulting from the public garden is discussed. This load is based upon the guideline ROK 1.4. All kinds of considerations which are related to the load model resulting from a public garden are outlined. A detailed explication of the parameters used is depicted in Appendix B as well. A brief overview is shown in this paragraph. Concludingly can be stated that the load resulting from the public garden consists of:

- 27 kN/m^2 permanent load resulting from the self-weight of the soil layer. The first layer consists of a drainage layer of 0.2 meters. On top of this layer it's assumed that 1 layer of soil is going to be constructed on top.
- 3.2 kN/m^2 variable load resulting from crowd loading.

It means that in the preliminary design in serviceability limit state (SLS) a load of 30.2 kN/m^2 is considered as the load resulting from the public garden. The design load in ultimate limit state (ULS) will be 41.6 kN/m^2 and is explained in Appendix B.

2.9.2 Traffic load: LM 1

In Appendix C the traffic load is calculated according a simplified method to get a conservative estimate of the load. It resulted in a design load of 18.2 kN/m^2.

2.9.3 The governing load model

Concludingly, the load model resulting from the public garden is much higher than the traffic load model. It is a substantial higher load, like 2 times higher. Normally, a more sophisticated method is used to calculate the traffic load. This results in a reduction of the traffic load of about 20% in comparison with the method in the annex. Since the load resulting from the public garden on top has such a high value it would be a waste of effort to use this more sophisticated method to determine the traffic load. Thus, the 41.6 kN/m^2 is the governing external design load. Again, one must consider that it's still an estimation of the total load. Normally, the self-weight of the concrete is taken into account, but this structure is still unknown. The self-weight of the structure is also a permanent load.

3. Bridge designs

Constructing The Green Connection is a huge task for several groups of people, like engineers and contractors. But, what is the point of departure to start the engineering of such an enormous structure?

In essence, the structure from The Green Connection is spanning between two abutments. It's almost the same as constructing a bridge. In fact, it's partly the same, because a small part of the connection consists of the newly to be built Koningsweg viaduct. The remaining part, like 90 % of its total width, is just a connection between two parts of a forest. It's like "bridging" between two forests and is comparable to a bridge deck structure. However, the load exerted upon the parts of The Green Connection differs. As mentioned in the paragraph *2.9.3.* the load originated from the public garden is substantially higher than the load resulting from the traffic load. Moreover, the load resulting from the public garden is roughly two times as high. The questions rest like how to build such a structure and what are the common or suitable ways to construct a challenging structure like this? It may be helpful to have a look at the current state of the art in bridge structures and the way how to construct bridges or viaducts.

Regarding to the methods of construction, it can be said that these methods can be globally subdivided in two main subgroups. The first one is constructing a structure, like a bridge deck for instance, at its final location. This kind of execution is casting in-situ. The second group is opposite to the casting in-situ method. In this case the new structure is fabricated at the location different than its final one. After fabrication, it will be transported to the final location. In case of larger projects like this one, the parts of the bridge structure are fabricated elsewhere. This could be concrete beams for instance. This method is called "prefab" construction; elements which are "prefabricated" in a factory.

Several examples are outlined in the next paragraphs, including some key figures. These key figures are retrieved from the concrete bridges course of the Delft University of Technology [16] [17] and are based upon normal traffic loads according to the Eurocode. Since the load upon The Green Connection is about to be twice as high, these key figures should be roughly divided by the square root of two. An explanation is provided in Appendix D. In the upcoming paragraphs, the original values are used. One must keep in mind that these values should be divided by $\sqrt{2}$.

3.1 In-situ casted deck structures

The construction of a bridge can be done via multiple ways, but some methods are a lot more extensive than others. Choosing between these methods can be beneficial in various aspects, for instance time dependency and hindrance to the surroundings. Depending on such a method, it could also save construction time and materials. This is not only beneficial for the environment with respect to sustainability considerations. It could also have economic benefits.

Cast in-situ bridges can be constructed as a massive slab as well as a slab with voids in it. This last version is considered when the span is relatively large. A reduction of self-weight can be established with polystyrene blocks or cast-in steel tubes. Both non-solid versions are visualized in Figure 3.1.

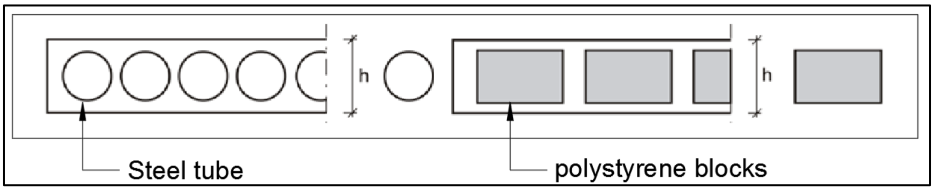

Figure 3.1: In-situ slabs [17].

The maximum span and slenderness depends on several aspects, but mostly upon the dimensions of cross section and global layout. Nevertheless, common spans of a voided slab are 30 and up to 55 meters and have slenderness around 30. This slenderness is based upon two or more spans (statically indeterminate structures). For a single span structures this value will be less than 30, especially in combination with the higher load.

For massive deck slabs the values differs. Both values are lower. The span will be lower as well as the slenderness. Besides the use of reinforcement, these bridges or viaducts are constructed with applying post-tensioning technique to increase their resistance against live loads.

Several ways of constructing slab bridges or viaducts are possible. If a bridge must be replaced as part of a new road, the easiest way is to close the road for all kind of traffic and replace it. However, it's highly unusual to do it like this and most of the time it's just prohibited by the (local) government or municipality. They won't approve a total closure of a road for a period of for instance a few months.

If such a total closure of a road for a long time is prohibited, solutions in methods of construction exist to prevent such a blocking of a road. One of them could be constructing two times half a bridge. This method is also applicable to for prefab construction. First, the traffic is redirected to one half of the bridge via a new, temporary road arrangement. After that, the other half of the bridge where no traffic is present, can be demolished and reconstructed. Then, during a weekend closure for instance, the traffic can be redirected from the temporary arrangement to the new part of the bridge and the second half of the bridge can be replaced. The bridge can be reopened, and the new bridge is constructed. The original situation where the bridge deck has to be replaced is schematized in the next Figure 3.2 as well as the other phases during construction. This method of construction implies that a total closure of the bridge for a long period of time isn't necessary and a lot of traffic hindrance can be prevented.

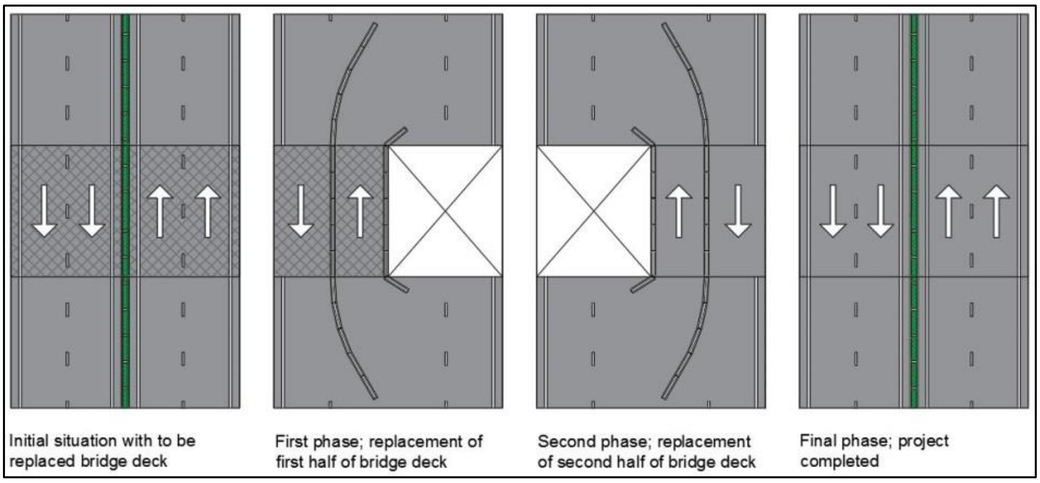

Figure 3.2: Bridge construction of half a bridge simultaneously.

A disadvantage of this method of construction is the fact that construction of the bridge deck is done in 2 separate shifts, which resulted in a more time-consuming way of construction, which automatically resulted in a costlier solution.

Another method of construction could be constructing the new bridge deck, or a part of a bridge next to the intended location. When construction takes place next to the road, it won't bother the traffic. When the bridge deck or a part of it is finished, the current bridge deck can be demolished during a weekend closure. After it's removed, the new bridge deck can be horizontally jacked to its final location during the same weekend closure of the road/motorway. This method will minimize the traffic hindrance during construction. It's schematized in the following Figure 3.3. A disadvantage of this method could be the required space next to the bridge and therefore this method is location dependent. The location where the bridge deck has to be replaced should be suitable for this kind of construction, like rural areas and is mostly not applicable in urban regions, due to the lack of space. The jacking equipment is also a costly one.

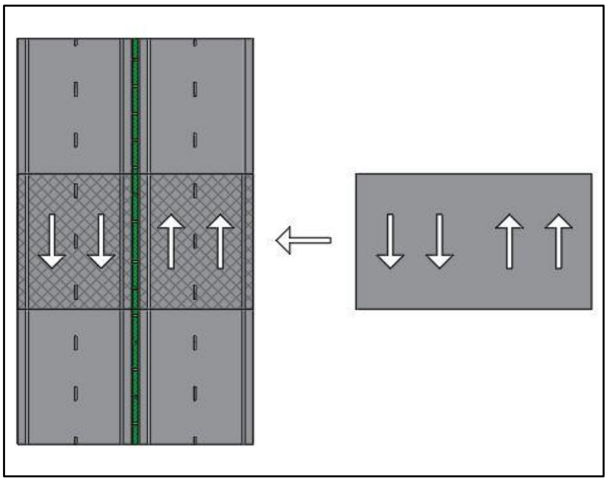

Figure 3.3: Bridge deck horizontally jacked of transported into position.

Besides these two methods, another one is frequently used. If a bridge deck must be replaced, a temporary road and bridge is constructed next to the location of the newly intended bridge. Then, construction of the bridge at its final location can start and traffic can still pass this junction and won't experience that much hinder. After construction of the new bridge deck the temporary road and bridge can be demolished, and the traffic can be redirected via the new bridge deck. This method is schematized in Figure 3.4. Disadvantage of this method are slightly the same as the previous one. A lot of space is required as well as temporary road and bridge.

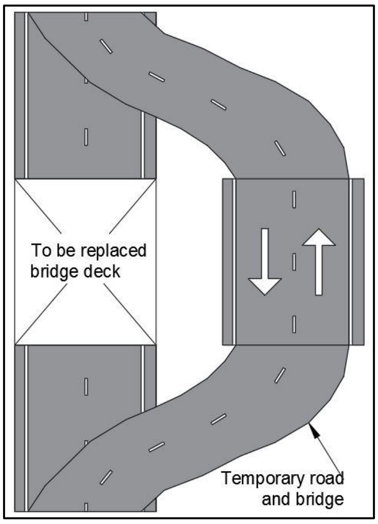

Figure 3.4: Bridge construction with a temporary road and bridge.

What must be kept in mind is the clearance beneath the bridge during construction. If for instance a bridge is crossing a road, a viaduct, the clearance is of great importance when constructing a bridge in situ. The final height of the bridge is designed to be at a certain height that the minimum prescribed clearance criterion is met. Every extra height in clearance costs a lot of money in constructing extra height in embankments in the approaches of the viaduct, so every extra non-required height is a waste of money.

However, if a bridge is constructed in situ and at its final height, one must consider the following. The falsework beneath the bridge which is necessary to construct the bridge takes in some space. This space diminished the amount of clearance, which results in problems to the traffic beneath during construction of this viaduct. A solution to prevent this situation is to construct the viaduct a bit higher than its final height and take into account the required height of the falsework. After the viaduct is constructed at this height, the deck can be lowered with the help of screw jacks to its final height. The two stages are visualized in Figure 3.5. The left figure shows a cross section of a viaduct during construction, when the falsework is clearly visible. The right figure is after vertical jacking of the viaduct to its final location and after complication of the viaduct.

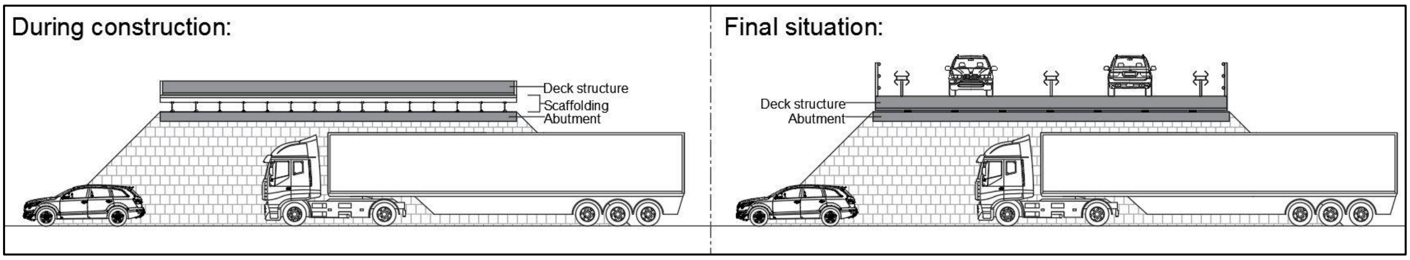

Figure 3.5: Bridge construction: Vertical jacking.

Furthermore, there are globally 3 methods of casting a multiple span bridge. These methods are briefly discussed, because this project has just one span. However, The Green Connection has a width of 249 meters, so possibilities may arise in cross direction instead of the longitudinal one.

3.1.1 Span by span method

One of these methods which is also typical for slab bridges is the span-by-span method. This method is used in the Netherlands and implies that falsework is made for a single span and can be re-used for the following span. It allows construction in a consecutive way and has economic benefits if a high repetition factor could be reached. The falsework used is most of the time movable mechanical falsework on rollers, so it can easily be slid or travelled to the next span after hardening of the first span. Then, the second span can be casted and after hardening it can be dragged to the next span et cetera. The next Figure 3.6 shows a very schematic view of the casting of a 3-span bridge with the help of movable falsework. The first span is casted and beneath the second span the falsework is visible. In case of multiple spans in longitudinal direction, the first span is about 0.75 times the main span. This is since the line of distribution of forces is about zero at the location of the joint.

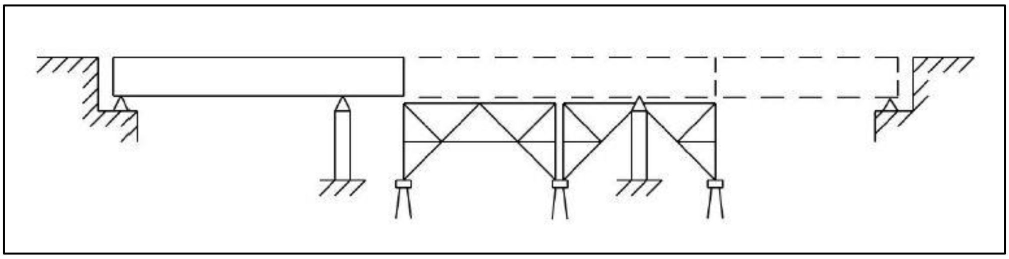

Figure 3.6: Span by span method [16].

Abroad, it's ordinary to use an assembly truss of about 1.25 times the span. This temporary solution is an expensive auxiliary structure and it goes also paired with high vertical forces due to the weight of the large, mostly made of steel structure. It could be a good solution when a lot of spans are going to be constructed.

3.1.2 Other cast in-situ cross sections

Besides the solid deck slab or the deck slab with hollow cores, more kind of cross sections are commonly used when other methods of construction are applied. For this reason, first other ones who are used frequently are shown in the next Figure 3.7. Here, a single cell and a double cell box girder section, a double T-girder section and a trough girder section are visualized. These cross sections are now briefly discussed. All these cross sections are mostly post-tensioned. In some cases, the sections are pre-tensioned (transversal) to prevent cracks and provide an increase in resistance against live loads.

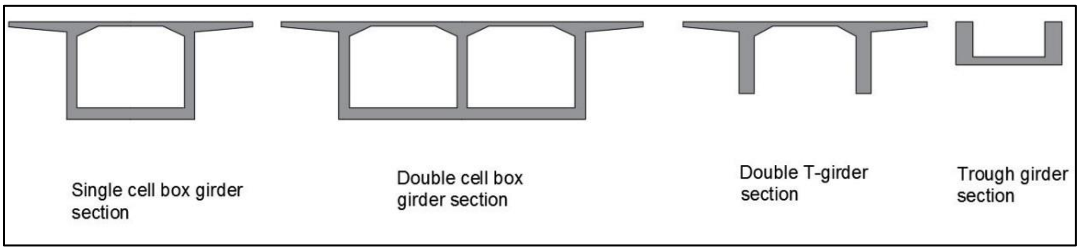

Figure 3.7: Cross sections.

Constructing a double T-girder bridge is also done via the span-by-span method and is often applied in the Netherlands. It's used as an approach bridge to cross wetlands. The slenderness of such a cross section is about 16 or smaller and the span should be equal of smaller than 50 meters. Both values are comparable to the trough girder cross section bridges. Both kinds of sections are visible in Figure 3.7.

The box girder sections are also frequently applied, but the values about slenderness and span are very dependent upon the method of construction. When such a bridge is constructed via falsework, the slenderness ratio is maximum 25 and common spans are 35 to maximum 80 meters. If other methods of constructions are applied, then these values become lower.

Next, the two other methods of construction are briefly discussed and considered whether it could be applicable in constructing The Green Connection.

3.1.3 Incremental launching method

With this method the bridge segments are casted in front of the bridge. After construction, the elements will be pushed forward, and the second element can be connected. This method is repeated multiple times. Each span consists of a same number of elements and each span must have the same length as well as a constant radius of curvature. Temporary piers could be used to prevent elastic deformation. A temporary steel nose reduces the self-weight and the bending moments. The method becomes interesting with a substantial number of spans which have the same length. The total length of the bridge should be at least 250 meters. A figure is added to clarify this method. However, The Green Connection has just one span, and due to this fact, it's not applicable to this project. It won't be discussed anymore.

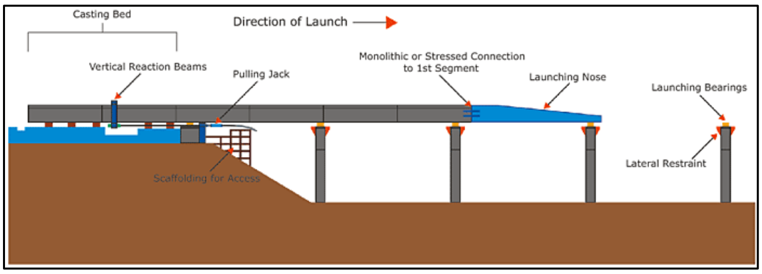

Figure 3.8: Incremental launching method [18].

3.1.4 Balanced cantilever method

The last cast in-situ method which will be discussed is the balanced cantilever method. With this kind of construction most of the time box girder sections are used. These sections could be single cell and double cell sections. Mostly two of these structures are made simultaneously or consecutively. The method of construction is briefly discussed here and schematized in Figure 3.9. First a foundation on piles is constructed followed by a pillar with on top a hammer head. After that, on both sides of the hammer head elements are going to be constructed. The elements are constructed with the help of travelling falsework and are applied one by one, so the global equilibrium of the structure is ensured. After all the elements are constructed, both structures can be connected with each other via a stitch. If one structure like this is going to be realized via the balanced cantilever method, the ends can be assembled at the bridge abutment.

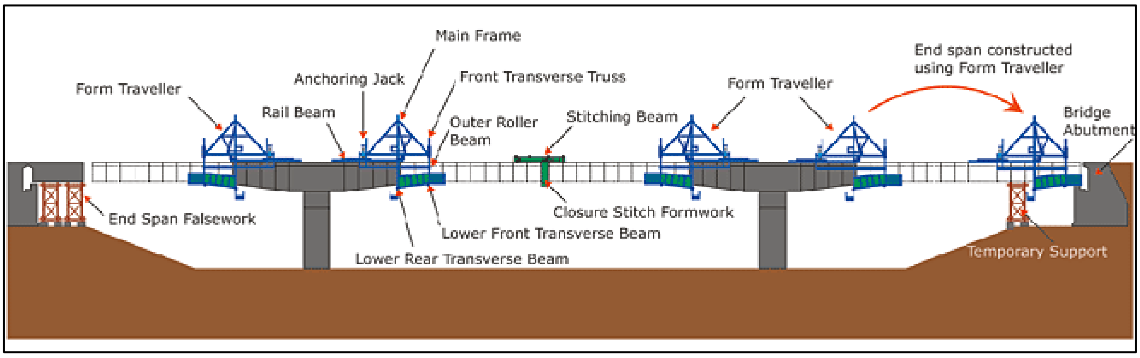

Figure 3.9: Balanced cantilever method [19].

This kind of construction methods becomes interesting if common spans of about 90-200 meters have to be overcome. Slenderness of the box girder sections are about 22. To apply such a method of construction at least two spans are required to ensure global equilibrium during construction.

3.1.5 Discussion

At first sight, the voided slab might be an interesting solution in constructing The Green Connection. Common spans are 30 to 55 meters. This will differ about 20 meters to the overcome the necessary span of 75 meters. Besides, considering the method of construction, these in-situ decks are mostly built via the span by span method. This implies that falsework is necessary below the deck which must be constructed. Especially this aspect of the construction method mentioned makes it unfeasible, because the falsework can't be situated beneath the deck structure. It will be in the middle of the busy motorway A27.

This solution results in too much traffic hindrance. Minimize traffic hindrance could be achieved via some adaptions in the execution methods or some additions in temporary designs for instance. Building two times a half bridge is beneficial for the traffic which crosses the bridge via the Koningsweg, but not for traffic at the A27. A better solution is to temporary use a certain part of the public garden as a temporary bridge while constructing the new viaduct of the Koningsweg. This could be a deliberate idea, since the traffic load is about half of the load resulting from the public garden. Therefore, it should be a better solution to temporarily use a part of the public garden instead of an extensive solution of partly using the new Koningsweg viaduct. This idea is also applicable to the third measure of prevention of traffic hindrance where a temporary bridge and road is constructed, schematized in Figure *3.4*. The accompanying traffic dynamics in several phases of construction won't be considered, since it's not a part of the scope in this thesis as described in paragraph *2.9*.

Another solution to prevent hindrance as much as possible could be bridge replacement in one piece with the help of horizontal jacking equipment or transportation. The Green Connection has global dimensions of 249 by

75 meters. So, jacking this enormous structure as a whole is almost impossible or at least inconvenient. However, a solution might be that parts of the bridge deck could be jacked into position, for instance 20 elements of 12 meters width. These elements are roughly 12 by 75 meters and must be constructed nearby. This topic will be outlined in chapter *6*.

The last method considered was vertical jacking of the bridge deck. Via this method, a reduction of the clearance of the A27 during construction can be prevented. If during construction problems related to the clearance of the A27 will rise, it could be kept in mind that vertical jacking is such a technique which could provide a solution.

At first, it could sound a bit weird to consider this span-by-span method, because the structure of The Green Connection just has one span. However, this technique could be applicable to this project when the thought of movable formwork is used in cross direction. The deck of The Green Connection could be poured in several shifts, while each shift makes use of the same travelling falsework and scaffolding.

However, a disadvantage is the costly movable falsework and scaffolding beneath the structure. In case of casting a viaduct, it crosses a road. In this case the movable falsework is at the location of the main motorway the A27. This falsework would block the road when no solution is found to prevent it. The consequence of applying this method of construction is comparable to the application of stationary falsework in constructing a voided slab mentioned in the beginning of this paragraph.

The double T girder is not a suitable solution since it spans to maximum 50 meters. It also has quite some height which results in relative low slenderness. Also, the structure is more prone to collision forces due to a non-continuous bottom.

Trough girder bridges are mostly suitable and used for railway or light rail bridges, so this kind of bridges is not suitable for The Green Connection. Furthermore, it's not a proper solution with regards to the same reasons as the double T girder.

The box girder bridge, single or double cell seems to be an interesting solution if the span is used as a criterion, because it can overcome spans up to 80 meters. However, feasibility in construction must be considered as well as construction height, since the elements are not that slender.

At first sight, the incremental launching technique as described is not applicable since only one span is present. If the cross direction is considered, as done with the span by span method, it is still not a feasible solution. In that case, elements should be pushed forwardly with equipment in front of The Green Connection at the motorway, which makes absolute no sense.

The last method mentioned is construction via the balanced cantilever method. It becomes interesting if spans of 90-200 meters must be overcome and at least two spans are necessary. However, only one span must be realized in construction of The Green Connection which makes it not an efficient solution. If one span has to be overcome, the hammer head have to be anchored or something like that. This anchorage is quite cumbersome, and it will extend the TB area. This TB boarder is a strict one and constructing activities of this project may not be exceeded this boarder.

3.2 Prefab deck structures

With prefab construction the bridge deck or parts of the deck structure are constructed elsewhere in the factory. Later on, these elements are transported to the building site and hoisted into their final position. In this paragraph the current state of the art of prefab construction methods and types of structures are mentioned and explained.

Prefabrication of concrete elements has some advantages in comparison with cast in-situ concrete elements or bridge decks. First of all, prefabrication of elements reduces the construction time at site. The elements can be produced elsewhere, while in the meantime construction of the foundation and abutments are executed at the building site. When these tasks are finished, the prefab elements can be hoisted into their final position, while no time must be taken into account for placing of the reinforcement, scaffolding and falsework, pouring of the concrete et cetera. In addition, the absence of scaffolding is an advantage since it's a time consuming and costly activity. The working conditions in the factory are much more favorable in comparison to in-situ construction. It is protected to all kind of weather conditions which results in a better quality of the final prefab product. When considering the prefab element itself, it could be more optimized in the factory which also increases the quality of the final product.

However, a disadvantage of precast bridges is the fact that every element, deck or slab has to be transported to its final location. If the elements are small, several elements could be combined with one transport, but larger elements must be transported individually. Transportation is one of the limiting factors, due to the weight of the elements. Therefore, the weight of these elements is mostly an impeding factor. Another disadvantage is also linked to its weight and are the dimensions of an element, which is another limiting factor. The hoisting capacity of cranes is important and goes hand in hand with weight and the distance over which the element must be hoisted at site, the lever arm. Solutions are certainly possible, but it could result in an expensive one and it would be beneficial to diminish both the weight and the dimensions of prefab elements.

3.2.1 Pre-tensioned precast bridges

As said in the paragraph In-situ casted deck structures, a possibility is to cast the solid deck bridges in-situ. However, a reasonable alternative is to prefabricate them into a factory. It becomes interesting to prefabricate the solid deck slabs in the factory when spans are 4 to 8 meters. In that case the slabs are pre-tensioned and transported to the final location. The slabs can be hoisted into location, which is beneficial for certain aspects. If the span is more than 8 meters some other prefab possibilities are more suitable. The answer can be found in beam solutions. In this case, several beams are constructed in the factory elsewhere. After transportation to the building site hoisted they can be hoisted into position next to each other.

Several custom-made options are feasible, and the dimensions or layout of the beams are depending on the type of bridge and its span. In short, three types of pre-tensioned precast beams can be distinguished with their own characteristics and will be discussed now.

3.2.2 Solid composite bridge structures – SJPFlex beams

Besides the prefab solid slab bridges, another possibility to construct such a solid deck is with the help of precast beams. These beams are the so-called SJPFlex beams and are the ones which are individual pre-tensioned and pre-casted in a factory. After transportation to their location and hoisting them into position, transversal reinforcement is placed through the voids in the beams, which are incorporated in the prefab design. The pre-tensioned tendons are functioned as the reinforcement in the longitudinal direction. After placement of the reinforcement in cross direction and at the supports, the final in-situ concrete layer can be poured. When the in-situ casted layer is hardened, a solid deck is acquired.

The spans are a bit higher than the prefab solid deck slabs, because of weight and transportation issues. The spans are in a range of 6 to 20 meters and the slenderness ratio is about 20-25 [20]. Figure 3.10 shows the SJPFlex beams and the accompanying edge beams.

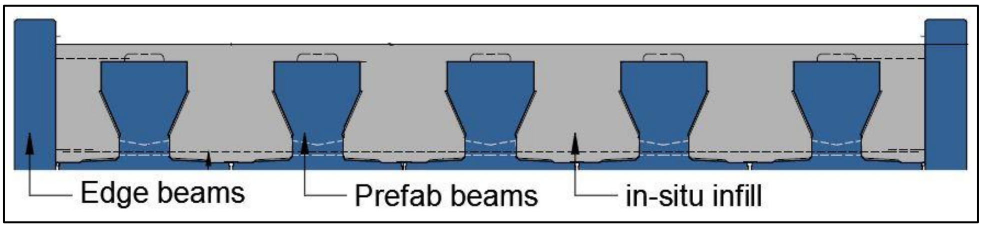

Figure 3.10: Solid composite structure with prefab beams and in-situ infill and top player [20].

However, these kinds of SJPFlex beams or precast bridge slabs are not applicable to this project since the maximum span is about 20 meters.

3.2.3 Inverted T-beam bridge structures – ZIPXL beams

To overcome a bigger span with a prefab solution, ZIPXL beams could be applied. These beams are applicable to overcome spans between 20 and 60 meters and slenderness ratios of 20 to 28 could be met. In total three versions of ZIPXL beams exist. Each type is based upon a certain span. The first and the second type have the most resemblance with each other and are applicable to the relative smaller spans in comparison with the third type. These two versions have a layout which is comparable to an inverted T-beam. The first version is visible in Figure 3.11 and the height of the beams does start from 700 to 900 mm. The method of construction is the same as version two, which will be discussed now.

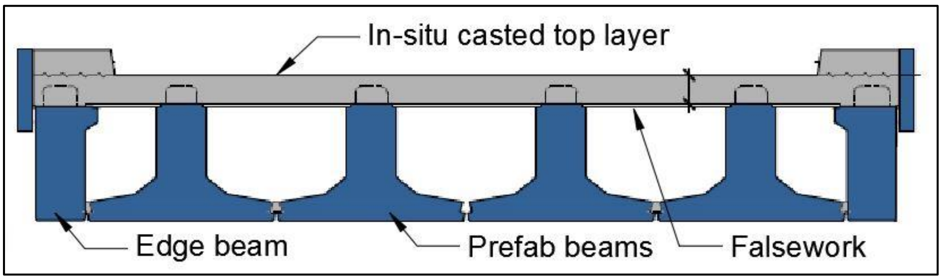

Figure 3.11: ZIPXL beams version 1 [21].

The height of the beams of version two scatters from 1000 mm to 1700 mm. Again, these beams are pre-tensioned and pre-casted in the factory and after construction transported to the building site. When hoisted into their final position next to each other, falsework can be placed between the beams at the topside and after assemblage of the reinforcement the top layer can be casted. A remarkable fact is that these ZIPXL beams have hollow cores in comparison with the SJPFlex bridge deck system. The material of the prefab beams is very efficiently used. These voids results in weight reduction which is beneficial to span bigger distances. This second version is visible in Figure 3.12. In this figure, a total bridge deck system is visualized. The blue beams are the prefabricated ones and the grey layer on top is the in-situ casted topping.

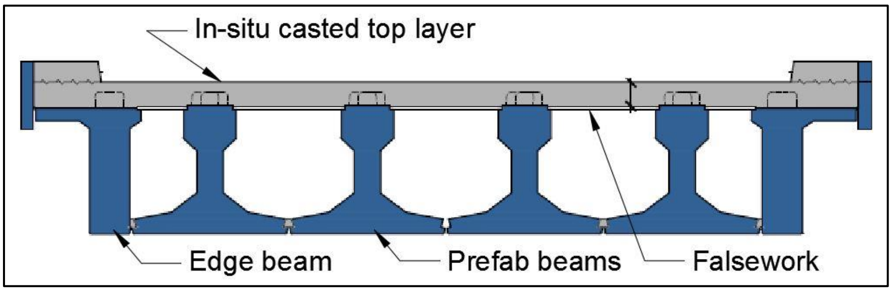

Figure 3.12: ZIPXL beams version 2 [21].

The third version of the ZIPXL bridge system has resemblances with the other two versions. The beams are constructed in the same way as prescribed in the previous paragraphs. However, the layout of these beams differs a bit and is more like a capital I instead of an inverted T-beam. The height of these beams starts at 1800 mm and will go up to 2400 mm. In Figure 3.13 a bridge deck system is visualized. These beams are more applicable to the bigger spans, up to 60 meters. The method of execution and pouring the in-situ concrete topping is done in the same way as prescribed by the other version of the ZIPXL beams.

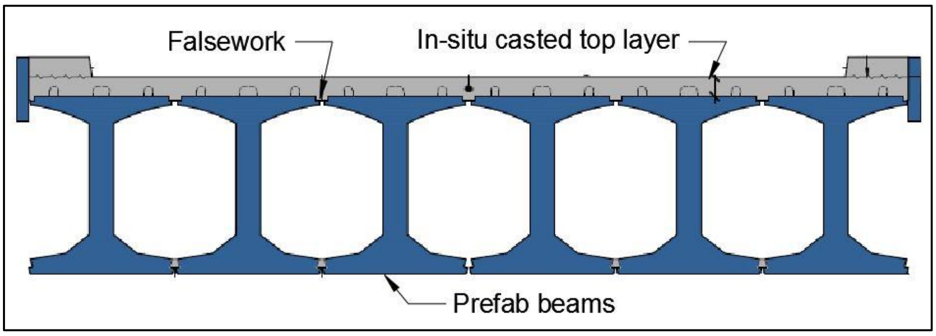

Figure 3.13: ZIPXL beams version 3 [21].

A difference in the Figure 3.13 above is that no edge beam is visualized in comparison with the other two figures. However, edge beams are certainly possible with this third version. Function of these edge beams are mostly esthetically related.

3.2.4 Box beam bridge structures – SKK beams

The last type of pre-tensioned precast beam systems is the SKK beams. When considering the span, SKK beams are slightly comparable to the ZIPXL beams. The SKK beams become interesting with spans starting from 15 meters up to 68 meters. Slenderness ratios of 28 to 32 are commonly reached. The slenderness ratio is a bit higher compared to the ZIPXL beams and therefore a reduction in height with the same span is feasible. The layout of the SKK beams are rectangular box shaped beams with hollow cores. These cores are filled with polystyrene blocks to reduce the self-weight.

Furthermore, the method of construction of these SKK beams is comparable with the ZIPXL beams and explained in the paragraph *3.2.3*. However, the execution process slightly differs. After transportation and hoisting into position, these beams are connected via longitudinal cast in-situ joins. After sufficient hardening time, the beams are post tensioned in transversal direction. No in-situ casted top layer is applied in comparison to the ZIPXL beams.

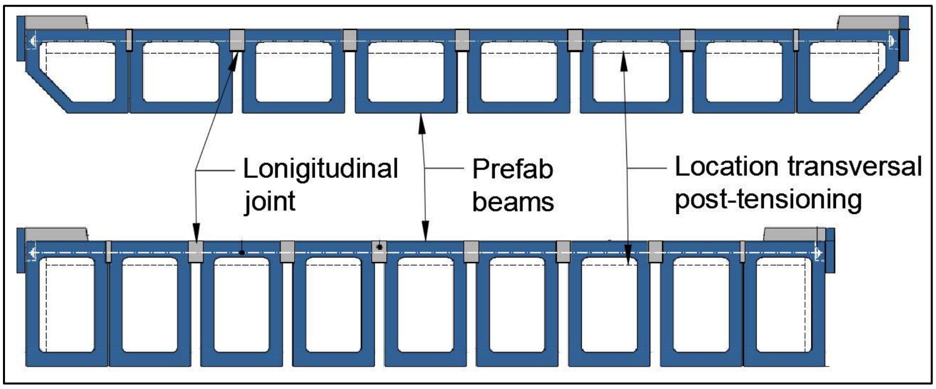

Figure 3.14: SKK beams [22].

Two types of SKK-beams exist. The method of construction is the same and described above. The first type of beams has a width of 1500 mm and the height differs from 700 to 1600 mm depending on the span and project. A schematic view of this version of a bridge deck system is visible in the top of Figure 3.14. In the second version, the SKK beams has a width of 1200 mm and heights of 1700 to 1900 mm are common. These SKK beams are visible in Figure 3.14 as well.

3.2.5 Discussion

The previous paragraphs outlined the current state of the art of prefab beams used for bridge deck structures. But, what could be a proper solution to construct The Green Connection? That's the main reason why these prefab systems were briefly outlined.

Solid slabs are not applicable for this project. The spans are 4-8 meters which is way too small. The SJPFlex beams are used for construction of such a solid deck slab with spans bigger spans in range of 6 to 20 meters, which is still too small. This is the main reason why these beams are not suitable for this project.

A solution must be sought in structure with a (partly) hollow core. Keeping this in mind and reflected to a prefab solution, the ZIPXL and the SKK box beams have such hollow cores in the total structure. In total 3 versions of the ZIPXL beams and 2 versions of the SKK beams are discussed. However, beams with the highest height are considered to be a plausible solution, because these beams can overcome the largest spans in their type. Therefore, the I-shaped ZIPXL beams visible in Figure 3.13 and the SKK beams which are visible in lowest part of Figure 3.14 could be suitable. But what are the main advantages and disadvantages of both beam systems?

As described in the previous paragraphs the ZIPXL and the SKK beams are slightly comparable if a bridge deck must be constructed, because both the beams can overcome almost the same span. However, SKK beams have some advantages compared to ZIPXL beams.

First of all, a SKK beam is a rectangular box beam, which implies a more torsional stiff solution compared to the ZIPXL beam. Also, a horizontal radius of curvature of 100 m is possible in the SKK beam, which is not the case compared to the ZIPXLs. However, curved box beams are not necessary to apply. Straight box beams will be sufficient and can be placed at most a bit skew to overcome the small horizontal radius of curvature in the alignment of the U-shaped concrete structure.

Furthermore, the SKK beams don't need a structural topping which is necessary if ZIPXL beams are applied. Box beams only need an in-situ casted longitudinal fill. The structural topping is already incorporated in the initial precast design. The transversal post tensioning is applied just to avoid the structural topping. Then, the structural height of the beam is diminished. When the structural height of the box beam is not important, it could be chosen to apply an in-situ topping instead of transversal post tensioning. This measure is less expensive than the addition of post tensioning.

However, the ZIPXL beams don't need post tensioning in transverse direction, which is necessary when SKK beams are applied without an in-situ casted topping. Post tensioning of a bridge deck will result is extra construction time, but in the end the overall construction time of a box beam bridge is faster realized than a ZIPXL beam bridge.

Concludingly, it seems to be the fact that the box beams are in favor in comparison to the ZIPXL beam. This is mostly due to:

- An increased torsional stiffness
- The possibility of an incorporated horizontal radius of curvature in the design

- A higher slenderness
- Less construction time on site
- No structural topping

The maximum span what is currently produced is 68 meters [23]. This is still a lower span than required. Besides, the static load of a public garden is higher than the load resulted from traffic. Therefore, some adaptions must be made in this box beam if this type of precast beam will be a plausible solution.

3.2.6 Tendency of the market

Besides the three standard prefab beam solutions mentioned above, some variations in the described designs do exist. In other words, custom made prefab beam solutions become more interesting. The variations in the design are interesting when the project is a unique one and the current standard solutions are not fulfilling all the requirements. Furthermore, the span must be a reasonable one and/or a substantial number of beams have to be constructed. Otherwise the custom-made solution won't be an economic one. Two kinds of custom made projects are mentioned.

The first one consists of a combination of the SKK beam and an in-situ casted layer on top. This project specific solution was used in the construction of the new Eco-duct crossing a provincial road. The new to be constructed viaduct crosses the road in an angle of skewness of 50 degrees. With this kind of skewness, the mandatory transversal post tensioning of the deck wasn't efficient/feasible. To allow no transversal post tensioning an in-situ casted top layer was applied [24].

The second custom made solution was applied in construction of the new Westrandweg in the city Amsterdam. This structure consists of a 3.3 km long road constructed with prefab elements. In total 80 spans must be overcome. Due to time issues fast construction was necessary, like 1 span each week which consists of 10 prefab elements a week. The width of normal elements is 1200-1500 mm. With these dimensions the criterion wasn't met. Therefore, the contractor came up with a solution. It was the design of a new beam, a PIQ beam shown in Figure 3.15. With this custom-made solution the project was successfully finished.

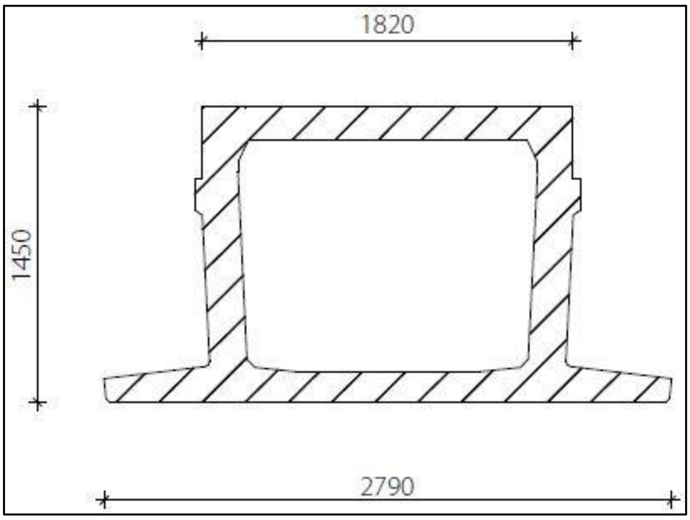

Figure 3.15: Custom-made PIQ-beam [25].

3.2.7 Post tensioned precast bridges

With this kind of bridges parts of the spans are constructed as one piece, which implies that a certain span is subdivided in slightly 4 elements. Depending on the span, it could be constructed at once. After execution and hoisted into position, the elements can be post-tensioned. The prefabricated elements could be pre-tensioned or just reinforced. Again, this depends on the span.

However, one big disadvantage is the dimensions of these elements and the accompanying weight. The dimensions are depending on the way of transport. Therefore, transport is a limited factor. Possibilities arise when a bridge must be constructed across a waterway. In that case the large elements can be supplied via water and the dimensions of the elements could be a lot bigger compared to other types of transportation. In other cases, the elements are almost restricted to the size of a truck trailer.

Nevertheless, this solution could be used with cross sections of mono-box bridges and trough bridges, as stated in paragraph *3.1.2*. These cross sections are visible in Figure 3.7 and can also be prefabricated. A box girder bridge seems to be the suitable one, because these kinds of elements can span up to 80 meters when this construction method is used [16].

When a segmental construction method is used, small sections with a length of about 2-3 meters are prefabricated mostly on-site due to transport advantages. After prefabrication, the beams are hoisted into position, which can be effectively done for multiple spans with a launching gantry. This auxiliary structure is schematically visualized in Figure 3.16.

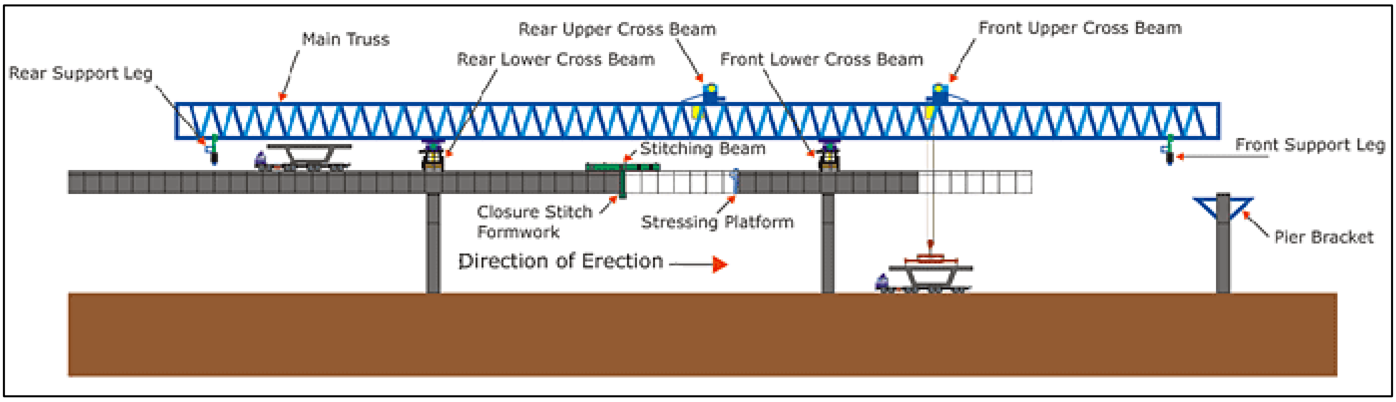

Figure 3.16: Segmental bridge construction [26].

4. Transport

In paragraph *2.5* the three main possibilities of transportation are briefly pointed out. These three groups were transport via the local road and motorway system, via the railway infrastructural network and via the waterway network.

The importance of transportation of a prefab solution is quite high. Most of the time transportation will be the dominated factor in the final structural design. Constructing elements or (sub parts of) bridges in a factory is done multiple times for a bridge with a comparable span. But the assemblage and other execution factors are playing a dominant role. Therefore, it's quite important to elaborate upon the possibilities in the method of transportation.

First of all, the possible locations of construction of these prefab elements are discussed. It is important to get insight where these locations are to consider the transport possibilities. Two of the larges pre-tensioned precast factories are known. These two are Spanbeton and Haitsma Beton. Spanbeton has maximal crane capacity of 170 tons. If prefab beams are considered as a suitable solution for The Green Connection, it's highly expectable or predictable that elements are heavier than this amount of 170 tons. Therefore, this company won't be discussed. The other company might be Haitsma Beton, which will be briefly outlined.

4.1 Haitsma Beton

This company is specialized in all kind of prefab concrete elements. As stated in paragraph *3.2.4*, the SKK beams could be a possible solution in constructing The Green Connection. Since the construction of the new fabrication hall is finished at Haitsma Beton, it is possible to construct elements with a weight up to 280 tons and lengths of about 70 meters [27]. With these huge prefab characteristics and such an enormous prefab facility, this company is market leader in prefabrication of elements. Keeping this in mind, it's considered to be the only feasible solution of constructing prefab elements elsewhere. However, if this kind of beams/elements are going to be prefabricated at Haitsma Beton, is it then still possible to transport such huge elements?

To investigate this topic, some small considerations about transport via water, by truck or by train are discussed. In other words, the geographical location of the company is of high importance.

In Figure 4.1, which captures a part of the province of Friesland, several parts are pointed out. In the red rectangle, the location of the company of Haitsma Beton is visualized. On top of Figure 4.1 the dashed black line schematizes the nearest possibility of a train track and in blue the water way is pointed out. This waterway is one of a kind and provides a proper connection to the Ijsselmeer. The company has almost direct connection to the provincial road system. These three possibilities will be discussed.

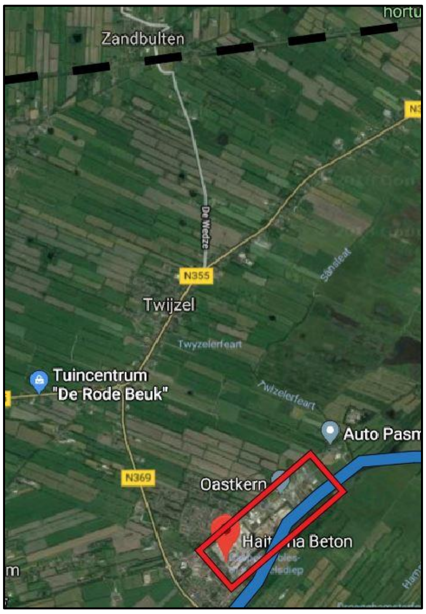

Figure 4.1: Overview location Haitsma Beton in the north of the Netherlands; Friesland [28].

4.2 Transport by truck and trailer

Small prefab elements can be easily transported via the motorway system in the Netherlands. But, if the total weight of a truck including the prefab element(s) exceed(s) the amount of 50 tons, some auxiliary/precautionary measures have to be taken. Beams with a weight exceeding 50 tons are definitely the case if a solution in prefab is chosen. A slightly comparable example is shown in Figure 4.2. Here, a prefab SKK beam of about 61.75 meters is transported via the motorway system. Special trucks with custom made trailers are necessary to transport beams like this.

Figure 4.2: Transport of a prefab element by truck and trailer [29].

Besides, some advantages are present if choosing for this kind of transport. The beams are pretty fast at construction site when transported by a truck. However, the beams are transported one by one. Depending on the amount of stock yard at the factory and the construction site, the amount of special truck/trailer combination influences the total time of the transport. Nevertheless, with this kind of transport, the beams could reach very accurate the final location, so the beams upon such a trailer are maneuverable. No other facility, like a stock yard, is necessary if the beams are hoisted directly from the trailer to their final position.

However, the transport time of one element could be less, but these kinds of beams are transported piece by piece, which will result in a high overall transportation time. With every transport, safety measures must be taken into account, like guidance in front of the truck as well as at the rear side. The transport route has to be investigated [30]. If this route is not suitable for this exceptional transport, some adaptions must be made in order to create a suitable route. In certain circumstances or at specific locations some temporary traffic blocks during transport are inevitable, although it will only be a few minutes. Other precautionary measures have to be taken into account, like the position of trees and street illumination in curved, local roads. If the truck and its trailer can't maneuver in this curved section of the road because of these obstacles, these obstacles have to be replaced or temporarily removed. Despite the possible removal of such obstacles, the whole track must be checked and planned if a truck and its trailer can make it to the construction side. And, if every element is hoisted into final position immediately from the trailer (not using a stock yard); every element means a closure of the road for a certain period of time.

Except the executional or transportation issues, some structural issues are accompanied with the chosen way of transport. In this case, the weight of the elements and structural height are the limited factors when considering the structural design of the beams or elements. In general, to find an upper limit for geometry and weight of the transport is nearly impossible, because negotiation between several organizations has to take place, such as RDW and transport companies. However, a general rule is 10 tons per non-propelled axle and 12 tons for a propelled axle. This is often not a real challenge since the number of axles can be easily added by the transport company. More important becomes the total weight when crossing a bridge or other structures. In that case a possible maximum allowable load is applied and differs at every structure [31]. Permits which are valid throughout the year can be provided by the RDW for vehicles with maximum weight of 100 tons. If two separate vehicles are carrying a beam as shown in Figure 4.2, this number can be doubled. Adding an extra axle will influence the structural behavior of the element itself, which can lead to catastrophic consequences during transport. In other words, adding a third axle is not a solution and won't be considered here.

Another restriction concerns the height of an element. If the total height of the trailer exceeds the 4.25 meter a permit must be acquired [32]. Globally, viaducts are dimensioned upon a clearance of 4.8 meters paragraph *2.3*. Besides, permits are released to vehicles with a total height of 4.25 meters [33]. But, taken into account the height of the truck trailer itself of about a meter, the possible protruding reinforcement, a precamber and some safety, the structural height of the beam or element shouldn't exceed 3 meters.

4.3 Transport by train

Another possibility could be to transport the elements by train, since a railway track is very close by, see Figure 4.1. The advantages of transport by train are the avoidance of the motorway track, which is normally busy enough. Less precautionary measures have to be taken into account while using the train track.

According to Rail Cargo information [34], the maximum train load is 4680 tons and a maximum length of 650 meters, which implies that several elements simultaneously could be transported. The following Figure 4.3 shows that transport via train is done before.

Figure 4.3: Transport of a prefab element by train [35].

However, more disadvantages exist. The railway track does not directly access the fabrication yards if Haitsma Beton is considered to be a feasible location. This implies that the elements have to be hoisted onto a truck and trailer, transported to the nearest train track. Figure 4.1 shows that the nearest railway track is not directly adjacent to the prefabrication yard. It implies that at the location of the train track a temporary yard has to be created. Think of a stock yard and some hoisting facilities. Then, the elements must be hoisted again to the train wagon. In case of several elements, it cost some time which implies a blocking of the train track. Especially this blocking of the railway track is highly unwanted or even prohibited. It results in the fact that a temporary side railway track has to be constructed. In this case the train can stop on a kind of by-pass, so it won't block the main rail track. This solution implies that a truck and its trailer are still necessary, while the main idea of transport by train was just to avoid it.

Besides these measures nearby the prefabrication site, the same measures must be applied nearby the final location. Again, a temporary yard with hoisting facilities, a temporary side railway track etc. is again necessary. This is a quite an extensive way of transport.

4.4 Transport by ship and pontoon

Besides the 'normal' transportation of the prefab elements via the road and motorway system and the (extensive) possibility of transport via railway system, a third possibility exists. Transport via waterways is often done, because it has several advantages. One prerequisite is that the fabrication yard has connection to a waterway. As shown in Figure 4.1 the company Haitsma beton is directly connected to a waterway. So, at first sight, it seems a reasonable solution.

The transportation of these elements via the use of the waterway network has quite some advantages. As seen in Figure 4.4 several elements can be transported simultaneously. The elements or beams are hoisted upon a pontoon at the location of the factory. The number of elements upon a pontoon depends on its dimensions and on the availability of the pontoons. The length of the elements is 75 meters, so a possibility of the pontoon combination could be 2 pontoons of 40 meter for instance. But the dimensions of the pontoons must be chosen very carefully because it must fit in the waterway itself and all kind of hydraulic structures, such as locks for instance.

Furthermore, transport via this method implies that the road and motorway system will be spared as well. And if the elements or beams are transported via vessels like in Figure 4.4, the maximal amount of weight per element can be raised as well as the structural height.

Figure 4.4: Transport of two prefab element of 68 meters by ship and pontoon [36].

However, transportation of the kind of beams is certainly possible with a vessel with pontoon(s) but some restrictions are present. As said before, a combination of 2 pontoons could be chosen, but in the most optimal choice, its maximal capacity is not more than 1000 tons [37]. This equivalent is about 3 or 4 prefab elements

Besides, the transport route is quite a long one. If these beams have to be transported from Haitsma Beton to project location via waterways, it's quite a distance of about 180 km. Considering this distance and a substantial amount of locks, the time to overcome this route will be roughly estimated upon 3 days to project location and back to the location in Friesland. The transport capacity will be estimated about three or four beams for each week.

Nevertheless, the project location is not directly adjacent to a main waterway, see Figure 4.5. This implies that comparable temporary measures have to be taken into account as stipulated in the previous paragraph *4.3*. Those measures are not desirable. A temporary harbor must be created nearby the project location adjacent to the Amsterdam-Rijnkanaal including a temporary stock yard and some heavy lifting equipment. It should be first unloaded from the vessel, then loaded on a trailer or first to the temporary stock yard and then loaded upon a trailer. It will be a quite extensive manner as well.

Figure 4.5:Overview transport route at project location (left) and possible location of temporary harbor (right) [38].

If this method of transportation is applied, the elements should be still transported to the project location. In Figure 4.5 a global map is visualized with a red rectangle. This rectangle is the possible position of the temporary harbor at the Amsterdam-Rijnkanaal and a close-up is visualized in the same figure next to the global map. At this location, the elements should be reloaded by truck and trailer. It's like a small distribution center of prefab elements. After that, the transport goes to the green circle in Figure 4.5, where The Green Connection is located.

Transport by truck and trailer means that it has its accompanying restrictions stated in paragraph *4.2*; Transport by truck and trailer, since it has to pass a few viaducts. These viaducts are located at junction Lunetten and the railway bridges up ahead. One of the big advantages of transport via the waterways is that the height restrictions are less severe. This benefit will be cancelled out after reloading the elements upon trailers. Then, the prefabricated elements still have to be transported by truck and trailer and these have to cross the two railway bridges and the other viaducts at traffic junction Lunetten.

4.5 Discussion

It can be said that none of the three possibilities of transport are very advantageous. The restrictions of transport by truck and trailer are incorporated in every method of transportation, since The Green Connection is not directly adjacent to a railway track or a waterway. Considering the global dimensions and its weight of about 250 tons of an element, it's highly unusual to transport elements like this on a regular base via the main motorway system. Besides, the example to use the facilities of the company of Haitsma Beton is based upon its characteristics. But is this factory available for a long period of time to construct these elements? In the most optimal way each day a custom-made beam can be constructed, after all the engineering is done [25]. If 200-250 elements have to be constructed, it takes at least a year of full production, without taking into account the engineering and other time-consuming activities. In this kind of tendency of the economic market the factory is almost constantly producing elements and it's just the question if this particular company Haitsma Beton is available for a long period of time. And if the company is available for a year production, still every element needs to be transported over about 180 km with all the restrictions emphasized in this chapter. According to the reference document of the prefabricated beams of 68 meters at Haitsma Beton [36], transport from this facility was impossible due to the enormous length of these beams. Therefore, it's ruled out that transport by truck and trailer will be possible with elements with a global length of 75 meters will be possible.

Nevertheless, one other possibility is considered as a plausible solution, but this solution consists not the transport of elements from the location of Haitsma Beton. The thought is to investigate the site in the surrounding area at The Green Connection. Could it be a possibility to create a temporary prefabrication yard nearby the project location? This will be outlined in the next chapter; Site investigation.

5. Site investigation

One last possibility to avoid the transportation of these prefabricated elements over a significant transport route is to investigate the possibility of a prefabrication yard on site, which will be done in this chapter.

5.1 A prefabrication yard on site?

A possibility to prevent the transport of these elements could be the construction of these elements in a factory on site. A severe restriction is the fact that enough space is present which will be necessary to construct such a factory. At this site, it is considered that at least enough space is required to facilitate a significant prefabrication factory and a considerable stock yard. The following Figure 5.1 and Figure 5.2 are produced by Rijkswaterstaat and extracted from their site [39]. The first Figure 5.1 is an aerial picture of the current situation at Amelisweerd. The motorway A27 can be clearly seen as well as the viaduct the Koningsweg. The two railway bridges are not considered for now.

Figure 5.1: An aerial view of the current situation at The Green Connection [39].

The second aerial picture visualized in Figure 5.2 is the same as the previous one, but the new to be constructed motorway alignment is schematized including The Green Connection. Besides, some area is hatched. These areas are appointed as extra construction area or construction site. It might be of great value if this area could be used as a local construction site.

Figure 5.2: An aerial view of the new intended situation of The Green Connection as well as the hatched areas which are appointed as construction sites [39].

From this surrounding area, a digital sketch is made. The total drawing can be found in pdf form [40]. This document consists of all 2D drawings of the whole masterplan. This document is converted to a different program, which can calculate area surfaces. This global picture is shown in Figure 5.3. The two areas of possible construction site are marked with a number.

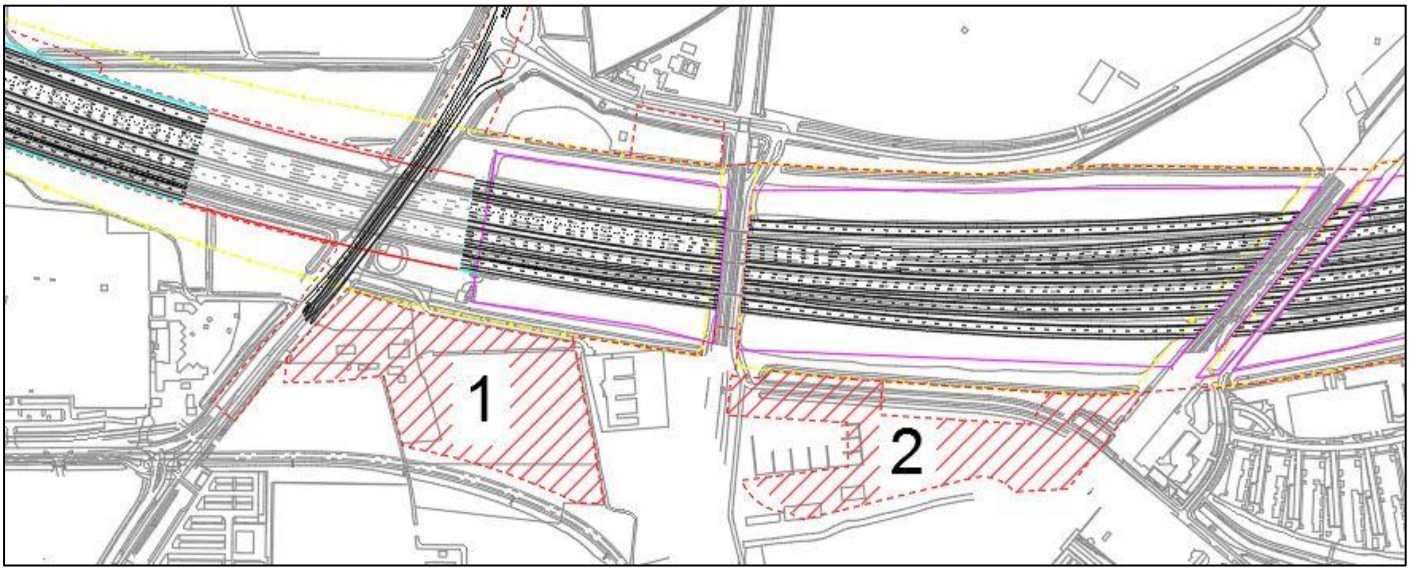

Figure 5.3: A digital 2D overview of Figure 5.2 with the two appointed construction sites, the new intended situation [40].

As said before, these two main areas are appointed as construction sites. The surface area of field one is about 2.8 hectares and surface area of field two is almost 2.3 hectare. If these two surfaces are going to be compared to the construction site facilities of Haitsma, it won't fit since the total area of the facility is about 10 hectares. But at this location multiple pre-tension facilities are present as well as a large stock yard which are both not necessary in total at the project location of The Green Connection.

The biggest factory hall of Haitsma Beton has rough dimensions of 150 meters long and 40 meters wide. The other ones are a bit smaller. But, even this biggest construction hall can be built at possible construction site 1. If a custom-made solution is considered, which is the case, these dimensions of the factory can be more optimized with respect to the global dimensions of the current facility at Haitsma Beton. This information about the global dimensions of the possible working areas 1 and 2 and visualized in Figure 5.3 shows that a factory on site is technically possible. But what are the criterions which will emphasize the necessity of such a prefabrication factory on site?

The two locations considered in Figure 5.2 and Figure 5.3 are both large enough to facilitate the necessary prefabrication halls and a reasonable stock yard. It is close by the final situation of The Green Connection. But the main advantage is that the transport of all the elements from the north of the Netherlands to the project location can be prevented.

The transportation of all the elements is very extensive as stipulated in the previous chapter *4*; Transport. Three transportation possibilities are mentioned in this same chapter. Transport by ship and pontoon seems to be the best solution. The elements could be directly loaded upon a ship and pontoon at the factory of Haitsma Beton. But one prerequisite is that the project spans across a water way or the project is very close by. Both are not present, which means that still trucks and trailers are required to transport the elements to the final location with the accompanying restrictions.

5.2 Discussion

It can be said that neither transport by train, nor by vessel nor by truck and trailer seem to be a perfect solution. Besides, it also has an economic part. The total transport of these elements, including all the precautionary measures, adaptions in obstacles along roads and other measures are very costly tasks.

Except the economic aspects, the feasibility of the total project is danger. Transporting elements with a weight of roughly 250 tons are normally not transported via the road and motorway system, especially not if the transport route is about 180 kilometers.

If a construction site is considered as a feasible solution to produce the elements, which of the two areas will be the most advantageous? The construction site location one has quite some advantages in comparison with the second area. The global area one has larger dimensions, so the surface area is bigger than the second one. Also, it's closer to the final location of The Green connection, so less transport distance has to be overcome.

Considering all the topics described in this chapter, the only feasible solution of constructing suitable prefab elements with lengths of 75 meters will be with the help of a prefabrication factory on site. From this point on, a prefabrication yard at construction site one, visualized in Figure 5.3, is a starting point in further research of this thesis.

6. Out-of-the-box ideas

The construction of The Green Connection as described in this report is a unique project. Constructing such a structure in prefab elements is never done before. Unique projects ask for unique solutions if the boundaries of current engineering are (almost) met. With this thought, some "out-of-the-box ideas" are produced. This chapter will emphasize three ideas, and these are discussed whether they are a feasible solution.

In the discussion of these possible alternatives the starting point of all is the same. The widening of the motorway has already taken place and the structural walls of the U-shaped concrete structure, the supports, are strong and suitable enough to connect and resist the loads.

6.1 Custom-made box beams

As stated in chapter *3.2.4*, box beams are rectangular beams with a hollow core. These beams are pre-tensioned and precasted in a factory. If the scale of production is large enough, it would be beneficial to choose an optimal profile, instead of a standard one. For instance, an optimal profile is chosen in the design of the Westrandweg, visualized in Figure 3.15. The same design approach could be applicable to this project to consider a custom-made solution. But what would be an optimal profile in this case?

Nowadays, the limitations of the standard prefab beams are mostly the way of transportation and/or the capacity of the hoisting equipment. In other words, the boundaries of the design are dimensions and weight if a standard transportation method is used. When the elements are going to be constructed on a site factory nearby the final location, possibilities may rise in increasing the dimensions. To be realistic, the weight of a single precasted beam may not exceed the 280 tons, the same as the maximum amount of weight which can be hoisted at the facility at Haitsma Beton.

However, the weight of these beams could be still a problem. Therefore, besides the custom-made optimized box beam, the idea is to reduce the weight of the beam by minimize the initial compression zone. This implies that the compression zone is just big enough to resist the temporary forces during construction and execution. After hoisting several beams into position, an in-situ casted top layer is going to be applied upon these beams. Function of this layer will be an enlarging of the compression zone and an increase in structural height. Nevertheless, if an in-situ casted layer is applied on top of the beams, no post-tensioning in transversal direction is necessary. Still the main idea of the in-situ casted top layer is initial weight reduction which is beneficial during the execution phase, especially during hoisting of the elements.

The custom-made box beams are normally pre-tensioned in longitudinal direction and this pre-tension force is of such an amount that the load resulting from self-weight and external load can be resisted. In other words, the internal bending moment capacity of the beam is always higher than external bending moment. It is expected that in this case the pre-tension force is of such an amount that the pre-tension force can't be applied at once, since the load is almost twice as high as the traffic load and the span is about 75 meters.

However, the idea in this case is to pre-tension the beam to resist the load resulting from the self-weight of the precasted beam and the load resulting from the in-situ casted concrete layer on top. If the maximum of the pre-tensioned force isn't met yet, this force can be increased, and a part of the total applied pre-tensioned force will also resist the externally applied load.

After hardening of the in-situ casted top layer, the residual load of the totally applied design load will be balanced with the addition of post-tensioning in longitudinal direction. The post-tensioning cables are applied in the hollow cores of the beams. The thought of this post-tensioning is that it balances the residual amount of load on top of The Green Connection. It results that the total structure is in equilibrium.

In short, this idea globally consists of three phases:

1. Design an optimal cross section of a pre-tensioned precast box beam which can resist the self-weight of the beam and at least the in-situ casted top layer.

2. On top of these beams, cast an in-situ layer to provide extra structural height and increase the compression zone capacity.

3. Apply post-tensioning in the hollow cores of the beams. Main idea is that the amount of post tensioning will balance the remaining load resulting from the public garden.

These three steps are visualized in the next Figure 6.1.

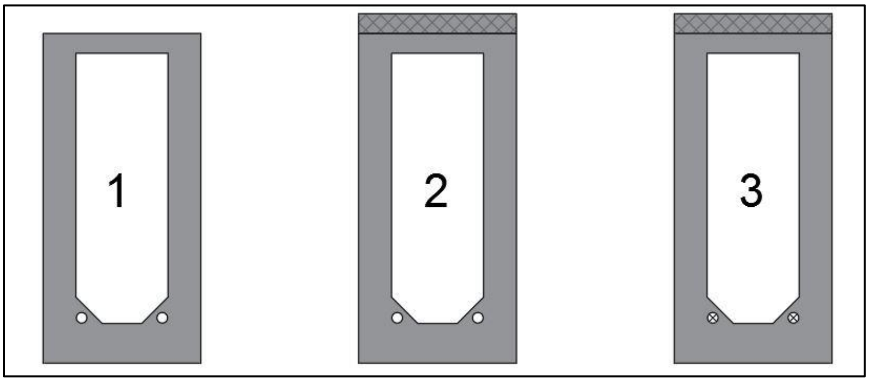

Figure 6.1: Out-of-the-box idea one: Custom-made box beam.

The post-tensioning of these beams is assumed to be necessary since the load is almost twice as high compared to the traffic load. The post-tensioning is a kind of 'assistance' to the pre-tensioned tendons to design a beam which can resist the total load resulting from the total self-weight and the load resulting from the public garden.

An advantage of this method is that construction becomes a repetitive task, so the temporary site factory can be used multiple times. Therefore, this solution could also be a cost effective one.

A disadvantage could be that every beam means a closure of the motorway. However, smart solutions can be developed to diminish traffic hindrance.

6.2 Balanced cantilever method with movable vertical support and anchoring

A normal balanced cantilever method of construction is described in paragraph *3.1.4*. Here is stated that construction at both sides must be applied simultaneously to ensure global equilibrium. In this case, the possibility is to start in the middle of the motorway and constructing elements at both sides. This results in an intermediate support, which is not a starting point in this thesis. However, an adaption in this construction method could result in a feasible solution. The idea consists of the following execution method.

Another possibility could be to use weight at the other side of the hammer head to counterbalance overturning of the global structure if only at one side elements are going to be constructed. This plausible method is not considered here, since no space is available next to the structural wall, because the structure is situated through the forest of Amelisweerd. Besides, the area next to the wall lays outside the TB border.

The pure form of the balanced cantilever method is discussed before. The structure globally consists of a foundation, some pillars or in this case a structural wall with on top a big concrete section, which is called a hammer head. This hammer head is not a normal one, because it is more like a top structure on top of the structural wall with a length of about 249 meters. But still, this top structure is called the hammer head in the continuation of this topic since the function of it is kept the same.

The idea consists of the construction of elements at one side of the hammer head in contrast to the normal balanced cantilever method. A structure like this must be constructed at both sides of the A27. First the structural walls with on top the hammer heads must be constructed. When this is finished, the elements can be hoisted to their location and the deck structure is under construction. Each element is about 3 to 5 meters in length and about 15 to 20 meters in width, so their weight is about 200 tons which can be easily hoisted.

But, global equilibrium of the structure isn't ensured during construction when only at one side of the hammer head elements are going to be built. To restore this equilibrium, measures must be taken. One of these measures could be to apply anchorages at the hammer head along the structural wall for over a length of at least 249 meters. It functions as a kind of horizontal spring support and provide resistance against overturning of the total structure.

Another measure can be added besides the anchorage to increase the resistance against overturning even more. It's adding a temporary vertical support during construction. This support can be a temporary movable vertical support which will diminish the moment distribution resulting from the own weight of the deck structure. The next Figure 6.2 schematized the method of execution.

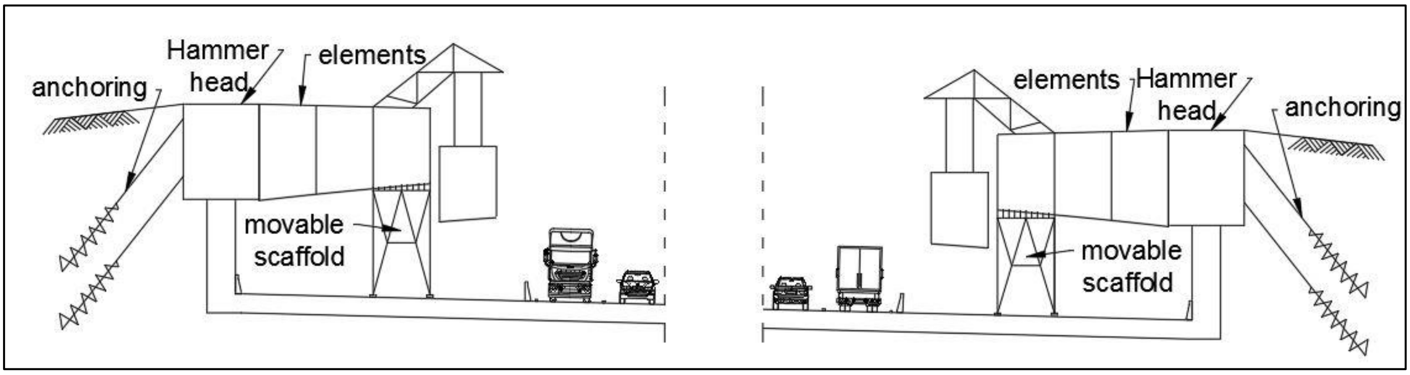

Figure 6.2: Out-of-the-box idea two.

The thought behind this idea refers to the question; How to adapt the current mechanical scheme of a single cantilever method to ensure its equilibrium? When anchors and a vertical support are applied, the resistance against overturning will be increased. It will result in the following mechanical scheme which is visualized in Figure 6.3. The left mechanical scheme is the one without any adjustments, while the right part in the scheme is the one with adjustments to increase resistance against overturning.

Figure 6.3: Out-of-the-box idea 2; mechanical scheme.

This plausible solution contains some basic assumptions and temporary adaptions in road arrangement. Construction via this adapted method can be started if the motorway is totally widened to the final width of about 74 meters. After that, a new temporary road arrangement can be applied which takes into account the space required for the movable vertical support or scaffold, visualized in Figure 6.2. If the amount of space required for the support isn't available, then the width of the driving lanes can be diminished with 0.5 or 1 meter. This result in temporary driving lanes of 2.5 and 3 meters in width instead of the normal 3.5 meters. The measure gains some extra space which could be advantageous.

However, some disadvantages arise with this method. The execution method is quite extensive because multiple times temporary measures must be taken in road design, which is almost the case with every extra element. Also, the anchorages of the hammer head will be located outside the TB border, which is not allowed. Furthermore, the structural height becomes higher than with other methods of construction, which is not desirable from esthetical point of view in connecting the forest of Amelisweerd to the city of Utrecht.

6.3 Segmental bridge construction

This third plausible idea consists of prefabricated parts of a bridge deck which are constructed on the construction site adjacent to The Green Connection. As pointed out in paragraph *3.2.7*; Post tensioned precast bridges, possibilities arise with the use of a box girder cross-section as a deck structure. A solution could be to prefabricate parts of the deck structure of about 25 meters long and a width of about 10 meters. After the prefabrication of three elements, these elements could be connected to each other in longitudinal direction followed by applying post-tensioning for the connection between these elements. It will also increase the bending moment capacity. The result is that one part of the deck structure is created with rough dimensions of 75 meters long and 10 meters in width. It's like a box girder bridge in itself.

A variation of this construction method could be to use the span-by-span method at the construction side. In this case, first one element of about 25 meters is constructed which rests at one side on a temporary support. From here on, the second element is going to be constructed to another temporary support followed by construction of the last element. The result is the same as mentioned above in the previous paragraph, a bridge structure of about 75 meters length.

This part of the deck structure could be transported via multiple SPMT's, which are multiple axle trolleys built to transport very heavy structures of this kind. Another possibility could be a comparable kind of hydraulic transport as visualized in Figure 6.4. After a small transportation route of a few hundreds of meters this part of the deck structure can be vertically jacked into final position.

Figure 6.4: Out-of-the-box idea three. Bridge deck transport [41].

Some advantages as well as disadvantages exist with this method of construction. An advantage is that less closures of traffic is necessary since a substantial width of the deck structure is transported at once (about 10 meters). However, feasibility must be judged with respect to the required vertical jacking equipment as well as transportation route via the SPMT's.

There might be another variant of post tensioned precast bridges. The variant consists of 3 parts with the same dimensions as before. But in this case the three elements which covered the span are not connected at the construction side. These elements are transported one by one to the location of The Green Connection. Then, the parts can be hoisted or vertically jacked into position. After assemblage of one part, the other parts follow.

The choice consists of start assembling the elements at the sides or assemble first the middle part and place them on temporary supports. For clarification, a schematization of both assembly methods is made and visualized in Figure 6.5. The main difference between the two methods is the sequence of assemblage of the precasted elements.

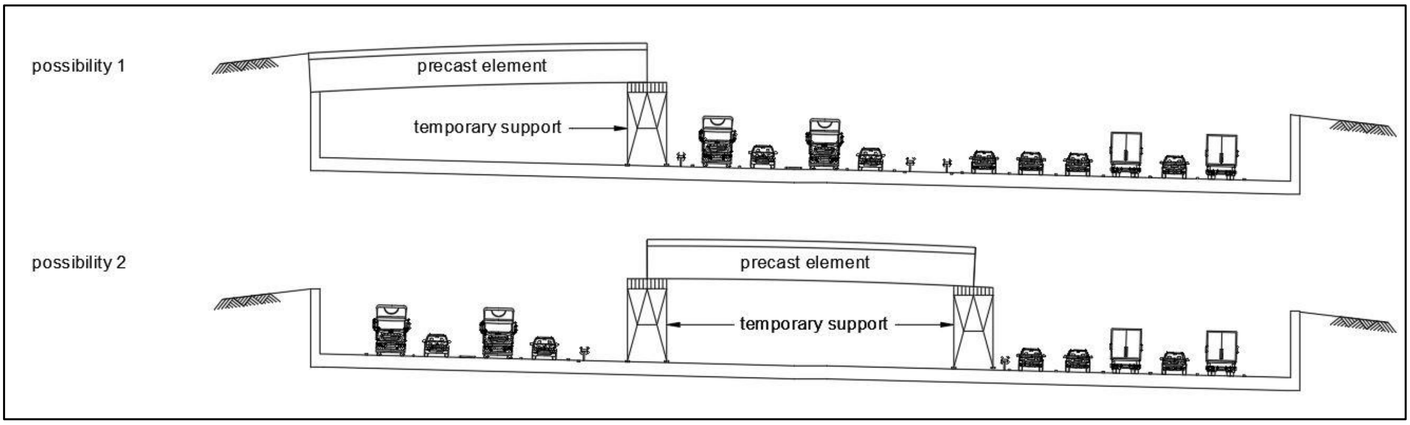

Figure 6.5: Out-of-the-box idea three.

What must be kept in mind is the fact that this kind of execution method goes hand in hand with temporary high vertical bearing forces during construction. As stated in paragraph *2.1*; The new intended situation, the U-shaped concrete structure is dimensioned to counteract floating and not to resist this kind of high bearing or gravitational forces. Therefore, it could be the case that these temporary support reactions are too high. It may be a solution to spread the load to a higher surface area on the concrete floor with the use of some kind of substructure, like dragline beams. These beams are also used in case of heavy equipment must be installed at a construction site for instance. Nevertheless, a point of attention is the construction of these precasted elements with each other.

If such an auxiliary structure is applied as temporary support and the vertical surface pressure is still too high, this method of construction is not feasible due to the lack of bearing capacity of the concrete substructure.

7. Reference projects

In this chapter, several existing projects are discussed which could have some interfaces with the method of construction of The Green Connection or with the structure itself. These interfaces are briefly emphasized and judged whether the knowledge is useful or could be useful. Globally, two subgroups are created. The part "Prefab bridge structures" discussed three projects where pre-tensioned precast elements were used. The other group is called "Tunnel projects". This group emphasizes some existing tunnels which are constructed upon land and covered afterwards. It has some resemblances with The Green Connection since a public garden is going to be constructed on top.

7.1 Prefab bridge structures

Three projects are briefly discussed. It concerns the project Bleizo, which consists of the construction of a light-rail station above a motorway. Project number two is different. It concerns the bridge at Zuidhorn. This bridge crosses a waterway. The last project consists of the construction of a surpass at a motorway A4 and A13 at Ypenburg.

7.1.1 Project Bleizo

This project concerns the construction of a light-rail station which crossed the motorway A12 at Zoetermeer. Because Rijkswaterstaat won't approve an infraction of the A12, a pillar in the middle of the motorway was prohibited. Therefore, the supports were constructed outside this area. It results in a considerable span of 61 meters and custom-made pre-tensioned precast box beams were designed.

The logistics of this project were quite challenging. In the original design the beams weigh about 200 tons each. Transportation of such beams results in very high loads exerting on the roads and limited equipment is available for transport. Therefore, the contractor in this project reduces the weight of the beams to 172 tons, without diminishing the capacity. This weight reduction was achieved by leaving a part of the compression zone in the prefab beam design. After hoisting the beams into position, the topping was casted in-situ. It results that the middle part of the precasted beams had a height of 2.20 meters, while the side parts were just 1.60 meters. This particular layout of the precast beam as well as the transportation by truck and trailer is shown in the next Figure 7.1.

Figure 7.1: Custom-made box beams used for project Bleizo [42].

The assemblage of all the prefab beams which crosses the A12 must be completed within one weekend, because only one closure of this motorway was allowed. It implies that 31 beams were hoisted into their finial position within one weekend. The first plan was to transport these beams directly from the factory to the construction site. If this method was chosen, some undesirable circumstances could occur, like a waiting queue of trucks in front of the construction site. Besides, much more truck and trailer combinations must be used, and this resulted in a risky option with respect to time delay.

To reduce the risk of time delay, the option of a temporary stock yard next to the span of 61 meters was created. Less equipment was necessary and the risk of a delay in time schedule in transportation of the beams was diminished. So, the use of a stock yard resulted in less risk in transportation and less use of equipment. Therefore, it was judged to be necessary to create a stock yard to accomplish the hoisting of the 31 beams within one weekend closure. In the end, the hoisting of the 31 elements was completed within one weekend closure.

7.1.2 Project bridge construction at Zuidhorn

This project consists of constructing a bridge across a waterway. Again, it wasn't allowed by Rijkswaterstaat to use a pillar or pillars in the waterway. Therefore, it was necessary to construct the supports at the waterside. It resulted in a perpendicular span of 60 meters. Due to the angle of skewness between the bridge and the waterway of almost 69 degrees instead of perpendicular, the element sizes of the prefab box beams were about 68 meters and weigh up to 240 tons. s

These beams were prefabricated nearby in the factory of Haitsma Beton. After prefabrication, it was impossible to transport the 68-meter-long beams via truck and trailer, because the route from fabrication yard to construction site wasn't suitable for such kind of transport. If the route was made 'transport prove' it was a costlier solution compared to transportation of the beams via the waterway by a vessel and pontoons, see Figure 7.2.

Figure 7.2: Transport of 68 meters long beams by vessel and pontoon [23].

Transport via the waterways was the most optimal option. The reasons were the fact that the prefabrication yard was situated along the same waterway as the bridge and transport by truck and trailer wasn't suitable.

Choosing for this kind of transport resulted in another benefit with respect to execution aspects. Hoisting the elements from a pontoon was in this case more beneficial in contrast to the transport via truck and trailer. If the beams were transported via truck and trailer the multiple beams would be supplied at one side of the waterway since the truck couldn't be situated parallel to the intended bridge. From executional point of view, it was quite a disadvantage, because the beams could only be hoisted at one side of the waterway. The beams must be hoisted with a connection to the crane cable in the middle of the beam. Then, it was impossible to lift these beams considering the dimensions and the weight. If the point of connection to the crane cable was half way the beam, the lever arm becomes enormous. The length of this arm would then be half the beam length and some length necessary to position the hoisting equipment. Hoisting 240 tons with one connection point in the middle of the beam over an arm of about 40 meters doesn't make sense. Even in the case if it was possible, what is highly doubted, it was certainly not an economical solution.

Via the chosen method, the beams were supplied by vessel and pontoon. This combination could be decoupled at the construction site in the waterway and the pontoon with the large and heavy elements could be tugged almost parallel to the shape of the new intended bridge. In this case, the beams could be hoisted from both sides of the element, because at both quays lifting equipment was present. The next Figure 7.3 shows a picture during hoisting of these 68-meter long, unique beams.

Figure 7.3: Hoisting the 68 meters long prefab beam into final position [23].

While discussing these two reference projects, some interesting information arises. Both projects consider the construction of a bridge structure with the use of pre-tensioned prefab box beams. In the case of project Bleizo, the contractor uses a smart feature to reduce locally the initial prefab design height. At the supports, the structural height of the beams was initially lower than the height at mid-span. This resulted in a reduction of weight of the single beam of 28 tons, without a diminishing the overall capacity of the beams. So, in case of the new custom-made design of beams for The Green Connection are too heavy, weigh reduction of the beams could be applied without diminishing the capacity of the beams itself. This is very beneficial during execution.

Besides the inventive manner to reduce weight, a measure or norm can be found in this project with respect to execution aspects. With this project 31 elements were hoisted within one weekend. This measure or norm could be quite a reference when the amount of traffic hindrance is judged because the circumstances are comparable. The Bleizo project uses a stock yard which is also the intention with the construction of The Green Connection.

In the case of the bridge in Zuidhorn, it was shown that a beam with such dimensions can be hoisted from two sides of the elements with two mobile cranes (a third mobile crane was used for assistance). This could be a feasible option in the final executional design of The Green Connection.

7.1.3 Project constructing a surpass at Ypenburg

To improve the mobility and traffic flow around the city of The Hague, project Rotterdamsebaan is designed. This masterplan consists of several subprojects. One part of it is constructing a surpass underneath an existing motorway. The method of construction was as follows. Next to the motorway a bridge deck was constructed. After completion of the bridge deck structure, the motorway was closed for in total two weekends. In the first weekend, the motorway was excavated at the location of the new intended structure. After excavation, the abutments were created and after construction of these abutments the building pit was filled. A temporary road was constructed on top of this fill and the motorway could be reopened again at Monday.

The second weekend closure was subsequently. First three SPMT's were applied beneath the deck. A picture is shown in Figure 7.4.

Figure 7.4: Transport of a bridge deck with SPMT's [43].

After locating the three SPMT's into position, the bridge deck was vertically jacked to its final height. In the meantime, at the intended location off the deck structure, the motorway was excavated again, and the abutments arose. These were made ready for the new structure. Then, the concrete bridge deck was driven to its final position and assembled. Because everything was scheduled, the motorway was opened on schedule.

The interesting fact of this particular project of creating a surpass is that within one weekend break a certain concrete bridge deck with global dimensions of about 25 by 25 meters and estimated global weight of 1900 tons is assembled with a minimum of traffic hindrance. The drive-in time of the bridge structure only took half an hour to overcome less than hundred meters. The main part of this weekend closure was necessary to take into account all the auxiliary structures and other execution aspects [43].

Concludingly, this project emphasizes the usefulness of driving a bridge deck structure into position. This kind of bridge decks with the above specified dimensions and weight can be relatively easily transported and vertical jacked into position with the help of SPMT's. This method of construction could be a solution with respect to the construction of The Green Connection. Due to the dimensions of The Green Connection, this method should be adjusted. A bridge deck with global dimensions of 250 by 75 couldn't be transported at once. Therefore, some subparts of this structure could be transported via this manner. This idea is explained in the previous chapter in paragraph *6.3* ; Segmental bridge construction. A point of attention is the way of constructing these elements to each other.

7.2 Tunnel projects

The aim of this paragraph is to explicate some tunnel projects and briefly discuss some basic assumptions with respect to the load which is considered in the design. The relevance of the load will be judged with the help of three reference projects. Some guidelines are provided in paragraph 2.8 according to the manual of tunnel construction.

7.2.1 Leidsche Rijntunnel

The Leidsche Rijntunnel is a tunnel which was constructed a few years ago at the west side of the city Utrecht. The length of this tunnel is 1650 meters and this structure is a tunnel constructed upon land. On top of the tunnel a kind of public garden is constructed in combination with some space for ecology. An aerial view of the entrance of the tunnel is visualized in the next Figure 7.5.

Figure 7.5: Leidsche Rijntunnel; the public garden on top is clearly visible [44].

In the design, the tunnel deck structure was dimensioned on a load of 30 kN/m^2. It seems to be the case that the third point according to the manual of tunnel construction is used (3).

7.2.2 Ketheltunnel

The Ketheltunnel is a tunnel constructed upon ground surface, but a large part is constructed below ground surface level as well. It is situated between Delft and Schiedam. Upon this tunnel, several different areas are pointed out, like a public garden and some sport areas for the local sport associations. In the design, the following loads are considered.

The load model applied consists of a variable uniformly distributed load of 5 kN/m^2 in combination with a maintenance vehicle of 300 kN, which is modelled as three-point loads (axle loads) of 100 kN. These two loads are according to the ROK 1.4 as outlined in Appendix B. Besides, due to the absence of a traffic load, a 20 kN/m^2 is applied to take into account the future prospects. Nowadays, a layer of about half a meter of soil is situated on top of the tunnel. It's not clearly stated if the permanent load of the soil layer is taken into account either in combination with the load models above or the load model according to the manual of tunnel construction [45].

7.2.3 Gaasperdammertunnel

This tunnel is again a tunnel constructed upon land. It is a 3 km long land tunnel which connects the two traffic junctions Holendrecht and Diemen situated at the south side of the city Amsterdam. On top of this tunnel a public garden is situated. Also, a provincial road crosses this land tunnel, so a traffic load model is also locally applied. But the greater part on top of the tunnel is appointed to be a public garden. The contractor had paid much attention to this kind of loading, especially in the way of modelling the load resulting from trees. The starting point of this calculation was the assumption of one-meter soil on top of this tunnel. The thought behind the height of this layer was the necessity for a tree to be rooted in at least one meter of soil. Besides this load of one meter of soil, some extra soil pressures are exerting on the roof due to wind loads against the trees on top.

Furthermore, no extra information is specified in the reference document [46]. But it is assumed that the ordinary regulations are met with respect to the design criteria.

7.2.4 Discussion

While discussing these three projects, some interesting aspects rise which will leave room for discussion. Some guidelines are provided to enable engineers to design a proper (tunnel) structure. These regulations are briefly discussed in the chapter 2, in the introduction in paragraph *7.2* and in Appendix B. Furthermore, it makes sense if a road crosses a tunnel via the tunnel deck that this deck structure is dimensioned upon traffic forces. But, when this is not the case, two other possibilities are sketched as a guideline. If no objective for the area on top of the tunnel is known, a 20 kN/m^2 is used.

Besides, tunnels are mostly built for a long period of time like hundred years. The development plan for the area on top of a tunnel is not known for such a long period. If in the future something is planned to be built on top, it will be going quite a costly solution if first the existing tunnel must be strengthened. To prevent this, future prospects will be taken into account to design a new tunnel with a severe load of 30 kN/m^2 as a variable load. This kind of load model is applied at the Leidsche Rijntunnel and it seems the case that this model is easily copied and mentioned as a restriction in the design criteria of The Green Connection [13].

However, some remarks have to be made with respect to the guidelines and the structure itself. First the aim of the structure is to connect the forest of Amelisweerd and involve the city of Utrecht to the forest with this connection. The high load of 30 kN/m^2 is meant to consider unforeseen future prospects, but is it relevant for this particular structure? It's highly reasonable that the function of this structure will be the same over the coming hundred years since it a compensating measure for nature which connects two parts of a forest, so the future prospect is likely to be the same for the coming period. Besides, it's still not a tunnel so restrictions with respect to the load might be too severe. All together it seems that the above specified regulations are too severe when no further information is specified.

However, it's the structure will be a bridging element between two forests. As mentioned in the paragraph 2.9.1 and outlined in Appendix B, the design load on The Green Connection consist of a one-meter layer of soil and 0.2 meter thick layer with an incorporated drainage layer. These two loads are permanent. Besides, a variable load of crowd loading is taken into account. In total it consists of a load of 30.2 kN/m^2.

8. Alternatives

This chapter is meant to provide other plausible solutions with respect to the construction of The Green Connection. In this Preliminary Study and the subsequent report Master Thesis, it's going to be investigated to construct this connection without the use of an intermediate support. If it turns out that such a deck structure is not feasible, too extensive or too cumbersome, it could be quite interesting to do research about this topic, with different boundary conditions and starting points. In other words, if a single span of The Green Connection is not considered as a suitable solution, it's inevitable to use an extra support if the road arrangement is kept the same. But, is the position of a support in the middle of the motorway as opted by Rijkswaterstaat the best solution if a single span is unfeasible?

Two alternatives of the structure of The Green Connection are briefly discussed. Both options consist of two spans, but the position of the support differs. In the design of the two alternatives the future prospects in the road arrangement are taken into account which implies that in both directions one extra driving lane could be established as described in paragraph *2.1* ; The new intended situation.

8.1 Alternative one

The basis of this design depends upon the fact that a single span of 75 meters isn't feasible. In this case, the span must be diminished, and a suitable solution is sought for. A second starting point was to take into account the current situation and came up with a proper design. As stated in paragraph *2.1* , constructing a new support in the current U-shaped concrete structure becomes quite an extensive task. In this alternative design of a deck structure it's tried to prevent such a support within this structure. This results in the following design of The Green Connection, schematized in Figure 8.1. In this figure, the line of the current U-shaped structure is drawn with a dashed grey line in the top of this figure. The small vertical red line is the middle axis of the motorway.

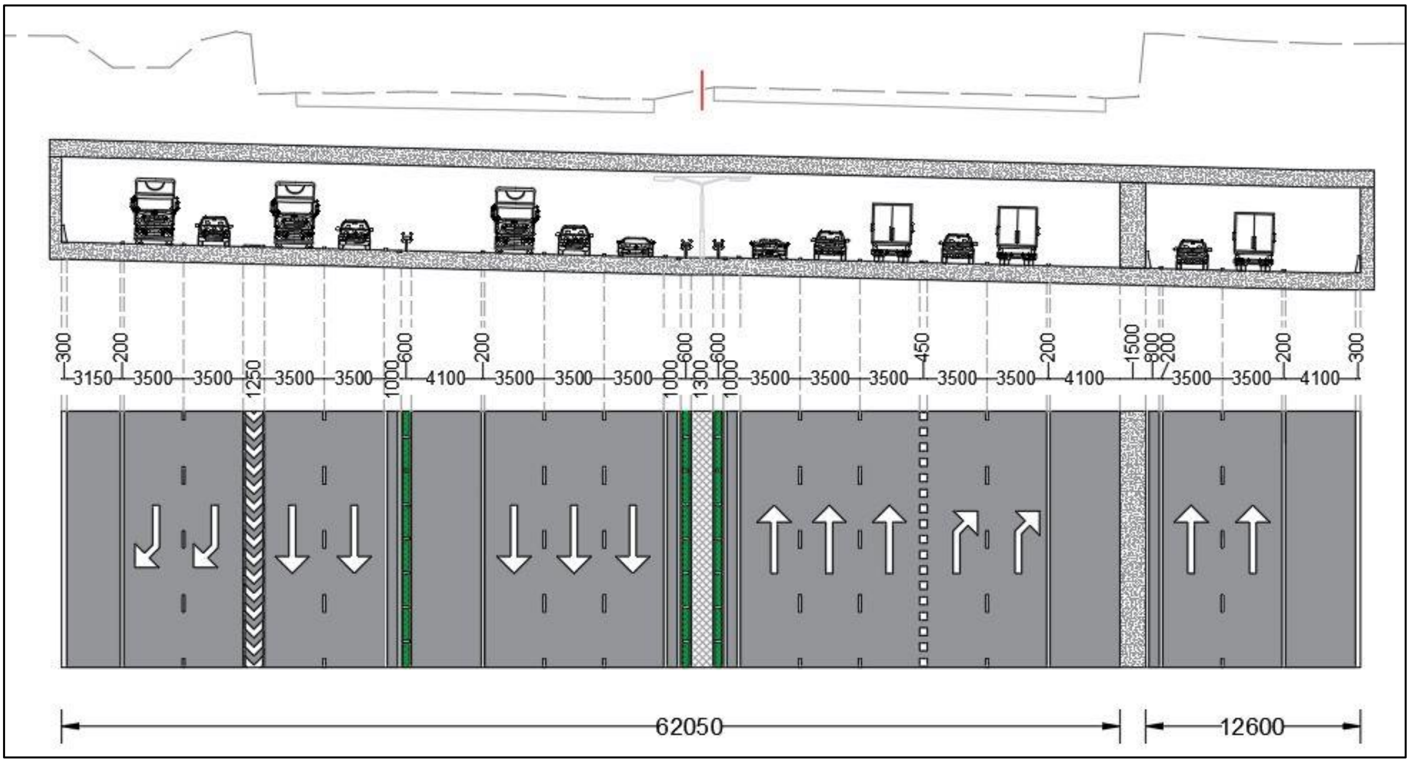

Figure 8.1: Alternative one.

The location of the intermediate support attracts the attention. The position of this support is well thought because it's exactly at the location of the current wall of the U-shaped structure. This wall could be possibly reused or strengthened and used as a support. With this position of the support, it's not necessary to construct a support and new foundation in the U-shaped concrete structure, with all their implications.

The support is designed to be in between the 5 driving lanes and the by-pass, which consists of two driving lanes. Between these two parts of the high way some space is necessary to meet all the safety requirement in the road arrangement. With some small adaptions, relatively less extra space is required to construct such a support. For this reason, it's only possible to construct this support at the right wall in Figure 8.1. If the support is going to be constructed at the other side of the road at the position of the other existing wall, this support is located in the middle of a driving lane, which is not allowed.

Besides the avoidance of all these implications of constructing a support inside the U-shaped structure, the biggest structural advantage is de reduction in span with about 12 meters. The span is reduced from almost 75 meters to about 63 meters taken into account the support distances. This reduction could be crucial in the new design of The Green Connection since span is such an important parameter in the force distribution of a structure.

If the span must be reduced with more than 12 meters, it is inevitable to construct a support in between the current walls of the U-shaped concrete structure. Another plausible alternative is designed with such a support in the current structure in the next paragraph *8.2* ; Alternative two.

If this alternative one is compared to the original design in Figure 2.1 of Rijkswaterstaat, it has several advantages and disadvantages. One of the biggest advantages is the fact that no support must be constructed in the current concrete structure. This is quite a big advantage since it's a substantial task, especially with respect to executional aspects. So, its major advantage would be that the supports can be constructed without influence the traffic flow at the A27. The current road arrangement could be kept unchanged, since the executional aspects can take place in the new extended part of the motorway, the 15 meters widening. Here, enough space is available for equipment and construction site.

A disadvantage could be that two different types of beams must be created. One type with a span of about 63 meters and one type of beam which can span about 13 meters. A double number of beams must be transported to the final position of The Green Connection. Although the smaller beams could be transported simultaneously due to their reduced weight. Besides, if first the beams of the biggest span of 63 meters are going to be constructed and hoisted into position, it's not necessary to close the road for hoisting the beams of 13 meters since the main road can be already opened.

8.2 Alternative two

The basis of this design depends upon the fact that the first alternative isn't feasible. A reason could be that the span of 63 meters is still too large and a structural design is not possible to be engineered in an effective way. In that case, the span must be diminished with some length to design a new structural layout of the deck structure which is feasible, and the road arrangement is (almost) kept the same.

This alternative plan also has one support. In alternative one the support is located at the position of the structural wall of the U-shaped structure at the right side in the figure. The advantage was that the current concrete floor of this structure could be intact. But when the structural span should be diminished even more, the support is situated in the current structure, which is an inevitable fact. The starting point of this second alternative reduces the span while keeping the span as long as possible. The support can't be situated between driving lanes because the road arrangement would be affected. Therefore, another starting point of alternative two is that the possible position of this support may not affect the original design of the road arrangement. If this support is going to be located at the same driving direction, the first opportunity of this position will be in the middle of the motorway, which already is opted by Rijkswaterstaat. Therefore, the location of the support is switched to the other side of the motorway. The first possible location of the support is in between the main driving direction and the by-pass in the design, which is schematized in Figure 8.2. Again, the original layout of the current U-shaped structure is drawn with a dashed grey line in the top of this figure. The small vertical red line is the middle axis of the motorway.

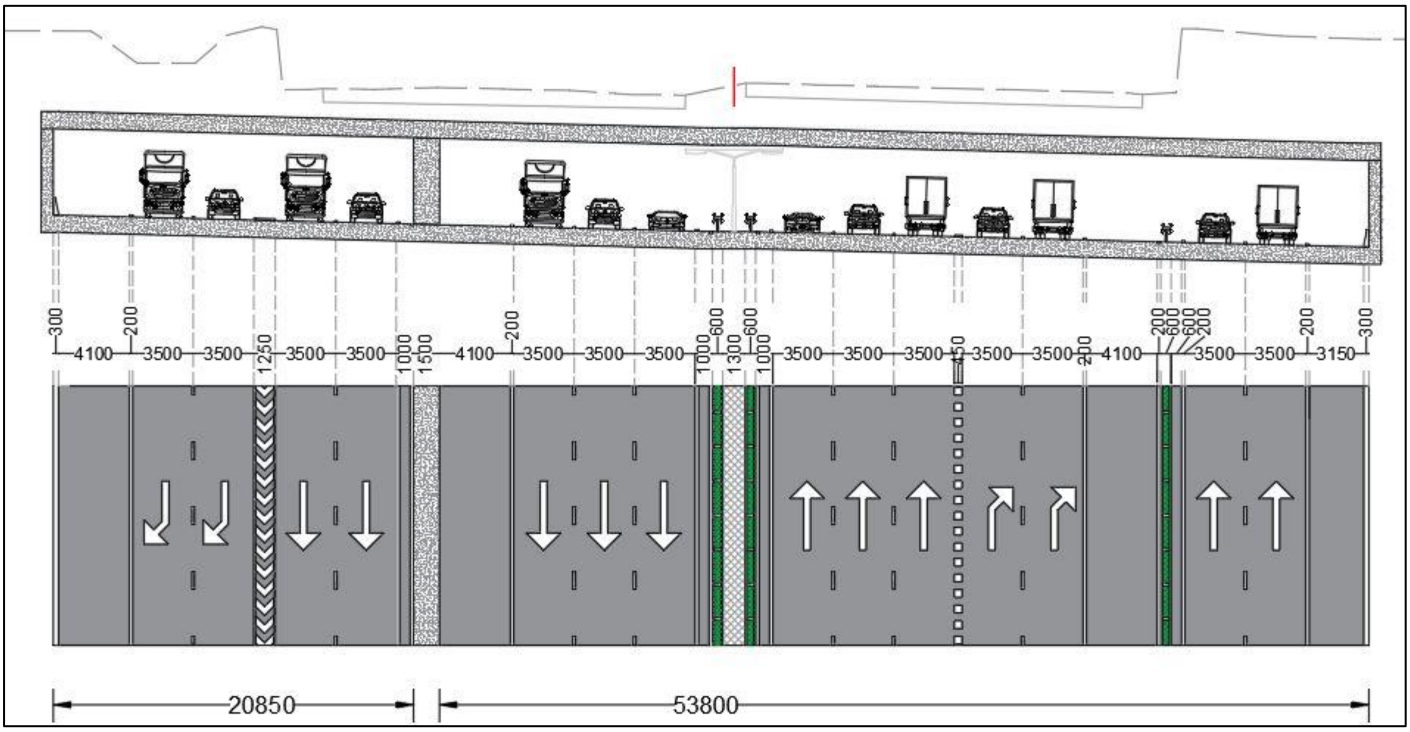

Figure 8.2: Alternative two.

In this case the structural span of the deck structure will be about 54.5 meters and about 21.5 meters. This implies that the main span is again reduced. Compared to alternative one the reduction amounts to almost 10 meters.

Comparing this alternative to alternative one it has several advantages and disadvantages. One advantage is the reduction of the span which results in smaller dimensions of the beam. This has several advantages in executional aspects, like easier handling of these beams. Also, less though equipment can be used with respect to hoist and transportation. Besides the motorway can be partly used during the construction of the deck structure. If the one part of the motorway must be blocked when the deck is under construction, the other part of the motorway can be still open which will result in better phasing of the traffic flow during construction.

A disadvantage is of course the construction of the support in the U-shaped concrete structure, but this is inevitable if the structural span must be reduced. Further research is necessary to examine which of the three alternatives is most advantageous with respect to all boundary conditions; alternative one visualized in Figure 8.1, alternative two visualized in Figure 8.2 or the one by Rijkswaterstaat visualized in Figure 2.1.

These two discussed alternatives won't be considered anymore in this thesis. The starting point of this thesis is a solution of the deck structure as a single span. The introduction of these two alternatives was just to show that other possibilities could be more suitable than the alternative opted by Rijkswaterstaat.

9. Conclusion and continuation

9.1 Conclusion

The following research question forms the basis of the upcoming report:

> *How to construct The Green Connection as a concrete structure with and without the use of an intermediate support?*

In order to answer this question in the Master Thesis, this Preliminary Study outlines the main design criterion and confines the project as much as possible. This final chapter of the Preliminary Study briefly emphasizes the main starting points and basic assumptions.

The chapter boundary conditions emphasized several important starting points which forms the basis of the subsequent report, the Master Thesis. From the original road arrangement, a new layout is designed without an intermediate support. This design takes into account the future prospects. An extra driving lane in both directions is possible, and still met all the safety requirements according to the Dutch ROA. This new layout consists of a 75 meters span deck structure instead of 82 meters. In this chapter, it is also discussed that the load resulting from the public garden on top is almost twice as high as the normal traffic load according to the Eurocode. From the additional guideline the ROK 1.4 can be deduced that extra requirements should be considered if a public garden on top of a structure is going to be realized. Furthermore, The Green Connection is appointed to be a bridge structure. It turns out that the governing load model consists of 27 kN/m^2 permanent load resulting from the soil layer on top and 3.2 kN/m^2 as a variable crowd loading. The self-weight of the structure is unknown yet. This load must be added to this model.

Furthermore, no in-situ method of construction seems possible as a deck structure since it causes too much traffic hindrance to motorway A27. A solution in a prefabricated bridge construction is necessary to reduce this amount of hindrance as much as possible. A prefab option is the solution for this structure, but what kind of prefab solution is still unknown. The normal prefab beam solutions aren't suitable due to the limited dimensions. A custom-made prefab solution will be necessary.

A precasted prefab deck structure for The Green Connection is constructed elsewhere and must be transported to the location of the project. The transport of these prefab elements, parts or beams is a impeding factor of the structural design of these elements. Considering the estimated dimensions of the prefab girders, transport by trailer, by train and by pontoon isn't an optimal solution. Therefore, the surrounding area of the project location is investigated, and a constructions site of 2.8 ha is appointed as a feasible construction site. Here, a prefabrication yard as well as a stock yard could be situated. The prefabricated parts of the new to be designed structure will be constructed at this construction site.

Since this project is a unique one, a special solution is necessary. Three plausible solutions are invented and two of them will be outlined in the next report, which is described in the next paragraph.

9.2 Continuation

During this Preliminary Study, all kinds of boundary conditions and design aspects are outlined in order to confine the project as much as possible. Also, some starting points and basic assumptions are pointed out. It results in a better designing environment for the next report, the Master Thesis.

To continue this research, the next report firstly starts describing the execution aspects when the original design of Rijkswaterstaat is going to be constructed. The aspects relate to the extended parts, the intermediate support and the deck structure itself.

In chapter *6* of this report, in total three plausible, out-of-the-box design options are outlined. Two of them seems to be a reasonable solution and need further research. One of them is discussed in paragraph *6.1* ; Custom-made box beams and the other one is described in paragraph *6.3* ; Segmental bridge construction. The third one outlined in paragraph 6.2 seems to be too cumbersome and too risky. It will not be considered anymore. For both the options, a global structural design is going to be performed which includes a rough description about the method of construction and other execution aspects which are necessary if this structure is going to be realized. After judging one of them as most beneficial, a structural design check will be performed which will be a more thorough calculation.

A structural design check of the most beneficial global design will be performed. This check will consist of a particular structural part, for instance as the bending moment capacity, a shear check or some other detailing.

The Master Thesis will end with a chapter relating both designs, the original design by Rijkswaterstaat with an intermediate support and the single span design. The comparisons and differences will be discussed, especially regarding the impact of the construction tasks to the availability of the A27.

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Appendices

Appendix A Clarification new road alignment

This appendix is meant to clarify the new road arrangement depicted in paragraph 2.1 . The new intended situation by Rijkswaterstaat has a total internal width of 81.7 meters. This amount includes space for an intermediate support. In paragraph 2.1 it's described that the span of the new road arrangement can be reduced with about 7.4 meters. First, the renewed road arrangement is shown in Figure A.1 which is the same as Figure 2.3 described in paragraph 2.1 .

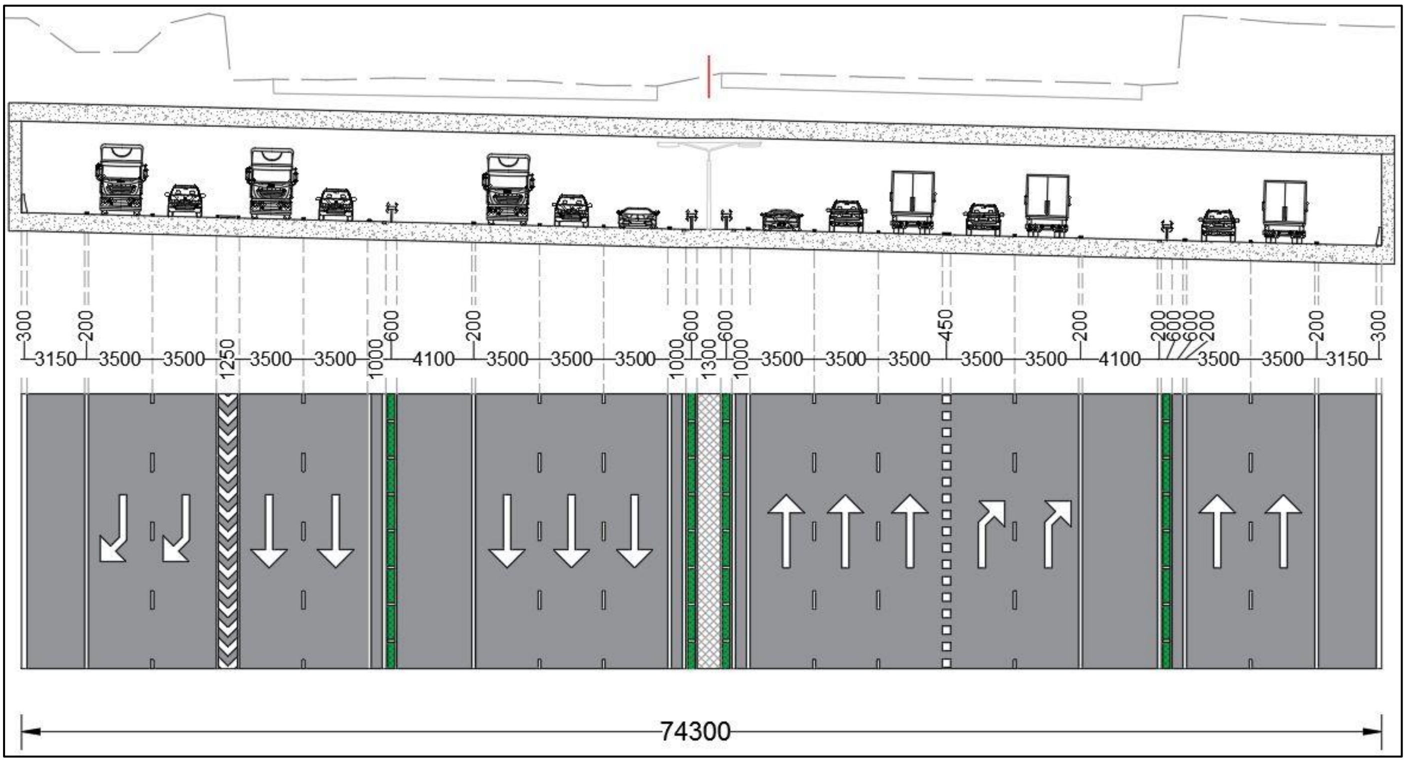

Figure A.1: The renewed road arrangement (same figure as Figure 2.3).

In this design future prospects are considered. But what does it exactly mean? And can this 74.3-meter span be reduced without taken into account the future prospects? In order to provide a proper answer to these two questions, two additional road arrangements are made in this appendix. The first arrangement shows the future prospect of Figure A.1. It consists of an extra driving lane in the main driving direction at the location of the extended hard shoulder in both directions. Normally, a hard shoulder has a width of 3.15 meters instead of 4.10 meters. The figure at the next page shows why this hard shoulder is planned to be 4.10 meters. In this case an extra driving lane could be realized and still met the minimum safety requirement of asphalt of 1 meter before the safety barrier. This 1 meter consists of 0.2 meters stripe width, a gutter of 0.2 meter for drainage and 0.6 meters extra asphalt to provide the motorist some margin. These numbers are according the ROA [8].

The extra driving lane in both directions are schematized in Figure A.2. According to paragraph 2.3.2 of the ROA *"Veilige inrichting van bermen definitief"* an exception should be requested to locally diminish the free zone next to the driving lane. This zone should be at least 1 meter [47]. Since this design is already a renewed version of the renewed road arrangement, the possibility of occurrence is small. Therefore, it seems that this exception could be justified.

In Figure A.2 the extra driving lane is schematized in the main driving direction and not at the location of the by-passes. However, if the future turns out that it's just necessary to apply an extra driving lane in the by-passes, it's also possible. An extra driving lane in the by-pass and the main driving direction is not possible.

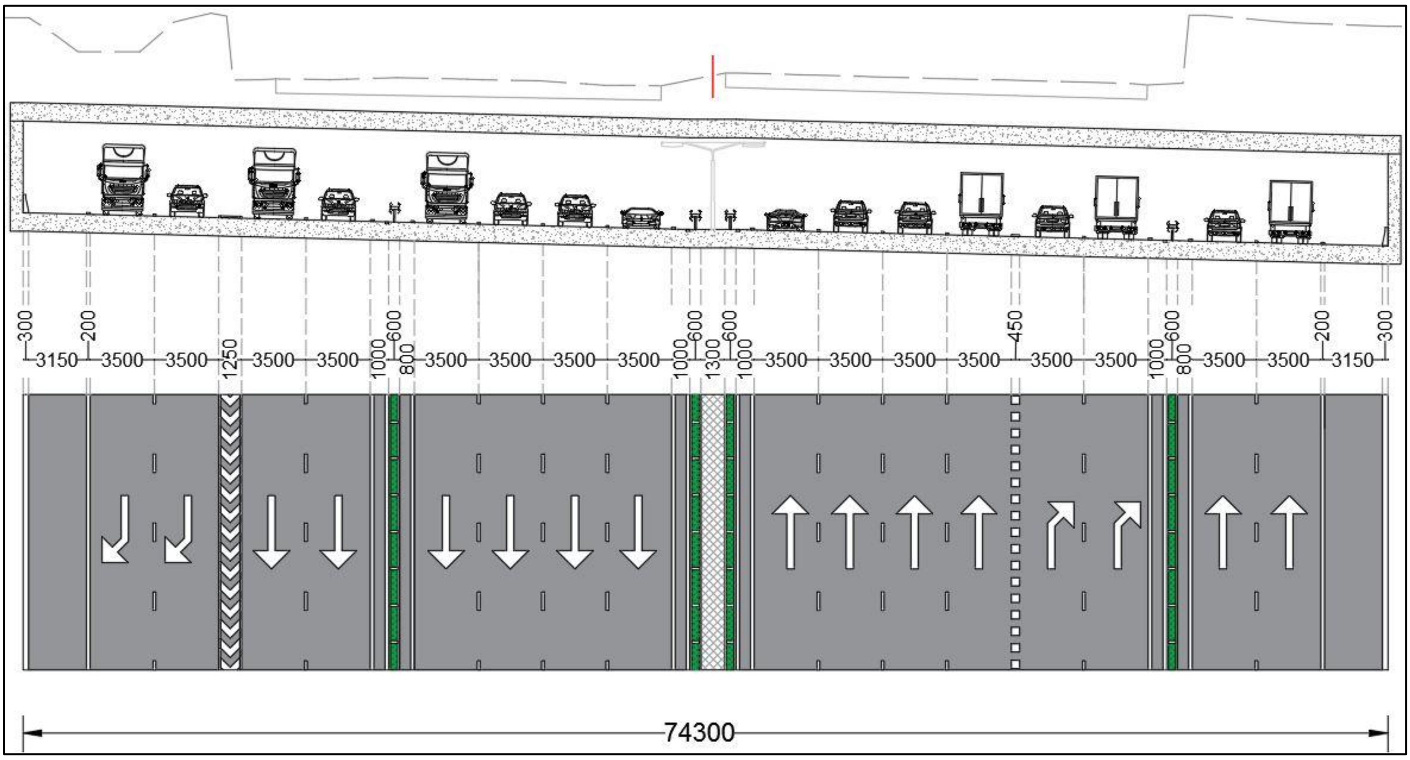

Figure A.2: Renewed road arrangement with an extra driving lane in each direction

Besides, if the future prospects of the new road arrangement are not considered, the hard shoulder of the main driving direction could become 3.15 meters instead of 4.10 meters. This is schematized in Figure A.3. Remarkable is the fact that the span could be reduced with another 1.9 meters to a minimum of 72.4 meters. If the support distances will be taken into account, the structural span will become about 73 meters.

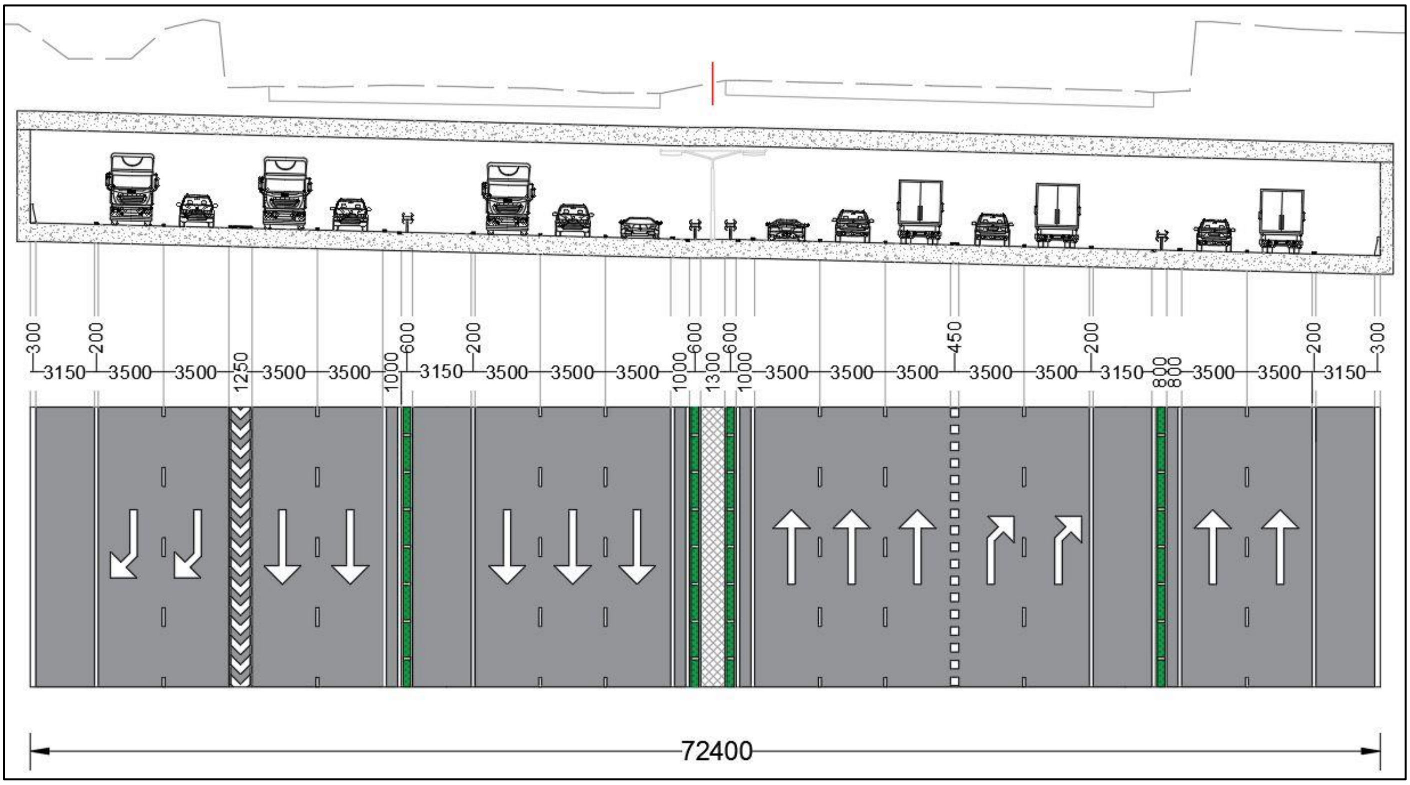

Figure A.3: Renewed road arrangement normal hard shoulder width

Appendix B Explanation about the ROK 1.4 and loads

This annex is meant to provide a clarification about the ROK 1.4. Can The Green Connection be appointed to a bridge structure or a tunnel structure? This question is of importance since differences in the partial factors in the load combination occurs. Both definitions are explicated in table 1.1 paragraph 1.4 of the ROK 1.4 [11]. According to the ROK 1.4 a bridge is a civil engineering structure which is part of a road or motorway, which crosses another road or motorway, railway track, water channel or different terrain level.

The definition of a tunnel however is a civil engineering structure which is part of a road or motorway, crosses another road or motorway, railway track, water channel or different terrain level and it have to be covered up for at least 80 meters.

At first glance, it seems to be a tunnel, since the structure covers the A27 for 249 meters. However, table 1.2 from paragraph 1.5 of the same document provides examples of structures which can be appointed as a bridge structure or as a tunnel structure.

First of all, what kind of structure will be The Green Connection? This is quite a controversial topic. The deck structure functions as multiple purposes. One of these purposes is a viaduct since the Koningsweg crosses the A27 as a traffic bridge. Besides, it's a different terrain level which crosses the A27 since a public garden is going to be constructed on top. This different terrain level also functions as an Ecoduct which ensures a safe passage for the wild life from the forest of Amelisweerd to the forest at the west site of the A27. According to table 1.2 of paragraph 1.5 of the ROK 1.4 an Ecoduct, a different terrain level and a viaduct can be appointed to the category bridge structure.

Besides, the deck structure can only be constructed after the widening of the A27 and after constructing the structural walls. It is more like constructing a deck structure upon two abutments, which has more similarities with constructing a bridge instead of constructing a tunnel.

However, the same table 1.2 also provides examples of structures which can be appointed as tunnels. This is outlined via the same manner as explained for bridges. One example is that a U-shaped structure which lays beneath ground surface is appointed as a tunnel. It implies that this U-shaped structure itself is a tunnel structure, but it does it apply for the deck structure on top?

In other words, it's quite arbitrary to appoint The Green Connection to a tunnel structure or to a bridge structure. It seems that neither of both types of structures is a wrong choice for this Green Connection. It can be stated that the current U-shaped concrete structure itself is a tunnel structure, but the focus in this thesis is not on this structure as discussed in paragraph *2.6* . The deck structure itself has more similarities with a bridge structure as discussed in this appendix. In the end, it could be the case that the walls of the structure are dimensioned as a tunnel structure, while the deck structure is dimensioned as a bridge structure. It implies that the walls are calculated with a higher partial factor of the load than the deck structure.

But what is the difference in load combination of a bridge structure or a tunnel structure? The main difference consists of the height of the partial factors. In paragraph 4.2: requirement A.1.3.1 of the ROK 1.4 the following sentence is outlined:

> The γ- and ζ-values must be used for buildings. This implies that the following load combinations are applicable according to table 4-1 of the ROK 1.4 for tunnel structures:
>
> 6.10a: $1.5 * G_k + 1.65 * \Psi_{0,i} * Q_k$
>
> 6.10b: $1.3 * G_k + 1.65 * Q_k$

However, if the structure is considered to be a bride structure, the partial factors are slightly different and according to the table NB.13-A2.4(B) of NEN-EN 1990 [48]:

6.10a: $1.4 * G_k + 1.5 * 0.8 * Q_{traffic} + 1.65 * Q_k$

6.10b: $1.25 * G_k + 1.5 * Q_{traffic} + 1.65 * Q_k$

G_k: *the permanent load*

$Q_{traffic}$: *the traffic load (crowd loading)*

Q_k: *remaining variable load*

From this point on, the deck structure is appointed to be a bridge structure and not a tunnel structure. The reasoning is discussed in this Appendix. In short, it has more similarities with a bridge than with a tunnel. Therefore, the formulae 6.10a and 6.10b are used with partial factors for the permanent load 1.4 and 1.25. The dominating formulae will be determined later. Since permanent load is about 95% of the total load, formula 6.10a will become governing.

More boundary conditions are applicable to this new to be designed deck structure. These can be found in the same guideline ROK 1.4 with respect to the load considerations on top of the structure. These conditions are listed below:

1. Paragraph 4.1: requirement B.3.1: Bridges of Rijkswaterstaat have to be appointed to consequence class III. The CC3 is already incorporated in the partial factors in the formulae above.
2. Paragraph 5.1: requirement 2.1 (4)P: The soil layer on top of structure must be considered as a permanent load.
3. Paragraph 5.1: requirement 2.1 (4)P: If no information about changes in thickness of the soil layer on top of the structure is specified in the requirements, the upper limit of this layer may be assumed to be the mean thickness multiplied with 1.25. The minimum value of this upper limit is the mean thickness added with 0.25 meters.
4. Paragraph 5.1: requirement 2.2 (1)P: Structures with a layer of soil on top of it must be accessible for a maintenance vehicle or a fire truck. If no further requirements are specified in the contract, one vehicle of LM1 one must be applied with $a_q = 0.5$ according to NEN-EN 1991-2.

Load consideration

In the previous paragraph some remarks from the ROK 1.4 are outlined with respect to the load considerations. The soil layer must be considered as a permanent load and a maintenance vehicle must have access everywhere on top of the deck structure.

Some assumptions have to be made since no information is provided about the thickness of the soil layer. In paragraph 7.2 some reference projects are discussed with respect to the load on tunnels if a layer of soil is constructed upon a tunnel. Considering this information, an assumption is made that 1 meter of soil is going to be constructed upon The Green Connection. Below this soil layer, a drainage layer is assumed to be constructed of 0.2 meters. The total height of the layer of soil will be 1.2 meters which will be the mean thickness. The density of soil is assumed to be 18 kN/m[3]. Besides the soil and drainage layer, a maintenance vehicle must have access at the deck structure. The following statements about the load can be considered:

- According to (3), this 1.2 meters must be multiplied with 1.25 which implies that the design height of the thickness of soil will be 1.5 meters.

$$q_{soil} = 1.5\ m * 18kN/m^3 = 27\ kN/m^2$$

- According to (2), the soil layer is considered as a permanent load which will be of importance when the design load is calculated.
- According to (4), the equivalent distributed load can be calculated via the same manner as what is done in Appendix C, which implies:

$$M = \frac{1}{4} * a_q * F * L \quad \rightarrow \quad M = \frac{1}{4} * 0.5 * 600 * 75 = 5625\ kNm$$

$$M = q_{Eq} * l^2 * \frac{1}{8} \quad \rightarrow \quad q_{Eq} = 8\ kN/m$$

$$q_{vehicle} = \frac{q_{Eq}}{b_{eff}} = 1.8\ kN/m^2$$

It implies that due to a maintenance vehicle an extra variable load of 1.8 kN/m^2 must be considered in the design.

REMARK: *The amount of 1.8 kN/m^2 is based upon an assumed structural height of 2.5 meters of the deck structure. This structural height is very ambitious. If the height will increase, it has a positive effect on the load (it'll diminish). Therefore, a conservative value is assumed as structural height.*

Besides the three points stipulated above, it is assumed that it can become crowded at the public garden. According to NEN-EN 1991-2 chapter 5.3.2.1 [14], the Eurocode prescribed the following about this kind of loading:

$$q_{fk} = 2.0 * \frac{120}{L + 30} \quad with \quad q_{fk} \geq 2.5\ kN/m^2; q_{fk} \leq 5\ kN/m^2$$

The length of the viaduct of bridge is parameter L in the formula above. Finally, it results in $q_{fk} = 3.2\ kN/m^2$.

REMARK: *Upon the structure, it is assumed that it's only crowded, or a maintenance vehicle is present. It's either one of the loads, not both. Therefore, the most governing one of the two loads is chosen as the variable load, which is* $q_{fk} = 3.2\ kN/m^2$.

Concludingly can be stated that the load consists of:

- 27 kN/m^2 permanent load resulting from the self-weight of the soil layers. It's assumed that 1 layer of soil is going to be constructed on top. In between this layer and the concrete deck structure a drainage layer of 0.2 meters is going to be applied.
- 3.2 kN/m^2 variable load of crowd loading.

It means that in the preliminary design in serviceability limit state (SLS) a load of 30.2 kN/m^2 is considered as the load resulting from the public garden. However, if the resistance of the structure must be checked, the ultimate limit state of the structure should be calculated. In this case, a design value of the load is necessary to determine according to table NB.13 A2.4(B) of NEN-EN 1990 [48]. From the following combinations, the governing one must be chosen:

6.10a: $1.4 * G_k + 1.5 * 0.8 * Q_{traffic} + 1.65 * Q_k$

6.10b: $1.25 * G_k + 1.5 * Q_{traffic} + 1.65 * Q_k$

6.10a: $1.4 * 27\ kN/m^2 + 1.5 * 0.8 * 3.2\ kN/m^2 = 41.6\ kN/m^2$

6.10b: $1.25 * 27\ kN/m^2 + 1.5 * 3.2\ kN/m^2 = 38.5\ kN/m^2$

The final design load entails 41.6 kN/m^2.

Appendix C Load model according to the EC2 and NB

This annex will provide a clarification of the traffic loads on which the viaduct the Koningsweg will be exposed to. Globally, two references documents are used (Eurocode 1 part 2 [14] [15]). The calculation is made via the basic assumptions of road arrangement of the Eurocode NEN-EN 1991-2 table 4.1. First of all, the viaduct the Koningsweg is a provincial road or city road, but it spans over a main motorway. Therefore, the integrated viaduct belongs to consequence class 3.

The total width of the viaduct must be divided into notional lanes of a width of 3 meters. On this notional road arrangement, the load models are applied.

Furthermore, in the Eurocode stated that in total 4 load models must be examined. The abbreviation of these load models are LM1-LM4. These models will be briefly discussed:

- LM1: This load model consists of roughly normal loading. It includes a uniformly distributed load combined with a tandem axle.
- LM2: This load model could be applied to consider whether the structure can resist local effects. These local effects result from one or more high point loads. In most cases it's determined with one single axle and this load model is not governing for the global distribution of forces in the total structure.
- LM3: This load model consists of abnormal loading and must be prescribed by the local municipality or government. It could consist of multiple axles which high loads for instance.
- LM4: This load model is an applied in case of a crowd loading, which is 5 kN/m^2 for bridges with a span less than 30 meters. For longer or wider bridges, the load is reduced to a lower bound of 2.5 kN/m^2 as specified in Appendix B.

In this case, the LM1 is applied via a conservative approach. This approach is simplified due to the fact that the bridge deck structure is not known yet. If the calculated load is higher than the 30.2 kN/m^2, the LM1 will be recalculated via the Guyon Massonnet method. This method is much more sophisticated and will roughly reach a reduction of the loads of about 20% in comparison with the used method here.

Load model

The width of the Koningsweg is yet unknown. However, in this preliminary design it's estimated to be about 20 meters, which is approximately the same width as the current viaduct. This results in the following layout with several notional lanes which is visualized in Figure C.1. The accompanying width is 3 meters.

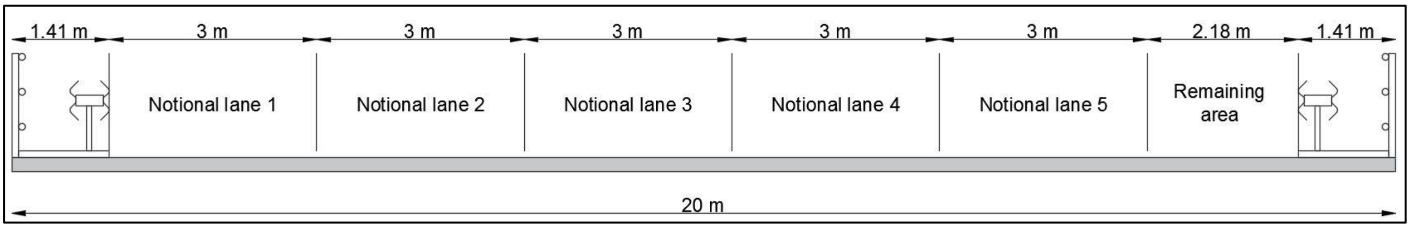

Figure C.1: Notional road arrangement of the Koningsweg viaduct.

In this arrangement a distributed load is applied for the slow lane of bridge with a value of 9 kN/m^2 and 2.5 kN/m^2 for the other lanes and remaining area. Note that it's a provincial road and no information is specified over the amount of trucks (N_{obs}). Therefore, the correlation factors are kept at a value of 1. Besides the distributed loads, the axle loads of the trucks are considered. The most unfavorable location has to be found and is applicable to every notional lane. The heaviest truck in the Eurocode is defined as 2 axle loads of 300 kN.

REMARK: According to the Eurocode, normally two or three trucks next to each other should be calculated, depending on the number of notional lanes. The second truck has an axle load of 200 kN and the third one has an axle load of 100 kN. With these additional trucks the load increases and the corresponding effective width increases as well. However, the ratio between the increase of the loads is less high than the ratio of the increase of the effective width and therefore the corresponding equivalent load will decrease. That's the reason why only the single governing truck is reported below with its equivalent effective load.

The span is determined to be 75 meters and the maximum bending moment can be easily calculated via

$$M = \frac{1}{4} * F * L$$

➔ F is the point load of 2 times 300 kN and L is the span.

The maximum moment is found at half span:

$$M = \frac{1}{4} * 600 * 75 = 11250\ kNm$$

The corresponding equivalent load is found:

$$M = \frac{1}{8} * q_{Eq} * l^2 \quad \rightarrow \quad q_{Eq} = 16\ kN/m$$

The effective width on which the load occurs is shown in Figure C.2. Some notes have to be made concerning this figure. Although the structure of The Green Connection isn't known yet, the neutral axis of the structure has to be found otherwise the effective width can't be calculated. Therefore, a deck structure is assumed and only used to provide an estimate for the effective width. It is a pure indicative one and no further thoughts or attention has to be paid to this structure. This fictitious deck structure is an ambitious one and is based upon a slenderness ratio of 30. This results in a lower effective width and a relatively higher distributed load. A beam height of 2.5 meter is chosen with an effective width of 4.5 meters when alpha is 45 degrees.

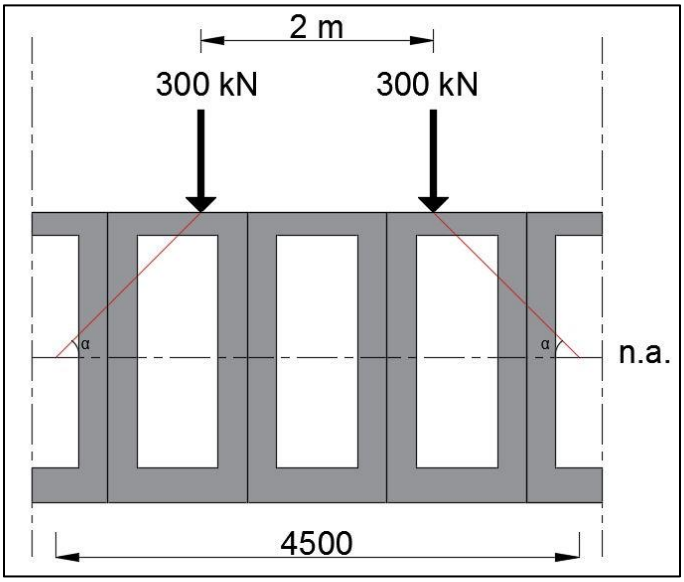

Figure C.2: Effective width of fictitious deck structure.

The equivalent uniformly distributed load per beam can be determined from the axle load and multiplied by the width of the beam. Then, this UDL has to be determined from LM1. As said before, the slow lane has a UDL of 9 kN/m² and the other lanes 2.5 kN/m². Again, the correlation factors are kept at a value of 1. First step is to determine the effective width, which is shown in the Figure C.2. Then, the effective load per meter squared is determined:

From axle loads: (16/4.5) * 1 m	= 3.6 kN/m²
UDL: (3*6.5)/ (3+2*1.25) +2.5 = 6.0 kN/m² x 1 m	= 6 kN/m² +
Load on one beam q	= 9.6 kN/m²

The distributed load per meter squared is 9.6 kN/m². This value only results from the traffic load. At the location of the viaduct also super imposed loads are present, like a layer of asphalt. A layer of 120 mm is assumed. This value is based upon a tight asphalt layer directly placed upon the concrete deck because of water tightness considerations and another layer of 70 mm of ZOAB-asphalt. A super imposed load of 3 kN/m² is used. Both kind of loads, the permanent load and load due to traffic must be multiplied with correlation factors and combined according to table NB.13 A2.4(B) of NEN-EN 1990 [48]. From the following combinations, the governing one must be chosen:

6.10a: $1.4 * G_k + 1.5 * 0.8 * Q_{traffic} + 1.65 * Q_k$

6.10b: $1.25 * G_k + 1.5 * Q_{traffic} + 1.65 * Q_k$

G_k: *the permanent load*

$Q_{traffic}$: *the traffic load*

Q_k: *remaining variable load*

6.10a: $1.4 * 3\ kN/m^2 + 1.5 * 0.8 * 9.6\ kN/m^2 = 15.7 kN/m^2$

6.10b: $1.25 * 3\ kN/m^2 + 1.5 * 9.6\ kN/m^2 = 18.2 kN/m^2$

From the above can be concluded that equation 6.10b is the governing one with a design value of 18.2 kN/m². Because of the fact that the beam width is still unknown, this value is calculated per square meter instead of per running meter of beam.

Appendix D Clarification square root of two

This appendix is meant to clarify the difference in key figures between bridges dimensioned on traffic loads according to the Eurocode and structures such as The Green Connection which are dimensioned on a different kind of load. In the course CIE5127 concrete bridges of the TU Delft, a lot of key figures are provided to give a rough estimation of the dimensions of the various kinds of bridge structures. Chapter *3* is meant to provide such an overview as well, but in this case for a deck structure with a different kind of load model. The load model is about two times as high than the normal traffic load. In this case the following question arises:

In what way do change the key figures such as slenderness and maximum span?

In order to provide a proper answer, one must determine which kind of parameters do contribute to these key figures. In fact, in this stage of the design, only global parameters are sufficient to judge whether a structure could be suitable.

The key figures slenderness and maximum span are roughly depending upon the distribution of forces exerting on the structure and the resistance of the structure itself (moment of inertia, which has a link to the height of the structure and thus indirect linked to slenderness). In other words, the key figures depend on the load on the structure. Since the load is about two times as high, it will affect the maximum span of a type of structure. In the case of The Green Connection, the structure is simply supported and statically determinate because it spans between two abutments. Therefore, the distribution of forces is described by:

$$M = \frac{1}{8} * q_{Eq} * l^2$$

The externally applied bending moment must be in equilibrium with the bending moment resistance of the structure. Every structure has a certain bending moment capacity depending on several parameters such as the dimensions. If these parameters and the dimensions are kept the same, the height of a structure is the same and thus the bending moment capacity. But, when the external load is almost doubled in height, in what way does it change the slenderness ratio?

The slenderness ratio is the span divided by the structural height. If the externally applied load is twice as high while the height of the structure is kept the same as well as the bending moment resistance of the structure, the structure can span a lower distance. In other words, if the dimensions of the structure are kept the same and the height of the load is doubled, the structure can overcome less span and thus the slenderness ratio decreases.

To determine the span l in the function when the load is two times as high:

$$M = \frac{1}{8} * q_{Eq} * {l_1}^2 = \frac{1}{8} * 2 * q_{Eq} * {l_2}^2$$

$$l_2 = \frac{l_1}{\sqrt{2}}$$

So, the answer to the question above: If the key figures such as slenderness and maximum span are mentioned, one must consider that these values must be globally divided by the factor $\sqrt{2}$ to get a more realistic value.

REMARK: *This measure is only meant to provide a more realistic value of the key figures which are meant to estimate the dimensions of this Green Connection. In fact, more key figures play a role in the bending moment capacity of a structure, for instance reinforcement ratio, concrete class strength and amount of prestressing force.*