Zandkreeksluis traffic improvement

Research to improve the conditions for agricultural vehicles at the N256

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Thesis Report Bachelor Civil Engineering

Thesis report

Final version

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Course	DA Final Thesis (CU11020)
Study year	2017/2018, Semester 2
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Document	Thesis Report
Version	1.0

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Abstract

As a result of the 1953 floods in the South West areas of the Netherlands, the Zandkreekdam was constructed. A lock within the dam connects the Veerse meer and the Eastern Scheldt. Additionally, it connects the island Noord-Beveland to Zuid-Beveland over the provincial road N256, by means of a movable bridge.
In 2002 a second bridge was implemented to reduce traffic delays. This has improved the situation for all traffic types, except for agricultural vehicles. Various regulations and problems regarding the existing situation are the combining factors that result in a disadvantage for this type of traffic

By means of this research, a solution is aimed to be found to reduce the waiting times for agricultural vehicles. Through a theoretical research it is found what the existing situation's impact is on the waiting times, and why agricultural vehicles use this crossing. By means of consultations with experts, the question on how to improve this junction is discussed with 10 experts in the working field. A result of these consultations is the program of requirements. This program displays the possibilities and limitations of what the best solution looks like

A variant analysis is performed, through which a variety of technical- and non-technical-variants is identified and evaluated. By cross referencing the variants with thee program of requirements, 1 variant is determined as decisive option.

This variant includes the redesign of the existing Zandkreekbrug. With a structural redesign, the layout can be reassigned, through which can allow agricultural vehicles to cross once again. This will likely reduce the waiting times with half, due to the creation of an additional crossing opportunity. When incorporated together with the current developments, agricultural vehicles might not need to wait at all any longer.

The technical design is elaborated through calculations and drawings. The calculations include several assessments, which cover the bridge's elements in several states and conditions. This includes aspects as strength, deflection and fatigue assessed at an open and closed bridge. The drawings display the selected elements used in the calculation. It provides a visualization which can later be used as basis for any further developments.

The results of the calculations are not all positive; some elements are not sufficient which results in additional challenges, discussed in the conclusion and recommendation chapters.

Keywords: Zandkreeksluis, Agricultural vehicles, Traffic delays, Zandkreekbrug, Technical design.

Preface

Before you lay my research report as part of the final thesis bachelor studies Civil Engineering at the HZ University of Applied Sciences. I am proud to present my findings to you – a fellow researcher, student, working field expert, or just somebody who takes a bit of time exploring this interesting subject.

What you will find in this report is a thoughtful description intended to formulate a solution to decrease time delays for agricultural vehicles a the Zandkreeksluis N256 road crossing. This paper includes background information, identifying the research question, performing theoretical research after which the results of this research are displayed and analyzed. This analysis produces a decisive variant which is further elaborated through a technical design, concluding with an answer to the main question.

Before I invite you to turn this page, I would like to thank my supervisors at the Province of Zeeland, ing. Fred Lindenberg and ing. Kees Steur, who provided me valuable feedback and great inspiration. Also, thank you to my HZ supervisor ir. Piet Dekker, who kept me focused and who's feedback is much appreciated. Thank you to all the experts and supporting people I had the opportunity to meet, your input is what serves as the basis of what is below. A last thank you goes out to my family and friends who supported me beyond the content of this report.

Iek Lambooij

Middelburg, June 2018

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1. Introduction

The introduction provides an overview of the problem as it exists and how this thesis helps resolving the issue. It is described through the history of the location, where the problem is elaborated and stated. The main question is thereby formulated, with limitations and boundaries taken into consideration. The chapter is closed with a guide towards the following chapters.

1.1. Background Information

This thesis is performed to research the possible improvements of the existing situation regarding the Zandkreeksluis road infrastructure which results in unfavorable delays for agricultural vehicles (AV’s).

The Zandkreeksluis is part of the Zandkreekdam, constructed in 1960 as part of the Dutch Delta-works. The dam marks the boundary between the Veerse meer (on the west) and Eastern Scheldt (on the east), but also the regions of Noord-Beveland (north) and Zuid-Beveland (south). The waterbodies are connected by the Zandkreeksluis (lock), the lands by the N256 provincial road, which crosses the lock by means of a bridge.

Until 2002 only one bridge existed, which resulted in major road traffic delays whenever the bridge was opened for vessels. To decrease these delays, a bypass structure was implemented, consisting of an additional bridge on the opposite side of the lock, linked to the main road with an additional road section (See figure 1)

Figure 1 Province of Zeeland map and detail of Zandkreekdam (Kadaster, 2018).

The lock, bridges and dam are under management of Rijkswaterstaat, where the N256 (also known as Deltaweg) and bypass road are under management of the Province of Zeeland.
The Deltaweg leads from Goes in the south, to Zierikzee in the North, making it one of the main crossing options of this province, therefore being part of the 'middle Zeeland' route. It is the busiest road in provincial management due to tourists, regional traffic, commuting traffic, bicycles and AV's.

The road section that crosses the Zandkreeksluis consists of a 2x1 lane structure and a separate parallel lane that also functions as cycling path. At the specific location of the lock, however, the structure consists of a complicated combination of entering- and exiting-lanes from the parallel layout and the bypass section, moveable barriers and other signaling armory and separate cycling lanes crossing the bridges (see figure 2).
Normally, the normal lanes are prohibited for bicycles and AV's, while the parallel lane is prohibited for ordinary traffic that is different from bikes, AV's and destination traffic (e.g. people that live alongside the parallel lane). However, at the Zandkreeksluis crossing, various regulations and exceptions to the rule have been introduced to enhance easier crossing for all types of traffic, regardless of its success.

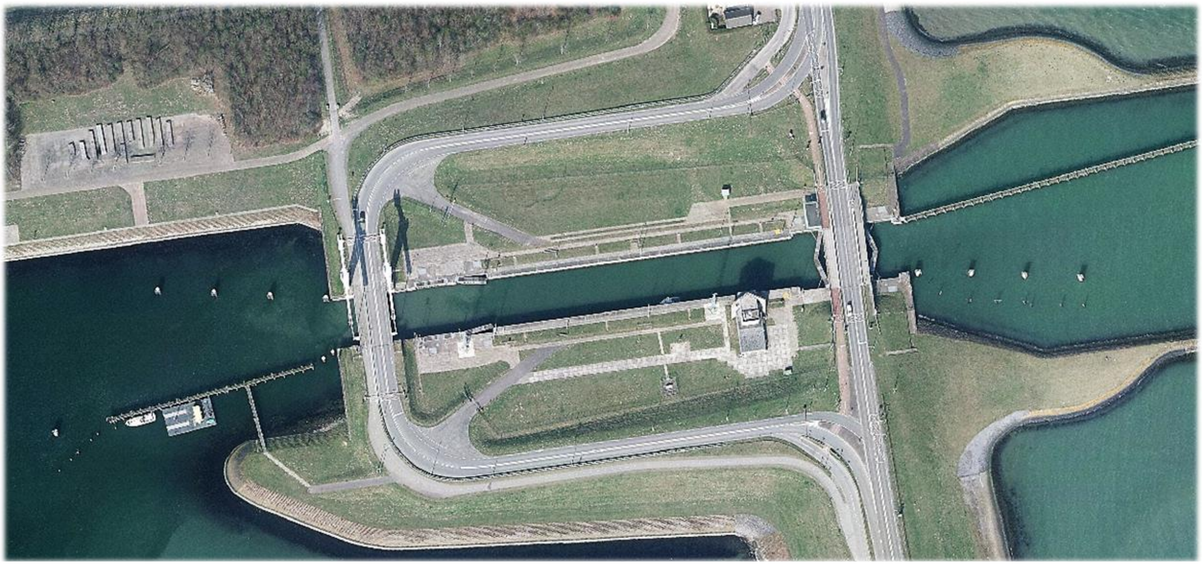


Figure 2 Birds perspective of Zandkreeksluis (Kadaster, 2018).

1.2. *The problem*

In this section the problem is identified, upon which the research objective and research questions are formulated.

1.2.1. Problem description

The capacity of the N256 is close to saturation considering the number of vehicles using this section. This number is a result of commuting traffic, regional traffic and tourists. Due to the complexity of a structure like the Zandkreeksluis, these tourists and other inexperienced drivers, occasionally perform strange maneuvers that unfavorably influence the flow of traffic. The maneuvers range from waiting for the bridge (which is unnecessary due to the bypass), to returning off the bypass.

AV's are not allowed to use the main bridge (Zandkreekbrug). Initially, the bridge was designed and constructed to support 2 traffic lanes, a cycling path and pedestrian lane. During the first years of its implementation, AV's used the main lanes to cross. However, as the amount of traffic increased, this could no longer be allowed (speed differential is too big between AV's and normal traffic). Therefore, AV traffic is moved to the bypass bridge. Maintaining AV traffic on the main bridge by simply adding a separate lane on the existing bridge is not possible due to its initial design, and lifetime. Therefore, agricultural vehicles are limited to use the bypass bridge (Hongersdijckbrug).
The bypass bridge is limited in its own way. The bridge is too small to allow all types of traffic present to cross at the same time. The 2x1 lanes for normal traffic is maintained, as well as a cycling lane. The cycling lane is big enough to allow agricultural vehicles up to three meters in width but sharing this road part with bikes results in unsafe situations. Therefore, AV's use the normal lanes whenever they are not occupied by normal traffic. This can be done only when the bypass is free of normal traffic, because it would create unsafe situations whenever the two types are mixed. This due to the speed differential between the two types and the dimension of AV's.

Figure 3 Zandkreekbrug (own picture)

Figure 4 Hongersdijckbrug (own picture)

To visualize the possible situations, the following is true at the Zandkreeksluis (See figure 3). Situation A shows crossing availability of both bridges for road traffic. There is no problem in this case because AV's can use the bypass structure. Situation B shows the opening of the Zandkreekbrug for vessels. Here, AV's (in blue) have to wait because the bypass road is occupied by normal traffic. A few AV's included in the exception regulation use the cycling lane. Situation C shows the opening of the Hongersdijckbrug for vessels. Here AV's also have to wait, due to their exclusion of crossing the Zandkreekbrug.

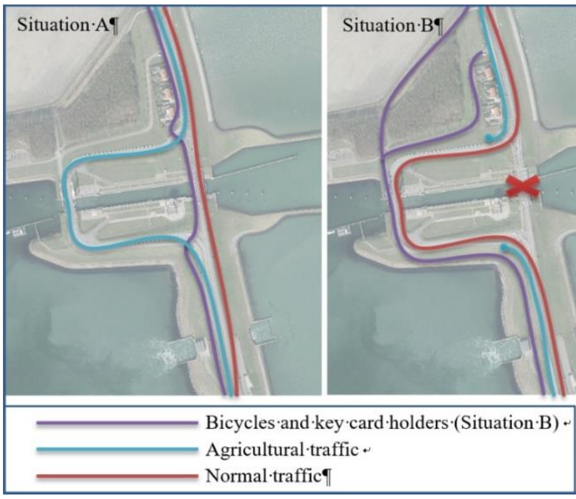


Figure 5 Schematic situation traffic types (Kadaster, 2018).

During Situation B (where AV's mix with cyclists) the traffic safety of the cyclist is jeopardized, due to the tight space on the cycling lane of the Hongersdijckbrug.
Both north and south of the Zandkreeksluis the parallel lane at which the AV's drive, is shared with cyclists. In an ideal situation this layout is separated into separate elements. However, the parallel lane is implemented in a spacious manner, which means that there is enough visibility and room for AV's to cross cyclists. The safety of the cyclist is therefor at a minimum risk on this parallel lane.
Nevertheless, the Hongersdijckbrug shared lane is subsequently 'thin' which means that this crossing space is (almost) eliminated. Additionally, the visibility is less due to road curves and slopes (from dike to hinterland) towards the bridge. Therefore, the situation for cyclists at this location could be dangerous when crossing with AV's.

1.2.2. Problem statement

Considering the problems identified above the problem statement is formulated as following:

> **The existing infrastructure of the N256 at the location of the Zandkreeksluis, and logistical travelling routes limit agricultural vehicles, resulting in unfavorable time delays and a jeopardized traffic safety situation.**

As AV's have to wait in two out of three situation cases, the infrastructure has an influence on the waiting times. The logistical travelling routes consist of the actual presence of AV's at this crossing, and the prioritized network of roads, which will be discussed in the relevance chapter of this report.
The time delays are coherent to the infrastructure, as is the traffic safety. In both cases where AV's merge in with normal traffic and merge in with bicycle traffic, the safety is jeopardized.

1.2.3. Research objective

The objective of the research, following the problem statement, is identified to transform the problem into a resolved issue, formulated as following:

1. **Decrease time delays as experienced by agricultural vehicles by considering logistical travelling routes and road infrastructure.**
2. **Improve traffic safety considering road sharing by different types of traffic.**

1.2.4. Research question

The main question is designed to, once answered, provide a solution that covers the full scope of the project, and therefore formulated as following:

> **What is the most optimal solution to decrease time delays as experienced by agricultural vehicles at the N256 Zandkreeksluis crossing, while locally improving the traffic safety, with logistical travelling routes and applicable regulations considered?**

The main research question is logically divided into sub-questions which facilitates the ability to formulate a complete answer.
These sub-questions are identified as following:

1. What is the impact of the existing situation on the problem stated?
   1.1. What are the quantitative specifications of agricultural vehicles related to this problem?
   1.2. What is the reason of agricultural vehicles using the Zandkreeksluis crossing?
   1.3. What are the specifications and extend of the time delays?
   1.4. What is the effective number of lock cycles and its impact on traffic delays?
   1.5. Which safety problems occur regarding the Zandkreeksluis road layout?

2. What are the requirements for any possible solution?
   2.1. What are the requirements from Rijkswaterstaat related to the lock, ships and bridges?
   2.2. What are the requirements of the agricultural sector (CZAV, ZLTO, CUMELA, farmers) related to agricultural traffic movements?
   2.3. What are the requirements from the Province of Zeeland related to the road sections?
   2.4. What are the traffic safety requirements and recommendations to the problem situation?
   2.5. What are the legal structural requirements related to the infrastructure of the situation?

3. What are the possible variants based on the requirements?
   3.1. What are the feasible non-technical variants?
   3.2. What are the feasible technical variants?

4. Based on different criteria, what is the most optimal solution out of the identified variants?
    4.1. Based on what criteria are the variants processed?
    4.2. Which variant scores best on the selected criteria, and is therefore the most optimal solution to the problem?
5. What is the most optimal technical design to support the selected most optimal solution?
    5.1. If the most optimal solution does not require a technical design, based on what criteria are the technical variants processed and evaluated?
    5.2. Which technical variant scores best on the selected criteria as determined in question 5.1?
    5.3. To what extend is the selected design worked out?
    5.4. What does the technical design look like, based on calculations?

6. What is the recommendation to the stakeholders, to facilitate the most optimal solution of the problem stated?

By means of this report, the answers will be formulated in order to conclude with a definitive solution to the main question and the problem stated.

1.3. Limitations and Boundaries

Within the full extent of this problem, this thesis research is molded within working boundaries to formulate a specified answer. This chapter only discusses the limitations and boundaries set to the research itself. The boundaries related to the possible variants are discussed in the program of requirements, chapter 5.3.

Future infrastructural developments related to the full extent of the N256 provincial road, will not be considered as processing factor related to the variants. Although the current number of vehicles on the N256 demands for an overall reevaluation of the road layout, at this moment there are no indications of rigorous infrastructural developments within the short or middle long term. Whenever a technical solution is selected, a shallow indication will show if the solution can benefit future developments. However, the indication has no meaning apart from a consideration for a future research into development possibilities.
On the other hand, limitations of the existing bridges currently in place will be part of the research. Investigation to the limiting factors is required in order to formulate a solution.
The optimization between the relation of that what is under management of Rijkswaterstaat and of Province is a requirement that will be investigated. The functioning of the lock will therefore, be considered within the research.

The research will furthermore investigate why agricultural vehicles are using this road section. This can have an influence towards selecting the decisive solution.

The traffic safety will be consulted and researched. This is necessary due to different types of traffic, using a similar section of the road. Legislations (national and regional) and technical possibilities will be investigated to serve the purpose of safety for all, while reducing delays for agricultural vehicles.

Additionally, tourist confusion within the infrastructure will not serve as requirement within selecting the decisive solution. This issue is currently being researched by the Province in a separate investigation to improve the understandability of the infrastructure. The traffic safety issues considered within the scope of this research is limited to road sharing requirements (especially concerning AV's and bicycles on the same lane), opposed to road sign clarity.

Measures against cut-through traffic, illegally making use of the parallel lane infrastructure is not considered in this research. However, similar restraints must ideally be maintained, in order to not encourage renewed increase of cut-through traffic.

Within the technical aspect of the answer to the problem stated, are limitations applied to the design of a new civil element only. This means that topics related to execution, costs, maintenance or renewed armory and road signs, is subject to further research outside of this thesis. The design as worked out, will be based on structural calculations to ensure the object's feasibility. The drawings reflect the design of the calculated object on a preliminary design level with crucial detailing included.

By these boundaries within which the research will be executed, the scope and extent to which the research will reach is clarified. Choosing to focus on a selection of a much bigger problem benefits the solution towards the aimed target.

1.4. Products

The products formed as a result of the research are of various specifications and purposes, and serve to benefit the solution to the problem.

The main product is the research paper as lays before you. It includes a description that systematically leads to the answer of the problem. To support and enforce the selected solution, a theoretical framework, professional consultation with experts in the field and a technical design based on calculations and drawings are formulated.

The theoretical framework serves as a basis to answer those questions subject to existing information. This information is acquired by means of a literature research.
The consultations are executed to obtain the full picture of the problem through the eyes of the stakeholders involved. The stakeholder's consultation can influence the thesis in two main ways. Firstly, it can elaborate certain aspects of the problem into more detail. Secondly, it can provide the requirements on which the decisive variant and design are based.

The competences of the bachelor Civil Engineering at the HZ University of Applied Sciences show a requirement of elaborating a technical solution. However, the possible solutions as this research will determine, might include non-technical solutions. In case a non-technical design solution is the decisive option, a 'second-best' option will be determined with which a technical design is worked out. This secures the acquirement of all requirements stated by the HZ University, together with a successful research.

The technical design and drawings are hence related to the selected solution in the manner described above. The calculations provide a justification of the selected elements and its feasibility. It will follow the applicable regulations used in The Netherlands.
The drawings related to the design are based on the calculations and design assumptions. Due to the absence of an architect related to this project at this point, the drawings will mainly portrait the structural aspect of the design. Therefore, the drawings include all the technical aspects on a preliminary design level, including crucial detailing.

1.5. Relevance

By validating the relevance of the research, the importance and necessity of a solution is justified.

Since 2002, when the bypass was implemented in today's road design, problems have been increasing for the agricultural vehicles that are passing the Zandkreeksluis. Due to ongoing concerns of the CZAV (Cooperative Southern Sales Association), the ZLTO (Southern Agricultural and Horticultural Organization), CUMELA (Organization of Contract Workers) and various individual farmers, the Province initiated research into the issue. Different from this thesis, currently planned investments can be regarded as 'quick-wins'; solutions that only looks at low-cost and little execution time. The research as currently proposed concerns a solution which can be seen as 'long-win'. Focusing on a solution that lasts for a longer, more substantial period of time, which requires more money, longer execution and (possibly) new infrastructure. Regardless, the solution will be more sustainable and ready for a developing future of the N256.

1.6. Guide

Following this introduction, the theoretical framework will be discussed in chapter 2. This framework describes what is known about the research topic including relevant information from the past. The methodology described in chapter 3 validates the literature research and introduces the consultations with experts. The results of both research methods are displayed in chapter 4, after which it will be analyzed in chapter 5. The analysis includes the identification of the program of requirements, the possible variants and the selection thereof. Chapter 6 discusses the prior by means of technical elaboration in calculations and drawings. The reliability and feasibility of the acquired design and theoretical research are discussed in chapter 7. The conclusion and recommendation described in chapter 8 accomplishes the thesis. It displays the conclusive answer to the problem and the necessary follow-up research required.

2. Methodology

2.1. Sub-question 1

What is the impact of the existing situation on the problem stated?

This first sub-question of the research requires a literature study. The theoretical framework, discussed in the next chapter is the start, but requires more elaboration. This applies to all five search queries. A more detailed current situation indication is acquired by consultations with experts in the field, or reference to reports by experts and colleagues.

2.2. Sub-question 2

What are the requirements for any possible solution?

Sub-question 2 is built of five search queries. The first four are related to the stakeholders involved to the problem. Therefore it is necessary to acquire their knowledge, recommendation and requirements regarding the problem. This to professionally formulate the potentially solving variants. Consultations with experts in the field are conducted with at least one representative, spokesperson or expert of all stakeholders involved.
The fifth search query related to this second sub question is less relevant to expert knowledge. Rather, it requires advises from existing reports. Due to the complexity of the situation, multiple reports might have multiple views on the situation.
Additionally, it requires rules and guidelines written in official norms and reports. Therefore, a literature research into those regulations is required to identify the structural and safety requirements related to any infrastructural approach of solving the problem.

2.3. Sub-question 3

What are the possible variants based on the requirements?

This third sub-question proceeds on what is established in the previous sub-question. Both research methods as literature study and consultations with experts in the field do not apply to the subject matter. Rather, an analytical approach is required to identify all possible variants based on previously acquired knowledge, scientific proof and expert insight. The answer to sub-question 3 will be discussed in chapter 5 – Analysis

2.4. Sub-question 4

Based on different criteria, what is the most optimal solution out of the identified variants?

Together which the previously acquired information, the decisive variant is selected. The criteria on which will be selected are based on the information from sub-question 2. To enhance a comprehensive selection procedure, the criteria are formulated within in a Program of Requirements.
The variants from which will be selected are identified in sub-question 3. During the selection procedure, the decisive variant will be selected by assessing all variants to the Program of Requirements. The selection will be formulated in a descriptive manner, displayed in chapter 5 – Analysis.

2.5. Sub-question 5

What is the most optimal technical design to support the selected most optimal solution?

This sub-question is related to sub-question four. However, this sub-question solely focusses on the selected technical variant that answers the problem stated.
A design related to the decisive variant is produced. This design includes the basic required calculations to validate the strength and bearing capacity of the civil element. Additionally, it includes drawings on a preliminary design quality level, related to the calculated structure.

The answer to sub-question 5 will be discussed in chapter 6 - Design

2.6. Sub-question 6

What is the recommendation to the stakeholders, to facilitate the most optimal solution of the problem stated?

The last sub-question is related to the feasibility of the solution as selected in the previous two sub-questions. It does not require a literature study, neither qualitative interviews. The recommendation will be based on all the acquired information prior to this stage. Meaning, it will be based on variables such as feasibility, solution potential, and the technical design.

The answer to sub-question 6 will be discussed in chapter 8 – Conclusion and recommendation.

2.7. Main research question

The answer to the main research question will be discussed in chapter 8 – Conclusion and recommendation. It will be based on the total sum on acquired information over the course of the research. Additionally, it will consider the answers provided for the sub-questions as discussed above.
By answering the main question, the research is complete and can be finished.

3. Theoretical Framework

This chapter displays the existing information related to the problem. The information is acquired by means of a literature research, looking into a variety of sources.

3.1. Sub-questions subject to literature review

Not all questions can, or should, be answered by means of a literature study. However, some of the question are best answered by existing material. By looking to previously executed research, the following sub-questions can be answered:

- Sub-question 1: What is the impact of the existing situation on the problem stated?
- Sub question 2: What are the requirements for any possible solution?

3.2. Sub-question 1

What is the impact of the existing situation on the problem stated?

What are the quantitative specifications of agricultural vehicles related to this problem?

The Zandkreeksluis is one of 45 bottlenecks within the main transport routes for AV's, identified by Schaipp & Louwerse (2017). This because, due to various circumstances, the current layout is a blockade for agricultural vehicles causing disturbance for residents at the north side of the lock (Royal HaskoningDHV, 2014), and delays for AV's (Pasveer, 2015).

The bottlenecks are prioritized by indication of the presence and amount of bicycles, cars, road-width, shared/separated traffic types (e.g. if AV's and bicycles share the road) and location on main routes (Schaipp & Louwerse, 2017). In figure 5 (see below), the situation related to the Zandkreeksluis is displayed through the indicators described above. It shows that the Zandkreeksluis has at least 600 bikes on an average working day (Provincie Zeeland, 2016), circa 18500 cars a day on average (Geoloket, 2015), and is part of the main regional infrastructural network (Provincie Zeeland, 2016). Bicycles and AV's have to share the same parallel road.

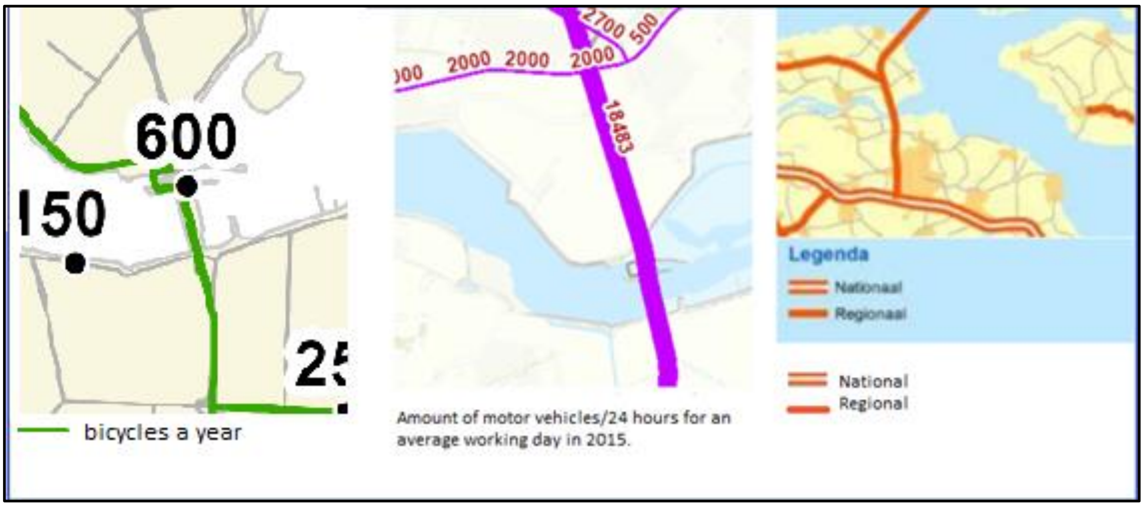


Figure 6 Maps indicating importance Zandkreeksluis section (Provincie Zeeland, 2016) (Geoloket, 2015).

Apart from the Geoloket values, various instances performed measurements ranging over multiple years and traffic types. The province of Zeeland themselves performed measurements in 2012. The counting shows 30 AV's on a normal working day on a year average, and 45 AV's average on a working day in August, passing the Zandkreeksluis (Oosthoek & Pouwer, 2013). Additionally, Groen Licht Verkeersadviezen BV (GLV) performed measurements in 2015 on various locations at the Zandkreeksluis. Analysis to their results show that circa 17 vehicles cross in south to north direction, and circa 15 cross from north to south on a daily basis, measured over 5 days (Pasveer, 2015). GLV also measured AV delays. These numbers will be shown later in this report.

Regarding normal traffic, the numbers increase with about 20% during the summer months June, July and August, bringing the number of vehicles up to around 21900 every 24 hours (Royal HaskoningDHV, 2014).

Specifications of agricultural vehicles

General maximum measurements for AV's are specified within the law. So is a tractor allowed be 3 meters in width, 4 meters in height and 12 meters in length. This also applies to changeable equipment pieces (equipment that can be connected and disconnected to the tractor either in front or behind the vehicle). However, loading of field crops may not extend a width of 3.5 meters. Nevertheless, loading of any kind (equipment, crops, undividable loads) may not extend more than 5 meters from the last wheel axis.
The total length is limited to 18 meters, regarding a tractor or AV for specific application, with limited speed, with one or more trailers or changeable equipment or a combination of both. Lastly, undividable loads/equipment may not extend more than 3.5 meters forward from the heart of the steering wheel. (Dijkema, Overeem, & Pouwels, 2014).

Not all AV's fall within the legal dimension boundaries. For access to public roads, it has to place an exception request.
For example, a self-driving agricultural equipment vehicle (e.g. backhoe, grass cutter) can be as wide as 4.25 meters. Or a double trailer can extend the total length to 25 meters (Beliën, 2015). More extreme widths, heights and lengths are possible to occur as well. But are unlikely to be applied in the Netherlands.

All AV's that enter the public road are allowed to a maximum speed of 25 km/h (Dijkema, Overeem, & Pouwels, 2014). However, almost all AV's pass that limit.

What is the reason of agricultural vehicles using the Zandkreeksluis crossing?

In 2013, it was stated that there is a clear relation between Zuid-Beveland and Noord-Beveland for agricultural vehicles due to properties on either side (Royal HaskoningDHV, 2014). This includes the necessity for transportation of materials, machinery, agricultural products and fertilizers. This statement is enforced by recent collaborations of Province, Water board and relevant agricultural sector organisations, who formed the "Kwaliteitsnet Landbouwverkeer Zeeland" (Quality Network Agricultural Traffic Zeeland). This network indicates the most important logistical routes that AV's use to transport, commute, and work along (Schaipp &

Louwerse, 2017). Figure 6 displays the roads subject to the network (see below). As indicated, the Zandkreeksluis is also part

Point 8 within figure 6 indicates the bottleneck at location Zandkreeksluis.

That the Zandkreeksluis is a part of the quality network stresses the importance of its connective abilities between Noord-Beveland and Zuid-Beveland. However, it lacks to explain why AV’s are present at this location. Further investigation and research is required to answer this question. In the method section, the answering approach will be identified.

As previously mentioned, the quality network included 45 bottlenecks once the Provinciale Staten prioritized them.

The goal is to have all 45 bottlenecks resolved by 2020 with a budget of 2 mln. euro (Provincie Zeeland, 2013).

Figure 7 Map Quality Network Zeeland 2017
(Schaipp & Louwerse, 2017)

What are the specifications and extend of the time delays?

As mentioned prior to this section, GLV performed measurements at the location of the Zandkreeksluis. Analysis shows the number of vehicles. Additionally, the delay time is measured. Display of the delays provides the following graph, showing the longest waiting times per measured day (Pasveer, 2015). The locations of the measurements are shown in figure 7.
A number of AV's is measured during 5 consecutive days in August 2015. The numbers displayed are only those AV's who suffered delays at the specific location.

Table 1 GLV measured data, source: Pasveer, 2015.

Tuesday	15:00:00	15:59:00	A	1	00:09:31	00:09:31	
	17:00:00	17:59:00	B	1	00:19:19	00:19:19	Longest time for single vehicle
	12:00:00	12:59:00	C	3	00:06:52	00:20:36	
	13:00:00	13:59:00	E	2	00:15:54	00:31:48	
Wednesday	17:00:00	17:59:00	A	2	00:08:11	00:16:22	
	09:00:00	09:59:00	B	1	00:04:30	00:04:30	
	14:00:00	14:59:00	C	1	00:14:12	00:14:12	
	15:00:00	15:59:00	E	2	00:09:46	00:19:32	
	12:00:00	12:59:00	D	1	00:02:15	00:02:15	
	16:00:00	16:59:00	F	1	00:06:40	00:06:40	
Thursday	12:00:00	12:59:00	A	1	00:15:29	00:15:29	
	15:00:00	15:59:00	B	2	00:16:08	00:32:16	
	18:00:00	18:59:00	C	3	00:02:43	00:08:09	
	12:00:00	12:59:00	E	1	00:15:47	00:15:47	
Friday	12:00:00	12:59:00	A	3	00:12:37	00:37:51	
	14:00:00	14:59:00	B	1	00:07:50	00:07:50	
	16:00:00	16:59:00	C	4	00:10:57	00:43:48	
	13:00:00	13:59:00	E	1	00:12:59	00:12:59	
Saturday	12:00:00	12:59:00	A	4	00:17:04	01:08:16	Longest time total
	19:00:00	19:59:00	B	1	00:14:29	00:14:29	
	14:00:00	14:59:00	C	2	00:12:14	00:24:28	
	12:00:00	12:59:00	E	2	00:06:59	00:13:58	
	12:00:00	12:59:00	Most significant time period for delays				7 times

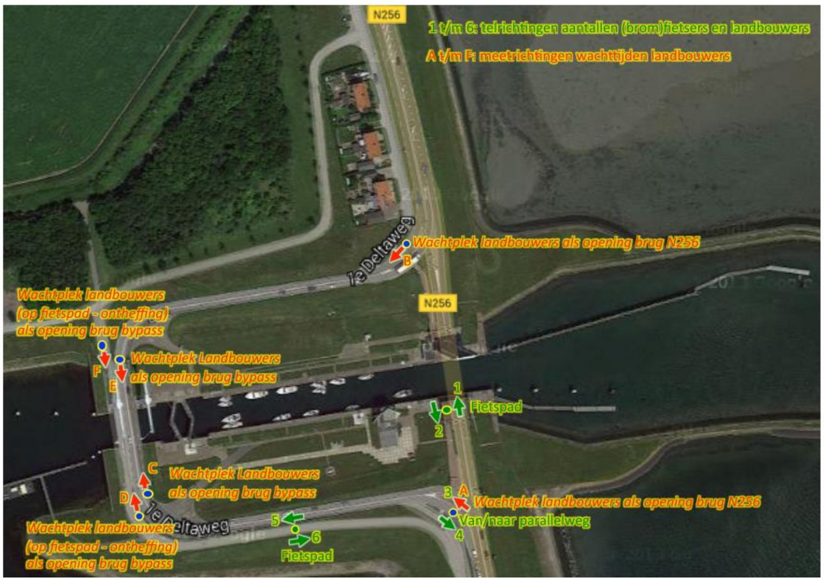


Figure 8 Measurement locations (Pasveer, 2015)

What is the effective number of bridge openings and its impact on traffic delays?

Rijkswaterstaat has accurate data of records that show the number of openings and time of openings related to both Hongersdijckbrug and Zandkreekbrug.
Table 2 shows the averages of openings and time duration. This information was delivered by Rijkswaterstaat on special request for this thesis.

It displays the acquired information relative to weekdays, measured between June 1st and August 31st. This information was requested considering the fact that summer is the busiest time period for both vessel traffic and AV traffic.

Table 2 measured data RWS, Rijkswaterstaat 2018

All measurements are performed between June 1st and August 31st of 2017					
	Vessels	Hongersdijckbrug		Zandkreekbrug	
Any given day within measurement period.	Number of crossing vessels (both directions)	Average amount of openings	Average duration cycle (min)	Average amount of openings	Average duration cycle (min)
Monday	245	16.23	11’49”	15.00	14’57”
Tuesday	148	15.38	11’18”	14.85	12’15”
Wednesday	170	16.15	13’38”	14.62	13’05”
Thursday	147	16.50	10’52”	15.21	12’54”
Friday	185	16.54	11’53”	15.85	13’36”

When analysing this data, and seeing how these numbers influence the AV traffic, one thing can be concluded. Since AV’s have to wait when any of the two bridges is open, it could potentially result in great delays. Not counting the time it would take to lower the barriers, and ‘clear’ the bypass, an AV would have to wait around 12 min every time a bridge starts turning. In total around 31 times a day a bridge turns. This adds up to 6 hours and 35 minutes of potential waiting time on an average day during summer, for AV’s.

As can be seen in the part prior, this is not the case. Waiting times are much less than the potential. That means that the impact of the opening of bridges is relatively small on the waiting times. However, on the other hand, numbers displayed above indicate that the chance is considerable that AV’s have to wait in front of an open bridge.

Which safety problems occur regarding the Zandkreeksluis road layout?

Over the past years multiple advisory reports and future visions regarding the Zandkreeksluis are written. For example, Goudappel Coffeng identified two viable options to increase traffic safety in combination with decreasing delays for AV's. The first option is a "om-en-om regeling" (priority traffic regulation), with still using the existing infrastructure. Here, bicycles and AV's are separated in terms of time, not in location. The second option proposed is to merge AV's in south to north direction with normal traffic, creating new entrance- and exit-lanes. At the same time, AV's traveling from north to south can merge with normal traffic using the existing entrance and exit at the bypass location (Goudappel Coffeng, 2013).

However, due to the intensity on the section between N664 – N255 a "stroomfunctie" (flow function) of the road is desired, regardless of the fact that the current situation cannot support this function (Royal HaskoningDHV, 2014) (Provincie Zeeland, 2016). With the numbers of vehicles and the speed limit of AV's considered, merging them within the normal traffic flow is undesirable and limits the 'flow'. Moreover, the agricultural vehicles and bicycle traffic is ideally separated, and handled through different sections (Royal HaskoningDHV, 2014).

Figure 9 Flow road section N256 (Provincie Zeeland, 2016)

Goudappel Coffeng describes that the traffic safety is improved with enlarging the bypass bridge and shared road sections (e.g. between AV's and cyclists). Now the cycling lane and available bridge part is around 3 meters. Enlargement of the cycling lane both south and north of the lock, plus incorporating the priority traffic regulation requires around 250,000 euros (Goudappel Coffeng, 2013), with bridge enlargement excluded.

On the other hand, Royal HaskoningDHV states that the ideal situation requires a multiple level crossing at the location of the Zandkreeksluis. This will involve a large amount of money (Royal HaskoningDHV, 2014).

3.3. Sub-question 2

What are the requirements for any possible solution?

In general, the requirements can be divided into several categories. These categories are explained within the program of requirements, later discussed in this research. However, all requirements are based on boundary conditions, which are formulated by stakeholders, or identified with regard to the existing situation.

The technical boundaries of the lock are dependent on the ships that are present. The decisive design of "beroepsvaart" (professional shipping) vessel dimensions, depend on CEMT-class with Rijkswaterstaat (RWS) annex included. Decisive measures on recreational vessels relate to advisory dimensions set by the European Union Economic Commission by the United Nations (Koedijk, Sluijs, & Steijn, 2017).

Figure 10 Vessel numbers Zandkreeksluis (Provincie Zeeland, 2016)

The height and width of moveable bridges in professional shipping environments are dependent on the CEMT-class, clearance height and waterway profile. When it comes to recreational vessels, it is advised to apply similar clearances in terms of height (with over 15000 yearly vessels), and width (more than 30000 yearly vessels) (Koedijk, Sluijs, & Steijn, 2017).

An indication of Rijkswaterstaat shows the number of vessels a year at the location of the Zandkreeksluis (see figure 8) in 2013. This enforces the design consideration for professional shipping requirements, regardless of the amount of professional shipping vessels (Provincie Zeeland, 2016). The size of the lock itself is also dependent on the vessel intensity per year and the minimal number of mooring facilities (Koedijk, Sluijs, & Steijn, 2017).

Besides the requirements as a result of influencing factors, calculation requirements related to aspects as weight and wind, have to be considered as well. Wind loads are regulated by Eurocode NEN6786 "Voorschriften voor het ontwerpen van beweegbare bruggen (VOBB) (regulations for design movable bridges) (Koedijk, Sluijs, & Steijn, 2017).

When locks and bridges are combined the descend of the bridge must be outside the lock wall-area to prevent collision (Koedijk, Sluijs, & Steijn, 2017). This rule applies to an ideal situation, where there is no lack of space. When there is lack of space, this rule can be slightly altered.

4. Results

4.1. Results of literature research

The literature research shows the existing material acquired through which sub-question 1and (part of) sub-question 2 can be answered.

Regarding sub-question 1, it illustrates the quantitative specifications of the existing situation. The importance of the junction is indicated by the combination of the number bicycles (600/day), cars (18500/day) and AV's (30-45/day). Additionally, its valuable connective property from Zuid Beveland to Noord Beveland, indicated by the Quality Network Agricultural Traffic Zeeland is discussed.
Moreover, it describes the properties of AV's, and the extent of their time delays. It is shown that in 2015, some AV's were destined to wait around 12 minutes, with extremes to 20 minutes, before being cleared to cross. Also, the impact of the total amount of lock cycles and bridge openings is evaluated.
Previously advised safety measures form the last part of the related information regarding sub-question 1. It describes the measures proposed by Goudappel Coffeng, related to traffic mixing, and entering/exiting lanes. Together with the traffic-separation approach of Royal HaskoningDHV, this marks the basis of many variants identified in chapter 5 – Analysis.

Sub-question 2 is only briefly touched by the literature research. This due to unknown information unclear at this stage. The consultations, following this section, hold valuable information in this perspective.
Regardless, the literature research does illustrate the basis of design considerations and requirements relative to the Zandkreeksluis. The number of vessels is displayed, which is important for clearance height and lock width. Additionally, it is made clear that the calculations must consider various influencing factors such as weight and wind.

4.2. *Results of consultations*

The full display of the results of the consultations can be found at appendix 3 – Consultation analysis and evaluation. The information below is an excerpt of that what is discussed in the appendix.

4.2.1. Introduction to experts

The following experts are consulted in order to answer the second sub-question and to formulate the Program of Requirements (later discussed in this report):

Wijnand Blommaert, Provincie Zeeland.

As policy officer for mobility and society, Mr. Blommaert has a good understanding of this problem, and is involved current developments related to the Zandkreeksluis. He is the one who initiated the problem statement for this research.

Adrie Welleman, Provincie Zeeland.

Mr. Welleman is a 'Rayonhoofd', and therefore responsible for the daily maintenance of provincial property of the Province falling under his jurisdiction.

Kees Slabbekoorn, Waterschap Scheldestromen.

Mr. Slabbekoorn is chairman of the monitoring and developing committee of the Quality Network Agricultural Traffic in Zeeland

John Augustein, CUMELA.

Mr. Augustein is a spokesperson and fellow quality network committee member of the Quality Network for CUMELA, a branch organization for agricultural contractors.

Denny de Meulmeester, Provincie Zeeland.

Mr. De Meulmeester is related to the current developments at the Zandkreeksluis, by means of designing the new infrastructure and preparing the construction phase.

Joop Wielart and Hans Wabeke, Rijkswaterstaat.

Mr. Wielart, asset manager, and Mr. Wabeke, nautical advisor, hold valuable insights in the vision of Rijkswaterstaat (RWS).
Later, a second meeting was scheduled with only Mr. Wielart this time, to illustrate the decisive solution direction of this thesis.

Ger Duerink, Rijkswaterstaat.

Mr. Duerink, also an asset manager was able to take show the bridge subject to this thesis by means of a field trip.

Chris Markusse, Markusse en Zn. BV.

As contractor and supplier of application specific vehicles required to work the land, Mr. Markusse has firsthand experience in the problem as identified for this thesis.

Paul Janssen, Riet de Ronde and Stephan Schwencke, Head Operators of Zandkreeksluis, Rijks-waterstaat.

To acquire an image of the operators of the Zandkreeksluis and all that is included with moving the bridges, a visit was scheduled with the Operators of the Zandkreeksluis at the ir. J.W. Topshuis. Mr. Janssen, Mrs. De Ronde and Mr. Schwencke accommodated a valuable addition to the complete vision (literally) on the Zandkreeksluis situation.

4.2.2. Results of the consultations

The conclusion drawn at the result of the consultations, is that a clear image is formulated through which the Program of Requirements can be formulated.

As Rijkswaterstaat indicates, no alterations can be made to the lock chamber. Special attention has to be considered in relation to the moving mechanisms of the lock doors and bridges. The bridges have their own limitations and opportunities.
As Rijkswaterstaat is, in this case, mostly concerned with the vessels that use this lock, close attention must be pain to any secondary consequences certain modifications might have. For example, with implementing a new element outside either side of the lock, the approach route for vessels must be translated accordingly.
Lastly, the operators of the lock indicated that the situation is confusing for road users unfamiliar with this junction, which results in a reduced traffic safety situation.

The main remark of the agricultural sector is the importance of the problem in this situation. Additionally, there seems to be no communication between lock operators and farmers. The road section is part of the Quality Network Agricultural Traffic in Zeeland. It is therefore an important location, at which traffic (especially AV's) should be able to cross without much resistance.
A solution approach is to create more space for AV's, which results in a safer situation.
Overall, the Zandkreeksluis is a high demanded junction, for both vessels and road traffic. This make the situation delicate.

This is also mentioned by the Province of Zeeland. The confusing layout, lack of space and visibility, result in unsafe situations, especially for cyclists.
The overall situation for road traffic has been improved since the implementation of the bypass bridge. This does, however, not count for AV traffic.
Since the implementation of the bypass, no special requirements are active with regard to busses and emergency vehicles.

The province is currently working on quick-win improvements for AV's. This include a new road section that goes behind the houses situated north of the lock. This benefits the tractors, but is likely to disadvantage cyclists, especially considering safety.

5. Analysis

The analysis chapter, which concerns the variant analysis, is fully displayed in appendix 5 – Variant analysis and evaluation. An excerpt of what is covered in the appendix, is displayed here, as following.

5.1. Variants towards a solution

5.1.1. Non-technical variants

1) Re-routing of agricultural traffic.
   Meaning, the providence of an alternative route for agricultural traffic at which they no longer use the Zandkreeksluis crossing.
2) Using other means of transport, while still crossing the Zandkreeksluis.
   Meaning, other means of transport for certain types of transport goals. This applies to those transports that include a tractor carrying bulk load such as weeds, potatoes, sugar beets, fertilizers and seeds.
3) Using other means of transport, while avoiding crossing the Zandkreeksluis.
   Meaning, while the previous variant describes the use of road trucks, this variant suggests transportation of goods by ship.
4) Applying schemes like those on the Zeelandbrug.
   Meaning, schemes and schedules can be drawn to provides time frames at which agricultural traffic can cross the Zandkreeksluis without interference of both normal traffic using the bypass and vessels.
5) Conducting parcel trade between farmers.
   Meaning, reduce the number of parcel a certain farmer as on the opposing side of the lock to where his farm and storage facilities are based.

5.1.2. Technical variants

6) Enlargement/widening of the Hongersdijckbrug (bypass bridge).
   This variant includes providing more space for a (shared) bicycle and AV traffic, similar to that of the parallel structure extending north and south of the Zandkreeksluis.
7) Enlargement/widening of the Zandkreekbrug (main bridge).
   This variant also includes providing more space for a shared bicycle and AV traffic (similar to the parallel lane layout), but here on the main bridge; Zandkreekbrug.
8) Additional bridge to the east of the Hongersdijckbrug
   Constructing an additional bridge to the east of the Hongersdijckbrug would create more space on the existing bypass bridge. This by implementing an additional element that support 1 or 2 traffic lanes for main traffic.
9) Additional bridge to the west of the Hongersdijckbrug
   Constructing an additional bridge, similar to the variant above, only now on the west side of the existing element.

10) Additional bridge to the east of the Zandkreekbrug
    This variant is similar to that of the Hongersdijckbrug, best compared to with the additional bridge on the west side.
11) Additional bridge to the west of the Zandkreekbrug
    This variant includes an additional bridge that is most likely to serve as AV's crossing.
12) Tunnel underneath the Zandkreeksluis.
    A tunnel underneath the complete structure would remove any difficulties of 'crossing' the lock.
13) High bridge over the Zandkreeksluis.
    By implementing a high bridge that goes over the Zandkreeksluis, the amount of bridge opening is reduced.

5.2. Current developments in solving the problem

In order to provide short term improvements on this situation, quick-win solutions are (to be) implemented in the existing infrastructure. These improvements mainly include redirecting the AV's behind the houses on the north side of the Zandkreeksluis. In the current situation AV's have to wait in front of the houses, which is the cause for irritation from the homeowners. By redirecting the waiting line, this problem is solved.
And additional proposal is to allow all agricultural traffic to go over the cycling path of the by-pass bridge. This provides a crossing opportunity whenever the bypass is used by main traffic. However, this harms the traffic safety of cyclists, as they have to be careful about more AV's on this section.

The quick-win considerations and variants have been selected and evaluated on the existing infrastructure, in relation to its short-term budget. The mid-long-term variants are independently evaluated, also in relation to its budget (however not specified in a concrete limit). Although it would be beneficiary to the project as a whole when both short-term and mid-long-term are in line with each other, one should consider the most optimal variant to spend its budget on when it comes to a technical design including a new civil element.

5.3. *Evaluation criteria*

The evaluation criteria of the proposed variants are identified are based on the Program of Requirements. An excerpt is displayed below to illustrate the decision criteria towards a decisive variant. The criteria are as following:

1) Solution potential in relation to the thesis objective
    a. Decreasing the delays for AV's
    b. Improvement of the traffic safety in relation to sharing road space between multiple types of traffic
2) Traffic flow of main traffic (considering function N256)
3) Traffic flow of bicycle traffic (considering cycling network)
4) Structural requirements Rijkswaterstaat
    a. The Zandkreekbrug may not be further loaded in the existing situation and cannot be strengthened with the existing deck.
    b. The lock chamber may not be reduced in length and width
    c. The approach route towards and from the lock must be considered
5) Traffic requirements
    a. Spacious berm on the dam itself must be maintained
    b. The horizontal alignment must be logical and easy to understand for road users.
6) Flood defense aspects
    a. The primary water retaining function of the dam must be maintained
7) Implementation/feasibility
    a. The decisive variant must be feasible in related to a budget/investment for mid-long-term
8) Situation residence
    a. The situation of the house owners north of the lock must be considered

5.4. Analysis of variants based on evaluation criteria

As a result from the literature research and the interviews, the variants are analyzed and evaluated as following.

1) Re-routing of agricultural traffic.

   Providing another route to the existing one proves very unfeasible. The closest route around the Zandkreeksluis is the Veerse Gatdam. This adds more time to the travel compared to the Zandkreeksluis, waiting time included. Therefore, considering both time and money aspects, dissatisfies this non-technical variant.

2) Using other means of transport, while still crossing the Zandkreeksluis.

   This variant has good potential to decrease overall delay times at the Zandkreeksluis. However, it is an unattractive option for farmers, agricultural contractors and those who use AV's. The applicability of today's tractors is far greater than that of road trucks. Again, the money aspect makes it unattractive. The additional activities of loading (from tractors from the crop lands to the truck) and unloading (after transportation) is ineffective measuring both time and money aspects.

3) Using other means of transport, while avoiding crossing the Zandkreeksluis.

   The same reasons given for the unsatisfying aspects of variant 2, apply to this variant.

4) Applying schemes like those on the Zeelandbrug.

   As this option functions well at the Zeelandbrug, it is not possible in this case. The Zandkreeksluis is the second busiest lock in Zeeland, facilitating more than 25 thousand ships east or westbound. In combination with the intensity, and unpredictability of AV's at this location, concludes to a measure which is unfeasible.

5) Conducting parcel trade between farmers.

   As farming companies are getting bigger in size, parcel trade would probably have only a limited effect on the reduced number of crossings. Additionally, agricultural contractors, who do not have parcels, do not benefit from this variant, as their costumers might still be on the opposite side.

In general, the non-technical variants have good potential of decreasing the total amount of waiting time for farmers or contract worker who own several AV's that make use of the Zandkreeksluis crossing. However, for an individual tractor, the waiting time is not affected by these measure, and additional costs (being measured in time or otherwise) are a consequence. Therefore, these non-technical variants are not decisive in the selection procedure.

6) Enlargement/widening of the Hongersdijckbrug (by-pass bridge)

Generally, this option has good solution potential, as it creates more space for AV's. However, translating the Hameistijlen might be very difficult and come with major secondary consequences. Budgetary wise, this variant faces less consequences with regard to other variants. However, execution wise, and the feasibility is quite low, for the reasons just displayed.

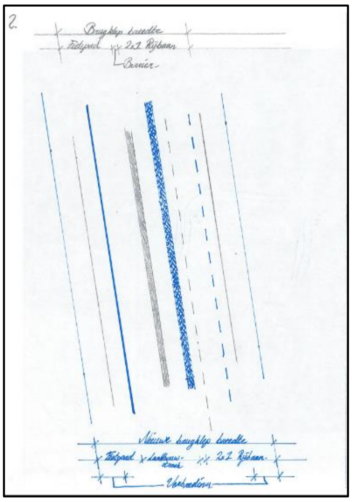


Figure 11 Sketch Hongersdijck-brug widening

7) Enlargement/widening of the Zandkreekbrug (main bridge)

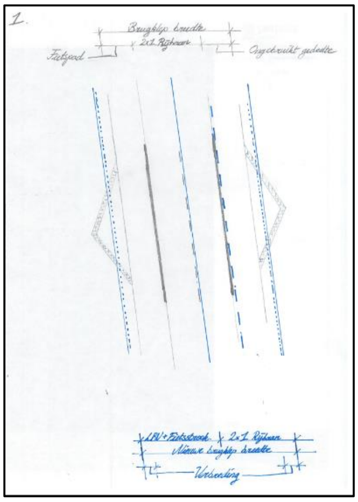


Figure 12 Sketch Zandkreek-brug widening

This variant is similar to the enlargement of the Hongersdijck-brug. However, it faces different challenges.
First of all, the enlargement itself faces less consequences, since this is a bascule bridge. No bridge towers have to moved outwards, and no new foundations have to be implemented. However, this bridge has its own limitations. For example, with enlargement comes redesign of the bridge layout. Secondly, the structural basis of the bridge is currently not able to support another traffic lane of heavy vehicles.
On the other hand, Rijkswaterstaat is currently looking into major maintenance work at the bridge. This enhances the potential costs of the project. Because the bridge is owned and maintained by RWS, it pays for the maintenance activities. If, with a redesign of the bridge deck, an enlargement of x amount of meters is required, a deal could be negotiated that the Provincie only pays for those additional meters.

8) Additional bridge to the east of the Hongersdijckbrug

This option would be very unlikely in terms of feasibility and construction. As mentioned in variant 5), building east of the bypass bridge will most likely interfere with the moving mechanism of the lock doors. Additionally, a requirement with regard to the lock chamber includes no shortage on the length of the lock. With an additional bridge to the east, this requirement is likely to be violated.

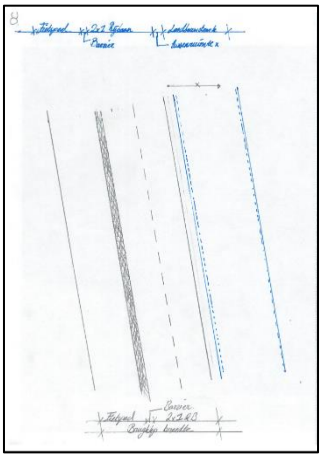


Figure 13 Sketch additional bridge east

9) Additional bridge to the west of the Hongersdijckbrug
The function of this additional bridge would be to support bicycle traffic (or, however unlikely, AV traffic). This favors this variant over the previous one, since the bridge requires less space, strength and therefore less money.
However, as mentioned in variant 5), building to the west of the by-pass bridge results in major secondary consequences.
This variant would, however, align with the current developments that will be implemented as quick-wins to this problem.

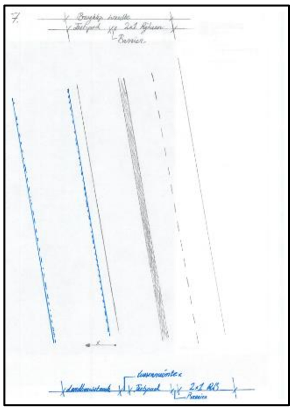


Figure 14 Sketch additional bridge west

10) Additional bridge to the east of the Zandkreekbrug
This variant is much like variant 7), in terms of function (being, supporting main traffic), and variant 8) in secondary consequences. One could look into combining this variant with variant 6), but than it would be logic to abandon this variant, and solely focus on the redesign with enhancing all traffic on the main bridge.
11) Additional bridge to the west of the Zandkreekbrug
This variant is similar to variant 7).
12) Tunnel underneath the Zandkreeksluis
This variant has the best solution potential, as main traffic and AV/bicycle traffic are completely separated at this location. However, budgetary and implementation wise, this option is highly unfeasible.
13) Tall bridge over Zandkreeksluis
This variant is similar to the previous one, considering investments in terms of money and time. The implementation is unlikely, due to its vast secondary consequences.

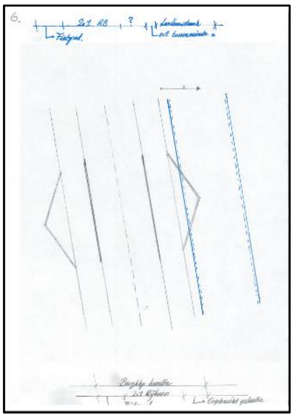


Figure 15 Sketch additional bridge east

Figure 16 Sketch additional bridge west

In general, all technical variants have a good solution potential with regard to the non-technical variants. However, the proposed solutions (with an exception of the tunnel) would only partially ‘solve’ the problem, since it only relates to 1 of 2 bridges. In an ideal situation, two technical variants related to both bridges would be combined, with thereby completely erasing the delays for AV’s. But this proves to be unfeasible as too much of a budget would be required.
On the other hand, the variants as proposed to enhance the thesis objective, as they are likely to drastically decrease the waiting time of AV’s. Therefore, these variants are individually relevant. In the next section a decisive selection will be made of the proposed variants, and a technical design approach will be determined.

5.5. Selection of decisive variant

Variant 6) Enlargement/widening of the Zandkreekbrug (main bridge) is determined to be the decisive variant toward the solution of the thesis objectives.
As displayed above, this variant has good solution potential in relation to the thesis objective. It decreases time delays for AV's, and with enough space, improves traffic safety for the shared AV-bicycle surface, while completely separated from the main road traffic.
It therefore maintains the flow of the main road traffic and enhances good traffic flow of bicycle traffic (albeit shared).
The variant complies with the requirements of Rijkswaterstaat, related to no reduction of lock chamber. However, it does not align with the requirement of no additional loading. But, as previously mentioned, to enhance a new layout (and thus create more space) a complete redesign of the bridge deck is required either way. If new structural elements, and up-to-date calculations are properly performed, a new bridge deck should be able to support the additional AV loads.
The edge of the dam is almost not affected and the primary water retaining function is maintained as well.
The situation of the house owners north of the lock is the only aspect on which other variables score better. This is due to the current developments that moved the AV's away from waiting in front of the houses north of the lock. By realizing this variant, AV's are brought back to this side of the houses. However, no AV's have to wait any more in front of the houses. As they can cross the main bridge, they would only drive by, without stopping.

This variant mainly outclasses the others on its feasibility and budget specifications. As Rijkswaterstaat inevitably plans major maintenance work on replacing the bridge deck within 7-8 years, this solution can be presented to improve the existing situation that goes beyond simply replacing the bridge deck with its current function. This also incorporates a cost effectiveness, that is not reached by any other variant. By collaborating with Rijkswaterstaat, a shared payment can be negotiated.

6. Design

6.1. Results of the calculations

The calculations performed to enhance the design of the new bridge are fully discussed in Appendix 6 – Calculation Report. The conclusion of which is discussed in this part of the design chapter.

6.1.1. Material properties

The material properties applied for the design of the bridge is construction steel S355. This means that the stresses occurring can (either individually or in combination with each other) not be exceed the yielding limit of 355 N/mm^2. The calculations, therefore, are assessed by applying these limits with respect to the related profiles to which the load acts.

6.1.2. Loads

The loads active at the bridge are separated into 2 categories, being permanent and variable. The permanent loads include the self-weight of the elements, and the resting load of the wearing layer.
The variable loads include traffic loads (respectively active on theoretical lanes 1 through 4) and wind loads. Other variable loads, that are not decisive in this situation are resultants of breaking/accelerating and snow loads.
A separate load case is formulated to account for the effects of fatigue. This is categorized under extraordinary loads and includes its own influences, separate from the properties of the loads indicated above.

6.1.3. Loading situations

Due to differences in bridge layout and situation, certain loading situations are identified. The first situation describes the case where the bridge is horizontal and open for road traffic. Here the bridge is required to bear the variable loads of traffic, while supported on two supports.
The second situation is the case which describes the bridge just opening. The deck will be considered as 1° opened, which means that it cannot rely on both supports. This means that the bridge is in an overhang situation, solely supported by the main turning point (hinge).
The third situation is where the bridge is fully opened (being 78°). Here the variable load of wind has a large influence. Also here, the bridge deck functions as an overhang to the main turning point.
Situation 4 describes the loads included in the assessment of fatigue. This includes the bridge being vertical again and open for road users.

6.1.4. Load combinations

Because loads never act individually, the loading combinations relative to the situations (described above) must be identified. Here certain load factors are incorporated, which account for the simultaneously of acting loads.

These factors rely on the assessment applicable. Meaning, either in an Ultimate Limit State ((ULS) where deflection is allowed), and a Serviceability Limit State (SLS). The latter being applied to assess the occurring deflection.

The following loading factors (ψ-factors) are applicable to the situation in consequence class 3 (CC3):

Load case	ULS	SLS
	STR/GEO	Frequent
	[6.10a/b]	[6.15b]
Permanent loads		
Unfavourable	1,40 / 1,25	1,00
Favourable	0,90	1,00
Traffic loads		
Dominant	1,50	1,00 * ψ_1
Simultaneously occurring	1,50 * ψ_0	1,00 * ψ_2
Variable loads		
Dominant	1,65	1,00 * ψ_1
Simultaneously occurring	1,65 * ψ_0	1,00 * ψ_2

After multiplication with specific factors for combinations on bridges, the ψ-factors are as following, categorized in the applicable combinations:

Dominant loading	$\gamma_{G,j,sup}$	Traffic (vertical)		Wind		Name of combination
		General	Local	With traffic (F^*_w)	Without traffic (F_{wk})	
Permanent	1.4	1.2	0	1.65	-	ULS1
Traffic general	1.25	1.5	0	1.65	-	ULS2
Traffic local	1.25	0	1.5	0	-	ULS3
Wind with traffic	1.25	1.2	0	0	-	ULS4
Wind without traffic	1.25	0	0	-	0.5	ULS5

Dominant loading	$\gamma_{G,j,sup}$	Traffoc (vertical)		Wind		Name of combination
		General	Local	With traffic (F^*_w)	Without traffic (F_{wk})	
Permanent	1.0	0.4	0	1	-	SLS1
Traffic general	1.0	0.8	0	1	-	SLS2
Traffic local	1.0	0	0.8	0	-	SLS3
Wind with traffic	1.0	0.4	0	0	-	SLS4
Wind without traffic	1.0	0.4	0	-	0.6	SLS5

6.1.5. Technosoft input

The calculations are mostly performed by Technosoft Liggers V6. The input in the program is based on the load identification described above, in related to the load combinations. This is positioned on the previously determined profiles.

For the deck assessment of situation one, the following loads and their combination factors are applied:

Table 3 Loads and combination factors deck general deck assessment

	Load		ULS1		ULS2		ULS3		SLS1		SLS2	
	kN/m^2	kN	$\gamma_{G,j}$	$\gamma_{Q,I}$	$\gamma_{G,j}$	$\gamma_{Q,I}$	$\gamma_{G,j}$	$\gamma_{Q,I}$	$\gamma_{G,j}$	$\gamma_{Q,I}$	$\gamma_{G,j}$	$\gamma_{Q,I}$
Self-weight	1.04		1.4		1.25		1.25		1.0		1.0	
Resting load	0.14		1.4		1.25		1.25		1.0		1.0	
BM1-UDL	9			1.2		1.5		1.2		0.4		0.8
BM1-TS		150		1.2		1.5		1.2		0.4		0.8
Wind	0.12			1.65		1.65		1.0		1.0		1.0

Belastinggevallen | Combinaties | Fundamenteel | Karakteristiek | Frequent | Quasi-blijvend | Blijvend | Brand

	Belastinggeval	F.C.1	F.C.2	F.C.3	F.C.4
1	Selfweight	1.40	1.25	1.25	
2	Permanent weight	1.40	1.25	1.25	
3	Veranderlijk - traf.	1.20	1.50	1.20	
4	Veranderlijk - wind -	1.65	1.65	1.00	

Figure 17 Load combinations ULS - fundamental combination

Belastinggevallen | Combinaties | Fundamenteel | Karakteristiek | Frequent | Quasi-blijvend | Bl

	Belastinggeval	Freq.1	Freq.2	Freq.3
1	Selfweight	1.00	1.00	
2	Permanent weight	1.00	1.00	
3	Veranderlijk - traf.	0.40	0.80	
4	Veranderlijk - wind -	1.00	1.00	

Figure 18 Load combinations SLS - frequent combination

The rib profile selected is based on the properties referred to in the Bridge Engineering Hand-book, chapter 16 (Alfred Mangus, 2014). The element looks as following:

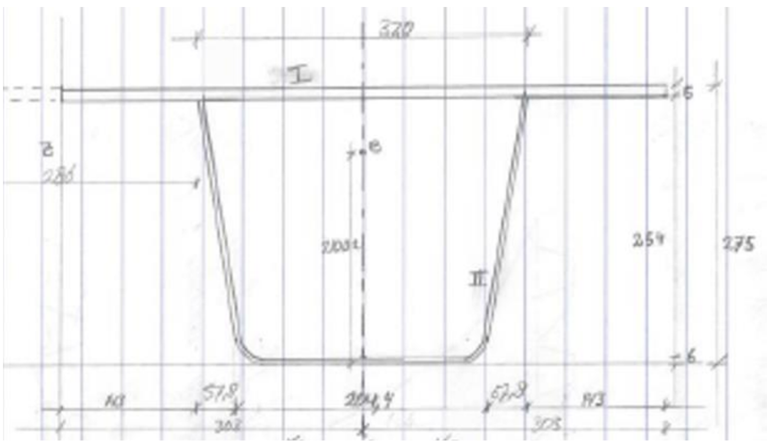


Figure 19 Deck rib 22

Because this element cannot be incorporated in the technosoft model, a profile is selected that share similar moments of inertia (I_y). For the rib element this is a HEM200 profile.
The profiles for the floor beam and main girder can be selected in technosoft. These profiles and their properties can be found in the appendix (6 – Calculation report).

To validate the reliability of the technosoft model, a hand calculation of the floorbeam is performed.
The bending and shear lines, as produced by the model look as following:

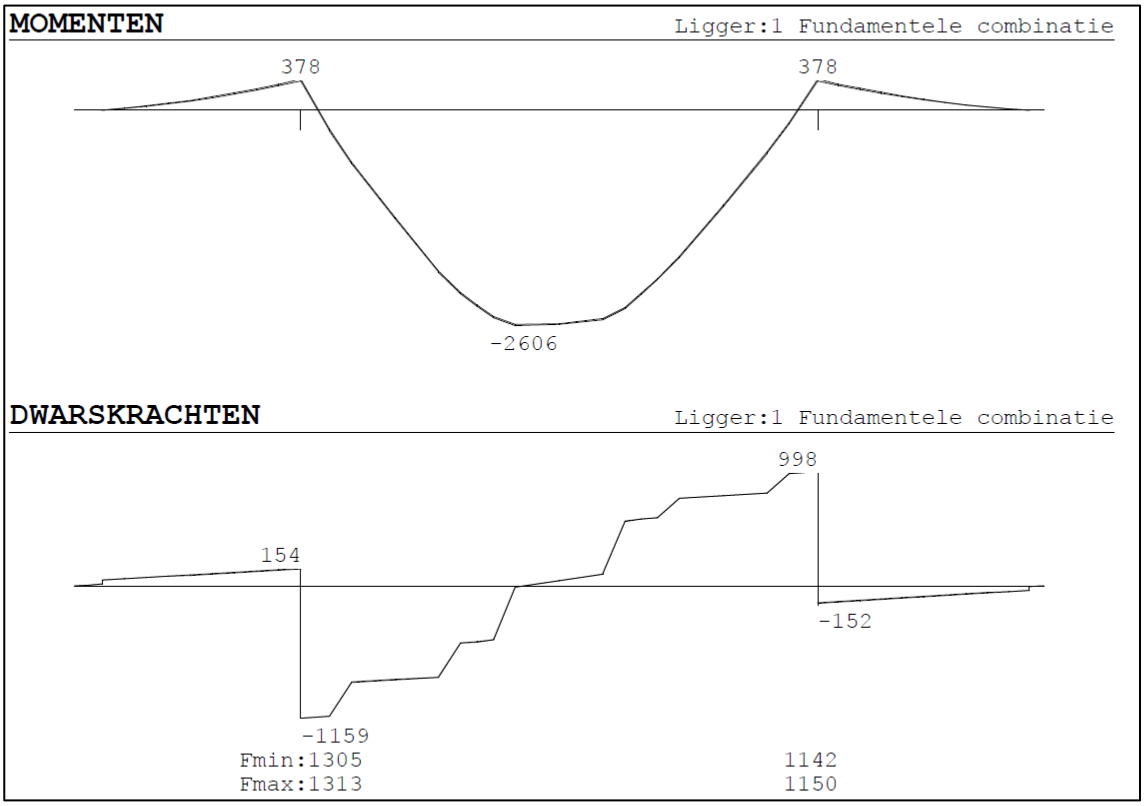


Figure 20 Technosoft outcome floor beam situation 1

These outcomes correspond with the decisive ULS load combination.
The hand calculations are performed by applying similar loads and loading combinations. The following bending and shear lines correspond with the hand calculation:

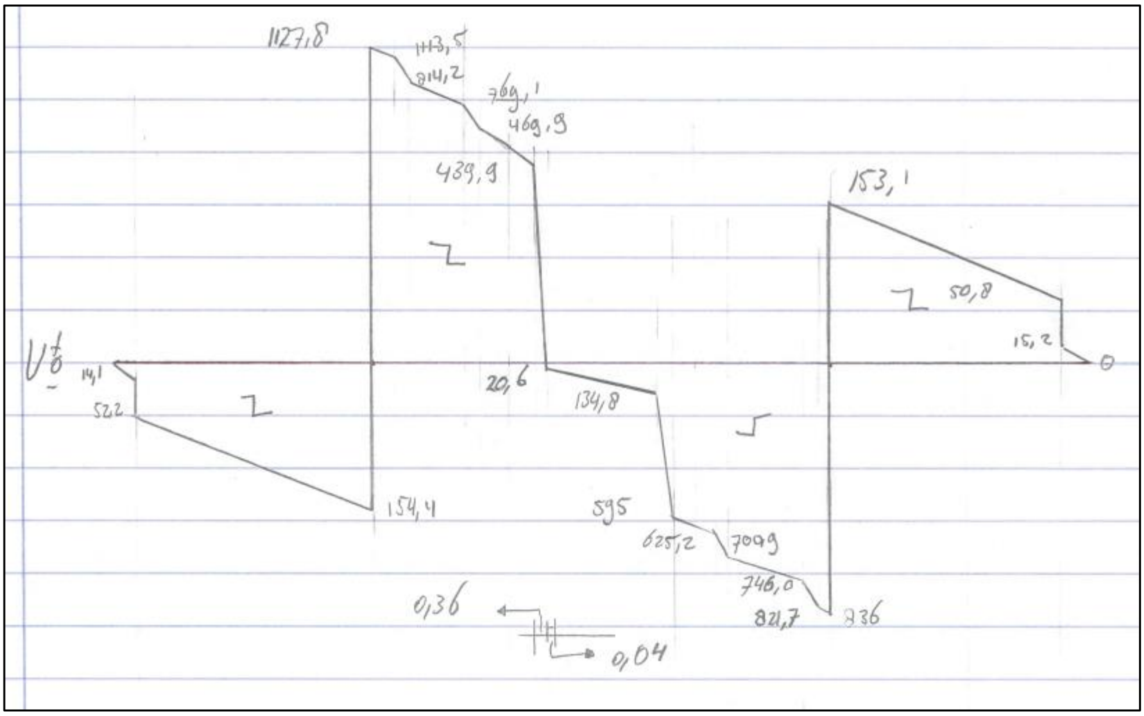


Figure 21 Shear line hand calculation floor beam

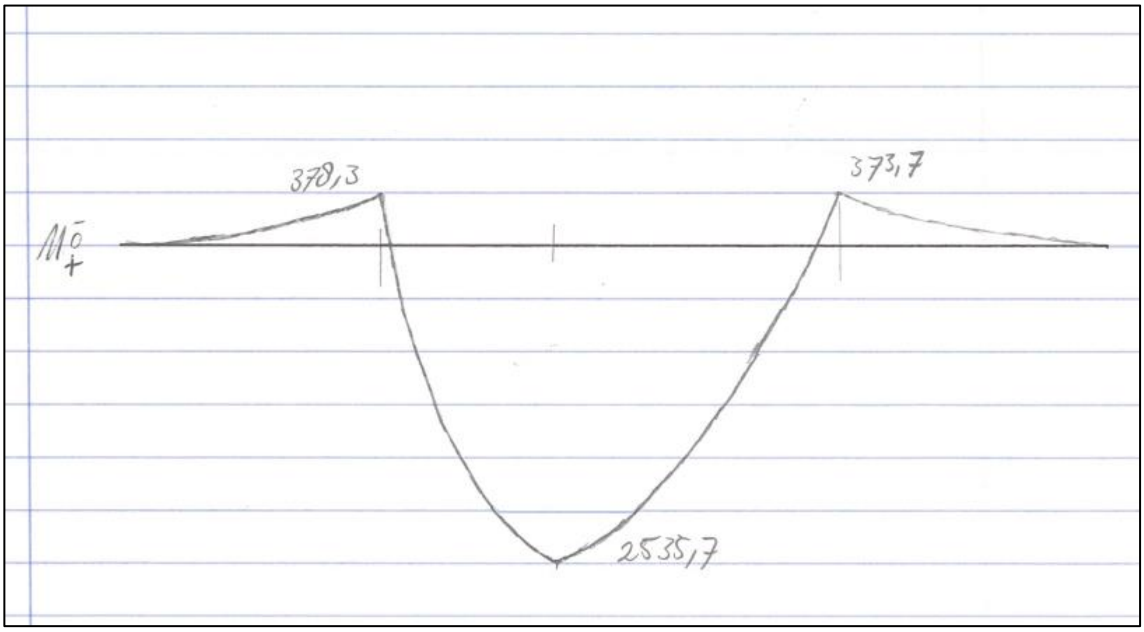


Figure 22 Moment line hand calculation floor beam

As can be seen, the differences between the two calculations are relatively small. The differences that do occur are due to loss of detail in rounding numbers in the hand calculation. Nevertheless, this verification shows that the technosoft model functions reliably. The remaing of the calculations can be found in appendix 6 – Calculation Report.

6.2. Calculations of aspects in technical design

This chapter describes the calculation made in favor of the technical design. It covers the overview of the full calculation. For the full calculation report, please find appendix 6 Calculation report

6.2.1. New road layout

Based on the results in previous chapters, the solution is proposed to be found in the main bridge of the Zandkreeksluis. This bridge has a current layout which provides room for main traffic, bicycles and pedestrians. Nevertheless, all these crossing functions have features which make them outdated and subject to renewal. The main traffic part is too tight regarding current standards, on the borders of the cycling lane are dangerous edges, and the pedestrian path (initially designed) is inaccessible for any pedestrian and therefore unused.

Apart from updating and reevaluating these functions, the new bridge layout must provide enough space for AV's to be able to cross as well. It was chosen to combine cyclists and agricultural traffic in the same manner as applied to the parallel lanes extending north and south from the Zandkreeksluis.

Due to the unreachability of the pedestrian strip, it was chosen to remove this separate path. This creates more space on the existing bridge and provides the following possible layout:

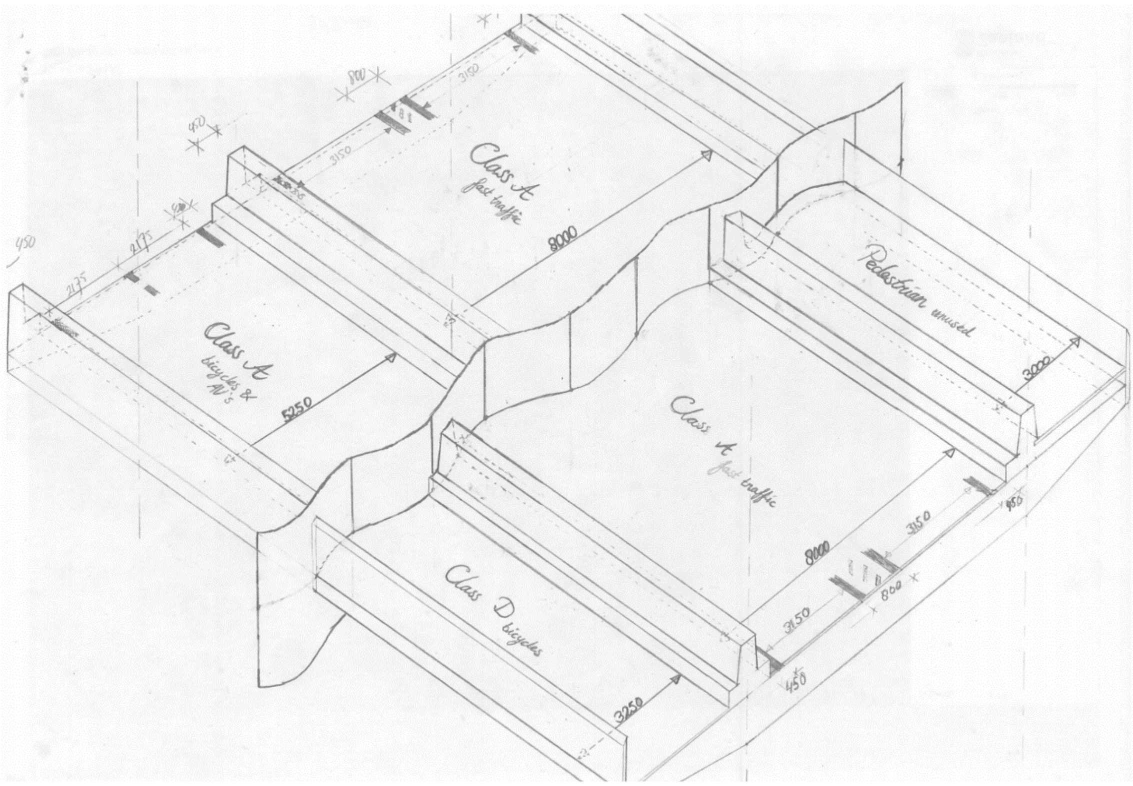


Figure 23 Sketch possible new layout

However, even with this layout the current standards regarding the main road, and preferable width of the 'parallel lane' are not enough, resulting in an inevitable extension of the bridge deck in cross sectional direction.
A layout with all lanes spaced out as optimal as possible is shown in the following sketch:

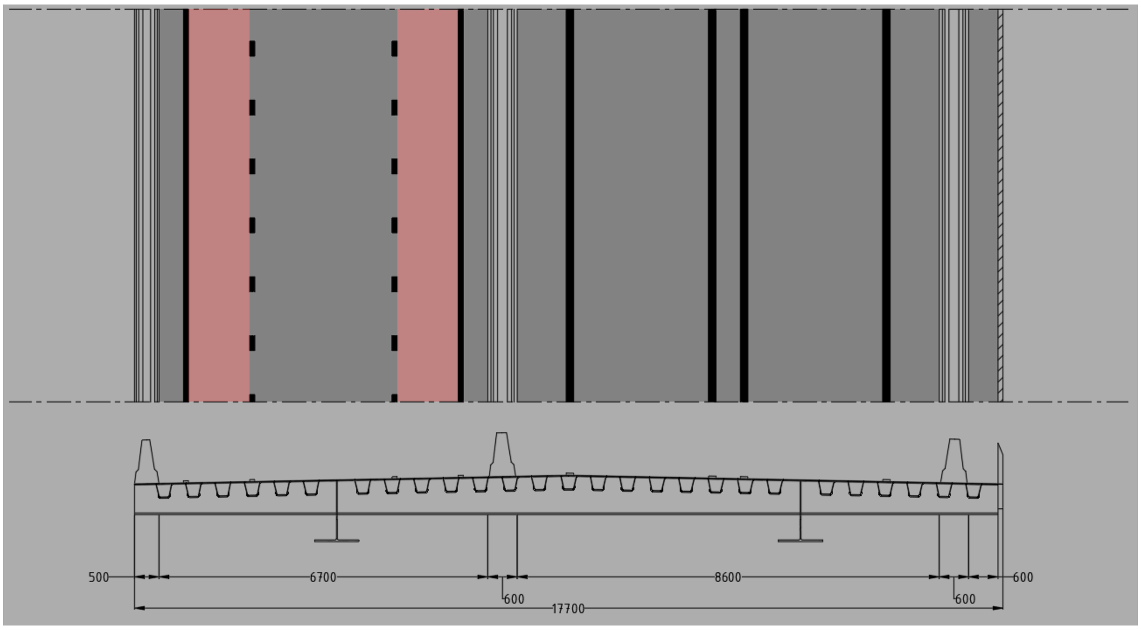


Figure 24 Sketch proposed new layout

From left to right, the bridge features the following:
On the far left is a structural border, which function is to retain any hitting objects. No inspection path is implanted here, because inspections can be done from the 'parallel lane' adjacent to the left border. The parallel lane consists of 5,5 meter wide lane at which different asphalt colors are applied. This serves a suggestive function as it makes cyclists stick to their 'lane', while AV's tend to stay clear of the orange parts. This increases the traffic safety in the sharing function of this section of the bridge. Next to the parallel lane a second border/guiding rail is implemented. This guiding rail separates cycling/AV traffic and the main traffic on the section right of the border.

6.2.2. New bridge structure

The proposed structure is based on the calculations performed in favor of the solution. The full calculation can be found at appendix 6 – calculation report. The following displays the outcome of the calculations, and its consequences for the proposed layout.

As mentioned before, in chapter 6.2, the bridge's situations have been divided into 4 categories. The first situation describes the bridge open for road traffic. By testing the bridge generally (in an overall approach), and locally (detailed approach on deck), the following is true.

The stresses in the deck (rib and plate) are sufficiently low to support the traffic designed. This counts for both the general and local assessment. The deck translates its loads to the floor beams. In the general assessment of the floor beams, the result is satisfactory.

When testing the main girders (which carry the load from the floor beams), the beam is unsatisfactory. This counts for 1 of 3 profiles considered. The profile which shows stresses higher that the yield force of the selected steel (S355) is profile 1. This profile is situated underneath the 'deck part' of the bridge (meaning, between the main turning point and the opposite land abutment). The stresses that occur here are max 202% of the yield strength. This exceedance results in unlikeliness of improving the situation within a similar design. It is expected that optimization can be found in the distribution of the loads, and profile properties. However, in this case, close attention must be addressed to the design of this profile, in relation to its position in the full bridge design.

Situation 2 describes a similar location, being positioned horizontally. However, opposed to situation 1, the bridge is now closed for road traffic and is considered being in its 'moving cycle', at 1% opening. This means that the land support is eliminated. The main beams are therefore in a major overhang, spanning from turning point to end of bridge.
The deck and floor beam assessment in this situation are not decisive, due to the absence of road traffic.
In the calculations it is found that the bending stresses are exceeding the yield strength limit of the steel profile. Again, profile 1 suffers from large stresses. And exceedance of 183% is determined, which makes optimization within the design unlikely. The recommendation chapter discusses the possible solutions to these problems.
Additionally, the deflection of the main girder is too big for its allowances. With 242% it bends a mere 540 mm. Apart from the strength determination, this deflection also means that the main girder is not stiff enough. However, the deflection calculated here is a theoretical deflection. In reality, the beam must be constructed with a 'sag'. This means that the girder will be welded and constructed with a 'negative deflection' in its profile. The feasibility of creating a sag of 540mm is displayed in the discussion chapter.

Situation 3 describes the bridge as fully opened (78°). Again, the deck and floor beam-load are not decisive for the design. The most influencing factor here is the self-weight of the profiles, the moment this creates towards the main turning point, and the wind load. The situation is assessed by calculating the total moment created on the main turning point, tested against the bearing capacity of the main girder. Profile 2 (situated around the turning point) proves to be strong enough to withstand the bending and shear forces. No deflection is present at this section. (Additionally, the bending created in situation 2 is decisive for the design)
The last and fourth calculation situation considered is considering the fatigue influences on the bridge deck. This assessment is similar to the local assessment of situation 1. However, detailed sections were tested against a modified fatigue load. The calculations show that the deck profile (ribs in longitudinal direction) are insufficiently strong to withstand fatigue influences over a 100-year period. The exceedance being 307% at mid span and 236% at the support (connection with floor beam). This percentage is too excessive to suspect an optimization within the proposed design.
Considering the deck plate itself, calculation show that an exceedance of 142% is present on the plate at the connection with the rib.

The last assessment performed is that of the total weight of the bridge, in relation to the originally designed weight. The 1957/1958 design calculations have been used as reference.
An inventory of the proposed bridge elements shows a weight that is 108% of the existing weight of the designed properties. It is also 99% of the counter weight, present at the ballast chamber. Due to the small exceedance, it is expected that the weight of the bridge can be optimized to reduce the 108% weight.

6.3. Technical drawings of design

Based on the calculations as discussed before, a technical design is made. This design incorporates the proposed elements and profiles accounted for in the calculations. The complete drawings can be seen at appendix 7 – technical drawings
A selection of screenshots is displayed in this chapter to indicate the design.

First of all the bridge is logically divided into a grid pattern. This makes is easier to understand where certain elements are located, considering cross sections, longitudinal views and details for example.

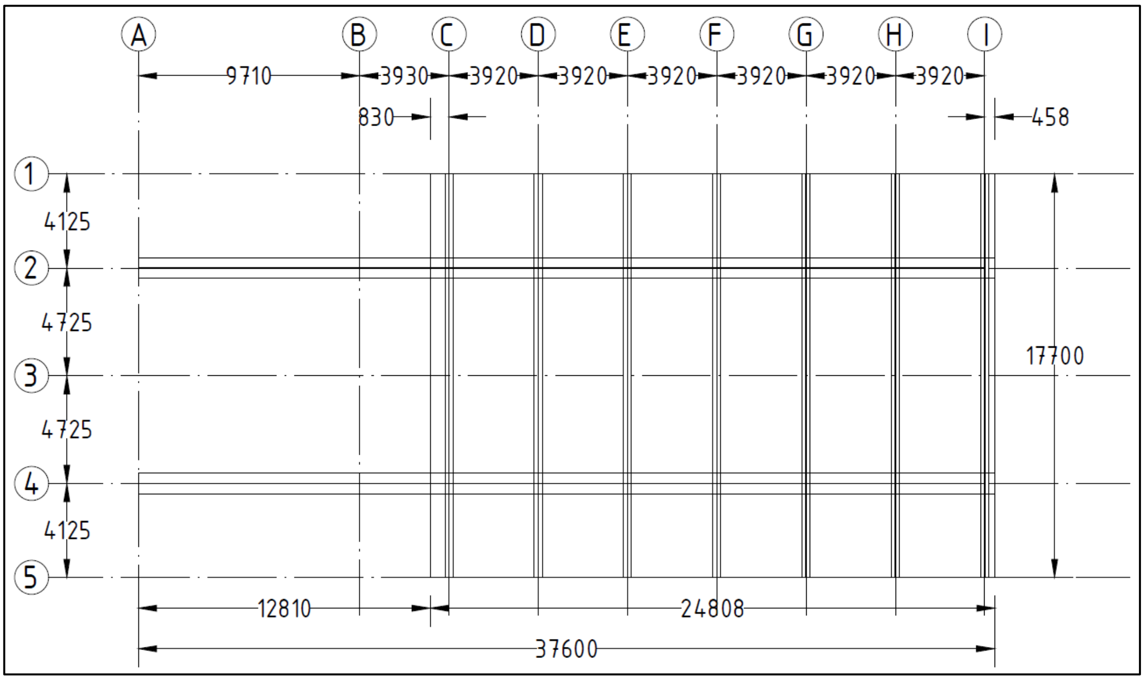
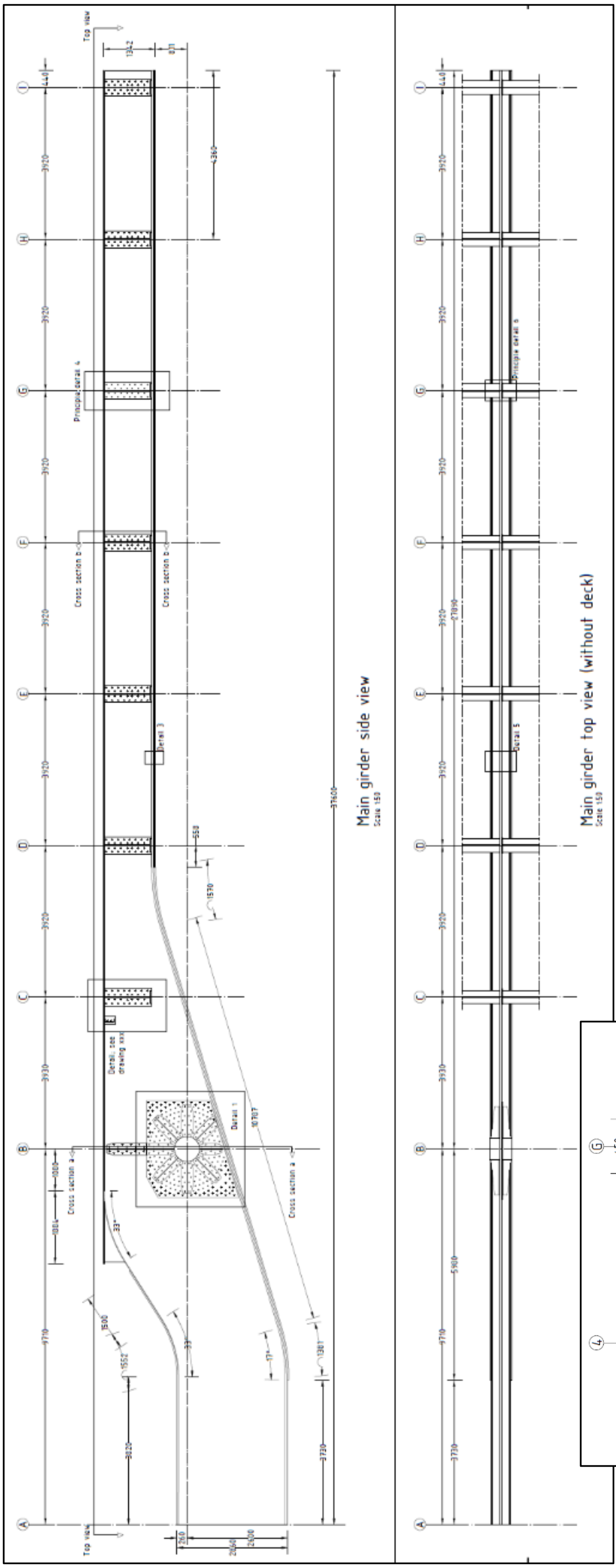


Figure 25 Snapshot AutoCAD drawing overview

The main girder is displayed as following. Some elements are based on the initial design. This includes the connection of the main turning point, and the girder profile which is located in grid A, where the ballast is connected.



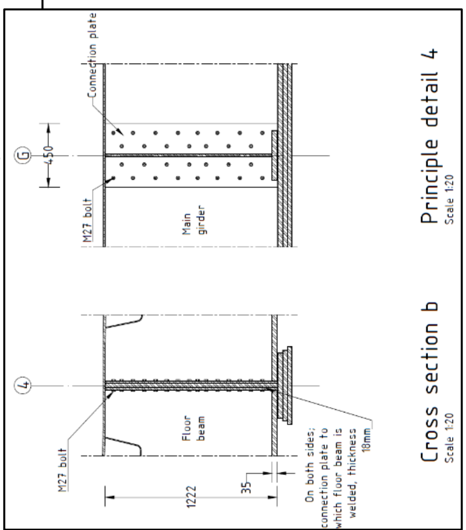


Figure 26 Main girder with detail

The third element drawn is that of the floor beam:

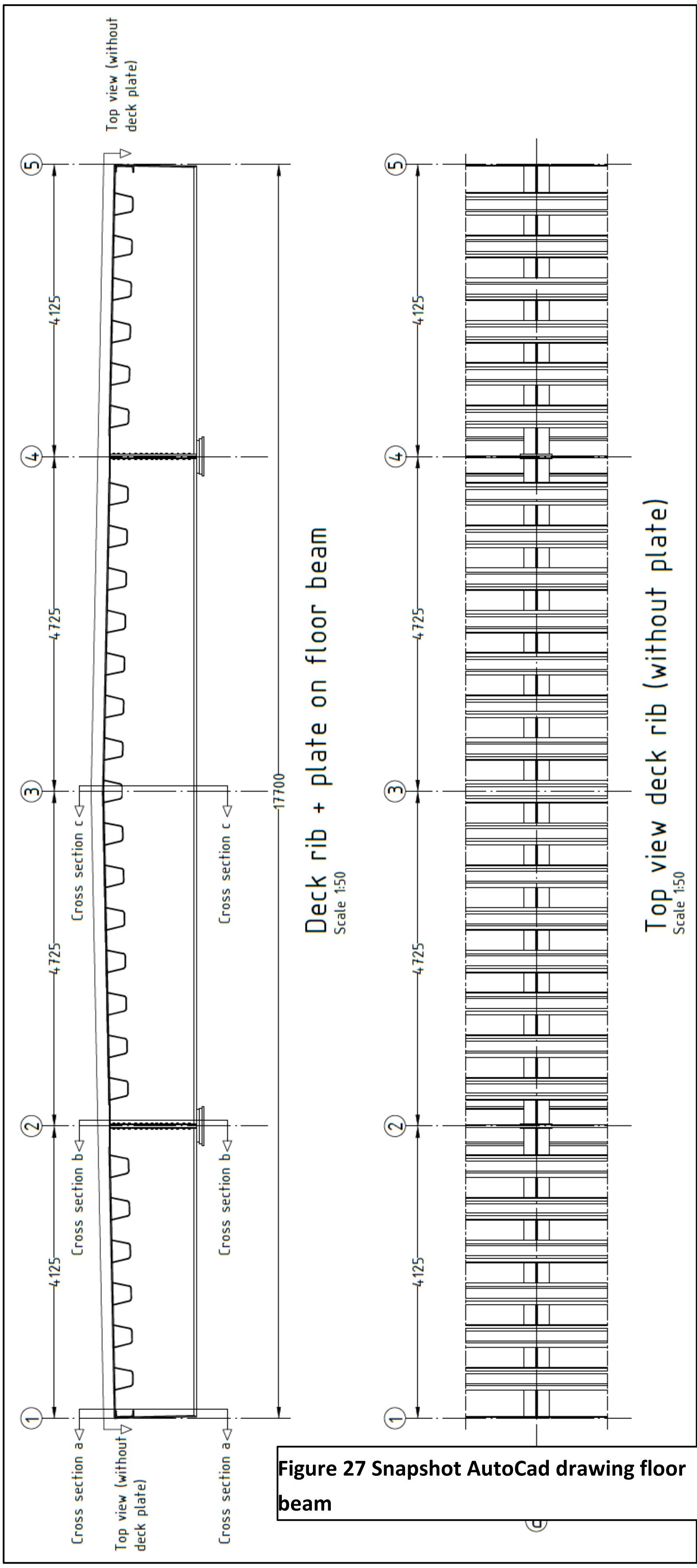
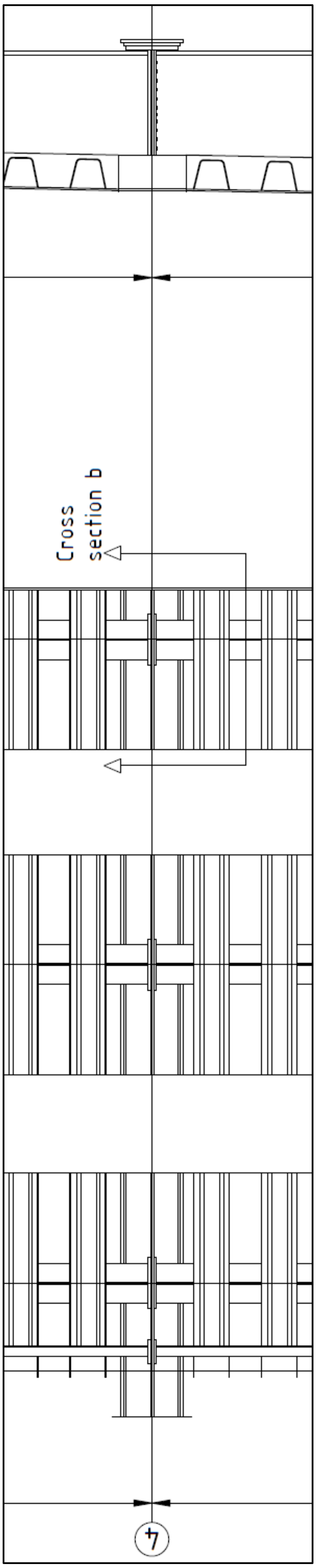
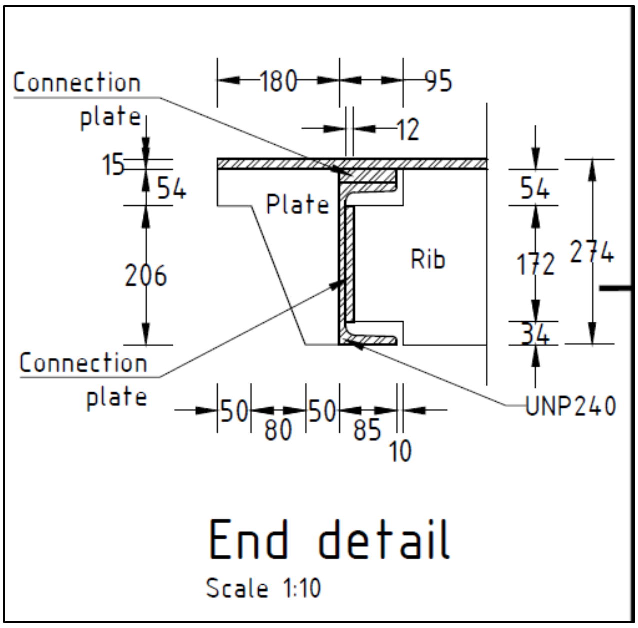


Figure 27 Snapshot AutoCad drawing floor beam

Lastly, the deck is worked out, as following:





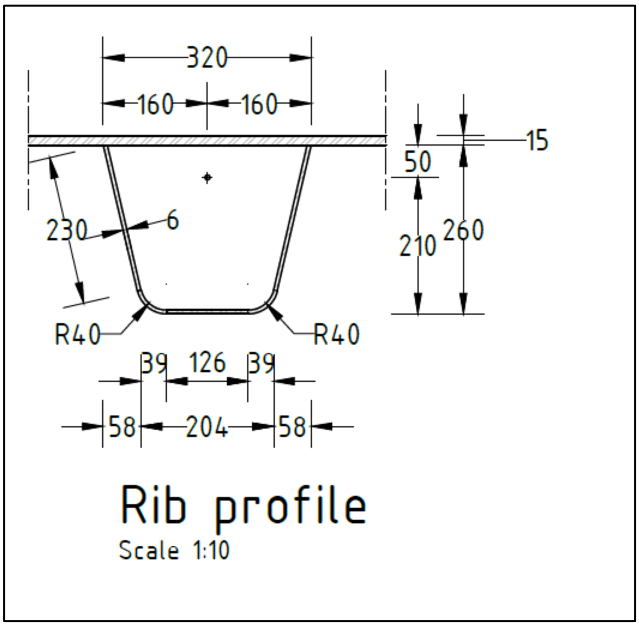


Figure 28 Top view and details of bridge deck

7. Discussion

7.1. Reliability of the acquired results

Firstly, the background information is reliable due to the detailed theoretical research into the existing situation. Through literary research and the consultations with the experts in the field, a realistic estimation of the problem situation is obtained.

Secondly, the product of the consultations and the literary research is the program of requirements. This document holds a reliable view on that what the stakeholders and situation require. Based on this program, the variants are initialized. Due to the variability of consulted stakeholders/experts and detailed background information, the variants are considered viable and reliable.

Through the requirements the decisive variant is selected and worked out into a technical design. As can be seen in the previous chapter this technical design is a new bridge deck for the Zandkreekbrug on the east side of the Zandkreeksluis. The calculations and determined layout are based on the existing codes and norms (CROW and Eurocodes). The application of the relevant codes and norms secures the reliability of the calculations.
However, certain parts of the design include elements, detailed calculations and material properties that are selected and determined based on assumptions and estimations. This method is not extraordinary and also applied in the professional working field. The process of designing and calculating is an iterative process, meaning that the results of the performed calculations can be used to optimize the preliminary design, and to acquire a more detailed result. Due to limited working experience (especially regarding bridge design), and time limitations, the acquired calculation results are must be refined and optimized, considering various input data. The calculations and their results are therefore considered reliable but basic.

Lastly the drawings are based on the new design of road layout, existing bridge features and calculations. Additionally, existing design standards are applied to enhance the quality, understandability and reliability of the images. In accordance with several (steel) producers and contractors, the design and its drawings can be updated to accommodate a more detailed result. Therefore, the drawings are considered to be reliable for a preliminary design level, but require more attention towards a final design.

7.2. *Reliability of the technical design.*

The outcomes of the technical design as discussed prior to this chapter, show the that some elements are insufficient in strength and deflection. On first sight this can have a big impact on the design and the feasibility of the project. However, some side notes can be made to the calculations and their reliability.

First of all, the reliability of the technosoft model is verified in an earlier stage of the thesis. However, due to the complex shape of the deck element (rib and plate) a substitute profile was selected. This profile is a HEM200, which shares similar properties. Nevertheless, this results in less refined outcomes (due to the differences in model and reality). As the self-weight of the rib and plate profile is applied, this difference is also limited to some extent. However, for more refined and detailed calculations, calculation software must be applied to acquire a better representing outcome.
This also counts for the representation of the distribution of loads in the elements. With technosoft, a 2-dimensional beam can be modelled. When a 3-dimensional technique is used, the outcomes will better display the actual situation. With this method, the influence that wind in cross sectional direction acting on the bridge can also be accounted for. This is not possible in technosoft.

Secondly, the calculations are performed using representative loads which are conservative to the actual situation. Prior to the calculations, the consequence class is selected to be CC3 opposed to CC2. However, in the professional field there is much discussion about which class to apply to what situation. The determination of both consequence classes can be motivated in this situation (considering economical impact if the bridge fails, the loss of lives, etc.). In this research consequence class CC3 was selected to approach the calculations in a safe manner. This can be reevaluated in future developments.

Thirdly, the bearing capacity of the elements is performed using a conservative approach. Only static situations in the elastic stage are considered. The assessment of checking the occurring stresses to the yielding point of the selected steel is a reliable approach. However, it is a coarse evaluation. Applying methods like 3-dimensional modelling and, finite element analysis, and plastic capacity can further refine the bearing capacity of the elements.

In general, much optimization can be achieved by optimizing the design, refining the calculations, using other calculation software. This does not mean that the major exceedance of the main girder profile- (202%) and fatigue-stresses (307%), can be solved by solely optimizing the designed elements.
An additional increasement of the stiffness of the elements is to enlarge its relative profile. The deck plate can for example be increased to 18 or 20 mm in thickness.
The main girder is limited in height expansion. This due to the fixed freeboard height considering the lock. To increase the profile, it has to be enlarged upwards. This means that the level of the road surface has to be increased as well. Road level elevation is possible, but only for about 20 cm without too many consequences.

A consequence of increasing the height/thickness of the elements is that the weight of the elements increases as well. This has negative influences on the main turning point, as this is already 108% of the initial weight.
However, as some elements suffer from exceeding stresses, some elements experience very little. In this case, the considered element can be optimized as well by refining the weight and dimensions of it.

The last element that is subject to discussion is the deflection of the main girder in situation 2. This deflection amounts to roughly 540 mm. However, this deflection is theoretical, as the beam’s actual support reaction on the land support will be minimal. This means that the deflection must be accounted for when making the main girder. This so call ‘sag’ (in Dutch, ‘zeeg’), or ‘negative deflection’ must be incorporated in the making of the girder. Nevertheless, one can question the feasibility of incorporating a sag of 540mm. The optimization to this problem follows the same measures as discussed for the stresses in the main girder.

Concluding, with my limited personal experience in structural engineering, I find it difficult to determine the feasibility of the new design. I recognize the major influence of the exceeding loads. However, I can hardly estimate what certain modifications to the element properties might result to. With calculating the moment of inertia (applied to find the moment of resistance), height increasement has an influence of a factor 3. This is positive to any enlargements, but I would not be able to estimate the extent to how positive.

8. Conclusion and recommendation

8.1. Conclusive answer to the sub-questions

8.1.1. Sub-question 1

What is the impact of the existing situation on the problem stated?

As the existing situation is researched through literature, it became clear that the Zandkreeksluis is an important junction in the Quality Network Agricultural Traffic of Zeeland. This network includes the most important logistical travelling routes within the province.
Due to the road layout, AV's have to wait as soon as the barriers go down and one bridge or the other starts turning. Research shows that both Hongersdijckbrug (bypass bridge) and Zandkreekbrug each turn on average 15 times a day (on any given weekday in the period 01-06 to 13-08 in 2017). A bridge turning cycle takes around 12 minutes. Similar times are found at research for the waiting times of AV's. This is also, on average, 12 minutes per AV per crossing. However, waiting times that exceed 20 minutes are not uncommon.
To limit the waiting times, some AV's can cross by using the cycling lane. This results in unsafe traffic situations for cyclists, as the lane is too narrow for a bicycle and AV to cross each other. Also, the difference in driving speed, the dimensions of AV's and the visibility at this location, contribute to the unsafe conditions. The limit for the allowed AV's to cross is lays on a maximum of 3 meter in width. This is in accordance with the maximum allowable width where no permit is required to access the public road.
Other safety issues are caused by tourists and inexperienced drivers. This, however, has no effect on AV's.

8.1.2. Sub-question 2

What are the requirements for any possible solution?

The first part of the requirements is based on the various consultations with experts in the field. The experts are from various field, including Rijkswaterstaat, CUMELA, Waterschap Scheldestromen, an agricultural contractor, and the Province of Zeeland.

From the consultations, the requirements are separated into 4 categories, being functional, internal, external and technical. The functional requirements explain the function of the solution. It should decrease the waiting times for AV's and fit for the mid-long term in term of investments and solution capacity. The traffic safety must at least be maintained, but ideally improved. This can be achieved by creating more space for all traffic types. It also includes the separation of main traffic and AV/bicycle traffic. The layout should not only provide more space but must also be flexible in redesign. It can hereby incorporate any future developments in the situation. The primary water retaining function of the dam and lock must also be maintained in any new situation

The internal requirements include the requirements that are related to the effect a new situation has on its surroundings. It should, for instance, not affect the existing bridge and lock moving mechanisms and its foundations. This to enhance the feasibility of the newly designed element. It is also specified that improvements can be found in both technical and/or non-technical solutions.

The requirements that specify that the lock chamber cannot be reduced in length and width, and that the freeboard of the Zandkreeksluis must be maintained, are categorized under the external requirements. It also includes the requirement that the approach route from water to lock on either side must be maintained, and that the situation of the house owners living north of the lock must be considered.

In infrastructural terms, the solution is required to create space for AV's to provide no interference with main traffic. It specifies that the new road layout must be logical and easy to understand for road users. This can be enhanced by less lane crossings. For esthetic purposes, the newly implemented civil structure should fit in the existing environment. Lastly, the spacious berms on the dam must be maintained, or shield constructions should be implemented.

The second part of the requirements include those applicable to a new technical design. It displays the requirements for the usage of various CROW and NEN (Eurocode) codes and norms. These apply both to the road layout as well as the technical specifications of a new bridge.
For example, the bridge design must be based on the calculation methods for wind, fatigue, and material resistance specified in the relative Eurocodes. The deck must be designed in correspondence with CROW guiding lines for Erftoegangswegen and Gebiedsontsluitingswegen and Eurocodes.
The static calculations must be tested on bending (σ), shear (τ) and deflection. Fatigue must also be calculated through similar assessments but based on separate loading combinations and detailed (local) bearing capacity properties.

8.1.3. Sub-question 3

What are the possible variants based on the requirements?

The variants are identified as following. Firstly, the non-technical variants are identified. These included re-routing of agricultural traffic, using other means of transport, applying schemes on bridge opening times or AV road usage and the exchange of parcels and or properties.
In general, these variants have good potential of decreasing the total amount of waiting time. However, for an individual tractor the waiting time is not affected by these measures. Considering other means of transport bring additional costs for farmers and agricultural contractors. They are, therefore, not feasibly.
This means that the non-technical variants are not decisive in the selection procedure.

Secondly, technical variants are identified. These range from enlarging/widening one of the bridges, building an additional bridge on either side, a tunnel underneath the lock and a high bridge over the lock. Many of these variants are not feasible. This either due to their required investments which do not correspond with the mid-term realistic approach or direct clashes with the previously set out requirements by the stakeholders/experts.

8.1.4. Sub-question 4

Based on different criteria, what is the most optimal solution out of the identified variants?

Based on the variant analysis, one variant is selected. As previously mentioned, the non-technical variants proved to be not decisive in the selection procedure.
The selected variant does comply with the requirements. This variant is the enlargement/widening of the Zandkreekbrug. It proves to be best solution considering the investments for province and Rijkswaterstaat. This because redesign can be combined with maintenance works and replacement of the old existing deck.
The lock chamber is not shortened, the berms can be maintained, the flexibility of redesign of road layout is enhanced, space is created for AV's and bicycles, it fits in the environment (because no real seeable changes are made apart from the main girders of the bridge), the water retaining element of the dam is maintained, and, most importantly, waiting times for AV's are decreased.

8.1.5. Sub-question 5

What is the most optimal technical design to support the selected most optimal solution?

As the technical specifications of the bridge deck need redesign, the approach of an orthotropic deck is selected. This includes a bridge deck, where the deck plate contributes to the bearing capacity of the structure as a whole. The deck is stiffened with longitudinal spanning ribs, welded to the deck plate. The ribs transfers the load executed on the deck to cross beams, which in turn transfers the load to the main girders. The challenge is to redesign the girders in a way that they do no longer penetrate the bridge deck. This enhances a freedom in redesigning the layout out the bridge.

The level to which the design and calculations are performed corresponds with a preliminary design level. This means that the basic design properties are identified and displayed. The calculations cover the basic principles regarding bearing capacity and deflection. Additionally, a fatigue assessment is performed

To create a safe crossing, the layout of the bridge is reevaluated. This results in a slight widening of the bridge deck (which is about 1 meter in total). The new layout shows a wider main traffic lane area, with room for a correction area on either side. A steel barrier is placed on the bridge to separate main traffic from AV/bicycle traffic. The remaining part of the bridge is used for a shared AV and bicycle traffic lane. Although the safest option would be to also separate these types of traffic, it is chosen to maintain the shared properties. This because the parallel lane both north and south of the lock share the same properties. The safety of the cyclists is enhanced by creating a spacious lane, which incorporates black and orange tarmac zones (to suggest separated spaces. This lane is 5.5 meters wide, which, according to the CROW guidelines is spacious enough to create safe crossing possibilities.

Regarding the calculations, various situations of the bridge location (up or down, loaded or unloaded) are identified and worked out.

The first situation is where the bridge is horizontal and open for road crossing. The deck is divided in theoretical lanes, at which representative traffic loading is applied. Since the bridge is horizontal, it is supported on two points; at the turning point and at the land abutment on the other side of the lock chamber.
Situation 1 is assessed by both a general assessment as a local assessment. The calculations corresponding with the general assessment show that the deck is sufficiently strong, as is the designed floor beam. The main girder (which is shortened in height) is divided into different profiles at different locations. Calculations prove the 1 of 3 profiles is not sufficient in its bearing capacity and deflection.
The local assessment is applied to the bridge deck. These results also validate the sufficient properties of the deck in bearing capacity and deflection.

Situation 2 is specified in case the bridge is no longer opened for road traffic, and just starts turning (theoretically being opened 1°). This means that the bridge is now supported by only 1 support, being the turning hinge. The bridge deck is now unloaded, which means that the calculations for deck and floor beam are not decisive in this case (they are still sufficient). However, considering the main girder, the same profile is determined not to be sufficient. Additionally, the overall deflection of the main girder is too large.

The third situation is the case in which the bridge is completely opened, and most susceptible to wind loads. The moment towards the turning hinge is calculated. Assessment show that the profile is sufficiently strong.

The fourth and last situation is the case at which fatigue loading is assessed. Through several detailed calculations, it is determined that the bridge deck and its longitudinal ribs are not strong enough to withstand loading for the upcoming 100 years.

The last calculation performed is that of an overall weight assessment. To enhance the feasibility of the variant, the self-weight of the complete structure must not be more that the weight as initially designed. Calculations show that the total weight of the new bridge excess the initial weight by 8%. However, it is still 99% of the counterweight. The combination of the small excess, and the overweight of the ballast, still makes this design feasible in terms of maintaining the existing moving mechanisms.

To conclude the calculations, with the current design the new bridge is not sufficient to withstand the determined loads for the determined lifespan. However, as will be discussed in the recommendations, optimization is possible which can still provide a positive outcome of the design. Also due to its preliminary design and calculation level, a more detailed approach will provide a more refined outcome of the calculations. These refinements are assumed to contribute positively to the determined design.

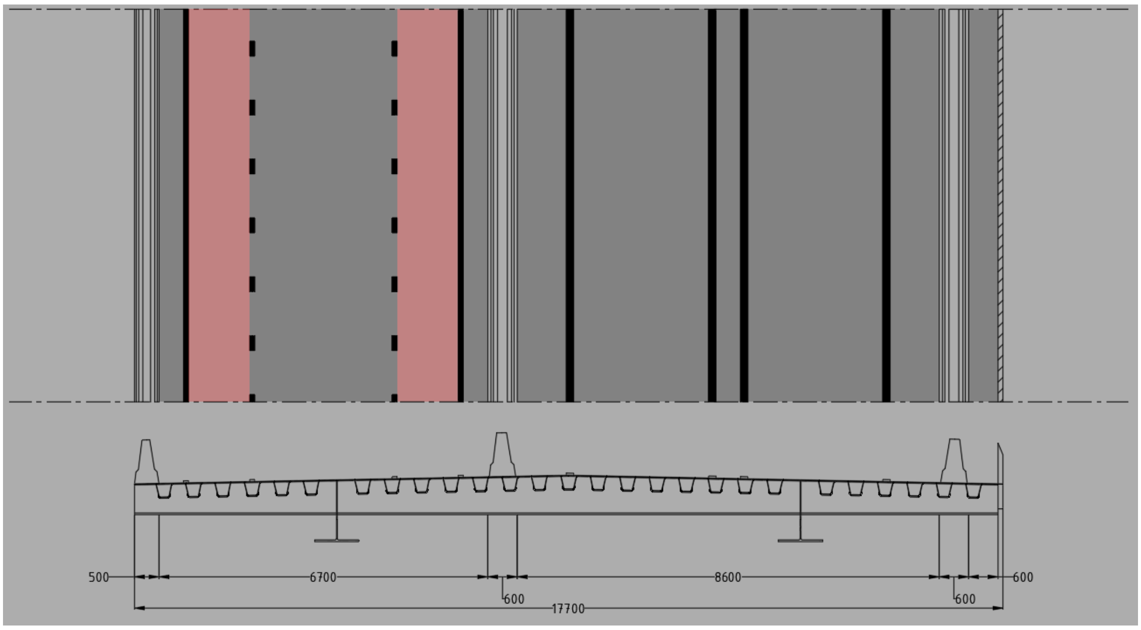
8.2. *Conclusive answer to the main research question*

The main question, as stated in chapter 1 of this report is as following:

> **What is the most optimal solution to decrease time delays as experienced by agricultural vehicles at the N256 Zandkreeksluis crossing, while locally improving the traffic safety, with logistical travelling routes and applicable regulations considered?**

Based on all acquired information, analysis and design/calculations performed, the conclusive answer to the main question is as following:

The most optimal solution to decrease time delays as experienced by agricultural vehicles at the N256 Zandkreeksluis crossing, while locally improving the traffic safety, with logistical travelling routes and applicable regulations considered is the redesign of the Zandkreekbrug, through which an additional crossing possibility for AV's is created. This possibility will likely reduce the waiting time with half, and can even be reduced further when incorporating the current developments in the situation.
The waiting time is decreased because additional space and crossing opportunity is created for AV's. With this solution incorporated, AV' only have to wait 1 out of 3 situations, instead of 2 out of 3.
The logistical travelling route as part of the Quality Network Agricultural Traffic in Zeeland is thereby strengthened, providing a more comfortable usage of this section. The relevant regulations apply to both traffic safety and technical specifications for the bridge. The layout of the bridge is based on the guidelines of the CROW, the bridge design is in full accordance with Eurocode regulations.
The traffic safety is improved by creating a spacious 5.5 meter wide shared lane for AV's and cyclists. In accordance with the CROW, this lane is wide enough for safe crossing of the two traffic types. The ideal situation calls for separated structures. However, this is not feasible within the situation.



8.3. Recommendations to future development

In general, the selected variant has the best solution capabilities. However, its technical design technical are reasonable concerns.
The recommendations are therefore mainly focused on these technical aspects. As far as the literature research and consultations with experts go, I managed to display the scope of the problem in a complete manner. The limitations and boundaries are relative to this thesis, through which I drew my conclusion. The variants identified display a variety of solutions. After evaluating the requirements, a decisive variant is selected.
To fully solve the problem, both bridges have to be widened (or reconstructed). This, however, does not align with the mid-term investment reality in today's economy. Therefore, I chose to focus on 1 of the two bridges. Due to the shared responsibility between Province and Rijkswaterstaat at this location, I believe that the redesign of the Zandkreekbrug is most beneficial to all parties and stakeholders involved.

In the calculations shown above, the bridge is only statically considered. Since this is a movable bridge, a dynamic analysis should also be performed. This must include assessments to the structure when abruptly stopped in any given position at any given time in the moving cycle.

To further refine the longitudinal rib elements it is recommended that this part is calculated by means of a Finite Element Analysis (FEA). This to determine where the stresses are actually located, in a 3-dimensional model. This FEA should include a detailed stress distribution assessment, the buckling stability of the rib itself, and the fatigue assessment of the rib and deck.
Also for other aspects, for example the deck plate, a 3-dimensional model is recommended to apply to the calculations. This because with the used calculations, it is very difficult to determine the actual stresses and its location in the elements.

The feasibility concerns of the construction as a whole is displayed in the discussion. In general, much optimization can be achieved by optimizing the design, refining the calculations, using other calculation software. The influence of an experienced structural engineer with the availability of professional software is additionally strongly recommended.
What is clear is that with simple optimizations in loads and profile capacity, the problems are not solved. The detailed and in-depth refinements of the current values will show if this design is feasible.

No attention has been paid to the moving mechanism of the bridge, and any additional influences the new bridge might have. It is recommended to fully assess the moving mechanism, according to current standards and in relation with the new design.
Additionally, the moving action of the bridge is recommended to be assessed on fatigue.

When the new bridge is recalculated, refined, and ready for construction, the loads that this construction produce as a result of its process should also be considered, and is therefore recommended to be performed.

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Appendices

1 List of symbols

2 Maps and tables

3 Consultation analysis and evaluation.

4 Program of requirements

5 Variant analysis and evaluation

6 Calculation report

7 Drawings