Fundamental Infrastructure in Reimerswaal

[Measuring erosion resistance and bearing capacity of the rail trajectory between Bergen op Zoom – Kapelle Biezelingen]

Final Thesis Report

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Summary

The Resilient Delta research group has been researching in infrastructures stability under a case study of 'flooding of the territory of the Reimerswaal municipality.' For this, this research is carried out by the research group to check the effect of the flood on the railway. This research had aimed to check the erosion resistance and the bearing capacity of the railway trajectory during and after the flood. For that, the flood scenarios on VNK2 (the Dutch safety map 2) has been used to check this railway.

The railway trajectory stability had been tested by applying different instruments such as desk research of the previous studies, a modeling program (D-Geo Stability Program) and geotechnical calculations. Furthermore, with this project technical and functional requirements of the railway structure had been set up. These requirements were used when the railway was checked.

Further, the Multi-Criteria Analysis had been applied to this research. The main idea of the MCA on this project is to come up with three designs to include the ballast and water currents on calculations of the railway test. After revelations, the ballast considered as revetments and considered as a load on the dike structure. In additions, the current as well has taken into accounts during this research.

The results of this report have been determined by the primary methods to check the slope stability, settlements, and currents. Slope safety factor checks have been done using D-Geo stability model. The results show that location one and two have a low safety factor (lower than 1.3). In both locations, the slope losing its stability during the flood when a train load is a presence. Also, location three has high slope stability and its slop still stable during the flood. Not only, the slope stability but also the slope grass revetment does not satisfy during checks. As for the three locations the grass has the different type of grass with big trees on the slope.

Furthermore, with settlements checks location three gets the highest settlements value during and after the flood. The research has concluded that the railway is eroded during present of water.

However, the soil properties of the embankments had been based on a historical data, due to the lack of data about the embankments soil structure. Also, the groundwater level measures applied in this research were based on 2001.

In conclusion, these research results are still could be improved by applying site analyses. In these analyses, a geotechnical test carried to measure the groundwater and to check the embankment soil structure.

Preface

In front of you is the final thesis report of ‘Measuring erosion resistance and bearing capacity of the rail trajectory between Bergen op Zoom – Kapelle Biezelingen.' This research is carried as part of Resilient Deltas research group, and it is part of my final thesis to the Civil Engineering course at the HZ University of Applied Sciences.

Within this research, I am supervised by Mr. Papenborg and Ms. G. Scuderi. In the start of this thesis, I have been well supported by my supervisors. The research central question and sub-questions formulated with research supervisors. There are some extra sources provided by Mr. Papenborg to understand the situation. Here I would like to thank Mr. Papenborg, ProRail and Ms. G. Scuderi for their help.

Hamood AL Rawahi
Vlissingen, 10th June 2018

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1. Introduction

1.1. Background

The municipality of Reimerswaal in the province of Zeeland is located between Bergen op Zoom and Kapelle. Figure 1 shows a location of the Reimerswaal Municipality. It is the primary connection between Bergen op Zoom with other cities in Zeeland (Vlissingen, Goes, and Middelburg).
Due to Reimerswaal is laying in low-level area dikes are surrounding all the municipality. In fact, these dikes range works as water defiance for all villages during a flood.

Figure 1 Municipality of Reimerswaal (Reimerswaal, 2018)

Many critical infrastructures pass through the area. There is a main railway which connecting Rotterdam port and Vlissingen industry port as shown in figure 2.
The port of Rotterdam is the most significant port in Europe and is ranked in the top 10 largest ports in the world (Port of Rotterdam, 2018). Also, Vlissingen seaport is home to 200 companies active in industry, logistics and maritime services. These companies within the port handled 18% of the total employment in the province of Zeeland (Zeelandseaports, 2018). The railway is used to transport the import and export products. Therefore, the vanishing of the railway within Reimerswaal due to the flood will affect the economy of the area.

Figure 2 Railway connection between the port of Rotterdam and Vlissingen-Oost port (openstreetmap, 2018)

The Westeshelde and the Oostershelde surround the Reimerswaal from two sides. For that, climate changes are likely to increase physical and economic effects of floods and extreme weather events (Eenennaam, 2017). The rise of water level in an area due to heavy rain or failure of surrounded dikes will cause directs and indirect economic effects in the area. The economic consequences can be by damage to the infrastructures which impacts the disruptions to supplies clean water, electricity, transport, and communications. Losing all these main infrastructures in livelihoods will cause communities economically vulnerable (Queensland Chief Scientist, 2018). The results of directs and indirect cost of sea level rise for Europe have been modeled for an average of sea level rise scenarios for the 2020s and 2080s. The results show that sea-level rise has adverse economic effects (Wilfried, 2018). In the Netherlands, the maximum sea level rise scenarios expected to rise by 85 cm in 2100. For that, the total costs for adaptation are assumed between 9 billion and over 80 billion euro (Aerts, 2009).

Figure 3 Railway structure (Rooijakkers, 2012)

Moreover, during flood period (1/10,000 years' storm) roads and railway are not accessible due to the rise of water level which covers the railway trajectory.
Therefore, the railway structure constructed at a higher ground level as shown in figure 3. An example of railway structures specifications of the existing situation can be seen in figure 4. Various sources describe that the security of the track foundation and the permanent way are crucial to keeping the railway track in operation during a flood event. Therefore, this research will consider the railway structure as a dike, to test its stability and erosion resistance.

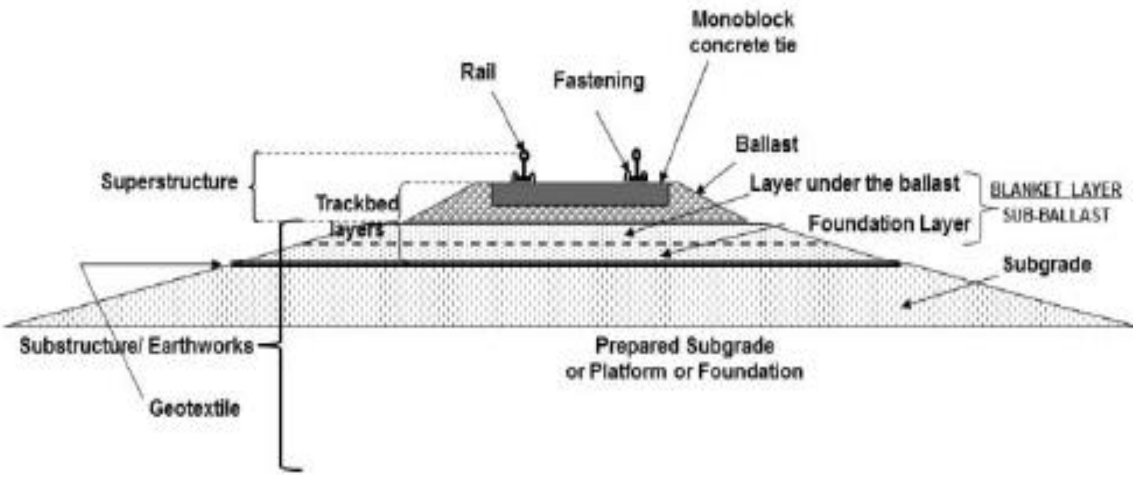


Figure 4 Railway technical structure (Giannakos, 2015)

1.2. Aim and Problem definition

The research aims to verify and check the railway trajectory foundation is sufficiently erosion-resistant and have enough bearing capacity during and after a flood.
The problem arises when cities flood due to heavy rainfall, sea level rise and climate changes. The Netherlands is a low-lying level country where sea level is higher than the ground level. In 1953, most lands in the Netherlands had been covered by water. After this flood disaster, the Dutch government has introduced new measures to protect county effectively and efficiently against flooding: The Delta Program is designed to protect the Netherlands against flooding and to secure freshwater supplies (DeltaProgramme, 2018).

In case of flood, it is conceivable that different infrastructures such as roads, gas, electricity, and railway will be unavailable for a specific time. Also, making evacuation for the population will be difficult when most of the service is inaccessible. The Municipality Reimerswaal has many demanding infrastructures such as railway trajectory, which considers as the connection between Bergen op Zoom and all cities in Zeeland province (see figure 5).

Figure 5 Railway trajectory(black line) and the A58 road in Reimerswaal (OpenStreetMap, 2018)

This railway trajectory and the A58 road are used to commuter and transport several industrial products to cities in Zeeland and Vlissingen port. For that, failure of these infrastructures can cause extensive social and economic disruptions.

In a previous research Steur (2016), the focus of the research was at the effect of the flood on the stability of the A58 highway. This study will focus on the railway trajectory between Bergen op Zoom and Kapelle. In addition, the erosion resistance of the railway embankment during and after a flood period will be determined.

1.3. Objectives

The railway trajectory in Reimerswaal must operate in function at all times. This cannot be guaranteed during the flood. The purpose of this study is to reduce this issue to ensure to circumscribe both social and economic disturbance. The final results of this research should provide an insight regards weakness at three locations of the railway trajectory.
By using different instruments such as desk research of previous studies, modeling programs (D-Geo Stability Program) and geotechnical calculations, the railway trajectory stability will be checked during and after the flood.

1.4. Main question

The research is aim to check the erosions resistance and bearing capacity of railway trajectory in Reimerswaal. The study is going to use VNK2 (Veiligheid Nederland in Kaart2) flood scenarios (Dutch water safety in map2). The central question for this research is formulated:
What are the effects of the erosion resistance on the resulting bearing capacity of the railway trajectory between Bergen op Zoom and Kapelle Beiezlingen during and after the flood?

1.5. Sub-questions

Locations

It is essential to determine the particular locations before start this research. For that, the first sub-question formed to identifies research locations:

1. **What parameters are necessary to determine the locations where flooding is experienced?**
   - **1.1. What is the railway trajectory ground level?**
   - **1.2. Which flood scenarios have the most effect on the railway trajectory?**
   - **1.3. What is the water level during the flood?**

Design

In order to check all failures mechanisms, a design will be used for calculations and checks. This will be defined by using MCA. The design choice will be disused in MCA section on method. The sub-question is formulated:

2. **What is the possible design to check the railway dike stability taking into accounts the ballast layer and currents?**

D-geo stability modeling program

In this research, D-geo modeling program will be used to check the stability of the railway trajectory. After the locations, it is essential to analyze the existing situations. For that, second sub-question is formulated to determine necessary parameters D-geo program:

3. **What parameters are required for D-geo stability modeling program in order to determine the erosion resistance of railway slope during the flood and after a flood?**
   - **3.1. What is the existing situations(cross-section) on each location?**
   - **3.2. What is the ground level?**
   - **3.3. What is the slope of existing locations?**
   - **3.4. What is the soil geotechnical condition?**
   - **3.5. What is the geotechnical condition of the railway foundation?**
     - ***What are soil embankments properties?***
   - **3.6. What is the groundwater level?**

Track foundation loads

The track foundation is the groundwork where the railway is laying. It consists of different soil types with stability slopes. Also, the embankment soil affects the stability of the railway trajectory. The properties of the locations need to determine in this research. The following questions are formulated to determine the foundation properties which could affect the bearing capacity of a railway trajectory:

4. **What parameters influence the bearing capacity of railway trajectory?**
    - **4.1. What is the track structure consisting of?**
    - **4.2. What type of rails does the railway have?**
    - **4.3. What is the railroad ties properties?**
    - **4.4. What is the ballast properties?**
    - **4.5. What is the train load?**

Failure mechanism /design

Different failures mechanisms affect the slope, bearing capacity and overall stability of the railway structure. This sub-questions formulated in order to determine the possible failure mechanisms:

5. **What are the possible failure mechanisms during and after the flood?**
    - **5.1. What are the possible slope failure mechanisms?**
    - **5.2. What are the soil embankments failure mechanisms?**

Method /test

There are different calculations and checks will be required to check the failure mechanisms. Also, there are some checks required to check the D-geo stability results. For that, the last sub-question is formulated:

6. **Which method/test used to check the erosion resistance and bearing capacity of railway foundation?**
    - **6.1 What type of calculations used to check the erosion and bearing capacity of railway dike?**

2. Theoretical framework

The following section contains the conceptual framework; through this passage of the research candidates define the basic principles and method for the development of the study to adequately determined the main focuses for the research.

2.1. Conducted research

2.1.1. Parameters influence on locations

The analysis of the railway trajectory is based on three locations which are used for the test and checks. Therefore, the central question in this section is; What parameters are necessary to determine the locations where the flooding is experienced?
First, the risk of the flood of surround dikes is defined to determine flood probability. Second, the ground level needs to be defined to determine three locations with different elevations (low, average and high).

1. Water safety policy

Dikes rings surround Reimerswaal. The risk of flood is defined as the flood probability multiplied by the estimated damage flood will cause of spatial area. In the Netherlands, flood probabilities are used to determine the legal minimum safety standards of dikes. Water management authorities are assigned the task of keeping the dikes levels above these minimum requirements. Due to population and capital stock, the flood risk is varying from dikes rings. There are about 53 dike rings in the Netherlands. Flood probabilities per dike ring were installed to tested flood policy as a response to the flood disaster in 1953. According to Deltares the flood risk norms and the estimated likelihood of flood is 1/10, 000 per year storm for Reimerswaal dike rings (Jonkhoff, 2009). For D-geo stability model and calculations, this flood probability is used.

2. Flood scenario

Flood scenarios used for management of flooding and the rising of the water level. The flood scenarios are used to determine the project locations for the research. In this research, flood scenarios will be used based on LIWO website (Landelijk Informatiesysteem Water en Overstromingen). LIWO has national information on water system and flooding. It has maps layers for professional from safety areas, water boards, and Rijkswaterstaat. These maps are essential for water disasters and floods in the Netherlands (LIWO, 2018). There are about 23 flood scenarios in Reimerswaal municipality (see figure 6). These scenarios are considered to choose the locations of this research.
In the Netherlands, the sea level rise is a significant issue due to most of the land elevation below sea level. The sea level in the Netherlands is projected to rise 80centimetres by 2100 (Muiswinkel, 2016).
For that, the flood scenarios are based on climate changes and on sea level rise. In this project, the worst flood scenarios need to be determined to find research locations. These following criteria are used to determine the worst flood scenario:

- The area covered by water

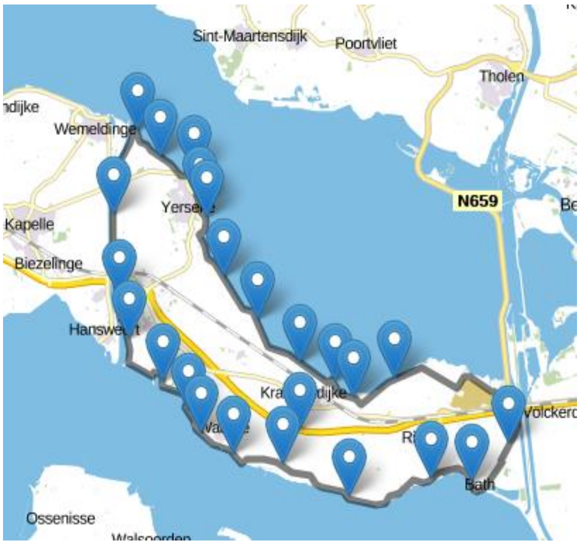


Figure 6 Flood scenarios (LIWO, 2018)

- Depth of water
- Effects on the railway line

During the method chapter later in this report, the steps of determining project locations are explained more extensive.

3. Ground level

The ground level is an essential factor that affects the effects of the flood on the area. When the railway is located in high ground level, the water level will be less compared with the lower area. For that, the ground level of the location should be determined. AHN can be used to determine the dikes height and ground level in
Reimerswaal.
The Actual height file Netherlands (AHN), has an accurate elevation of the Netherlands. The height and cross-section elevations of areas in the Netherlands is known by using this source. In additions, the AHN is used by water board and Rijkswateraat to address the flood defenses. Figure 7 shows an example of an elevation cross-section (AHN, 2018).

Figure 7 AHN elevation (AHN, 2018)

From figure 7 the flowing can determine:

- The ground level of railway trajectory: +2 m NAP
- The subsoil surface level: -1 m NAP

2.1.2. Parameters are required for D-geo stability program

In this research, the modeling program that will be used is the D-Geo stability Deltares program. This modeling program has been created to check Dutch dikes for system stability. The program offers a various specific function that detail the security of railway construction can be determined. Deltares has provided a model manual which it extensively described all several steps should be followed to build a model (D-Geo Stability, 2018). In this section, the parameters that the program required is mentioned.

1. Ground level

The ground level and crest are determined by using the AHN. The ground level has been mentioned above in more detail.

2. Slope

The slope is a primary factor in assessing railway network. The slope used in railway and dikes to stabilize the embankments and reduced the effect of erosions. However, there are different failures of railway structure due to the slope. A study has been done to assist "Failure and Repair of the Slope of Railway Embankments" by Guangxi University student (Chang, 1988). This study has shown what the reasons of slope failures are. One reason for the failure that the slope is unstable to construct such a high embankment with the expansive soil with a slope of 1:1.5 to 1:1.75 (Chang, 1988). However, in the Netherlands, the minimum slop used is 1:2 (see figure 8). In failure mechanism section, the slope failure mechanisms will be mentioned in detail.

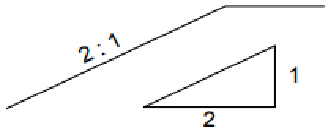


Figure 8 Minimum slop of dike (Esveld, 2001)

3. Soil geotechnical condition

The properties of subsoil play a significant role in the balance of all the small dike (railway embankments and railway foundation). As internal erosions, settlements and loss of stability of dike depend on type and properties of soil. A detailed investigation of the earth is essential to understand the geotechnical characteristics of the material at railway area. There are different tests that can be used to realize and determined all soil properties. As in research of ‘‘the use of engineered sediments for dike construction in the flood control area of Vlassenboek'' different tests were used to analyze subsoil properties. These tests include particle size distribution, soil consistency/water content, organic content and determination of shear strength characteristics using the laboratory test (IADC, 2015). In this research, the soil structures determined by using publicly available in Dinoloket.

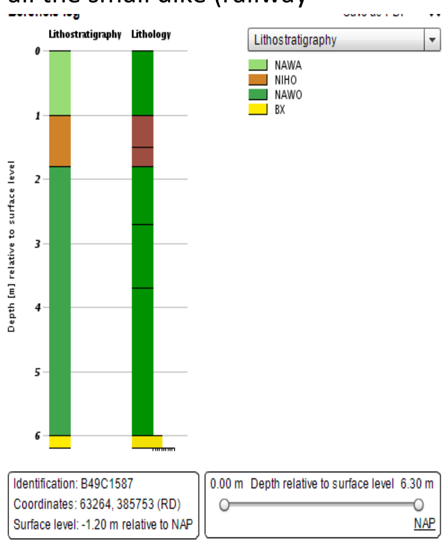


Figure 9 Soil structure (dinoloket, 2018)

Figure 9 shows an example of soil structure in Reimerswaal area. The upper from 0-1 m layers is clay, very silty soil. Then peat is present for 1 meter. The below layer from 2-6m is mostly clay.

4. Groundwater level

Groundwater levels are significant for the stability of railway trajectory structure. As too high groundwater level within railway embankments, the land is easily washed out. Like the soil structure, water levels are determined from the Dinoloket. The groundwater level in Reimerswaal is measured at -1.84 m NAP with a surface level of 0.12 m NAP (Dinoloket, 2018). However, this groundwater level will differ from one location to other. For that, the groundwater is essential for the model. As the water too high will affect the stability of railway embankments (Steur, 2016).

2.1.3. Parameters influence the bearing capacity of railway trajectory

This section is providing the parameters that will influence the bearing capacity of the railway trajectory. The bearing capacity of the railway structure will be checked by determining the load that is going to be transferred by the superstructure to the substructure of the railway foundation.

Railway infrastructure components can be classified as superstructure and substructure (See figure 10).

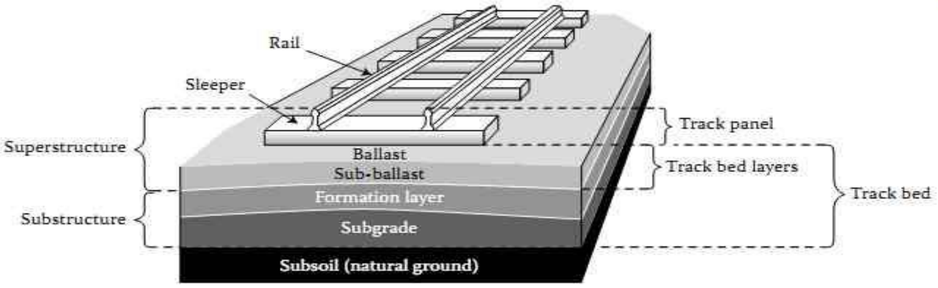


Figure 10 Superstructure and substructure of the railway (Remennikov and Kaewunruen, 2008)

The most visible parts of the track such as rails, rail pads, concrete sleepers and fastening system are superstructure parts. The substructure mainly associated with a geotechnical system including ballast, sub-ballast and subgrade. The superstructure and substructure are commonly crucial in ensuring the stability of railway and safety of passengers. (Remennikov and Kaewunruen , 2008).

1. Track structure

The components of track structures should be classified to check the bearing capacity of railway trajectory. The materials of railway structure give a significant amount of force is transferred to the track foundation. In upcoming paragraphs, the existing track structure described.

2. Rails

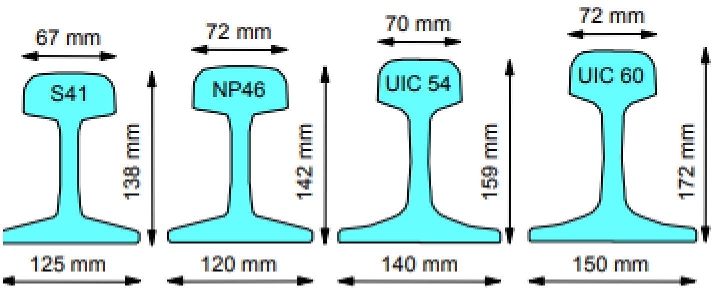


Figure 11 Vignoles rails (Esveld, 2001)

Rails are longitudinal steel members that are constructed on spaced sleepers to guide the rolling stock. Rails should have exceptional strength and stiffness that should be sufficient to maintain a constant shape and smooth track configuration. Another function of the rails is to accommodate and transfer the wheel loads onto the supporting sleepers. There are different typical rail profiles. The most commonly used pattern is flat bottom which called Vignoles rail (Remennikov and Kaewunruen , 2008). The Vignoles ULC 54 standards rails are used in railway trajectory in Reimerswaal (Esveld, 2001). However, the dimensions and weight of track have to be determined in order to find the maximum load transfer by rails to railway foundations.

3. Fastening Systems

The Fastening system is composed of all parts that connect the track to the sleeper. All vibration and impacts from traffic are dampened and decelerated by fastenings. Besides, fastening sometimes is used to perform electrical insulation between the rail and sleepers. Figure 12 shows a typical concrete fastening system.

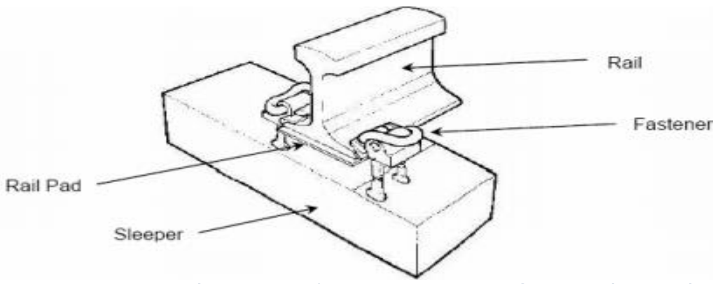


Figure 12 A typical concrete fastening system (Remennikov and Kaewunruen, 2008)

4. Rail Pads

Rail pads are mostly placed on the sleepers to filter and transfer the applied forces from rails and fasteners to sleepers (see figure 12).

5. Sleepers

There are different types of sleepers, for example, reinforced concrete sleepers and a limit extent steel sleeper. Figure 13 shows the real sleepers in existing railway structure in Reimerswaal.
In each country, there are different sleepers used. For the Netherlands, the concrete sleepers used are called NS 90. The figure 14 below shows the simplified railway track loads from ProRail design rules standard (ProRail, 2016). In the railway of Reimerswaal, the same ProRail design rules are used in this project.

Figure 13 Sleepers in existing railway structure (google maps, 2018)

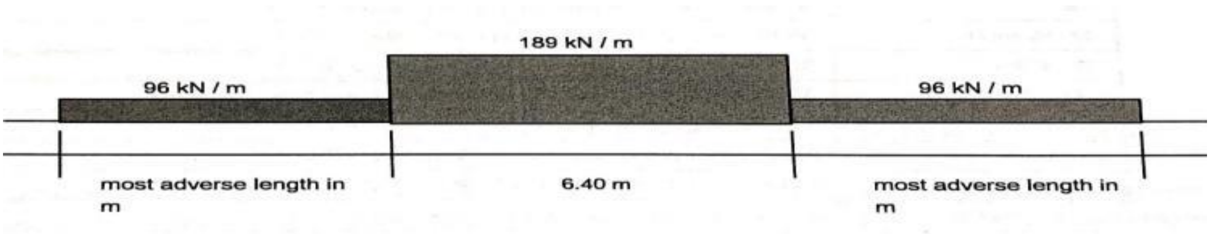


Figure 14 Simplified railway track loads (ProRail, 2016)

2.1.4. The geotechnical condition of the railway foundation

The geotechnical condition is mostly the physical properties of soil and rock around on the construction of the foundation. The track foundation properties are the properties of a basis or groundwork of railway. The railway foundation consists of different layers: embankments, ballast, and sub-ballast (Alemu, 2011).

1. Embankments

In this research, the embankments height is different along the railway structure. For that, the embankment heights and soil properties of these embankments are essential parameters in order to check the track foundation capacity.
The railway embankments are made of unbound coarse-grained materials. These materials are different from most natural soils in their physical characteristics to respond to applied cyclic load. The main consequences of having a granular nature are that these materials, untreated, cannot stand against tensions pressure as they could be washed away quickly.
On the other hand, they can support (small) shear stresses indefinitely. Only gravity and applied external forces create intergranular contact pressures and frictional forces that can resist relative movement of particles (Kolisoja , 2006). The study by Ciotlaus, 2017 tested the stability of railway embankments. In this study simulations for different soil embankments were studied: clay, gravel mixed with sand and rock. Also, the simulation is carried for varying height of embankment: 4, 6, 8,10 and 12 m. For each soil type and embankments height, it simulated the stability of the railway infrastructure.

The results show that for railway embankments up to 12m stability is satisfied with cohesive soil (dust clay). For rock fill soil type the loss of stability was noticed for height from 10 to 12 m (see figure 15). Moreover, for all height studies of gravel and sand, the results show the instability of embankments (Ciotlaus, 2017).

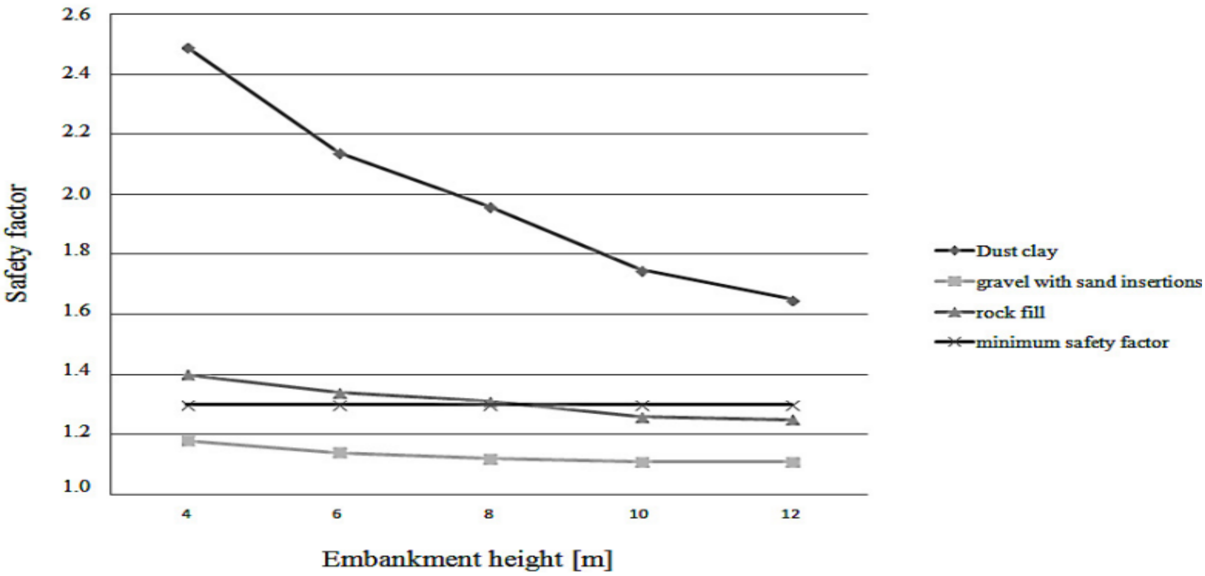


Figure 15 Safety factor for different embankments heights and soil types (Ciotlaus, 2017)

From this study (Ciotlaus, 2017) it is clear that soil embankments have different stability with changing the soil type. For that, during this study the embankments soil properties and layers height influence the overall bearing capacity of railway foundation.

2. Ballast and sub-ballast

In the upper part of the railway foundation, the ballast is used for stability and drainage reasons. Figure 16 shows the existing railway foundations ballast layer used in Rilland-Bath railway station. In this research, the properties of the ballast used in Reimerswaal railway foundation need to be specified. For that, 'Survey of Railway Ballast Selection and Aspects of Modelling Technique' (Alemu, 2011) is used in order to understand the primary function of using ballast in railway foundation. This study described the ballast as the primary layer in railway where sleepers are laid. The primary function for ballast is to transfer the loads from the superstructure to the subgrade without causing failure.

Figure 16 Ballast layer used in Rilland-Bath railway station (Kraai, 2017)

Different materials are used in ballast construction, such as limestone, basalt, and gravel. Significant mechanical properties of ballast can be obtained from the combination of physical properties of the individual ballast material, such as particle size, shape, angularity, hardness, surface texture and durability and its in-situ place that used (Alemu, 2011).

In this research, the properties of ballast are required to check both the deformation and the drainage of the foundation structure. Esveld (2001) mentioned in his book that the ballast and sub-ballast layer thickness properties as flowing as following:

- 25 - 30 cm ballast (crushed stone 30/60)
- In 10 cm sub-ballast layer (gravel) 20/50

The existing railway ballast and sub-ballast layers have to be on these properties. These ballast and sub-ballast properties used while checking erosions resistance of railway trajectory.

2.1.5. Failure mechanisms

Different failures mechanisms affect the slope, bearing capacity and overall stability of the railway structure. In this section, the slope and ballast failures mechanisms are mentioned. These failure mechanisms will be checked in this research by using calculations and D-geo stability program.

1. Slope failure mechanism

There are frequent problems affecting slope stability. These failures are shallow translational landslides caused by flood, settlement due to pore soil layer and deep-seated rotational shortcomings caused by weak sub-soils which are caused by increased loading and drops in the water table. There is detail description of these failures (Kenneth, 2016).

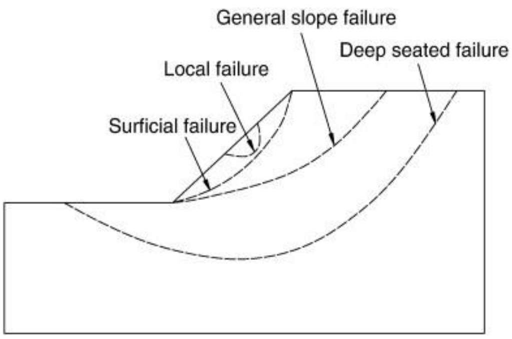


Figure 17 Slope failure mechanism (Abushara, 2018)

Shallow Translational Failures:
The stability of soil reduced due to heavy rainfall or floods which results in shallow translational landslides (see figure 17). The consequences of superficial translation slides are usually low and depend on the clearance between the slope edge and track. However, when a failure occurs in the slope above the trail, the soil can cover the railway trajectory which impacts the passing of the train (Kenneth, 2016).

Deep rotational failure:
Profound rotation slope failures mostly include a large volume of material (see figure 17). It occurs even in new construction due to weak sub-soil and on older assets when some changes in the boundary conditions arise (Kenneth, 2016).

2. Soil embankments failure mechanisms

There are different failures mechanism of the railway foundation structure due to flood. These failure mechanisms will mostly will effects the overall stability of the railway foundation. Alemu (2001) has determined different ballast failure mechanisms. These failures are:

Settlement: the settlement failure can be divided into two parts: settlement of embankments and settlements of ballast (See figure 20). The settlement of embankment is happening when there is an increase in vertical strain stress. The cause of ballast settlement is ballast fouling. The settlement of ballast frequently depends on the quality such as (mechanical, physical, shape and strength of the ballast structure) and the underlying structure (Alemu, 2011).

Figure 18 Settlement (Kruglikov, 2018)

3. Erosion of slope due to Wave run up

Most of the Dutch dikes are covered with grass. The primary function of the grass revetments is to increase resistance against erosion caused by rainfall, waves, and flood. For that, the grass revetments need to be checked to ensure the erosions resistance of the railway trajectory. Figure 19 shows the structure of grass cover.

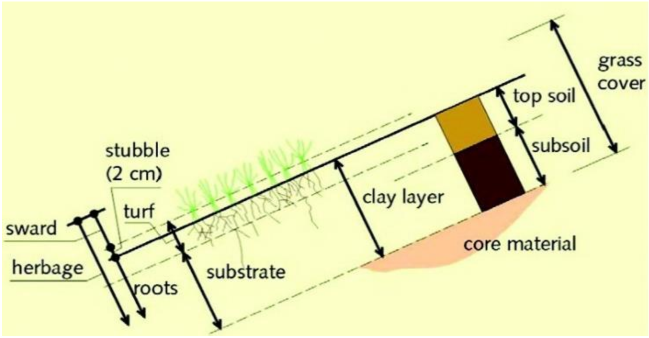
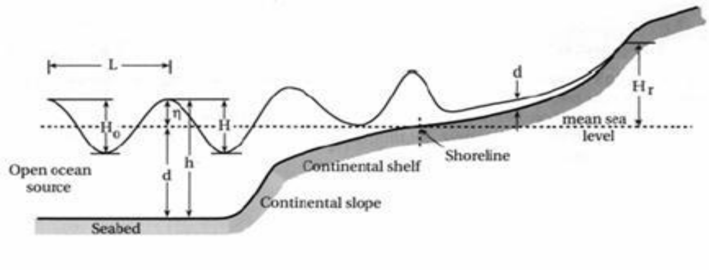


Figure 19 Structure of grass cover (Verhagen, 1998)

Furthermore, the wave run-up is the maximum vertical extent of wave uprush on a beach or structure above the average water level during the flood. Wave run-up is an essential factor in causing slope and revetment erosions (Swenson, 2006). The figure 18 below shows the main parameters needed in order to check the wave run-up. These parameters need to be taken into account during calculations.



L	:	wavelength (m)
H_0	:	wave height at deep water (m)
d	:	water depth (m)
η	:	wave elevation (m)
h	:	water elevation (m)
H	:	wave height (m)
H_r	:	wave run-up (m)

Figure 20 Wave run-up parameters (Wijaya, 2005)

2.1.6. Methods/tests used to check the erosion resistance and bearing capacity of the railway trajectory

The failure mechanisms of embankments of railway foundation will need to be checked. In this section are determinations of calculations that will be used in order to test the erosion resistance and bearing capacity of the railway trajectory.

The dike design should be checked if its sufficient for erosions resistance and bearing capacity during the flood. The Eurocode 7 provides all type of possible limit state, GEO and HYD types, and usability limit state that should be checked for embankments including the following:

- Loss of overall stability Failure in the embankment slope or crest
- Failure by internal erosion
- Failure by surface erosion or scour
- Excessive deformation

General stability analyses

Slope failure mechanisms can be checked in this research by using Infinite slope analyses. This is done by analyzing the stability of slop using the equilibrium equation.
However, there is also a different method which used in ***D-geo stability program***. This method used in order to check circular failure. In this method, the effects of forces on the sides of each slice considered.

The global factor of safety F in **Bishop's simplified method of slices** is equivalent to the partial element on the soil strength parameters with appropriate partial factors this method has been mentioned in calculations section in Appendix 1.
As the embankment is constructed in different phases and with different loads condition analyses should be carried out step by stage. The design should show that settlement of an embankment will not cause a serviceability limit state in the embankment or on the structure above it. **Settlement** can be calculated by using this formula provided in Appendix 1.
After checking the sliding stability and settlements, erosions of grass revetments will have to analyze. The checks will base on **wave run-up a formula** which has been mentioned in appendix 1. Then analysis of grass revetments will be done by using **a simple analysis based on general characteristics plan** which mentioned in appendix 1.
In conclusion, all the results will be collected in order to see if all the functional requirements have satisfactory or not.
All these checks are done in order to check the failure mechanisms that have been mentioned before. In conclusion, most of the mentioned calculations will use to guideline the checks in order to determine both erosion resistance and bearing capacity of the railway trajectory. There are some of these calculations will be done by D-geo, stability program.

During this chapter, the research has been done for each question. Through this passage of the research, report candidates define the basic principles and method for the development of the study to adequately determined the main focuses for the analysis. However, there was some information which could not mention in detail due to lack of sources in English.

2.2. Program of Requirements

During this sub-section of the theoretical framework, the limitations, requirements, and expectations will be discussed. In other words, aspects are taken into account during this research in order to test the stability of the railway trajectory. It may be for example that in the track structure slope has to be tasted to stand against certain water level. There are two parts of the program of requirements, technical and functional requirements.

1. Functional requirements

Three different cross sections based on locations have to check: The locations of the railway trajectory will be used in this research should have Max, Min, and average height during the flood.

- The stability model of the railway dike should be standing with flood probability 1/10,000 years storm
- The dike can hold for over maintenance time of 50 years
- The dike design stability should hold with flooding of 1/10,000 years' storm
- The train is allowed to pass through the dike structure when water level higher than crest level with 50 cm
- The dike has sufficient crest slope to enable train pass on top of it with speed 130km/h
- The design slopes have stability during a presence of water on sides
- The railway structure should be protected during flood and maintenance cost is reduced
- Railway trajectory dike is sufficient erosion resistance during and after the flood
- The magnitude of the water level difference between the inner side and the outer side of the dike should not affect the inner and outer slops
- The dike can stand during changing between high and low water
- The design has to be sufficient for inner erosions, settlements, piping, and seepage

2. Technical requirements

To check the design of the railway dike there are technical requirements will be carried:

1. *Dike main cross-section requirements*

- The height of the primary structure is adding to freeboard of 0.6: the height of the dike should be sufficient for overtopping and should flow the guidelines formula. *See Appendix 1*.
- The width of the crest: The width of the crest has impertinence factor on the stability of dike for that crest width should be at least 3m wide. *See Appendix 1*
- Berm: If the height of the dike is more than 5 meters, a berm shall be provided along the slopes for stability, repair and maintenance purposes. The berm width shall be 3.00 meter or more. However, it might change due to locations differences.
- Slopes: In Dutch standards shows that dike mostly has a slope of 2:1. The slope can be checked by using the **Infinite slope analyses formula** mentioned in theoretical frameworks.

2. *Geotechnical condition*

- Extra-embankment: shall be planned due to a consolidation of the dike. The standard for extra-embankment height is shown in *See Appendix 1*.
- Permeability soil types, for each soil there is different permeability. Checking the permeability soil types of each location is important. In Appendix 1 there is table shows the permeability soil types**.**
- Water level near the dike structure: the water level should be taken into accounts because it could lead to loss overall stability of the dike. If there is a difference in water level piping and seepage need to check.

3. *Railway structure*

Railway structure could add extra load to the arrangements for that it is vital to defined the railway structures.

- Rails: Vignoles rails is the specific type of rails in the Netherlands. The dimensions of this rails can be found in *Appendix 1*.
- Track loads: 76 KN/m^2 load on the bottom of 2.5 m transverse beam width for bearing capacity checks
  63 KN/m^2 over the width of 3m (bottom ballast bed) for determination of the overall stability of the soil structure (ProRail, Desgin Rule , 2016). In *Appendix 1* there is a table which defined all tracks loads.
- Ballast: The ballast layer is having thickness 25 - 30 cm ballast and diameter of (crushed stone 30/60) according to Dutch railways standards (Esveld, 2001).
- Sub ballast: sub-ballast layer is 10 cm, and it is (gravel) 20/50 dimeters. According to Dutch railways standards (Esveld, 2001).

4. *Failures mechanisms*

The failure mechanisms of embankments of railway foundation will need to be checked. In theoretical frameworks section are determinations of calculations that will be used in order to test the erosion resistance and bearing capacity of the railway trajectory. The slope stability will be determined by Bishop's simplified method of slices. The formal used to calculate the safety factor is as follow:

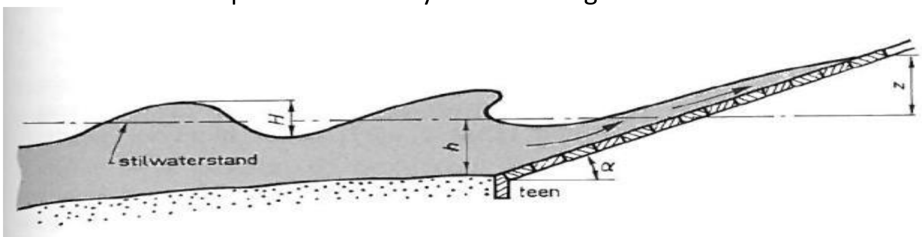
$$T_{mob} = \frac{C}{F} + \sigma_n \frac{tan\varphi}{F} = \frac{C}{\gamma_{M,mob}} + \sigma_n \frac{tan\varphi}{\gamma_{M,mob}}$$

$$\gamma_{M,mob} = \frac{1}{\sum \gamma_G \,.\, w.\, sin\alpha} \sum \frac{\lfloor C_K b + (\gamma_G\, W - \gamma_G\, ub) tan\varphi_k \rfloor sec\alpha}{1 + \frac{tan\alpha .\, tan\varphi_k}{\gamma_{M,mob}}}$$

This formula is used in D-Geo stability program in order to determine the slope safety factor. In addition, the ProRail design rule standard indicates that the minimum safety factor of the slope is 1.3 (ProRail, 2016).
To check the bearing capacity of railway trajectory, the settlements of embankments need to test during and after the flood.
The formula used for settlements calculation is as follows:

$$S_t = h * \left(\frac{1}{C_p} + \frac{1}{C_s} * \log t \right) * \ln\left(\frac{P_0 + \Delta P}{P_0} \right)$$

For the wave run-up is calculated by the following formula:



z = √(H*Lo) * tan α   (Nortier, 2000)
There are different parameters required to check the wave run-up. In appendix 1 there are all graphs and figures needed for the calculation. These parameters need to be considered during calculations of wave run-up.

Then, the grass revetments analyzed by using the ''guidance keys grass coatings dikes serving to draft the manager judgment (B0)'' (More, 2012). In this report, the behavior of coatings on grass has studied. From this guide, the assessment carried to check the grass revetments. The assessment carried by using the following steps:

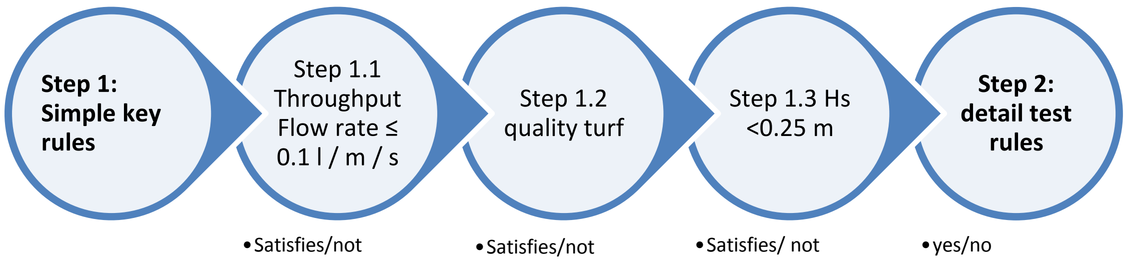


Figure 21 Steps to check erosion of grass revetments

From these steps, the erosions of grass revetments will be checked. These steps mentioned in the method section (See appendix 1 for the Dutch scheme).

In conclusion, all the results will be collected to see if all the functional requirements have satisfactory or not. In appendix 1 and 2 there are different technical information used in this project (More, 2012).

3. Method

3.1. Overview

This research completed by the student systematically to ensure the delivery of a product of high quality. Various activities have been completed to find the most suitable and efficient result for the research in the railway trajectory on the area of Reimerswaal. These have been determined based on the knowledge in Dutch research called [Vitale infrastructure in Reimerswaal] which translated into English as ''Vital infrastructure Reimerswaal''. It has an assessment of stability and erosion resistance of the A58 road.
In additions, research based on the information gathered from the additional literature. The activities and the products resulting from them are as follows:

- Formulation of research locations and selection parameters
  - Data collection
  - Analysis of data
  - The determined number of parameters used to choose locations
- Selection of the most suitable method to select locations to test the erosion and bearing capacity of railway trajectory which will be described in this chapter.
- Determined locations
  - Use AHN.nl to find the average elevation of Max, Min and an average height of railway trajectory line
  - Choose three locations with MAX, Min and an average height in the total railway trajectory
- Flood scenarios
  - Check each flood scenario (VNK2) on the railway trajectory
  - Check if the three cross sections: flooded, almost flooded and not flooded
  - Calculate the hydraulic head of each location during the flood
- The primary design used for calculations(MCA)
  - Determined three alternatives
  - Criteria
  - Weight
  - Results
- Determined the railway cross-section dimensions and slope
  - Determined the detail cross-section heights and width in existing locations
  - Determined the slop on the existing situations
  - Make detail cross-section drawings with dimensions
- Check the geotechnical conditions of the soil structure
  - Determined the subsoil properties
  - Determined embankments soil properties
  - Unite weight of saturated and unsaturated soil
  - Determined the groundwater level

- Loads
  - Determined loads on top of the crest
  - Load combinations
  - Train weight
- Slope stability
  - Situations used for calculations
  - Develop the modeling program D-Geo stability by using all information above
  - Build cross sections model in the D-Geo stability programme
  - Check the slope stability

  - ➢ Overview safety factor of the structure
- Determined the total settlement
  - ➢ Determined the settlement formula
  - ➢ Determined the settlement periods check
  - ➢ Calculate settlement in a normal situation before the flood
  - ➢ Calculate settlement during the flood
  - ➢ Calculate settlement after the flood
- Wave run up
  - Check the wave run-up
- Erosions of grass revetments analysis
- Collects results

3.2. Data collection sources

The qualitative and quantitative data required to complete the research which gathered using public information that available digitally.
Also, various formulas and safety standards refer to perform the calculation. These, as well as the modeling guidelines for the task, can be found in Deltares guidelines and/or from research ''assessment of the stability and erosion resistance of the A58 trunk road Reimerswaal'' by Steur (2016), which will have a significant influence on the outcome of the research. For the safety guidelines required for this calculation, the Eurocode and the NEN standards (Dutch National standards) for the respective chapters will be applied. Also, the design rules provided by ProRail used in this research.

Resources and Materials

To complete the research, the student will require access to the information sources mentioned in this section:
Data collection method
The specified websites, literature and other sources. Furthermore, the report of Mr. Papenborg will be overseeing the progress of the project, and the received feedback is used as a basis for the correct use of the gained knowledge.
Software
This project completed by using specific software, such as:

- MS Project
- Q-GIS
- D- D-Geo stability
- Excel

Optimization: obstacles

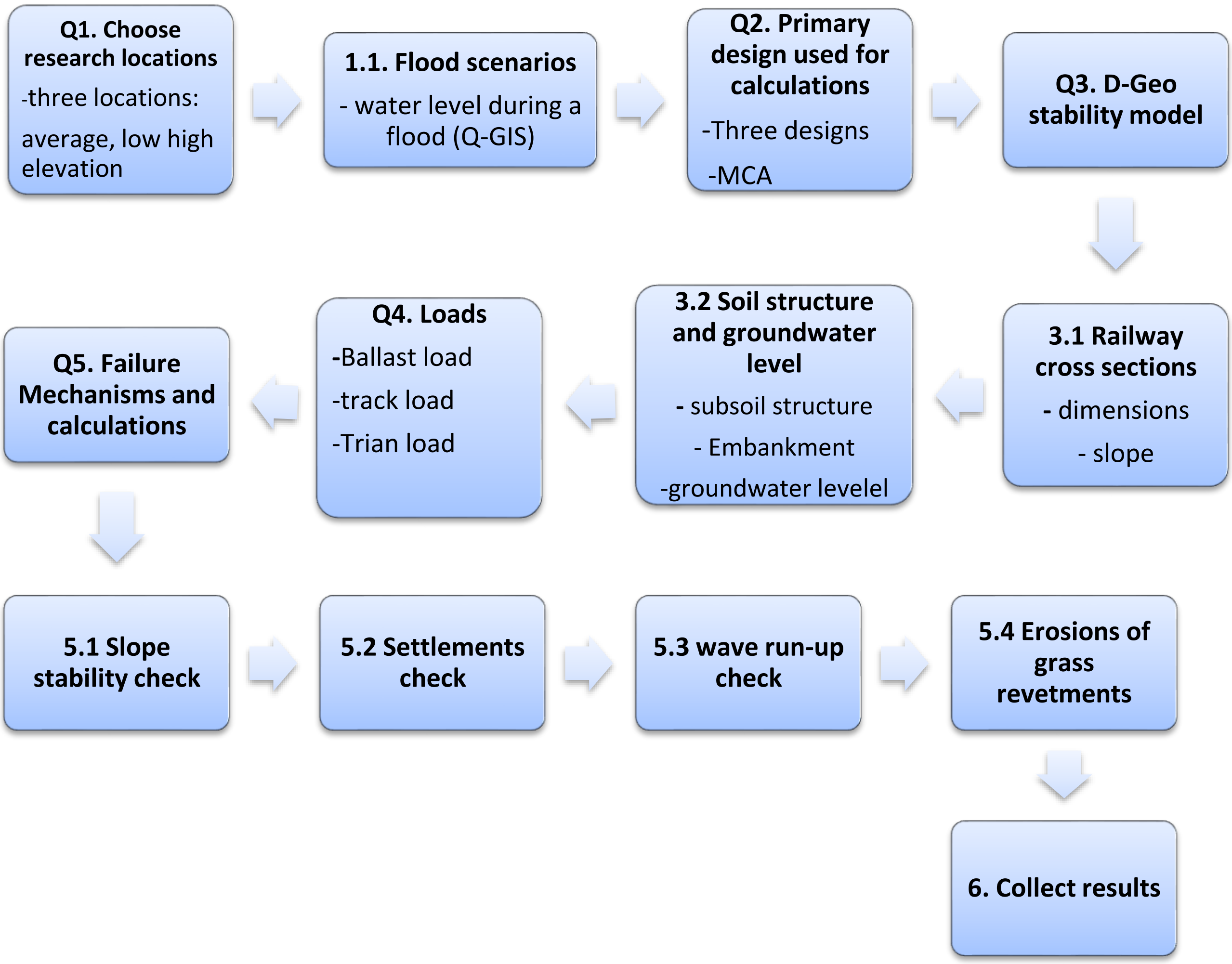
1. Data: old, unreliable, not sufficient
2. Lack of experience and insight

The method for the planning of the assessment railway trajectory stability involves the following stages and activities:

Data Analysis

Based on the data gathered from the various sources mentioned above, guidelines, safety standards, and calculation formulas all will be used to check the stability of railway trajectory.

3.3. Detailed research steps - Calculation Methods:



1. Choose research locations:

In this study, the railway trajectory visualized as a dike. Also, with the start of the research three locations at least is determined to check erosion resistance and bearing capacity of each cross-section. These steps are used to determine the locations:

- Check the area and highlight the main railway trajectory path.
- The AHN.nl used to find the Max, Min and an average height of railway trajectory (range of area).
- The railway trajectory evaluations with MAX, Mine and Average elevations determined by using AHN.*nl*.
- Defining the coordination for Max, Min, and average height
- Three locations coordination determine

1.1 Flood scenarios

The flood scenario used to identify three locations. The Reimerswaal municipality is protected by dikes from both sides north and south. However, in case of flooding the water level will be less on areas of railway trajectory due it built into an embankment. For that, water level during flooding determined for each location by using Liwo.nl website. The flood scenarios have provided by Mr. Lukas Papenborg. Then, these steps have been followed to determine three flood scenarios:

- The 23 flood scenarios in the area of Reimerswaalare checked by using VNK2
- All these flood scenarios modeled using Q-GIS
- The elevation and flood scenarios added in same Q-GIS model/map
- The three locations defined as follow: flooded, almost flooded and not flooded

2. Primary design (MCA)

The design of the dike is determined by using MCA. The dike design defined to check the worst situation during the flood. The design determined by using the steps mentioned in MCA section. These steps are:

- Three designs alternatives to include ballast and currents in calculations
- Criteria to analysis the worst design
- The weight of each criterion from 100%
- The result of the MCA

3. D-Geo stability model

In this study, model program D-Geo stability used which is developed by Deltares. In the introduction, some information has been mentioned regards this program. D-Geo stability program has chosen to see the balance of railway trajectory structure. There are some investigations need to be carried before the start of modeling. There are some parameters required for D-Geo stability program. The flowing parameters have to determine:

- Research site
- Ground surface
- Construction build up
- Groundwater/reclamation
- Flood water level
- Ballast load
- Traffic load

The parameters determine by applying desk research. After all parameters and standards founded and adapted, modeling can start. Within the model, different scenarios are tested. As based on the A58 road research (Steur, 2016) the following scenario has been tested:

1. Zero situation: (no train presence normal railway structure load):
    - Before the flood: in which the water level is equal to groundwater level and standard upper structure load
    - During the flood: standard upper structure load and high water level
    - After the flood: standard upper structure load and groundwater level is still under a high pressure
2. Loaded situation: (with train load)
    - Before the flood: in which the water level is equal to groundwater level and train load presence
    - During the flood: train load and high water level
    - After the flood: train load and groundwater level is still under a high pressure

These situations used to determine the slope stability of the dike structure. There are site investigations needed to model these situations in D-Geo stability program. These sites investigations as follow:

3.1. Railway slope and cross section

After that, the existing cross section of railway structure is demonstrated for three locations. Dimensions are determined by using GIS evaluation and global height maps in the Netherlands. The coming two steps are carried for each location:

1. These five dimensions specified:

- The height of main railway structure
- Ground level
- Height of slope
- Embankment width
- Embankments slope
- Ditch depth
- Ditch width

this is done for right and left of railway trajectory.

2. Sketch cross-section of the existing location

(All these steps carried for the three locations)

3.2. Soil structure and groundwater properties

3.2.1. Soil structure

The soil properties play a significant rule in the stability of dike. The soil data determined by using Dinoloket.nl. This website is available publicly. Dinoloket.nl website has detail information of the subsoil structure in the Netherlands.
However, Dinoloket includes none info regards the railway embankment. For that, the dike/embankments properties based on historical data on topotijdreis.nl.
Soil properties determined for all three locations. Soil properties of the track foundation and subsoil specified by using both websites (Dinoloket.nl and topotijdreis.nl).

3.2.2. Groundwater properties

Groundwater level plays a significant rule on the stability of railway trajectory structure. As too high groundwater level within railway embankments, the land easily washed out. Like the soil structure, water levels determined from the Dinoloket. The groundwater levels assessed for all three locations.

4. loads

The railway structure determined during this project by using desk research and site investigations. This information used to check the erosion resistance ballast.
To check the bearing capacity and erosion resistance of ballast the flowing has to determine:
• First, the desk research done to specify the loads affects the stability of the embankments.
• Loads combinations
• Then determined the train load

5. Calculations and Checks

With modeling the D-Geo stability, it is possible to produce different results such as slope stability. There are different calculations required to check the slope stability of railway trajectory embankments:

5.1. Slope stability

First, the overall stability of slopes in this research tested by using D-Geo stability program. Slope stability checked by using the design values of actions, resistance, and strengths obtained using the

appropriate GEO/STR values for the partial factors. Then, the D-Geo stability results provided by the safety factor and safety overview of the structure.
This result based on Bishop's simplified method. A global factor of safety F in Bishop's simplified method of slices is equivalent to the partial factor on the soil strength parameters with appropriate partial factors on the actions as shown in the following equations:

$$T_{mob} = \frac{C}{F} + \sigma_n \frac{tan\varphi}{F} = \frac{C}{\gamma_{M,mob}} + \sigma_n \frac{tan\varphi}{\gamma_{M,mob}}$$

$$\gamma_{M,mob} = \frac{1}{\sum \gamma_G \,.\, w.\, sin\alpha} \sum \frac{\lfloor C_K b + (\gamma_G\, W - \gamma_G\, ub) tan\varphi_k \rfloor sec\alpha}{1 + \frac{tan\alpha .\, tan\varphi_k}{\gamma_{M,mob}}}$$

In, γG = 1,35 is applied to permanent actions, including the soil weight force via the soil weight density and γQ = 1,5 is applied to variable actions when analyzing the overall factor of safety, F using the method of slices. Then it is checked that F, which is equal to γM; mob, is greater than or equal to 1,0 (Bond, 2013).

5.2. Settlement

In this phase, the settlement of the structure is checked before, during and after flooding. The embankment constructed in different periods and with different loads condition analyses should be carried out by steps. The design should show that settlement of an embankment will not cause a serviceability limit state in the embankment or on the structure above it.
To check the bearing capacity of railway trajectory, the settlements of embankments need to test before, during and after the flood. The method is used to calculate the settlement is requiring comparison of:

• One-day settlement before, during and after the flood
• Two weeks' settlement before, during and after the flood
• One-month settlement before, during and after the flood
• Two months' settlement before, during and after the flood

Above situations are done for each cross section.
The settlement for each location calculated by using the following formula
:

$$S_t = h * \left(\frac{1}{C_p} + \frac{1}{C_s} * \log t \right) * \ln \left(\frac{P_0 + \Delta P}{P_0} \right)$$ (Esveld, 2001)

The settlement calculated for each 0.05 m height. The calculation is done by using excel files.

5.3. Hydraulic failure

Wave run up

Hydraulic failure is focusing on the presence of water below ballast or embankments. For that, checks will be carried to determine the wave run-up. The calculation is done by using wave run-up formula:

z = √(H*Lo) * tan α (Nortier, 2000)

The wave run-up calculation carried by using the following steps:

- The effective fetch determined by checking the wind direction
- The velocity during flood specified for each location
- Then, the water depth during flood calculated using the ground level and water level during flood
- Wavelength and wave heights are determined using the formula and graphs in appendix 1

Then, the wave run-up calculated for each location.

5.4. Erosions of grass revetments

Then, an assessment carried to check the grass revetments by using the ''guidance keys grass coatings dikes serving to draft the manager judgment (B0)'' (More, 2012). Th assessment carried by using the following steps:

- **Step 1: Simple key rules:**
- Step 1.1 Throughput Flow rate ≤ 0.1 l / m / s
  If the flow rate is lower than this value, it assumed that the damage is tiny on the grass revetments.
- Step 1.2 quality turf
  Step 1.2 comprises an assessment the quality of the lawn. This determined through visual maintenance inspection. If there are small grass with no dry trees, the maintenance has carried recently. If there are big trees with low-density grass, it means an erosion of the outer slope (not satisfy).
- Step 1.3 Hs <0.25 m
  If the significant wave height at the toe of the flood defense is less than 0.25m, then the score 'satisfies.' If not, the test continues with Step 2.

- **Step 2: detail test rules**
  Review the bank exposed to a cumulative overload. In this step, the following has checked:
- The grass covers should be closed and must have the same vegetation
- Slope angle should not be more than 1:2.3
- There should be clay layer thickness 0.4m present
- Tress and objects not allowed to present on the slope
-

Note: If the first step satisfies the next step does not need to be checked.

6. Collects Results

All activities carried out at the same time for the three locations. In conclusion, the results of all failure mechanisms of all locations analyzed together to get the final results.

4. Results

In this research, there are different analyses and calculations had been carried to check the erosion resistance and the bearing capacity of the railway trajectory. In this section, the research steps and results are shown.

4.1. Choose research locations

In the start of this research, it was essential to determine three research locations to analyze the railway trajectory. Three locations were identified with a high, a low and an average height. The research location specified by using (AHN) the height map of the area. Figure 23 shows the three locations used in this research. These locations coordination (x, y) are:

- Average elevation area: location 1: 67258.47072, 383084.0487
- Low elevation area: location 2: 63552.85868, 385538.3253
- High elevation area: location 3: 60049.76304, 387639.1533

Figure 22 Research locations (openstreetmap, 2018)

4.1.1. The overall height map of the Netherlands

The three locations have a different ground elevation. The height map used to determine the height for each location. Figure 23 shows the research locations and NAP level of each location. A blue presents a low area and green with a high elevation area.
(Location 1: +1. 3m NAP; location 2: +0.55 m NAP and location 3: +6m NAP).

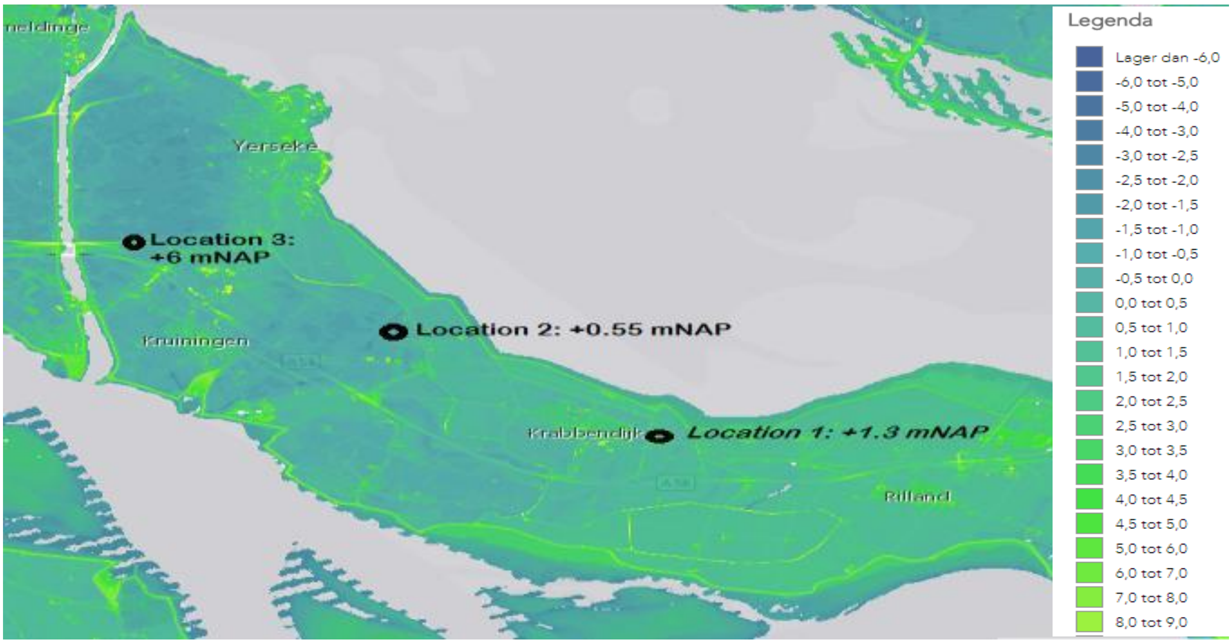


Figure 23 Height map for research locations (AHN , 2018)

In addition, the AHN used to demonstrate the height taken for the D-Geo stability model. There were several height parameters required for the program. These heights are determined in the table below:

Table 1 Parameters for D-Geo stability model

	Location 1		**Location 2**		**Location 3**	
Main railway trajectory	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**
Ground level (m NAP)	+0.81	+0.9	-0.48	-0.47	-0.96	-0.40
Ground Water level (m NAP)	-2.1		-2.6		-1.81	
Crest width (m)	6.5		7.5		10	
Crest level (m NAP)	+1.27	+1.33	+0.51	+0.61	+6	+6
Embankments slop	1:5	1:7	1:7	1:15	1:4 1:2	1:4 1:2

These values on table 1 used to model the existing cross sections. Then, these cross sections with detail height levels used for calculations and checks.

4.1.2. Flood scenarios

The next step was to determine the water levels during the flood. Water levels during flood were classified by using the VNK2 flood scenarios.
Water level during flood used on the calculations and the checks of the railway trajectory during the flood. In the Reimerswaal, there are about 23 flood scenarios as shown in figure 24 below.

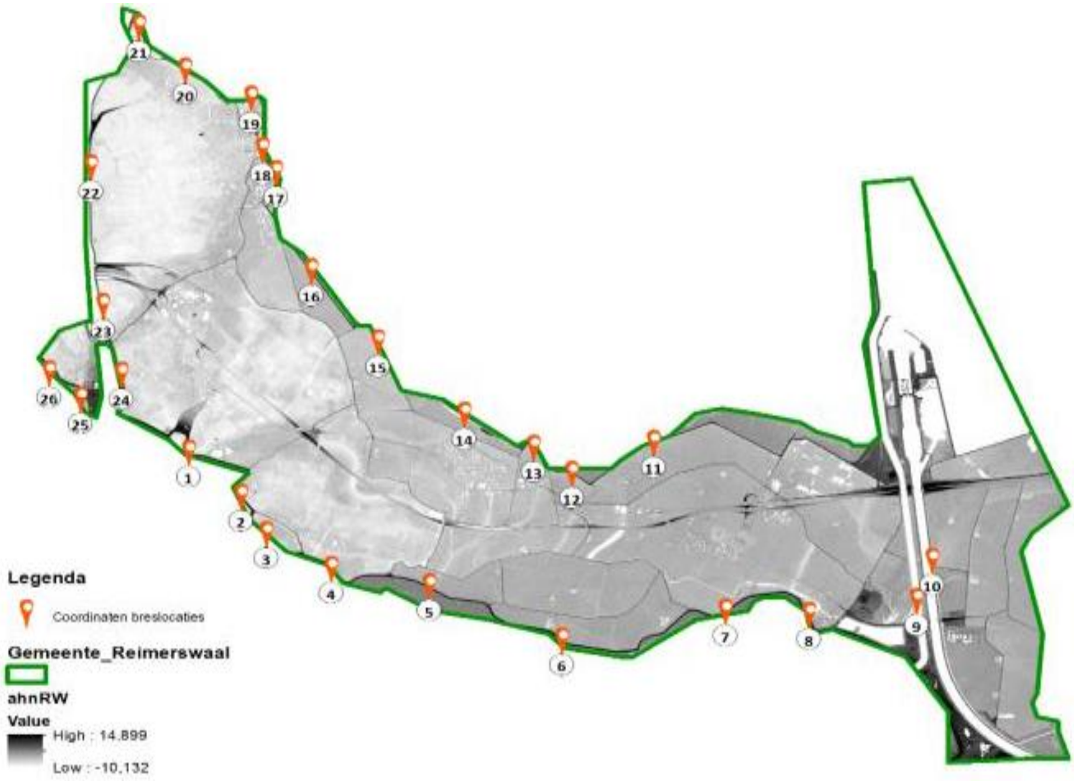


Figure 24 Flood scenarios in Reimerswaal (Steur, 2016)

There were different effects for each flood scenario. These 23 flood scenarios checked by using Q-GIS to determine the impact on the railway trajectory. The worst flood scenarios of each location were defined. There are three main flood scenarios chosen for this research:

- Twee de Bath polder
- St. Pieters polder
- Yerseke More

The flood scenarios selected based on the area covered by water and the effect of water level on the railway trajectory. The following figures (25,26 and 27) show the flood scenarios were chosen for this project. The red points show the area where the dike breakthrough.

Figure 25 Flood Scenario for research location no.1 Twee de Bath polder (LIWO, 2018)

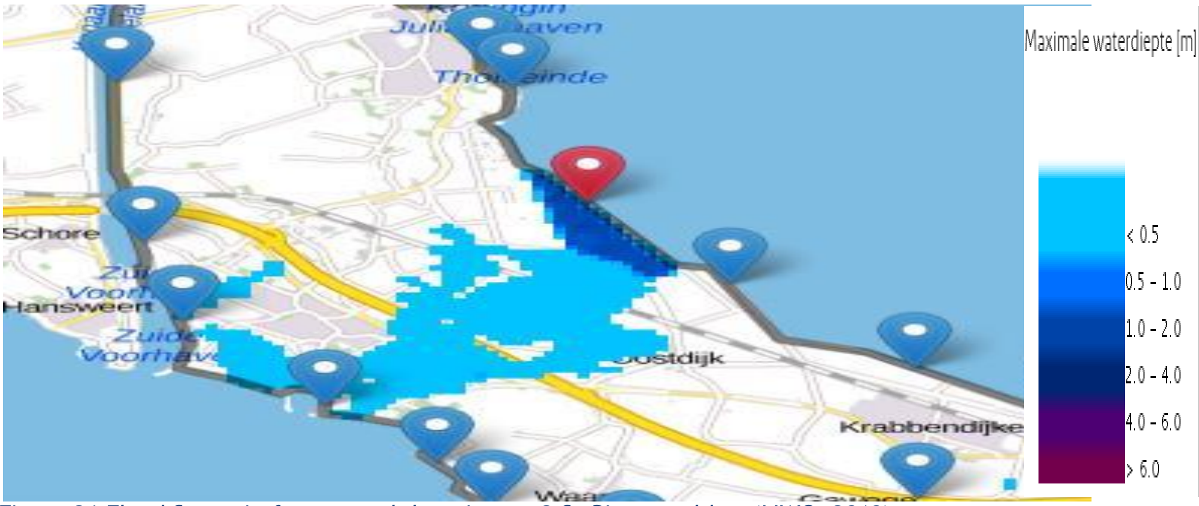


Figure 26 Flood Scenario for research location no.2 St.Pieterspolder (LIWO, 2018)

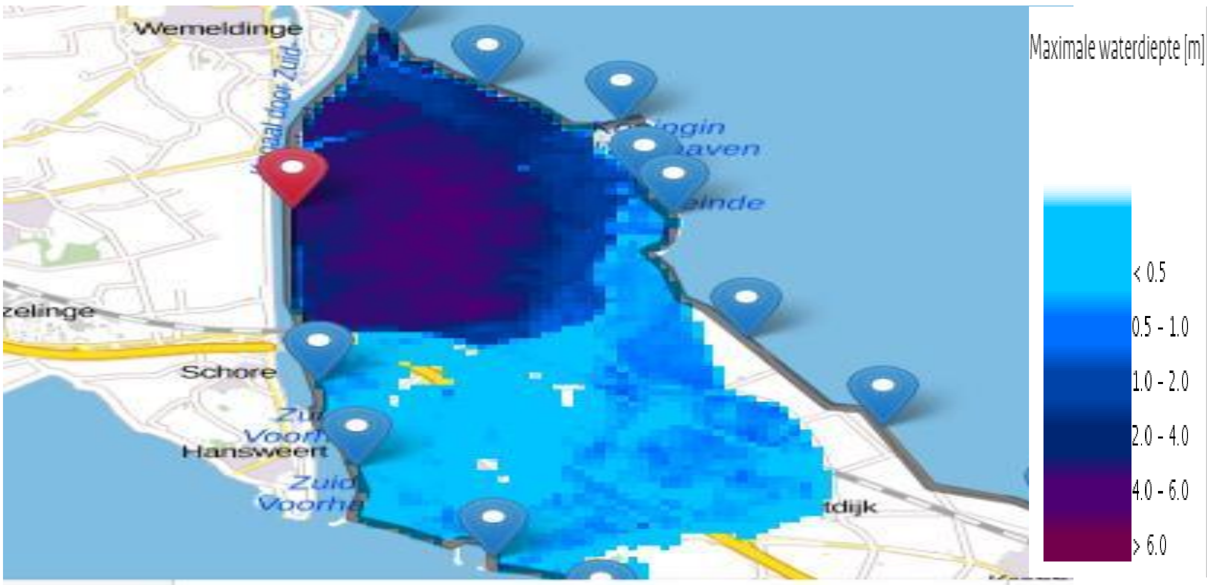


Figure 27 Flood Scenario for research location no.3 Yerseke Moer (LIWO, 2018)

By using the flood scenarios mentioned above the water level during the flood identified. The water level during a flood specified by adding flood scenarios to the ground level map. Then, the water depth during a flood had been determined by using the Q-GIS. The following table shows the water level during the flood for each location. See appendix 4 for Q-GIS flood scenarios models.

Table 2 Water level during flood determined from the Liwo and Q-GIS

	Flood Scenario	**Ground level**			**Flood water level (Liwo)**	**Water depth (Q-gis)**		
		[m NAP]			[Range m]	[m NAP]		
		Left	Mid	Right		Left	Mid	Right
Location 1	Twee de Bath polder	+0.81	+ 1.3	+0.9	0-4	+1.6	+1.6	+1.6
Location 2	St. Pieters polder	-0.48	+0.57	-0.48	0-4	+0.21	+0.21	+0.21
Location 3	Yerseke Moer	-0.96	+6.2	-0.4	0-6	+4.5	~+2.3	+0.9

From the table above, the water level during a flood, location one is entirely under water during the flood. Besides, location two is almost flooded where the water level during the flood is 0.5m lower than the crest. Location three is not flooded, but the water level during the flood from both sides is different where the left side is 4.5, and the right side is almost 1m.

In fact, the standard dike structure of the ballast load does not present on the crest. For that, it was essential to analyze the effects of ballast and currents on the slope stability of a dike. For that, the next section is analyzing the design to include ballast and currents during the calculation of this project.

4.2. Preliminary design

This section will comprise the Multi-Criteria Analysis (MCA), to determine the dike design of that used in calculations of this project.
The railway embankment in this research designed as dike structure. In fact, this design has a different design than a general dike design due to the presence of the ballast load and currents. For that, the Multi-Criteria Analysis (MCA) carried out to choose one design to include ballast and currents on this research.
This design should have the worst situation expected during the flood. The design used to determine the worst failure mechanisms that should be checked in this project.

4.2.1. Design of railway dike

In the start of this MCA, five steps used to find the worst design due to the presence of ballast and the currents (see figure 28). The first step of this process was to come up with three models to include the ballast and current on calculations of the railway trajectory. Afterward, there were other steps taken during the MCA analyzed such as criteria, weight and the grading process. In the final step, results were shown and discussed.

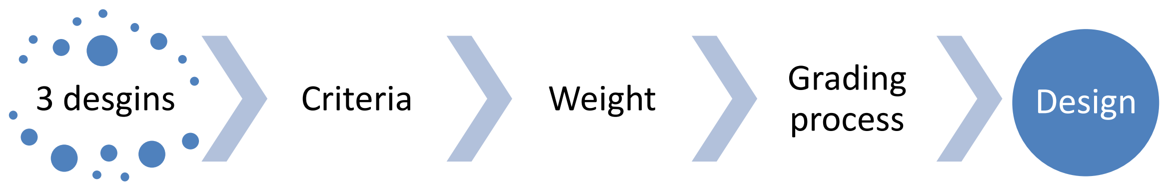


Figure 28 MCA

4.2.2. Alternatives

The first step was to come up with three designs to consider the effects of ballast and water currents. The Multi-Criteria Analysis (MCA), was done for overall designs with same dimensions. The water level assumed to be the same for all models. For each design loads were different as shown down.

Design 1: The ballast is a revetment of the crest of a dike with the presence of currents

The cross-section of the railway trajectory assumed a dike with same slop from both sides. Also, the ballast considered as gravel revetments on the top of the dike. In this situation, the currents of water will be present, and the water level assumed to be the same on both sides.

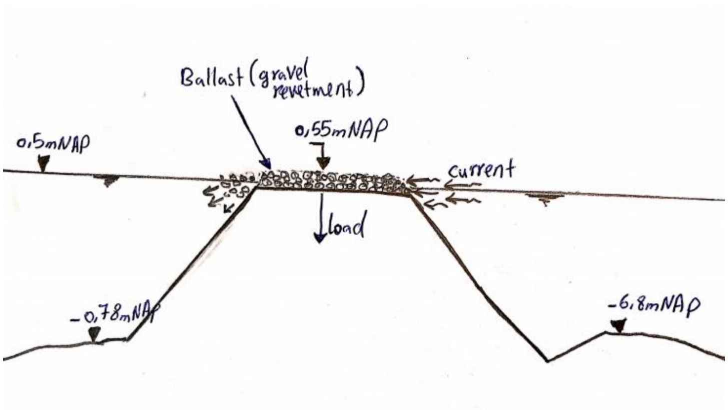


Figure 29 Design 1

In this situation, the risk of failure is high due to the presence of water from both sides with currents. Also, the ballast will act as a load on the dike. Also, if the water goes through the ballast and currents could cause erosions to gravel revetments parts. If the crest is eroded the failure will not affect the ballast itself only, but it affects the inner slope and other structures of the dike. For that, there are different dike failure mechanisms will have to be checked with this design.

In this design, the calculation has to be based on checking the erosion of the revetments of the dike when there is overtopping. The other part of the calculations is based on testing the stability of the dike when water is presented from both sides. For that, this design has a high probability of failure.

Design 2: The ballast as a load on the dike without currents presents

This design of the dike has the same cross-section as option one, but there is no current on the dike. In this situation, a ballast is taken into accounts as a load on top of dike structures. This load will be distributed in the dike structure. For that, it will affect the stability of the dike structure.

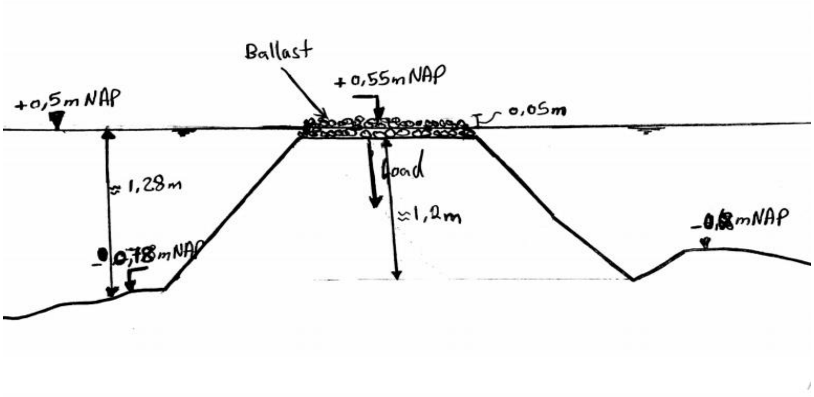


Figure 30 Design 2

In this situation, the calculations are based on checking the stability of the dike when there is an extra load is present and how this load is distributed on the dike. The other part of the calculations is based on checking the stability of the dike when water is presented from both sides.

Design 3: Currents and the ballast is not presented on the crest

The cross-section of the railway trajectory is assumed as dike with same slop on both sides. In this situation, the water level is considered being the same on both sides, and the currents are presents. There will be no ballast on the crest of the dike. The dike structure is more open to water particles on the crest because there is no ballast revetment on the top.
In this situation, the calculations will focus on checking the stability of the dike during a presence of currents of the water.

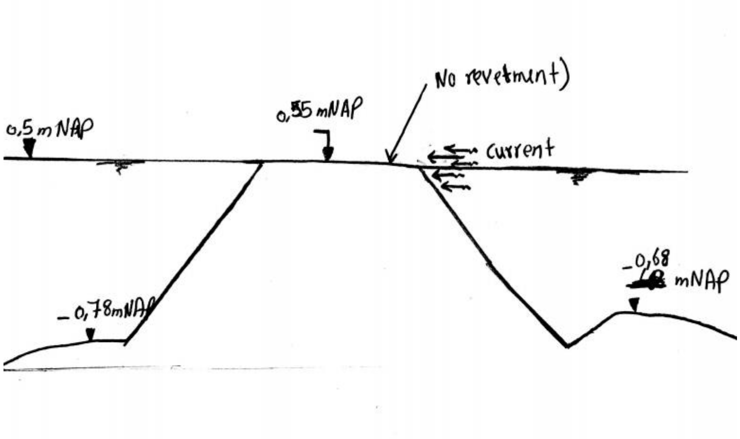


Figure 31 Design 3

4.2.3. The Criteria

The three designs above were determined to take into accounts the ballast and currents during the checks of the research. For that, four criteria used to choose the worst design that could be considered during calculations in this project.

1. Load distribution

The load distribution is taken into accounts as criteria to determine the effects of the loads and currents on the overall design. In this section, the measurement will depend on how the load will be distributed in the structure, and what are the effects on the design structure. Extra load leads to more consequences such as increase settlements.

2. Overall slope stability

The design stability is an essential factor in determining the results of the currents on crest revetments and the load of the ballast on the dike. For that, the first criteria to check if the dike has enough baring stability or not. These risks measured by how the design affected by currents or the load. From all these designs, one considers causing more effect on the stability of the dike slope and have to take it into accounts during this project.

3. Erosion of the dike structure

The decay is a dangers failure mechanisms which should be taken into consideration when choosing a design that affected by two factors (currents on crest revetments and/or the load of the ballast on the dike). Where the presence of erosions on the outside slop, inner slop and revetments will have a different risk on the dike structures.
For that, the design tested on what will erode on the design and which the dike structure will be affected. The more erosions mean the worst damages on the design.

4. Settlements

The settlement is an essential factor that used to check the effects of loads and presence of water near the dike structure. The settlement could be a difference on these dikes due to the change of the load on the top of the dike. Also, Failure mechanism is an essential criterion to choose different factors have affected the design. Different failure mechanisms expected to happen in each of the models. The more failure mechanisms of design will have more interest to check during this project.

4.2.4. Weight

For all criteria above the pressure in percentage has been given as shown down. These percentages have been estimated for the importance and damage of criteria. The criterion with higher weight means the criterion has more effects on the dike stability than other criteria. The overall stability and erosions criteria have a higher weight than other criteria because both are the worst failures effects the dike.

Criteria	Weight
Load distribution	25%
Overall Stability	35%
Possible erosion of the dike structure	30%
Settlements and other failure mechanisms	20%
Total	100%

For each of the four criteria, the impact is rendered measurable by using five categories. These categories used to evaluate how serious is the consequence of the criteria on the stability of the dike.

1. Limited impacts
2. Substantial impacts
3. Serious consequences
4. Very serious consequences
5. Catastrophic consequences

The limited impact means that the criteria have small effects on the design. Also, the catastrophic consequences indicate that there are high effects of the criteria.

4.2.5. Results

In this section, each design will be graded through all criteria to choose the most affected design. The evaluation is done from 1-5 for each criterion as shown in table 3.

Table 3 MCA Result

Criteria	Weight	Design 1	Design 2	Design 3
Load distribution	**25%**	4	2	2
Overall slope stability	**35%**	4	3	3
Possible erosion of the dike structure	**30%**	3	1	5
Settlements and other failure mechanisms	**20%**	4	4	2
Total weight	**100%**	4.1	2.65	3.45

1. Load distribution

In the design one, there are two different loads will presence. The first load is a ballast load on a top of the crest. The ballast load is about 12.5 KN/m2 based on ProRail design Rule (ProRail, 2016). This load causes higher stress and vertical force on the overall dike structure. The second load is the horizontal load due to the presence of water. There will be a horizontal load presence from sides due to the pressure of water. For that, both two loads weaken the stability of a dike.

Design one has a score of (4) due to the presence of both loads. Besides, the forces and moment increased due to due to friction between the structure and the fluid. Also, under ballast pressure force considered due to the current.

The second design has a score of (2) in load distribution due to the presence of one load. In design two, the ballast is acting as a vertical load, but the current not considered. For that, there will be a few loads effects on the stability of the dike.

However, the third design has the same score as design two (2) for the load distribution effects. The ballast load is not present which means less vertical load on the top of the crest. The current load still affects the dike design for that cross-section three has a score of two.

2. Overall slope stability

The slope stability has analyzed for each design by determining the effect of extra load or presence of water currents. The extra load on the crest causes instability of the slope. Also, currents cause slope materials to wash out or undermining of the slope.

In the three designs, instability of the overall slope score is higher due to the presence of current and/or a load of ballast on top of the dike.

The first design has the highest score (4) due to the presence of both the ballast and currents. The ballast effects the dike slope stability by an extra load on the top of the crest. In addition, the slope instability increased due to the presence of currents which decreased the stability of slope material. In addition, designs two and three have a score of (3). For design two, the effect of water current neglected for that fewer effects on slope stability than design one. Design three the currents present, but there is no ballast load on the crest. For that, the slope instability is less because of instability caused by currents only.

3. Possible erosion of the dike structure

According to the dike design rules, the dike crest should be fully covered with the revetment. Besides, a crest of the dike should be impermeable. In most cases, there is a revetment on top of the dike to protect the erosion during current. Also, the analysis of erosion possibility depends on the presence of currents.

Design one has a score of (3) on erosions possibility due to the presence of currents. Besides, there is ballast revetment which is gravel, and it is a high permeable type of soil. For that, there will be minor erosion due to currents because the current neglected for that less erosion of the dike structure. However, the second design has the low score in the possibility of erosion (1) because there is no current in design two. For that, there will be limited erosion on this design.

Also, it is clear from the table above that the third design has the highest score (5) on the possibility of erosion. In the third design, a current is present and the design with no revetments. For that, the possibility of erosion failures occurs too high.

4. Settlements and other failure mechanisms

The three designs analyzed to determine the highest value settlement design. Soil considered to be the same on all three designs. For that, the analysis depends on the change of loads on the settlement value. The extra load will lead to a higher settlement. In fact, ballast load settlement is more important than the total track settlement.

For that, in all three designs, there will be a standard settlement. However, due to the presence of the ballast load on designs one and two, the settlement expected be higher. For that, design one and two have a high score (4). The increased of the settlement will influence the stability of the design which it should consider in this project.

The third design has a low score (2) because the ballast load not considered in this design. Besides, the value (2) recognize due to the regular embankment settlement is still occurred which considered during this assessment.

5. Total weight

After analyzing all three designs, the total weight from 5 calculated by using the criteria weight and the consequences score. The table above shows that design has a total weight of 4.1. Design one has the highest score due to existing of both currents and ballast load which increased the failure mechanisms in this design.
For that, during this research, both ballast load and currents effects will be checked for each location mentioned in the previous section 4.1.

4.3. Soil structure

In the previous section, the three research locations had been determined by using the height maps (AHN). Besides, the water level during the flood had been specified for each location. Then, subsoils and embankments properties had been determined for each location by using the following steps.

4.3.1. Subsoil structure

The Embankment soil properties and subsoil ground structure were required for the D-Geo stability model. The subsoil ground structure was determined by using dinoloket. There were different boreholes near to the three research locations. The nearest point had been chosen to identify the subsoil properties as shown in figure 32.

Figure 32 Dinoloket.nl borehole locations (dinoloket, 2018)

The subsoil ground structure for each location was specified by using the boreholes (see figure 32). Below the detail results of soil structure for the three locations are shown:

1. Location one

For location one, the borehole used is B49C1324 which has a depth of 6m. In location one, the borehole shows that the top subsoil contains clay layer for about 2.5 m. Then Peat layer presence for about 1.5 m and the bottom part includes mostly clay. Table 4 shows the subsoil structure on location 1.

Table 4 Subsoil structure location 1

subsoil structure location 1		
	From	Until
Clay	0.00	-2.50

Peat	-2.50	-4.20
Clay	-4.40	-6.00

2. Location two

Location two the subsoil properties have used from borehole B49C1579 which has a depth of 11 m. In location two, the clay layer is presence almost to -8 m. Also, the bottom part contains sand for about 3m. Table 5 shows a subsoil structure in the second location.

Table 5 Subsoil structure location 2

subsoil structure location 2		
	From	Until
Clay	0.00	-2.10
Peat	-2.10	-2.70
Clay	-2.70	-8.10
Sand	-8.10	-11.00

3. Location three

For location three, the borehole used is B48F0053 which has a depth of 20m. Location three contains sand subsoil for about 17m. However, in the upper part, there is a clay layer for about 2.40m depth. In table 5 below is the subsoil structure in location three.

Table 6 Subsoil structure location 3

subsoil structure location 3		
	From	Until
Clay	0.00	-2.40
Sand	-2.40	-18.50
Clay	-18.50	-20.00

Appendix 3 shows boreholes structure of the three locations exported from dinoloket.

However, there is still a further investigation has to be carried to determine the embankment soil properties. In the next chapter, further steps are mentioned which used to determine the type of embankments.

4.3.2. Embankments

There is no a specific source to determine the railway embankment soil properties. For that, the investigation is based on a historical data which is available to the public on the website (topotijdreis). The website used in this project to determine the type of soil on the embankment for the thee cross-sections.
The assumption based on a comparison between old and the new railway structure. If the railway structure has same as a new structure that means, the embankment is still clay. As in the past, the Dutch used natural farm clay to make railway embankments (Verhagen, 1998). Besides, if the new railway line has a different place of the old embankment, that means the embankments has changed from clay to sand.

Location one

For each location, the comparison was made between 1852 and 2017 to check the embankments soil type. For location one as shown in the figures 30 and 31 below the embankments has the same soil that removed from the ditch. Also, there is no difference between the map of 1852 and 2017, so the embankment soil type is clay.

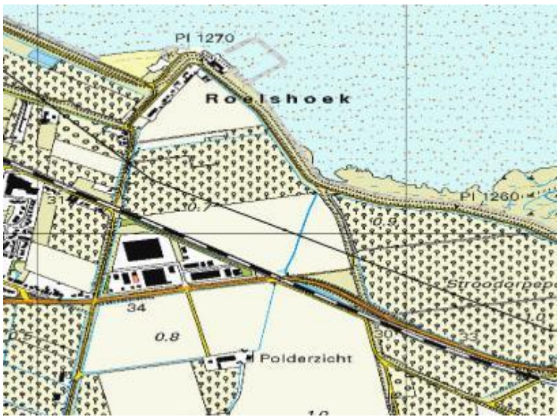


Figure 33 Location 1 1852 (topotijdreis , 2018) *Figure 34 location 1 2017 (topotijdreis , 2018)*

Location two

The second location has also checked, the figures 32 and 33 below show the compression of the railway line between 1852 and 2017. Figure 32 shows the railway trajectory embankments in 1852 where it built of clay. In addition, figure 33 shows the railway embankments in 2017 which almost the same area and bath as in 1852 (figure 32). From both figures, the railway trajectory embankment is still the same which is clay.

Figure 36 Location 2 1852 (topotijdreis , 2018) *Figure 35 Location 2 2017 (topotijdreis , 2018)*

Location three

In location three the compression was challenging to organize due to various embankments presences on this location. In figure 34 and 35 are the railway trajectory in 1852 and 2017, respectively. There are few changes done on the railway trajectory embankment. For that, the soil type has changed from clay to sand in the new design. Also, the ProRail experts have confirmed that location three new embankments of sand.

Figure 37 Location 3 1852 (topotijdreis , 2018)

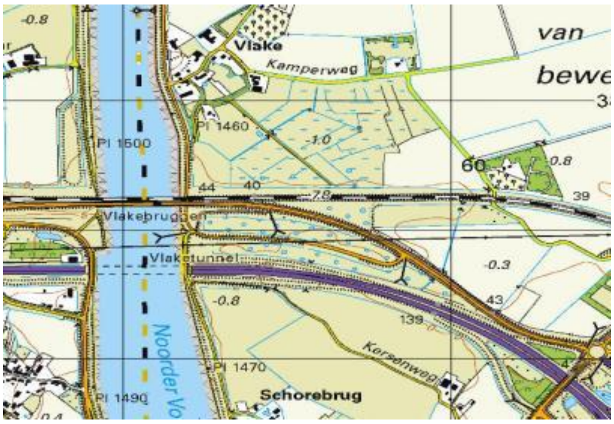


Figure 38 Location 3 2017 (topotijdreis , 2018)

4.3.3. Groundwater level

The groundwater level determined by using the website dinoloket. The groundwater level is an essential factor for the D-Geo stability model and checks. The groundwater level has identified for each cross section. The figure 39 shows the three points had been selected to check the groundwater level of each location.

Figure 39 Points used to check groundwater level (dinoloket, 2018)

By using the dinoloket, the groundwater level has been determined for each location. Table 6 shows the groundwater level for all the three locations. This groundwater levels will be used for D-Geo stability checks and settlements calculations.

Table 7 Locations groundwater level

	Bore	Ground level	Groundwater level
		NAP	NAP
Location 1	B49C0143	+1.3	-2.10
Location 2	B49C0129	+0.57	-1.84
Location 3	B49A0203	+6.2	-1.82

4.4. Cross section and dimension

The cross-section of each location was determined by using the existing information above such as the ground level, a slope and soil properties. The figures (40-43) show the existing cross sections and essential dimensions for each location. Appendix 5 shows cross sections sketch for each location. These designs used on the D-geo stability model before and during the flood.

- **Location one cross section**

The first cross-section has elevation level of +1.25m NAP (See figure 38). During the flood, the railway structure covered by water (See figure 39)

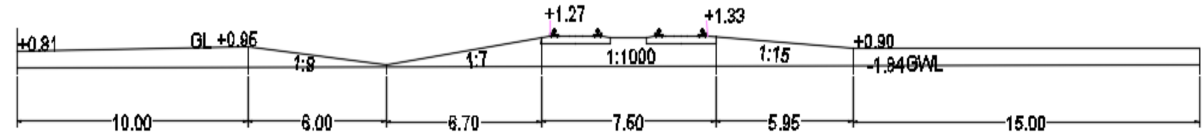


Figure 40 Cross-section location one before the flood

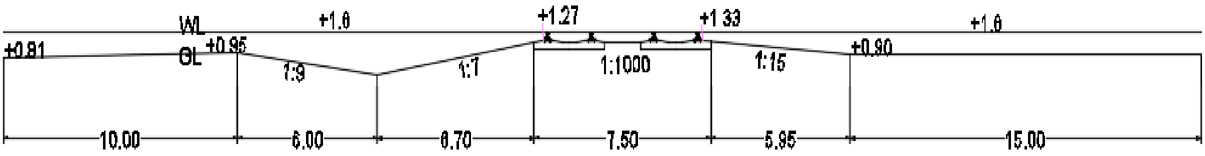


Figure 41 Cross-section location one during the flood

- **Location two cross section**

Location two in low elevation area as the crest level is on +0.52m NAP (See figure 40). This cross section almost flooded as the water level is 0.5m lower than the crest level (See figure 41).

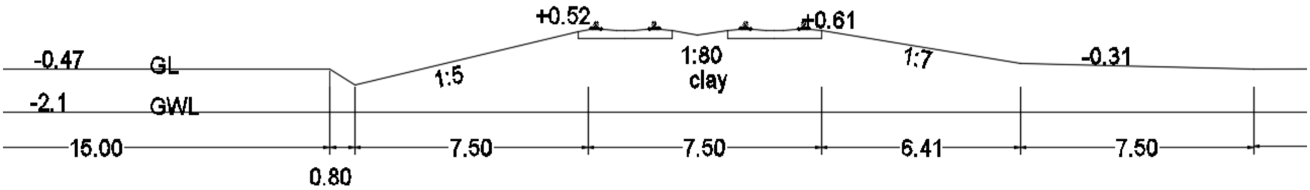


Figure 42 Cross-section location two before the flood

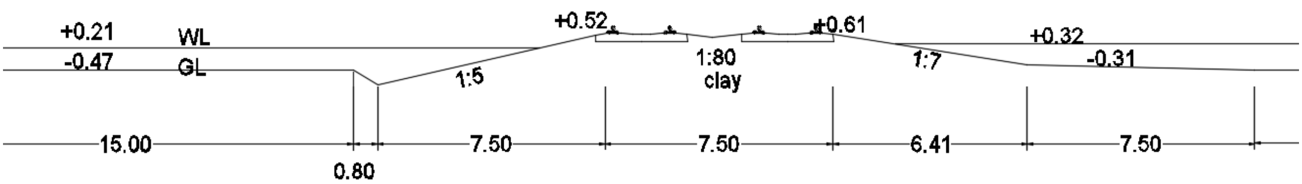


Figure 43 Cross-section location two during the flood

These cross sections used to check slope stability, settlement and wave run-up for each location.
Not: Appendix 5 has all the cross sections including the cross-section 3.

4.5. Loads

In this section, the different loads that included in D-geo stability model are mentioned. The loads include the permeant and vertical loads. These loads are based on ProRail design rules which are based on NEN-E1991-2 standards.

4.5.1. Permeants loads

The permanent load consists of the base weight, a weight of the building structure above and the overhead support structure. The weight of the upper building structure includes:

- Underlay
- Ballast
- Sleepers
- Rail UCL54

The top building structure has load value of ($Q_{K,\ rep}$) 12.5 KN/m^2 which must be used. This value based on the ProRail design rules.

4.5.2. Vertical Loads

The railway track loads as has been mentioned on NEN-EN1991-2 has schematized as shown in figure 38 below.

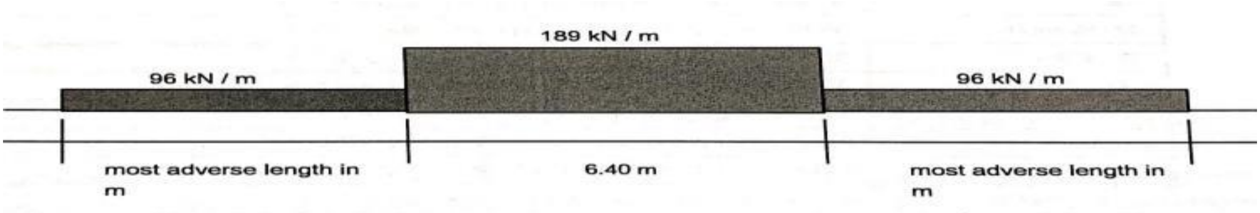


Figure 44 Simplified railway track loads (ProRail, Desgin Rule , 2016)

As has been mentioned in the design rules, the loads on the figure can be simplified to representative load $Q_{mob;\ rep}$ from:

- 76 KN/m^2 load on the bottom of 2.5 m transverse beam width for bearing capacity checks
- 63 KN/m^2 over the width of 3m (bottom ballast bed) for determination of the overall stability of the soil structure (ProRail, Desgin Rule , 2016).

From this, the $Q_{mob;\ rep}$ used for stability check is 63 KN/m^2, and for settlement calculation 76 KN/m^2 load is applied.

4.5.3. Loads combinations

After determining different loads, the load's combinations used to specify the total load.

1. Load combinations used for the stability:

Ultimate limit state: The first load combination is related to stability checks. All cross sections have a slope not steeper than 1:1.5. For that, the flowing combination used:

1 $Q_{K,rep}$ + 1.5 $Q_{mob;rep}$ (ProRail, Desgin Rule , 2016)

So when $Q_{mob;rep}$ = 63

= 1*12,5 + 1.5*63 = 107 KN/m^2

4.5.4. The weight of the Train

The weight of a train depends on what kind of train it is, the length of the train and the amount of wagon. The maximum length of a freight train in the Netherlands is 650 meter. This limit is implemented because guard rail is only intended for freight trains with a maximum length of 650 meters. A locomotive can drag 46 wagons. That gives a maximum weight of 4.680-ton (Railcargo, 2010).

4.6. Slope stability checks

Dike checks started after all the information for the research cross sections specified. There are four main checks carried during this research. These checks are slope stability check, settlements, wave run-up checks and the erosion of the slope grass revetments.
First, the overall stability of the slope in this research tested by using the D-Geo stability program. This program used to check a safety factor and a safety overview of each cross section. These results are based on the Bishop's simplified method.
In the D-geo stability program, six models developed for the three designs by using the following situations:

- Zero situation: (no train presence):
  - Scenario 1: before the flood: in which the water level is equal to groundwater level and standard upper structure load.
  - Scenario 2: during the flood: standard upper structure load and high water level.
  - Scenario 3: after the flood: standard upper structure load and groundwater level is still under a high pressure
- Loaded situation: (with train load):
  - Scenario 4: before the flood: in which the water level is equal to groundwater level and train load presence
  - Scenario 5: during the flood: train load and high water level
  - Scenario 6: after the flood: train load and groundwater level is still under a high pressure

After all these situations developed by using the D-Geo program, the result of the slope stability had been collected for each location as follow:

4.6.1. Location 1

The first cross-section built in D-Geo stability program (see figure 45). This model used to check the stability of the slope for the situations had been mentioned above.

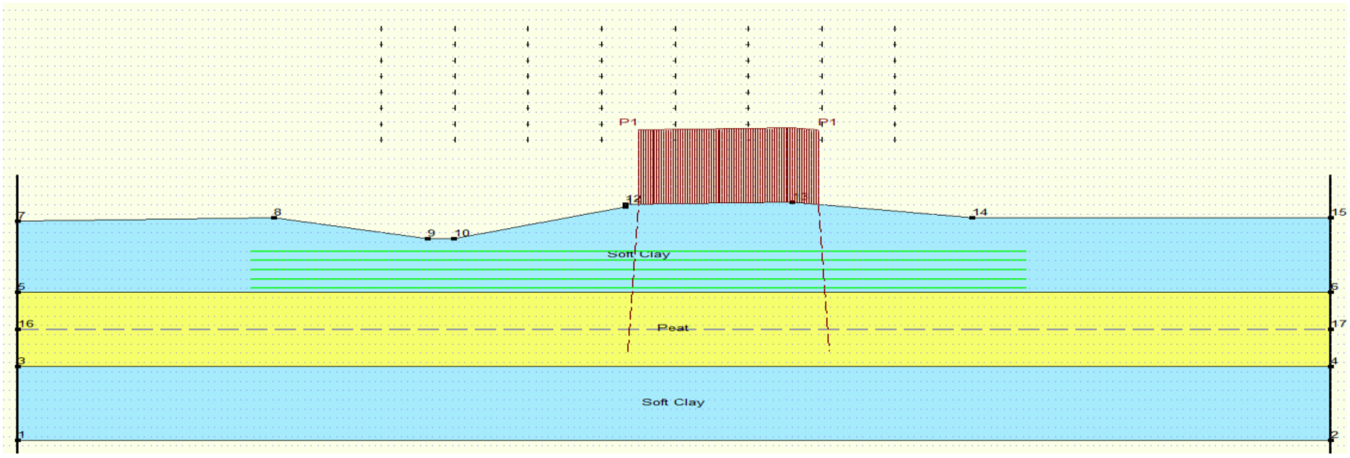


Figure 45 D-Geo stability model location 1

Then, the slop safety factor was determined for the cross-section one. Table 8 shows the safety factor results that had been calculated by the D-geo stability. These values discussed in detail down.

Table 8 Location 1 safety factor results

Location 1	Before/during/ after flood	Load	Safety factor
Zero situation	Before flood	Normal load	4,79
	During Flood	Normal load	4.19

	After Flood	Normal load	4.79
Loaded situation	Before flood	Extra train load	1.37
	During Flood	Extra train load	1.07
	After Flood	Extra train load	1.37

According to NEN9997 and ProRail design rules in the Netherlands the minimum safety factor that track is 1.3. In standard load without a train, the safety factor is around 4.5. For that, the dike still safe with regular ballast and structure load during flooding because 4.19 > 1.3 see figure below. Green color means the slope safety is higher than 1.3 (minimum safety factor)

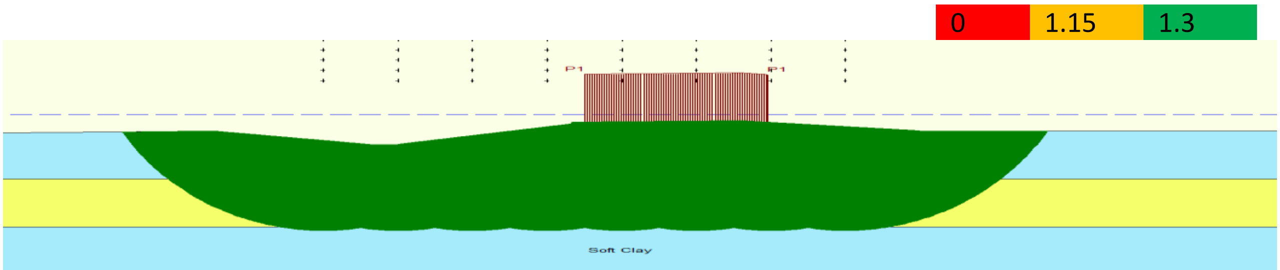


Figure 46 Slope stability overview zero situations

Also, the slope stability decreased when the train is passing on the crest. From the table above, the safety factor is too low during the flood and when the trainload added. That means the railway slope is not stable during the flood in cross section one (1.07<1.3 not safe) see figure below.

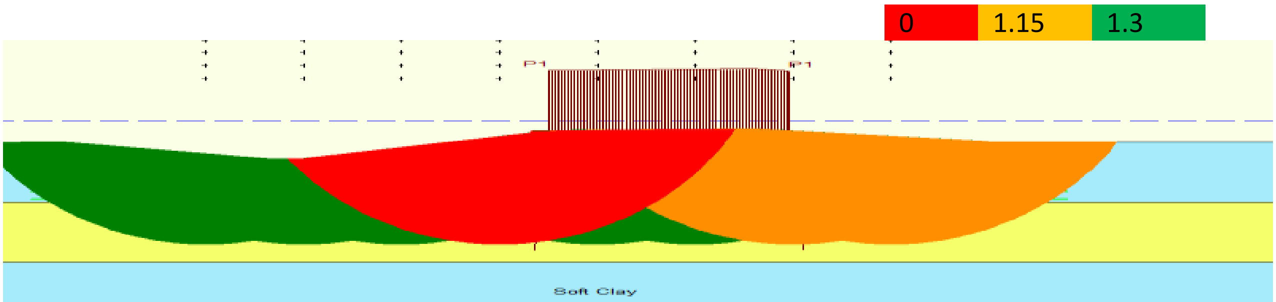


Figure 47 Slope stability overview loaded situation during the flood

4.6.2. Location 2

The second cross-section built in D-Geo stability program (see figure 48). Table 9 below shows the slope safety factor in both standard and loaded situations on location 2.

Table 9 Location 2 safety factor results

Location 2	Before/during/ after flood	Load	Safety factor
Zero situation	Before flood	Normal load	3.76
	During Flood	Normal load	3.66
	After Flood	Normal load	2.62
Loaded situation	Before flood	Extra train load	1.33
	During Flood	Extra train load	1.12
	After Flood	Extra train load	1.10

From results, the cross-section two is safe with the standard load as the safety factor (before, during and after the flood) is higher than 1.3. The figure 48 below shows the overview stability in cross section two with a standard load.

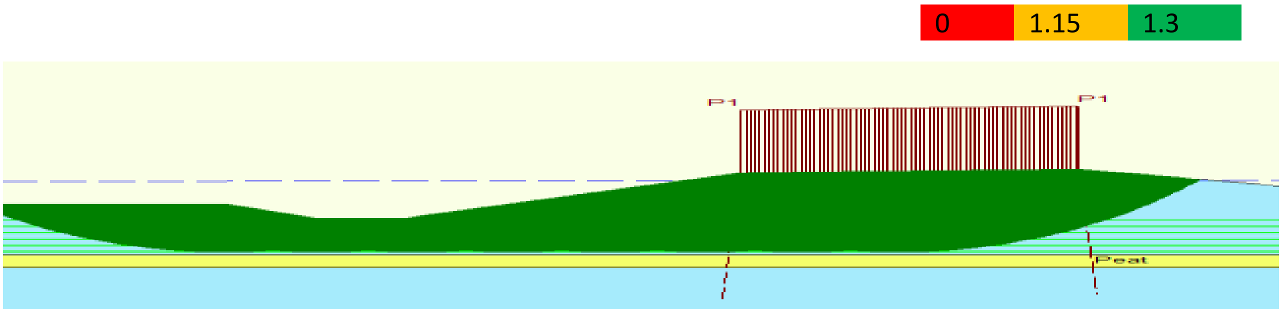


Figure 48 Slope stability overview zero situations

However, by adding the trainload, the safety factor decreased significantly. As shown in table 9 above, during the flood and presence of train load the safety factor is 1.12 (1.12 <1.3). The safety factors during and after the flood are lower than 1.3 (see figure 49 below).

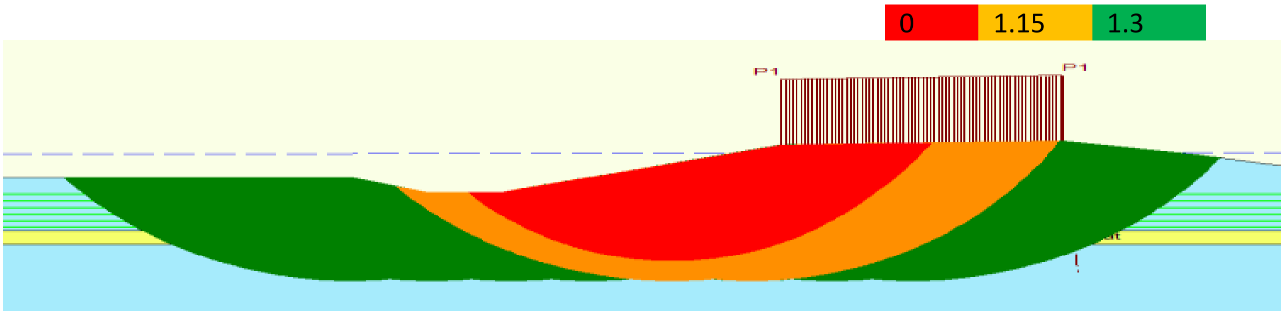


Figure 49 Slope stability overview loaded situation during the flood

4.6.3. Location 3

For the third cross-section, the slope stability check had been done for both sides left and rights spritely due to the large width of this cross-section. In the following sections, slope stability checks of both sides have been given.

1. *Left side*

First, the left side of cross section three had been checked with both standard load and train load for three scenarios before, during and after the flood. Table 10 below shows left safety factors results.

Table 10 Location 3 left side safety factor results

Location 3 left side	**Before/during/ after flood**	**Load**	**Safety factor**
Zero situation	Before flood	Normal load	2.19
	During Flood	Normal load	1.46
	After Flood	Normal load	2.02
Loaded situation	Before flood	Extra train load	1.84
	During Flood	Extra train load	1.76
	After Flood	Extra train load	1.75

From the table above, all scenarios have a safety factor higher than 1.3. The safety factor decreased during the flood, but it is still higher than the minimum safety factor (see figure below). For that, the dike on the cross-section three is safe to use during and after the flood.

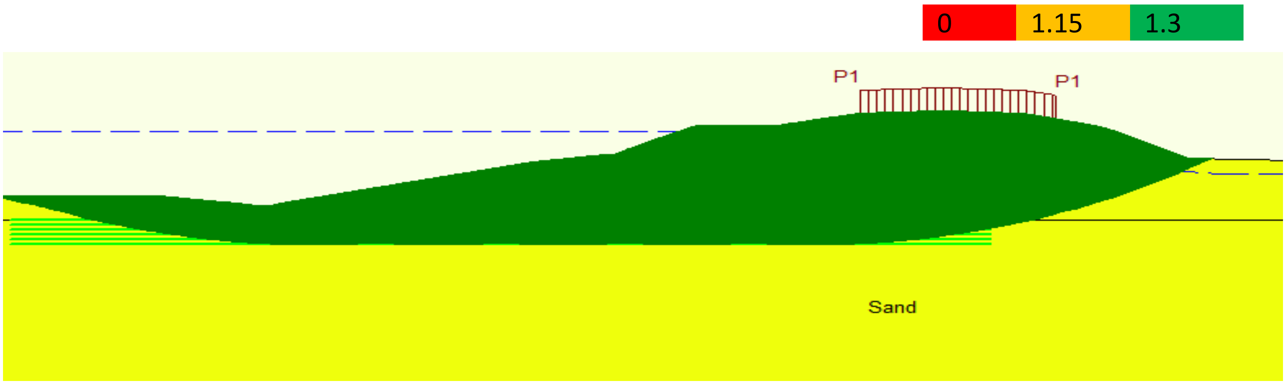


Figure 50 Slope stability overview of location three left

2. Right side

Second, the right side of cross section three had been checked with both standard load and train load for three scenarios before, during and after the flood. Table 11 below shows left safety factors results.

Table 11 Location 3 right side safety factor results

Location 3 right side	**Before/during/ after flood**	**Load**	**Safety factor**
Zero situation	Before flood	Normal load	2.24
	During Flood	Normal load	2.02
	After Flood	Normal load	2.08
Loaded situation	Before flood	Extra train load	1.62
	During Flood	Extra train load	1.47
	After Flood	Extra train load	1.53

The safety factors of cross section three on the right side are higher than 1.3 minimum safety factor. For that, the railway trajectory is accessible in cross-section three during and after the flood. The figure below shows the safety overview of the right side of location three.

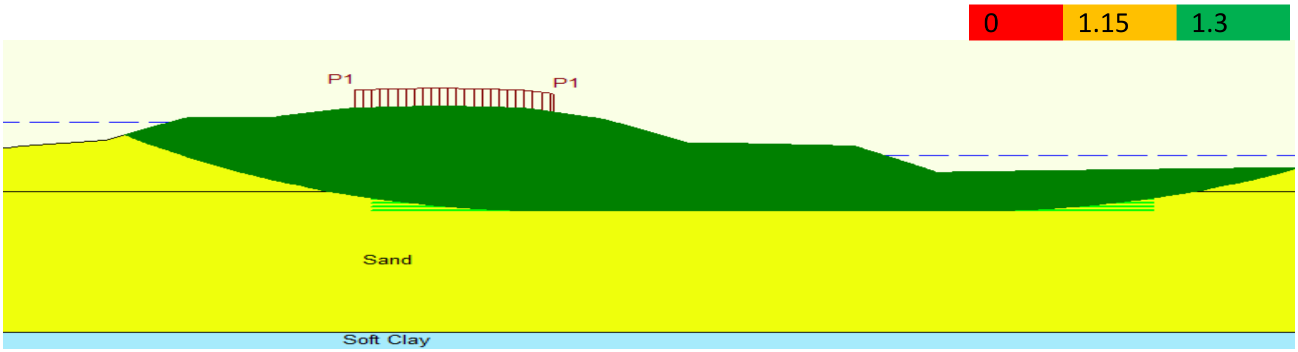


Figure 51 Slope stability overview of location three right

In conclusion, after checking all three cross-sections, the results show that cross sections one and two have safety factors loads lower than 1.3 during the flood when train load presence. For that, both locations are not accessible during the flood. However, location three is still accessible during and after the flood.

4.7. Settlements

In this phase, the settlement of the structure checked before, during and after a flood. The settlements checked in different periods and with different loads. For that, analyses had been carried out on steps. These steps mentioned below:

- One-day settlement before, during and after the flood
- Two weeks' settlement before, during and after the flood
- One-month settlement before, during and after the flood
- Two months' settlement before, during and after the flood

The settlement calculated by using the following formula and parameters:

$$S_t = h * \left(\frac{1}{C_p} + \frac{1}{C_s} * \log t \right) * \ln \left(\frac{P_0 + \Delta P}{P_0} \right)$$

- The settlement calculated for each 0.05m height.
- The settlement checked by time periods mentioned above.
- The table in appendix 3 use to determined C_P and C_S
- The time used to calculate settlement for each cross section before, during and after the flood
- If the settlements different is higher than 0.10m that mean the settlements are too high

4.7.1. Settlement results

After the settlement checked for the three cross sections, the result collected as shown down.

Location 1

First, the settlements checked for the first location before, during and after the flood for with different time periods. For cross section one the results have found as shown in the table below. (For detail calculations check appendix 6)

As shown in table 12 the settlement is high for all time periods due to clay embankments. Form table 12 the settlement results difference after and before the flood is lower than 0.10. However, the settlement difference before and during the flood is almost 20 cm in all time periods

Table 12 Location 1 settlement results

Scenario	**Settlement {m}**			
Before flood	**One day**	**14 days**	**30 days**	**60 days**
	0.5335	*0.5855*	*0.6005*	*0.6142*
During flood	*0.7047*	*0.7733*	*0.7931*	*0.8111*
After flood	*0.5386*	*0.5911*	*0.6063*	*0.6201*

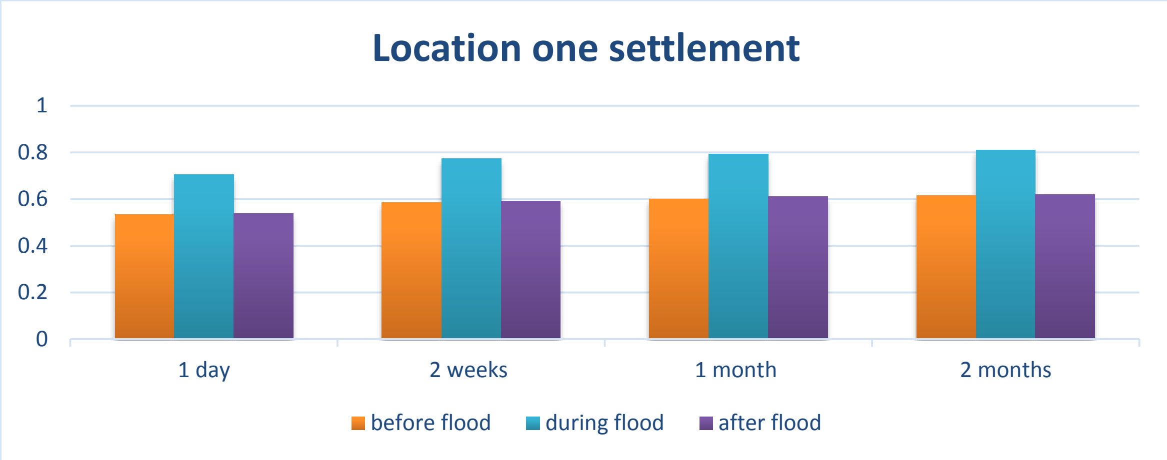


Figure 52 Location 1 settlement results

The graph 52 shows the settlement results for the first location. The settlement during the flood gradually increased when time increased. Due to the large settlements difference which is higher than 0.10m, the railway structure on location one during the flood is not safe for location one.

Location 2

For location two the results founded are shown in the table below. The settlement is still high due to soil type (clay). The settlement difference during and before the flood is almost 8cm. While the settlements difference after and before the flood is virtually is 0.01 in all time periods (For detail calculations check appendix 6).

Table 13 Location 2 settlement results

Scenario	Settlements {m}			
	One day	**14 days**	**30 days**	**60 days**
Before flood	*0.5098*	*0.5597*	*0.5741*	*0.5872*
During flood	*0.5777*	*0.6342*	*0.6505*	*0.6653*
After flood	*0.5179*	*0.5686*	*0.5832*	*0.5966*

Figure 53 shows the settlements results for cross-section two before, during and after the flood. In all time periods, the settlement values before and after the flood were almost the same. However, the settlement values increased during the flood.

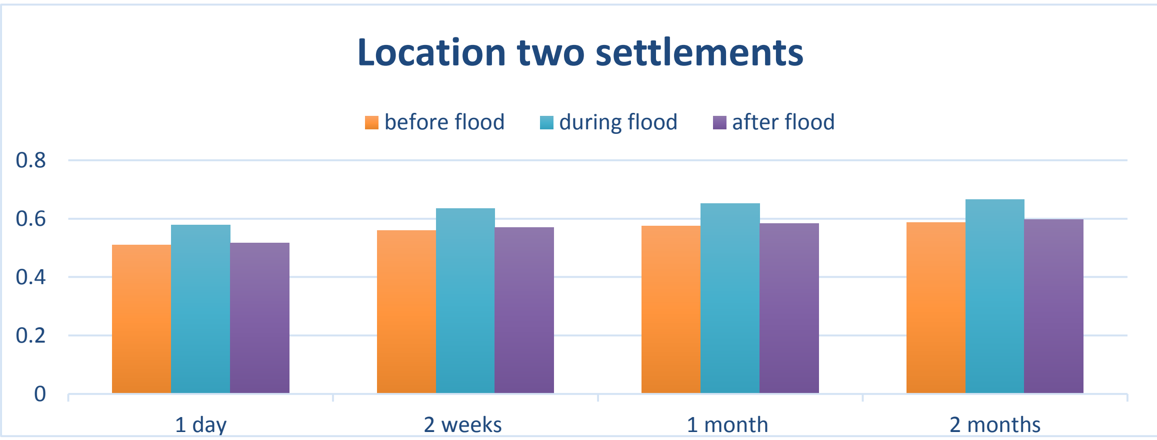


Figure 53 Location 2 settlement results

Location 3

The settlements checked for the third location before, during and after the flood with different time periods. Table 14 shows the settlement values on the third location.

For location three the settlement is low before flood with normal water level because most of the embankments are sand. The settlement is almost the same for one day during and after the flood as the difference is 0.003.

Table 14 Location 3 settlement results

Scenario	Settlements {m}			
	One day	**14 days**	**30 days**	**60 days**
Before flood	*0.0672*	*0.0732*	*0.0749*	*0.0765*
During Flood	*0.0649*	*0.8332*	*1.0550*	*1.2568*
After Flood	*0.0675*	*0.8467*	*1.0718*	*1.2765*

However, the settlement values increased significantly during the flood and with more extended time. The increase of the settlement values was continuing after the flood with extra time as shown in figure 54.

From the result, the difference between settlements values during and before the flood is higher than 0.01. For that, the settlements values in location three increased with time when water presence.

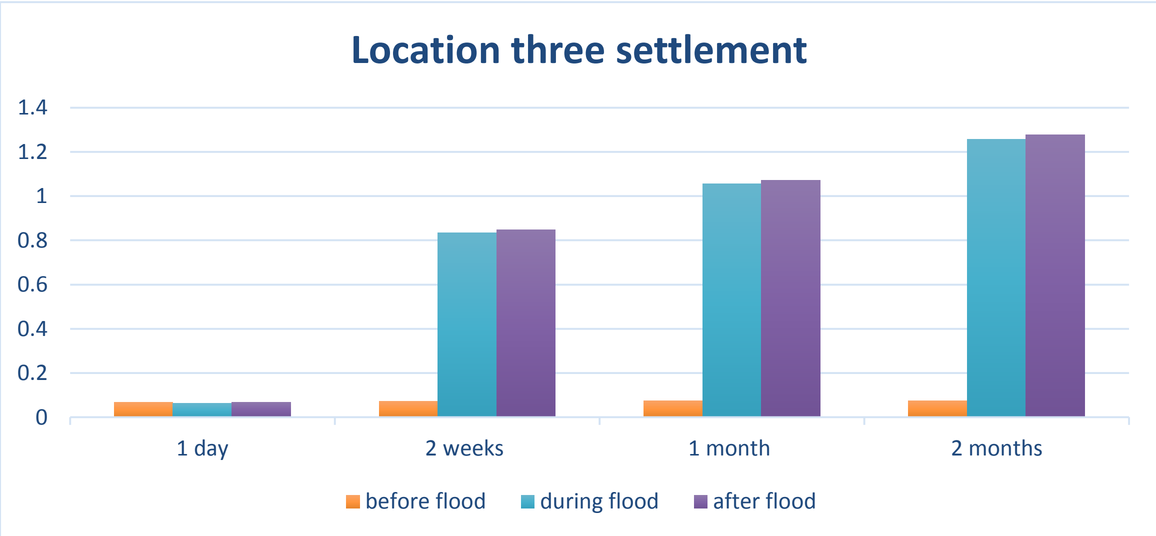


Figure 54 Location 3 settlement results

In conclusion, by checking the settlement for all the three cross sections, cross section one and two had large settlement values during the flood. The third location checks show that the settlement values during and after the flood were a relatively high compared with before the flood values.

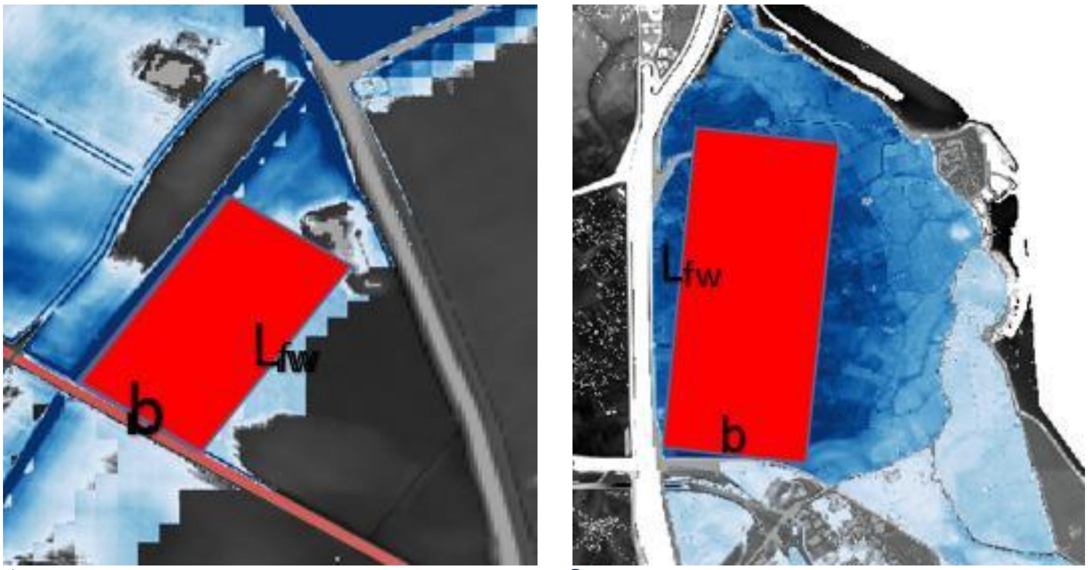
4.8. Wave run up

Hydraulic failure checks are focusing on the presence of water below the ballast or embankments. For that, a test carried to determine the wave run-up for each cross section.

Wave runs up calculated by using the formula and graphs in appendix 1. The following steps have been carried to determine the wave run-up of each location during the flood. Location two (almost flood) and location three (high elevation) checked. Location one was not tested because the water level is higher than the crest level. There were different parameters required to calculate the wave run-up height. These parameters calculated by these steps:

4.8.1. Effective fetch

The first step is assuming the maximum area that wave and wind which act on the dike. The following figures (55 A- B) show the area considered to determine the width (b)and length (Lfw).



A *B*

Figure 55 Maximum area that wave act on location two(A) and three(B)

The flowing table shows the assumed area b and Lfw measured by using the Gis. Then, effective fetch calculated by using the figure 9.2. The effective fetch values are used during wave run-up calculations.

Table 15 Effective fetch (Lef) results

Location	b(Km)	L_{fw}(Km)	b/ L_{fw}	Lef/ L_{fw}	Lef
Location two	0.22	0.46	0.48	0.61	0.3
Location three	2.0	4.2	0.48	0.61	0.3

The effective fetch calculated by using the table 15 and graph in figure 9.2. Down This an example for the effective fetch calculation for location two:

The ratio $\frac{b}{Lf{,}w} = \frac{0.22}{0.46} = 0.48$

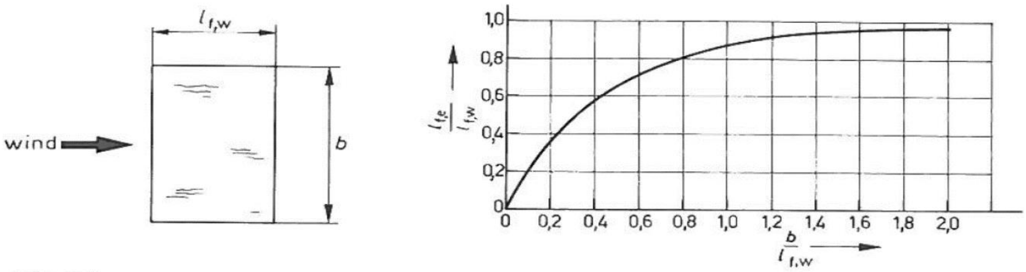


Fig. 9.2

→ From graph 9.2 $L_{f,e}/L_{f,w}$= 0.61

$L_{f,e}$ = $L_{f,w}$* 0.61 = 0.46* 0.61 = **0.28 =~ 0.30 km** (see table 15)

4.8.2. Velocity (V)

The velocity had been determined by using the floodinglizard.net (Marie,2018). This website has all the flood scenarios and with the velocity value for each point. From this website, the velocity values for each cross-section had been determined:

Location 2: 0.23 m/s **Location 3:** 0.30 m/s (Marie, 2018)

4.8.3. Water depth (h)

The water depth during the flood is required to find the wavelength and wave height. The water depth had determined before (See table below).

Table 16 Water depth during the flood

	Flood Scenario	**Ground level**			**Flood water level (Liwo)**	**Water level (Q-gis)**			**Water depth(h)**
		[m NAP]			[Range m]	[m NAP]			[m]
		Left	Mid	Right		Left	Mid	Right	left
Location 2	St. Pieters polder	-0.48	+0.57	-0.48	0-4	+0.21	+0.21	+0.21	0.69
Location 3	Yerseke Moer	-0.96	+6.2	-0.4	0-6	+4.5	~+2.3	+0.9	3.54

(Red color indicates the water depth in m)
After the water depth had been determined, the wavelength and wave height can be checked.

4.8.4. Wavelength (Lo) and wave height (H)

The water depth and effective fetch used to determine the wavelength and wave height. The wavelength and height specified by using the following graph.

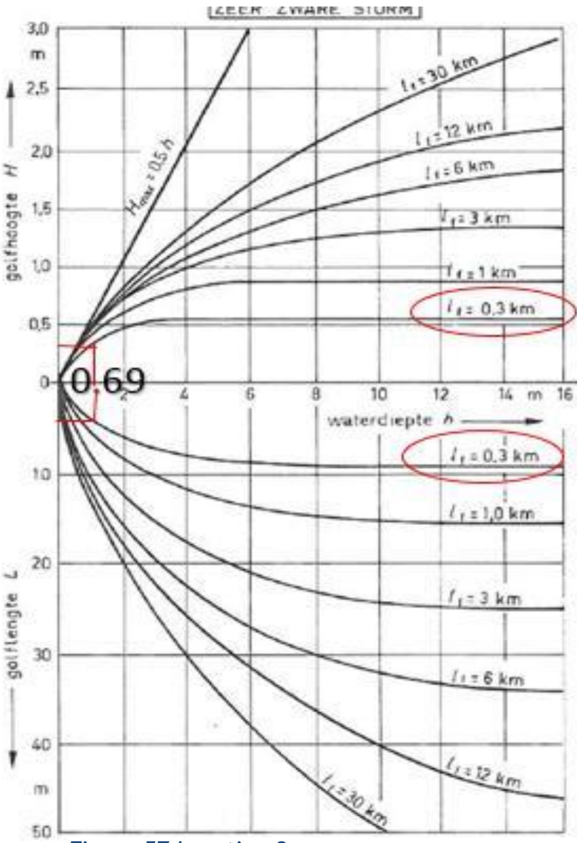


Figure 57 Location 2

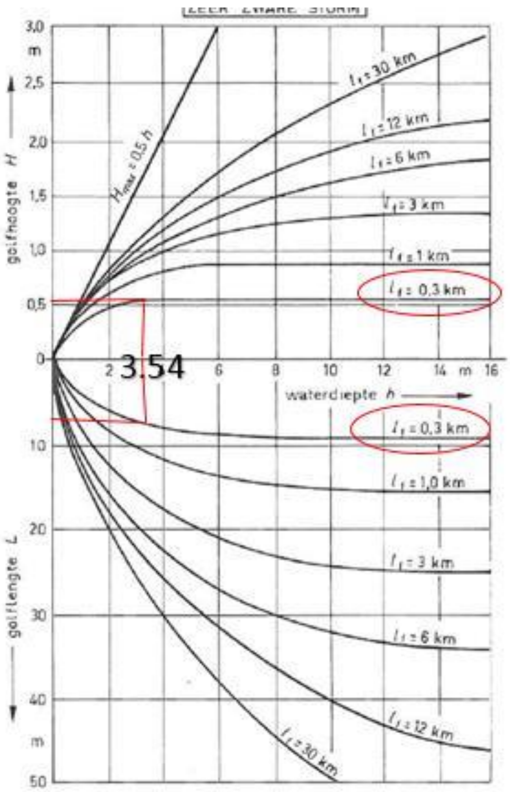


Figure 56 Location 3

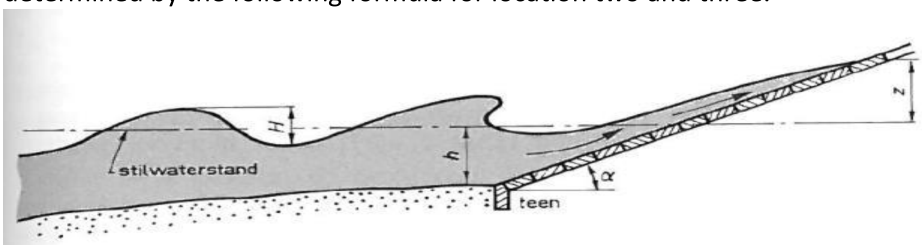
From both figures above, the wavelength and height have specified. The following table 17 shows the results for each location.

Table 17 Wavelength L0 and Wave height H

Locations	Wavelength L_0(m)	Wave height H(m)
Location 2	0.30	0.51
Location 3	4.00	7.00

4.8.5. Wave run up

When all the wave parameters were measured, the wave run-up had been calculated. The wave-run determined by the following formula for location two and three.



z = √(H*Lo) * tan α

- **location 2:** slope 1:7 so α= 0.8°

  z = √(0.51*0.30) * tan 0.8 = 0.0055 m

  So water level when wave run up = +0.21 + 0.0055 = + 0.21555 mNAP

  + 0.21555 mNAP < + 0.57 (Crest level); Ok

- **location 3:** slope 1:4 so α= 1.4°

  z = √(7.00*4.00) * tan 1.4 = 0.13 m

  So water level when wave run up = +4.5 + 0.13 = + 4.63 mNAP

  + 4.63 mNAP < + 6.2 (Crest level); Ok

In conclusion, the calculation of the waver run-up was done for both locations (two and three). From result above, location three has higher wave run up (0.13> 0.0055). Location two has low wave run-up which not erode the revetments. However, location three has higher wave run-up, but current could not cause erosions to the dike revetments during the flood due to 4.63(wave run-up level) < 6.2 (crest level).

4.9. Erosion of slope grass revetments

In this section, the results regarding the slope grass revetments are shown. The grass treatments tested by using ''guidance keys grass coatings of dikes serving to draft the manager judgment (B0)'' (More, 2012).
The grass revetments could be affected by wave run-up. For that, the grass should require maintenance inspection regally. In the start, for each location slope grass revetment has been analyzed by using a simple key rule. The following steps had been carried out:

Step 1: Simple key rules:

Step 1.1 Throughput Flow rate ≤ 0.1 l / m / s

For each location, if the flow rate is lower than this value, it assumed that the damage is tiny on the grass revetments.
Explanation: In fact, the slope of three locations accepted to be under water once. For that, there are not satisfied with throughput over 0.1 l/m/s. By this, the vegetation might be eroded on this step for all locations.

Step 1.2 Quality Turf

Step 1.2 comprises an assessment of the quality of the grass. This is determined through visual inspection and maintenance.
Explanation: The vegetation along the railway trajectory was built in the 80's. The grass has had plenty of time maintenance developments. In location one and two the grass revetment is the same size, and there is no presence of big trees (see figure 58).

Figure 58 Grass revetment on location 2 (Googlemaps, 2018)

However, nowadays the slope of location three has different grass and trees with different sizes (see figure 59). It clear that the maintenance has not been done for a while. Due to the presence of big trees with low-density grass, the quality of the revetments is not sufficient.

Figure 59 Grass and trees on location 3 slope (googlemaps, 2018)

Step 1.3 Hs <0.25 m

If the significant wave height at the toe of the flood defense is less than 0.25m, then the score 'satisfies.'
Explanation: From wave run up the wave height had been determined for location two and three. The wave height was higher than 0.25m for both locations. For that, this step has not met the requirements. Because the three steps are not fulfilled, step two has to be checked.

Step 2: Detail test rules

Review the bank exposed to a cumulative overload. In this step, the following has checked:

- The grass covers should be closed and must have the same vegetation
- Slope angle should not be more than 1:2.3
- There should be clay layer thickness 0.4m present
- Tress and objects not allowed to present on the slope

Explanation:
As previously described above, location one and two have close grass revetments with the same size. The slope for both locations has met the requirement not more than 1:2.3. The underlying clay layer cannot be measured, but it is assumed that required 0.40m clay layer is present on location one and two. There are no big trees or any objects on the slope.
However, location three has a different type of trees with different sizes. Also, the slope is high to be steeper than 1:2.3. For that, location three does not satisfy the requirements.

Table 18 summarized all steps results for all the three locations.

Table 18 Grass revetment check

step	**Location 1**		**Location 2**		**Location 3**	
	Satisfies	Does not suffice	Satisfies	Does not suffice	Satisfies	Does not suffice
Step 1.1						
Step 1.2						
Step 1.3						
Step 2						

In conclusion, both locations one and two the grass revetments for the slope were not eroded. This based on the results shown in table 18. However, the grass revetment on the slope of the third location was not sufficient to erosions as shown on check steps above.

4.10. Result summary

The bearing capacity and the erosion resistance of the railway had been checked in this research. In the previous section, the check results had been collected. In this section, these results will be analyzed.
First, the slope stability of the railway trajectory checked by using the D-geo stability program. The results for the location one (flooded) had shown that slope safety factors were high values in zero situation (with standard structure load) before and during a flood. The value decreased when the trainload added to be lower than the minimum limit (1.3) during the flood to 1.07<1.3.

The second location (almost flood), has a similar result as location one. The slope safety factors were high in a zero situation (with standard structure load). These values drop significantly when the train presents during the flood. Besides, for location two the slope safety factor with the trainload (1.10) was still lower than 1.3 (minimum safety factor) after the flood.

From both results, locations one and two are not accessible during flood due to the low slope stability. The location one expected to be accessible after food and the train can pass through it, but location two will not be accessible after the flood (1.10<1.3).
However, location three (high elevation cross-section) cheeked from both sides due to the large cross-section. The results have shown that both sides have slope safety factor higher than 1.3 in both situations and all scenarios. As the lowest slope safety factor from both sides is 1.46, which is bigger than the minimum safety factor (1.3). For that, location three is accessible even during the flood.

Second, the bearing capacity of the railway trajectory checked by using the settlement check. The result shows that cross sections one and two settlements is large before the flood. The settlement in both locations (one and two) increased during the flood. The difference is higher than 0.01 for all time periods (one day, two weeks, one month and two months).

The third location had low settlement values before the flood. These values increased when water and time increase during and after the flood. For that, the three locations during the flood will be not accessible due to the large settlements.

The figure below made to compare the settlement between the three cross-sections with the period of two weeks. From figure for location one and two, settlements changes due to the presence of water were small. In location three, settlements changes due to the presence of water are too high, and this expected due to sandy soil type.

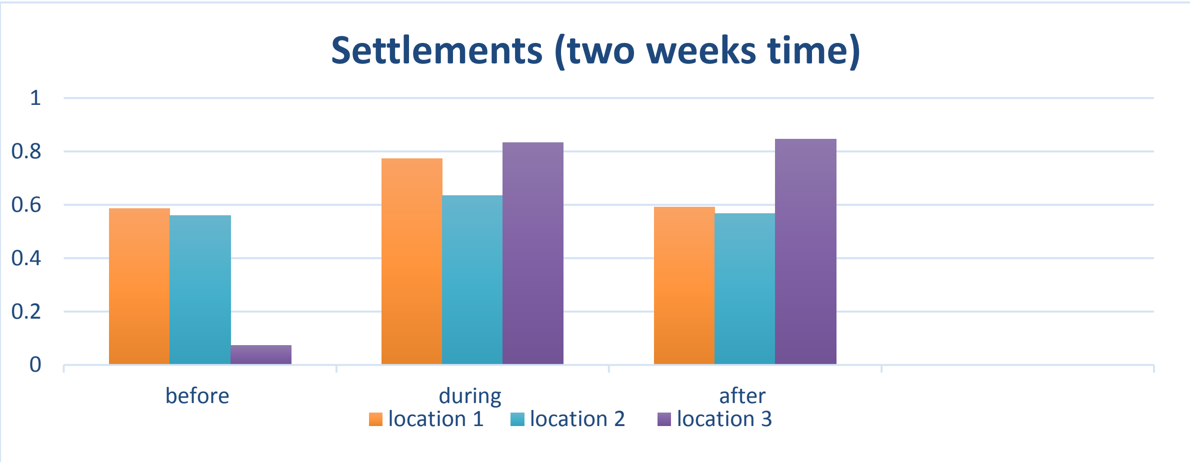


Figure 60 Compare the settlement between location one, two and three in two time periods

Thirdly, the wave run-up checked for locations two (almost flooded) and three (high elevation). Location one had not included during calculation because the water level is already higher than crest during the flood. The wave run-up result has shown that location two has a low wave run-up height (0.0055m) while location three has a high wave run-up height (0.13m). However, the wave run-up height is relatively low compared with crest level in location three. From both results, it includes that currents effects during the flood are relatively small as shown from wave run-up results above.

Finally, the erosion resistance of the grass revetments has been analyzed. The check has been based on ''guidance keys grass coatings of dikes serving to draft the manager judgment (B0)'' (More, 2012). The result shows that the grass revetment on the slope is not sufficient to erosions. Therefore, the slope revetment expected to erode during wave run-up. Extra maintenance needed to improve the slope grass revetments.

5. Discussion

This research has been checked the erosion resistance and the bearing capacity of the railway. The result has shown that the slope stability decreased during the flood and when a train passes on top of the crest. Likewise, the settlement values increased during the flood. For that, the railway does not have enough of both the erosion resistance and the bearing capacity during the flood.

In this section, the research method, parameters, and the result will be discussed to come up with a reliable conclusion.

Flood scenarios

The flood scenarios used in this research to check the water level during the flood for each location. In the area of the Reimerswaal, there are about 23 flood scenarios. In this research due to lack of time, just three flood scenarios had been checked. For each flood scenario, expected there would be different effects on the separate area. Furthermore, the water level is going to be different for each flood scenarios. This change had been considered during this project.

However, the results will be more specific if other flood scenarios had been checked with the different water level. For that, the method would be more specific if there were more flood scenarios effects had been tested.

Erosion resistance result

The was unexpected results regards the clay safety factor of the slope stability of the railway. As the slope safety factor of clay dike is lower than the sand dike.
According to the results of this research, the railway does satisfy with the erosions resistance in zero situation (without trainload). However, the slope safety factors for clay dikes were all below 1.3 when the trainload added. This result was applied to all dikes except for the sandy dike which has a high elevation cross-section. This sandy dike was still had slope stability higher than the (1.3) minimum slope safety factor. The lowest slope safety factor from both sides was higher than the standards safety factor. This result was not expected as that the slope safety factor of clay is smaller than sand during flood according to Ciotlaus study (2017).

The previous study by Ciotlaus, in 2017 it has tested the slope stability of the railway embankment. In his study, a simulation for different soil embankments studied: clay, gravel mixed with sand and rock (Ciotlaus, 2017). From Ciotlaus study, a clay dike had a higher slope safety factor than sand dike.

However, in this research, the sand dike has a higher safety factor than clay. In this research, the water considered during checks but Ciotlaus focus in his study to changes of the embankments with heights and water not considered. For that, the results were different between both two of research.

Soil properties

In this research, the soil properties of the embankments were based on a historical data. From the results, the settlement increased significantly on the sandy dike during and after a flood. The increase continues with longer time over than a one day. This was not expected due to the decrease in the water level after the flood, but the settlement was still increased. This increase was just on the sandy dike. In fact, that sandy soil dike has a higher permeability than clay. For that, the soil properties of the embankments have a significant influence on the bearing capacity of the railway.

A site investigation for the railway line was not allowed during this research. For that, the soil type of the embankment was based on a historical data which was not entirely sufficient. Therefore, soil geotechnical tests have to be done to determine the soil properties of the embankments. This test will help to have an adequate result.

Groundwater level

There were some difficulties in determining the cross sections parameters during this project due to the lack of a data and old resources. The groundwater level is an essential factor for the checks. During this project, the groundwater level was determined by using the Dinoloket. The groundwater level in the Dinoloket is based on the 2001 masseurs, which are old measures. Now the groundwater level might be higher than it was put on the website.

For that, the results founded is based on the groundwater level measures has been collected in 2001. For future research, the sufficient groundwater level has to be measured.

Results application

The thesis topic and the problem analyzed in this report can be high a relative to the work field of Civil Engineering. This report provides much information regarding the study of the railway trajectory stability.

The research result can be used for the social and economic works plans. The Reimerswaal becomes a high demanding on the infrastructures. For example, the railway is considered as a primary connection between the Bergen op Zoom and the other cities on a province of Zeeland. The railway will not be safe for use during the flood according to the research results.

Also, this railway is used to transport different of industrial products to Vlissingen port. For that, during a flood, this can cause extensive social and economic disruptions. For that, these data can be used by researchers to identify solutions to develop the railway trajectory during a flood.

6. Conclusion

In conclusion, this section will review and summarize the final research results. Also, the final answer to the central question is given in this section.

This research has been carried to check the railway on the Reimerswaal. The bearing capacity and the erosion resistance of the railway had been tested during and after the flood. The central question of this research formulated as:

What are the effects of the erosion resistance on the resulting bearing capacity of the railway trajectory between Bergen op Zoom and Kapelle during and after the flood?

According to the results of the slope test, the stability safety of the slope decreased significantly during the flood with a presence of a trainload. This is just applied to the low elevation clay dikes. In a high elevation sandy embankment, the slope is not eroded during the flood according to the slope stability check.

However, the settlements test had shown that the settlement of the sandy embankment increased during the flood. During these checks, it has been noticed that the settlement value increased significantly with the presence of water for the sandy dike. Also, for the clay dikes, the settlement value is not affected by the increase of time of occurrence of the flood.

From that, the railway is not accessible during the flood in the low elevation areas. Also, during the flood, the slope loss its stability when the train passes through it to be lower than 1.3(minimum safety factor). Besides, the railway in the sandy embankments of the railway must not be used during the flood due to the high settlement. The settlement values increased with drainage time more than one day as shown in settlements calculation for the third location (with a high elevation cross-section). For that, the railway has not used until the groundwater returned to it is original level.

The erosion resistance of the grass revetments had been analyzed. The checks had been based on ''guidance keys of grass coatings for dikes''. From the result, the grass revetment on the slope was not sufficient to erosions. Furthermore, the slope revetment expected to erode during wave run-up. This increased the effects on the slope stability.

In conclusion, the railway is not affected by the flood with the standard a railway structure load. However, the railway does lose its stability, and the erosion increased when the train passes on the crest.

7. Recommendations

In this section, a recommendation for further studies to check the railway stability is given. Likewise, there are some adjustments can be carried out to improve the results of testing the erosion resistance of the railway on this research.

At the end of this research, the final results can be improved by determining the soil properties of the embankment. For that, future research has to be carried to determine the geotechnical condition for each location. The research must focus on the characteristic of the soil properties of the railway embankment. Two main tests can determine soil properties. These tests are a site investigation (borehole test) and a laboratory test. From the test results, the properties of soil used for the modeling and calculations to have more accurate results.

Also, a groundwater test should be carried with the soil investigations. The purpose of this test should be to measure the water pore pressure. The measurements will help to determine the water stress, the location of this stress and the strain within the embankment.

In addition, in this research, the checks had been based on a global safety factor calculated by the Bishop's simplified method of slices by using the D-Geo stability program. The Bishop method considers the driving moments by soil weight, water pressures and loads a round of a slip circle. There is other calculations method could be carried out by this program. Talren program could be used to check this research results. Talren is a software for testing the stability slopes of dikes but with more stages than D-Geo stability program. Also, by using Talren more methods of checks can be used.

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Appendix 1: calculations formulas

Bishop's simplified method

The global factor of safety F in Bishop's simplified method of slices is equivalent to the partial factor on the soil strength parameters with appropriate partial factors on the actions as shown in the following equations:

$$T_{mob} = \frac{C}{F} + \sigma_n \frac{tan\varphi}{F} = \frac{C}{\gamma_{M,mob}} + \sigma_n \frac{tan\varphi}{\gamma_{M,mob}}$$

$$\gamma_{M,mob} = \frac{1}{\sum \gamma_G . w. sin\alpha} \sum \frac{\lfloor C_K b + (\gamma_G W - \gamma_G ub) tan\varphi_k \rfloor sec\alpha}{1 + \frac{tan\alpha. tan\varphi_k}{\gamma_{M,mob}}}$$

In, γG = 1,35 is applied to permanent actions, including the soil weight force via the soil

weight density and γQ = 1,5 is applied to variable actions when analyzing the overall factor of safety,

F using the method of slices. Then it is checked that F, which is equal to γM; mob, is greater than or

equal to 1,0. (Bond, 2013)

Settlement

To check the bearing capacity of railway trajectory, the settlements of embankments need to test during and after the flood.

The formula used for settlements calculation is as follows:

$$S_t = h * \left(\frac{1}{C_p} + \frac{1}{C_s} * \log t \right) * \ln \left(\frac{P_0 + \Delta P}{P_0} \right)$$

Where:

S_t: total settlements

h: thickness

C_P: primary comparison factor

C_s: secondary comparison factor

T: time

P_0: initial effective stress

ΔP: extra load

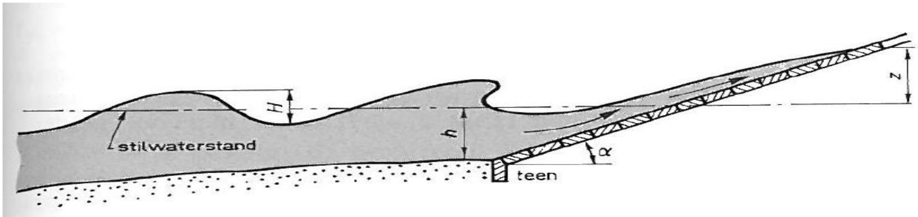
In addition, the different soil properties and the comparisons factors will be determined by using the table in appendix 3.

Hydraulic failure

There are failure mechanisms caused by a present of water. As the check of erosion resistance requires during the flood, this section will mainly focus on Hydraulic failure checks.

1. **Wave run up**

The wave run-up is checked by using Hydraulics for Hydraulic Materials (Nortier, 2000). The wave run-up calculated by the following formula:



z = √(H*Lo) * tan α   or   z (2%) = 8 H * tan α

reduction factor: z rough = f * z smooth (see table for f factor)

f berm = (1 – (b / L)) b= with of the berm, b max = 0,4 L

There are different parameters required to calculate the wave run-up. These parameters as following:

<u>Effective fetch</u>

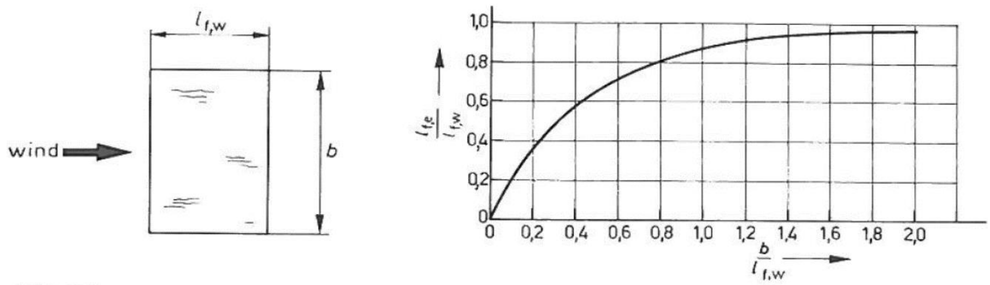


Fig. 9.2

Waves length in shallow water:

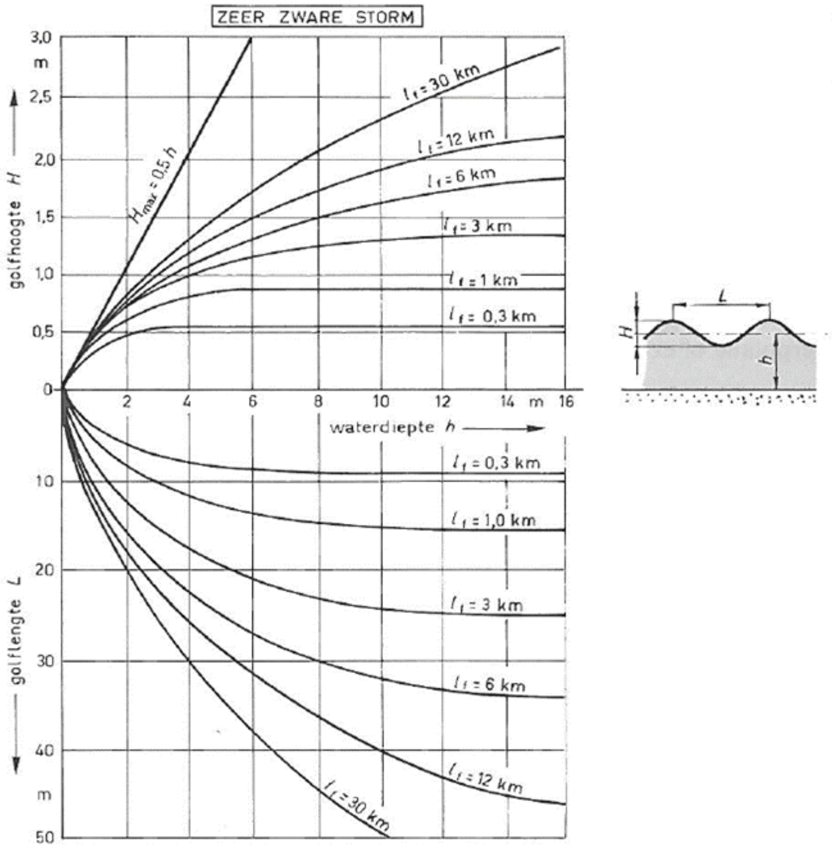


Fig. 9.11 Maximale golfontwikkeling bij een gegeven strijklengte en waterdiepte tijdens zeer zware storm (windkracht 11 of windsnelheid ongeveer 30 m/s)

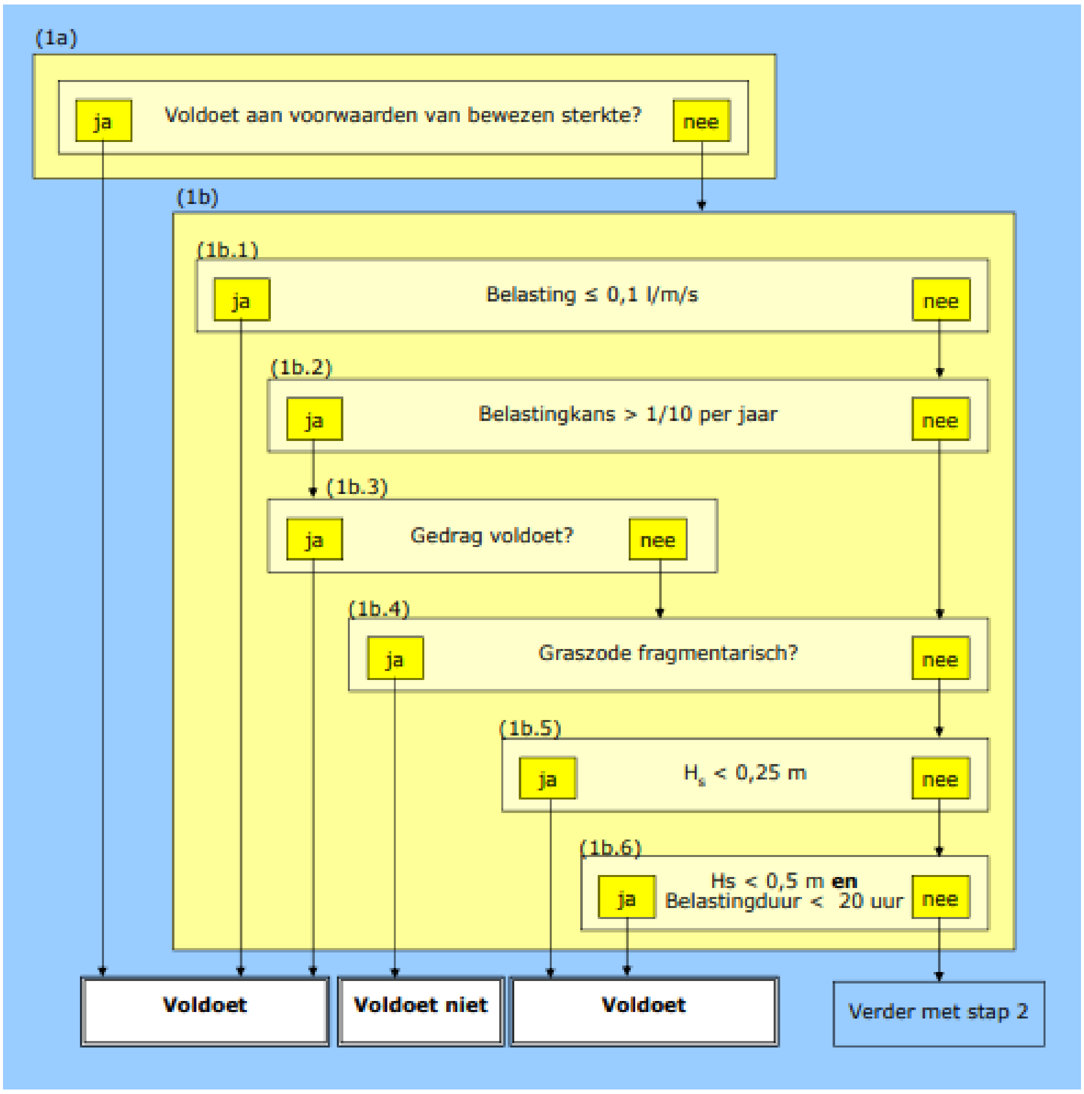
$$h > \frac{1}{2} L_0$$

$$L_0 = \frac{g}{2\pi} \cdot T^2 \approx 1{,}56 T^2 [m]$$

$$c_0 = L_0 / T$$

However, for shallow water $h<1/2L_0$

Grass revetments analyses



Figuur 7-1 Schema eenvoudige toetsregels op Erosie buitentalud

Appendix 2: Technical requirements

1. Determination of the research locations requirements

Information provided by (Mr. Lukas)

- The flood scenarios in Reimerswaal area
- Max, Min and average heights of the area are determined by using Ahn.nl website.
- GIS checks

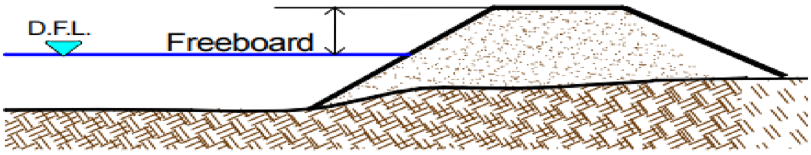
2. Dike main cross-section requirements

(checks on the existing situation and compared with standards)

Information will be based on:	• Technical standards and guidelines for the design of flood control structure (Technical standards and guidlines for design of flood control structure, 2010)
Requirements	

The height of the primary structure in (m)

The height of the dike should be sufficient for overtopping and should flow the guidelines formula.



Dike height = Design flood level + Freeboard

Design flood discharge Q (m^3/s)	Freeboard (m)
Less than 200	0.6
200 and up to 500	0.8
500 and up to 2,000	1.0
2,000 and up to 5,000	1.2
5,000 and up to 10,000	1.5
10,000 and over	2.0

The width of the crest

The width of the crest has impertinence factor on the stability of dike for that crest width should be at least 3m wide.
By using Technical standards and guidelines for the design of flood control structure:

Design flood discharge, Q (m^3/sec)	Crest Width (m)
Less than 500	**3**
500 and up to 2,000	**4**
2,000 and up to 5,000	**5**
5,000 and up to 10,000	**6**
10,000 and over	**7**

Berm	• If the height of the dike is more than 5 meters, a berm shall be provided along the slopes for stability, repair and maintenance purposes. The berm width shall be 3.00 meter or more.
Slopes	➢ 1:2 in Dutch standards ➢ The upstream slope of earth fill dams may vary from 2:1 to as flat as 4:1 for stability; usually it is 2.5:1 or 3:1. ➢ Low rock-fill dams may have upstream face slopes of 1 vertical on ½ horizontal; usually have face slopes of 1 to 1.3, the natural angle of repose of rock fill. Downstream slopes of all rockfill dams should be about one in 1.3. (Technical standards and guidlines for design of flood control structure, 2010)

3. Geotechnical condition

Information will be based on:	• Technical standards and guidelines for the design of flood control structure (Technical standards and guidlines for design of flood control structure, 2010) • Dinoloket.nl (dinoloket, 2018)
Extra soil used for the embankments of the dike	• Extra-embankment shall be planned due to a consolidation of the dike. The standard for extra-embankment height is shown below:

Dike Height (m)	Dike Foundation Materials			
	Ordinary Soil		Sand/ Sand & Gravel	
	Extra Embankment Materials			
	Ordinary Soil cm	Sand/ Sand & Gravel cm	Ordinary Soil cm	Sand/ Sand & Gravel cm
≤ 3 m	20	15	15	10
3 m – 5 m	30	25	25	20
5 m – 7 m	40	35	35	30
≥7 m	50	45	45	40

Type of subsoils/ ground soil	• This can be determined by the thickness of each ground soil layers by using the Dinoloket.nl (dinoloket, 2018)
Permeability soil types	Table 1.4.1b Relationship between D_{20} and Coefficient of Permeability (k)

Table 1.4.1b Relationship between D_{20} and Coefficient of Permeability (k)

D_{20}	K (cm/s)	Soil Classification	D_{20}	k (cm/s)	Soil Classification
0.005	3.00×10^{-6}	Coarse clay	0.18	6.85×10^{-3}	
0.01	1.05×10^{-5}		0.20	8.90×10^{-3}	Fine sand
0.02	4.00×10^{-5}		0.25	1.40×10^{-2}	
0.03	8.50×10^{-5}	Fine silt	0.3	2.20×10^{-2}	
0.04	1.75×10^{-4}		0.35	3.20×10^{-2}	
0.05	2.80×10^{-4}		0.4	4.50×10^{-2}	Medium sand
0.06	4.60×10^{-4}		0.45	5.80×10^{-2}	
0.07	6.50×10^{-4}		0.5	7.50×10^{-2}	
0.08	9.00×10^{-4}	Minute sand	0.6	1.10×10^{-1}	
0.09	1.40×10^{-3}		0.7	1.60×10^{-1}	
0.10	1.75×10^{-3}		0.8	2.15×10^{-1}	Coarse sand
0.12	2.60×10^{-3}		0.9	2.80×10^{-1}	
0.14	3.80×10^{-3}	Fine sand	1.0	3.60×10^{-1}	
0.16	5.10×10^{-3}		2.0	1.80	Fine gravel

D_{20}: Diameter at 20% of grain-size distribution curve.

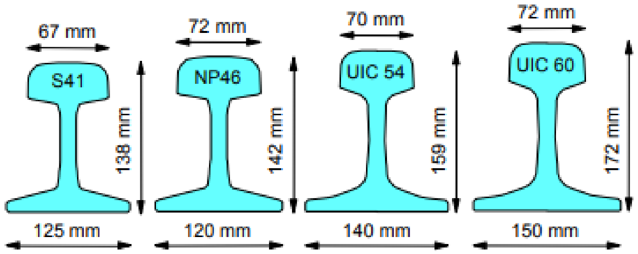
Ground level	• **Subsoil level** (NAP): This can be determined by using Ahn.nl • **Surrounded by area ground level** (NAP): This can be determined by using Ahn.nl

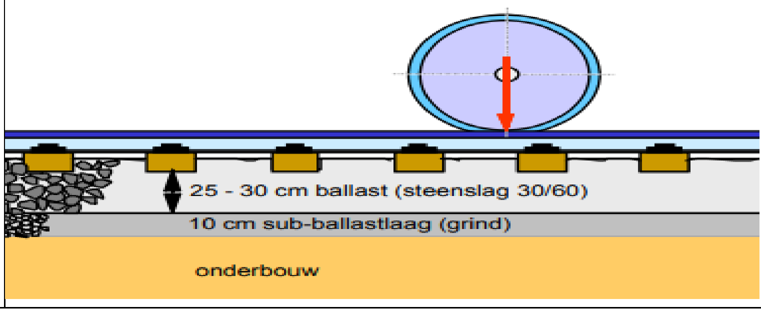
4. Water level

Information based on:	• Dinoloket.nl (dinoloket, 2018) • GIS Calculations will be done during the project
Groundwater level	• by using the Dinoloket.nl (dinoloket, 2018)
Water level during the flood	• by using GIS Calculations
Water level after the flood	• by using GIS Calculations

5. Railway structure

(This information is used in during calculations checks)

<table>
<tr><td>Information will be based on</td><td>• Modern Railway Track book (Esveld, 2001)</td></tr>
<tr><td>Rails</td><td>• Vignoles rails
• Dimensions


(Esveld, 2001)</td></tr>
<tr><td>Track loads</td><td>axle load determines the required strength and stiffness; varies from 70 kN (tram vehicle) to 350 kN
<table>
<tr><th></th><th>number of axles</th><th>empty</th><th>loaded</th></tr>
<tr><td>trams</td><td>4</td><td>50 kN</td><td>70 kN</td></tr>
<tr><td>light-rail</td><td>4</td><td>80 kN</td><td>100 kN</td></tr>
<tr><td>passenger coach</td><td>4</td><td>100 kN</td><td>120 kN</td></tr>
<tr><td>passenger motor coach</td><td>4</td><td>150 kN</td><td>170 kN</td></tr>
<tr><td>locomotive</td><td>4 or 6</td><td>215 kN</td><td>--</td></tr>
<tr><td>freight wagon</td><td>2</td><td>120 kN</td><td>225 kN</td></tr>
<tr><td>heavy haul (USA, Australia)</td><td>2</td><td>120 kN</td><td>250-350 kN</td></tr>
</table>
(Esveld, 2001)</td></tr>
<tr><td>Ballast specification</td><td>25 - 30 cm ballast (crushed stone 30/60)</td></tr>
<tr><td>sub-ballast layer</td><td>10 cm sub-ballast layer (gravel) 20/50</td></tr>
<tr><td>Cross-section</td><td>

(Esveld, 2001)</td></tr>
</table>

6. Calculations and modeling programs

Modeling program (D-geo stability)

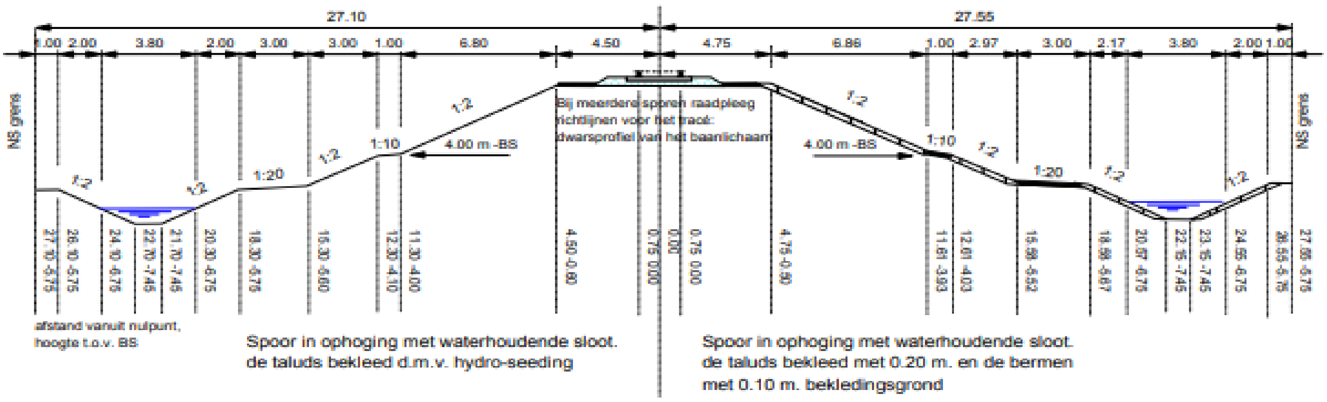
Modeling program (D-geo stability)	• The program will be used to check the stability of the dike and the following parameters required for model: ○ Research site ○ Ground surface ○ Groundwater/ reclamation ○ Flood scenarios ○ Traffic load

GIS program	• The program used to determine the research locations, and it required these things: ○ Heightmaps • Flood scenarios VNK2

Calculations

Calculations based on	• Euro code 7: geotechnical calculations ○ Euro code 7 require the execution of a reliability analysis • NEN 9997: Dutch standards • Modern Railway Track book (Esveld, 2001)

7. Railway on dike cross-section dimensions

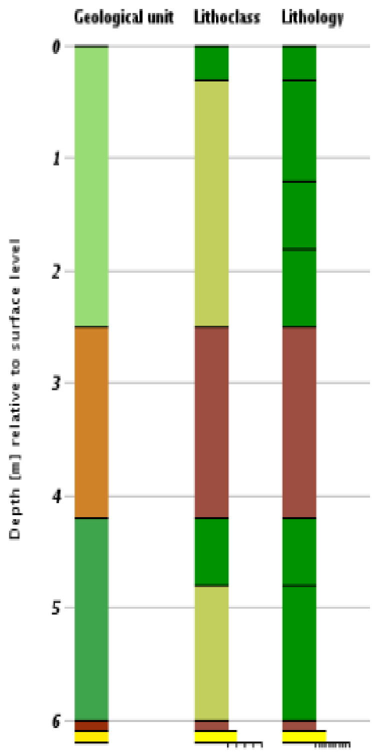


(Esveld, 2001)

Appendix 3: Soil properties

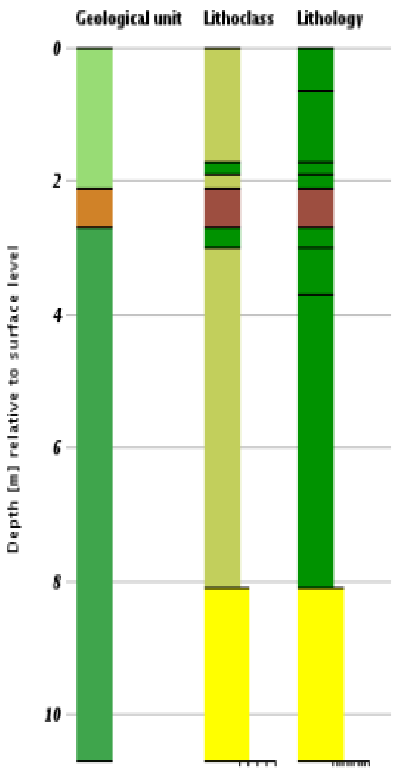
Location one:

Identification: B49C1324
Coordinates: 67251, 383028
Surface level: 0.70 m
Depth relative to surface level: 0.00 m - 6.20 m



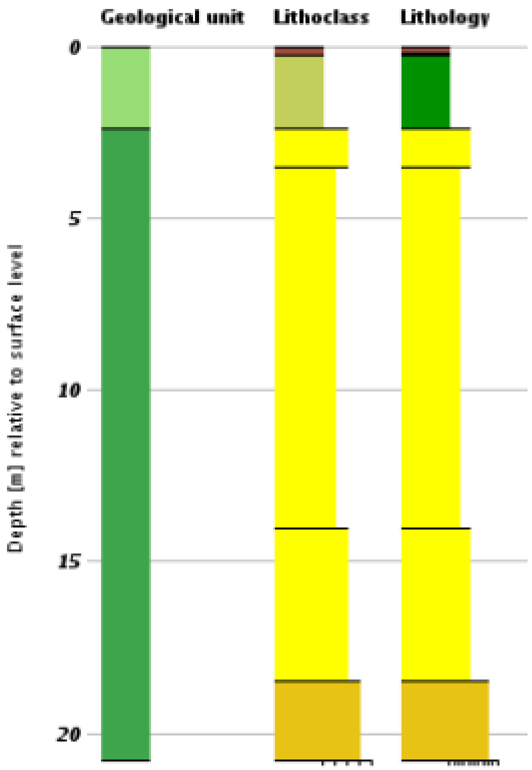
Location two:

Identification: B49C1579
Coordinates: 63404, 385616
Surface level: -0.20 m
Depth relative to surface level: 0.00 m - 10.70 m



Location three:

Identification: B48F0053
Coordinates: 59475, 387620
Surface level: -1.35 m
Depth relative to surface level: 0.00 m - 20.80 m



Appendix 4: Representative values for soil properties

Table 1 – Representative values for soil properties

Soil type		Representative average value of the soil properties												
Main name	Additional Info	Consistency 1)	*Y* 2) kN/M3	*Y*sat kN/m3	*qc* 3)6) MPA	*C'* p	*C'*s	*Cc*	*Ca*5)	*Csw*	*E*6 MPa	*Ø'*	C'	*f*und r kPa
Gravel	Slightly silty	Loose Moderate Fixed	17 18 19 or 20	19 20 21 or 22	15 25 30	500 1000 1200 or 1400	- - -	0.008 0.004 0.003 or 0.002	0 0 0	0.003 0.002 0.001 or 0	75 125 150 or 200	32.5 35 37.5 or 40	n/a	n/a
	Very silty	Loose Moderate Fixed	18 19 20 or 21	20 21 22 or 22.5	10 15 25	400 600 1000 or 1500	- - -	0.009 0.006 0.003 or 0.002	0 0 0	0.003 0.002 0.001 or 0	50 75 125 or 150	30 32.5 35 or 40	n/a	n/a
Sand	Clean	Loose Moderate Fixed	17 18 19 or 20	19 20 21 or 22	5 15 25	200 600 1000 or 1500	- - -	0.021 0.006 0.003 or 0.002	0 0 0	0.007 0.003 0.001 or 0	25 75 125 or 150	30 32.5 35 or 40	n/a	n/a
	Slightly silty		18 or 19	20 of 21	12	450 or 650	-	0.008 or 0.005	0	0.003 or 0.001	25 or 35	27 or 32.5	n/a	n/a

	Clay-like													
	Very silty		18 or 19	20 or 21	8	200 or 400	-	0.019 or 0.009	0	0.006 or 0.001	20 or 30	25 or 30		
	Clay-like													
Loam 4)	Slightly sandy	Soft Moderate Fixed	19 20 21 or 22	19 20 21 or 22	1 2 3	25 45 70 or 100	650 1300 1900 or 2500	0.168 0.084 0.049 or 0.030	0.004 0.002 0.001	0.056 0.028 0.017 or 0.005	2 5 10 or 20	27.5 or 30 27.5 or 32.5 27.5 or 35	0 2 5 or 7.5	50 100 200 or 300
	Very sandy		19 or 20	19 or 20	2	45 or 70	1300 or 2000	0.092 or 0.055	0.002	0.031 or 0.005	5 or 10	27.5 or 35	0 or 2	50 or 100
Clay	Clean	Soft Moderate Fixed	14 17 19 or 20	14 17 19 or 20	0.5 1.0 2.0	7 15 25 or 30	80 160 320 or 500	1.357 0.362 0.168 or 0.126	0.013 0.006 0.004	0.452 0.121 0.056 or 0.042	1 2 4 of 10	17.5 17.5 17.5 or 25	0 10 25 or 30	25 50 100 or 200
	Slightly sandy	Soft Moderate Fixed	15 18 20 or 21	15 18 20 or 21	0.7 1.5 2.5	10 20 30 or 50	110 240 400 or 600	0.759 0.237 0.126 or	0.009 0.005 0.003	0.253 0.079 0.042 or	1.5 3 5 or 10	22.5 22.5 22.5 or 27 5	0 10 25 or 30	40 80 120 or 170

								0.069		0.014				
	Very sandy		18 or 20	18 or 20	1.0	25 or 140	320 or 1680	0.190 or 0.027	0.004	0.063 or 0.025	2 or 5	27.5 or 32.5	0 or 2	0 or 10
	Organic	Soft Moderate	13 15 or 16	13 15 or 16	0.2 0.5	7.5 10 or 15	30 40 or 60	1.690 0.760 or 0.420	0.015 0.012	0.550 0.250 or 0.140	0.5 1.0 or 2.0	15 15	0 or 2 0 or 2	10 25 or 30
Peat	Not preloaded	Soft	10 or 12	10 or 12	0.1	5 or 7.5	20 or 30	7.590 or 1.810	0.023	2.530 or 0.600	0.2 or 0.5	15	2 or 5	10 or 20
	Moderately preloaded	Moderate	12 or 13	12 or 13	0.2	7.5 or 10	30 or 40	1.810 or 0.900	0.016	0.600 or 0.300	0.5 or 1.0	15	5 or 10	20 or 30
Variety Coefficient			0.05		-	0.25						0.10	0.20	

The table indicates the low representative value of averages of the soil type in question. Within an area, defined by the row of additional information and the parameter column (a “box”), the following applies: for y, y_{sat}, C_p, C_s, E, $Ø'$, c' and f_{undr}: if an increase in value leads to an unfavourable situation (larger foundation measurements), then the right value on the same line needs to have been used, or, if there is no right value, the value on the line below should be used; for C_c, C_a and C_{sw}: if a reduction in value leads to an unfavourable situation, then the right value on the same line needs to have been used, or, if there is no right value, the value on the line below should be used

loose: moderate:

fixed: with a natural moisture content

the q_c values (cone resistance) given here serve as an entry in the table and may not be used in calculations

saturated loam is calculated

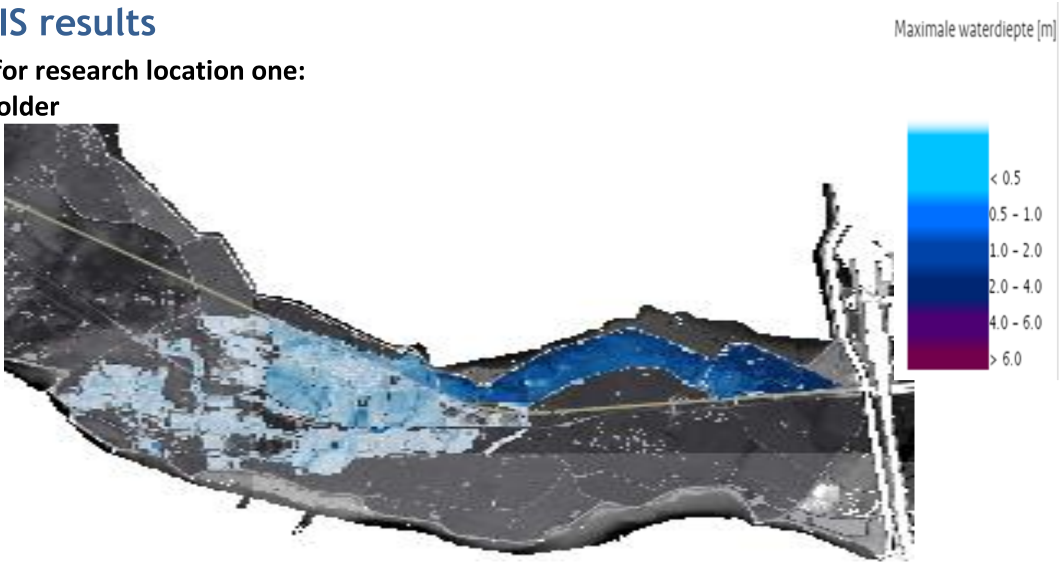
C_a values apply to an increase in pressure project of no more than 100%.

q_c and E are normalised on an effective vertical pressure of 100 kPa. In order to acquire a correct entry in the table via q_c, the measured values of q_c can be converted to an effective vertical pressure level of 100 kPa. The C_n conversion factor needs to be determined with the graph in figure 2A.

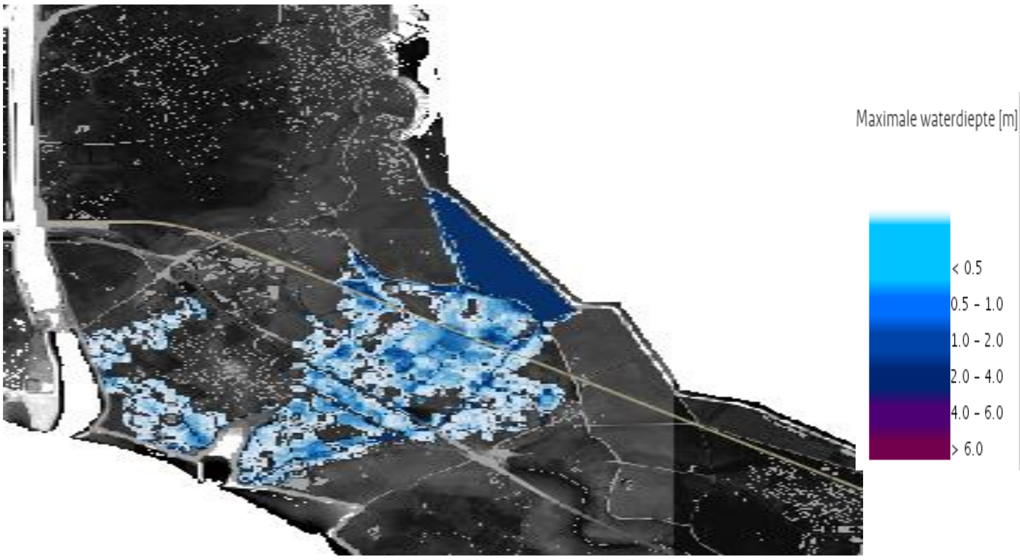
(Steur, 2016)

Appendix 5: Q-GIS results

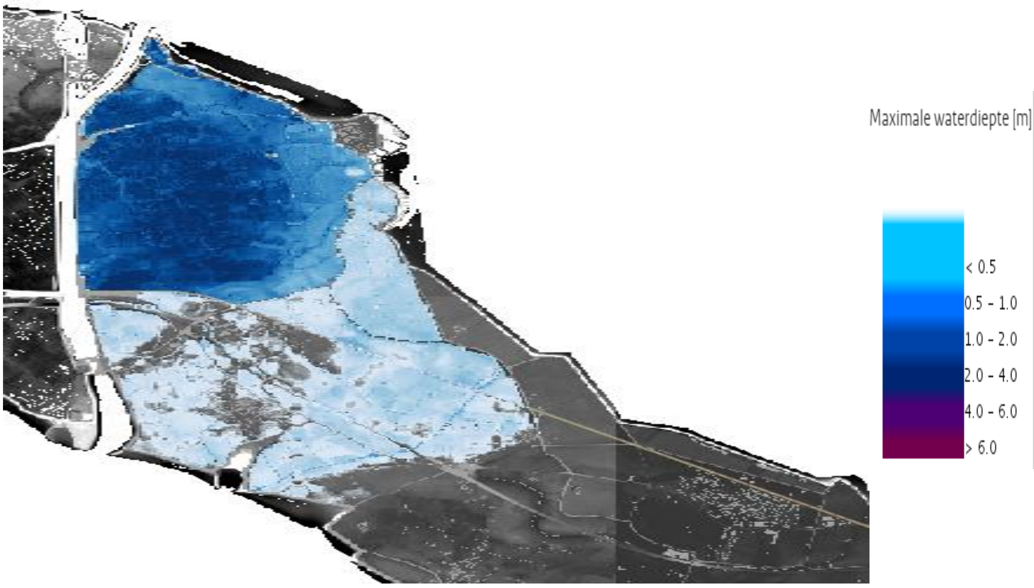
1. **Flood Scenario for research location one: Twee de Bath polder**



2. **Flood Scenario for research location two: St.Pieterspolder**

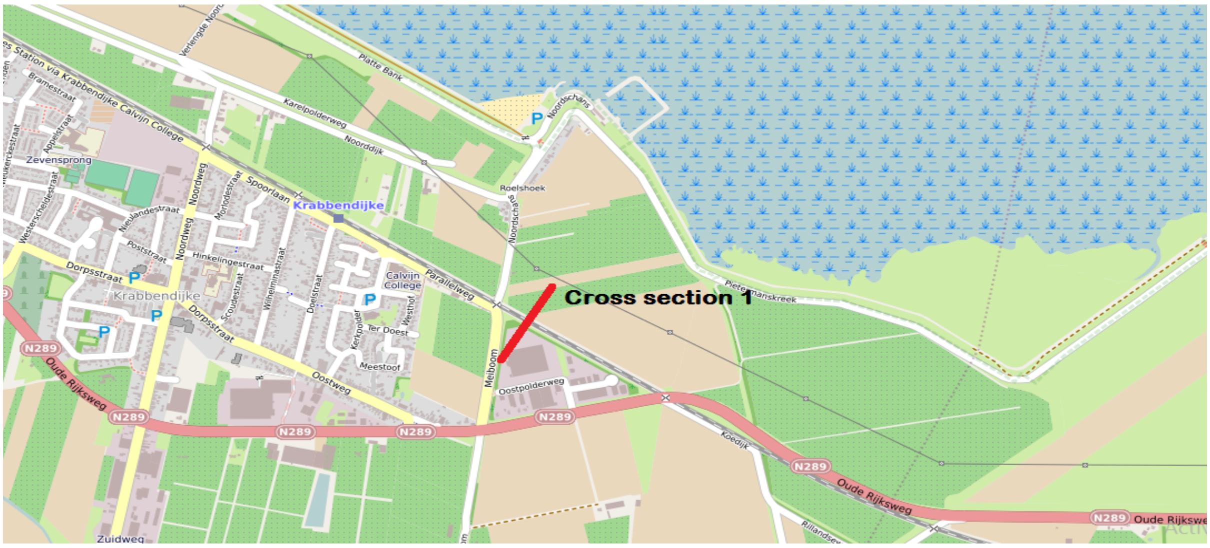


3. **Flood Scenario for research location three: Yerseke Moer**

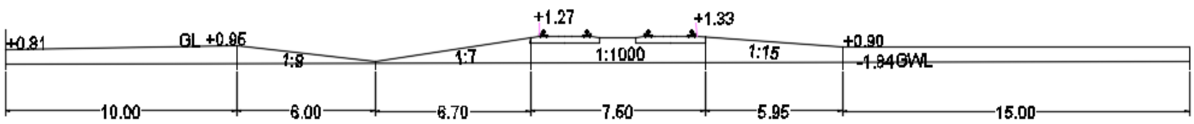


Appendix 6: Cross sections

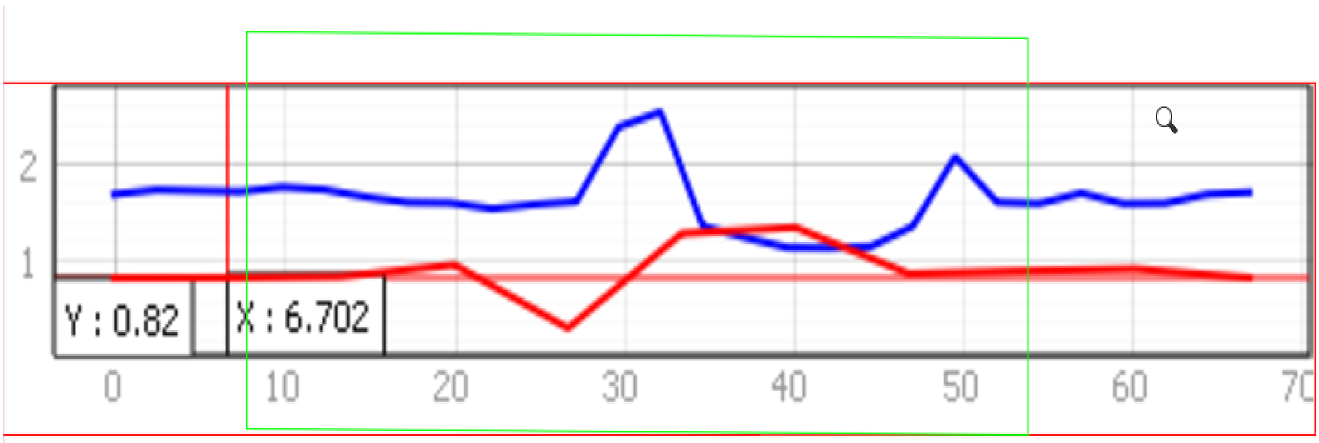
1. Location one

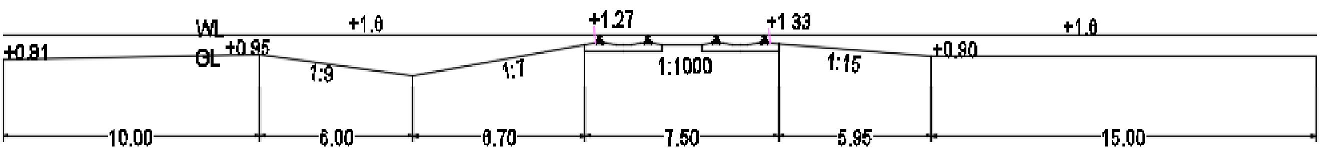


➢ **Before flood**

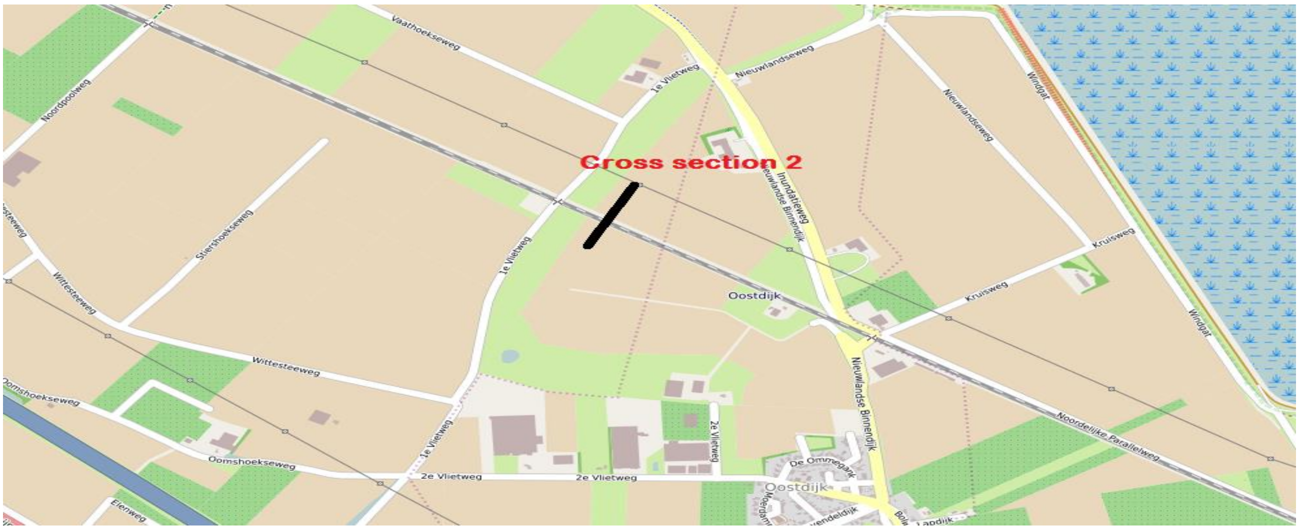


➢ **During Flood**

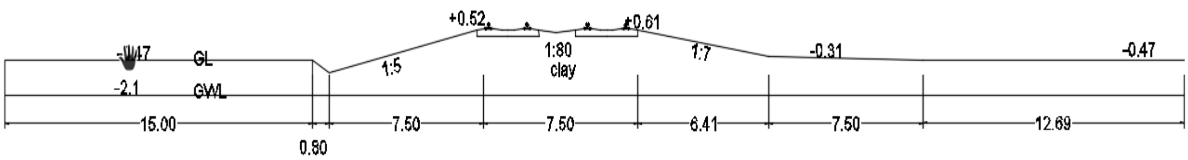




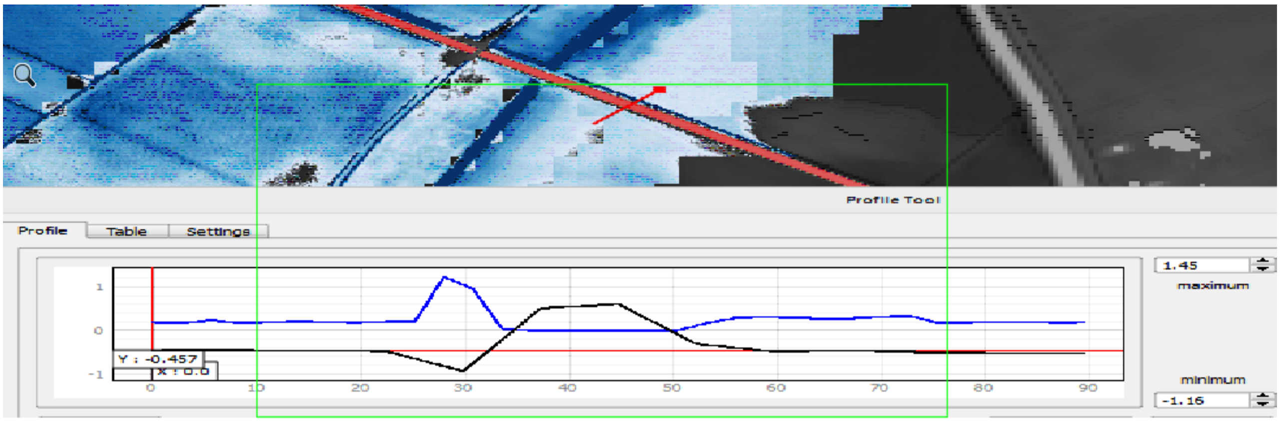
2. Location two

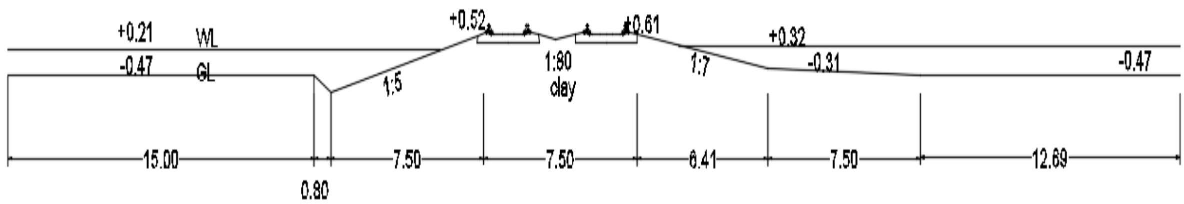


- **Before flood**

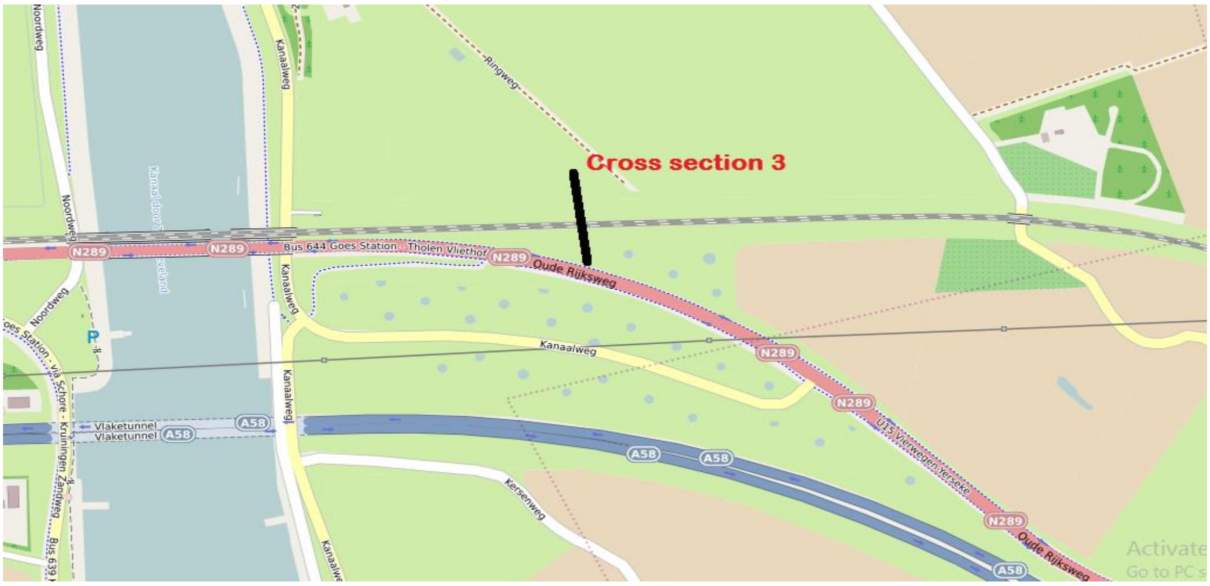


- **During Flood**

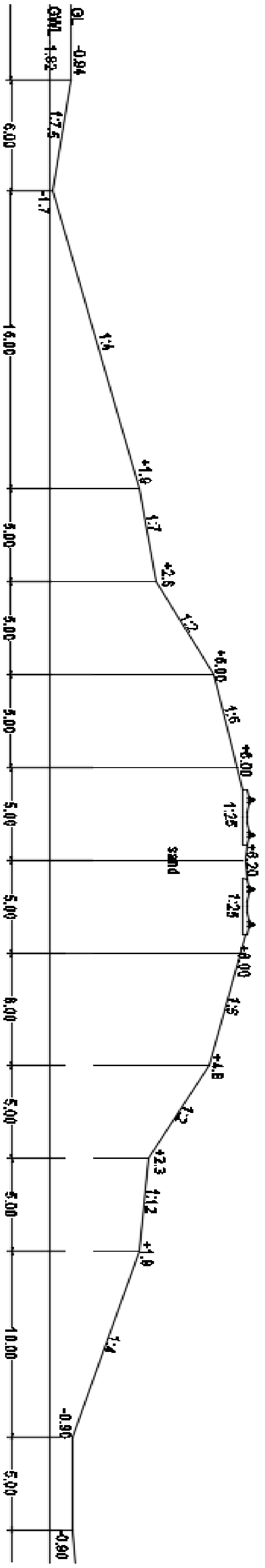




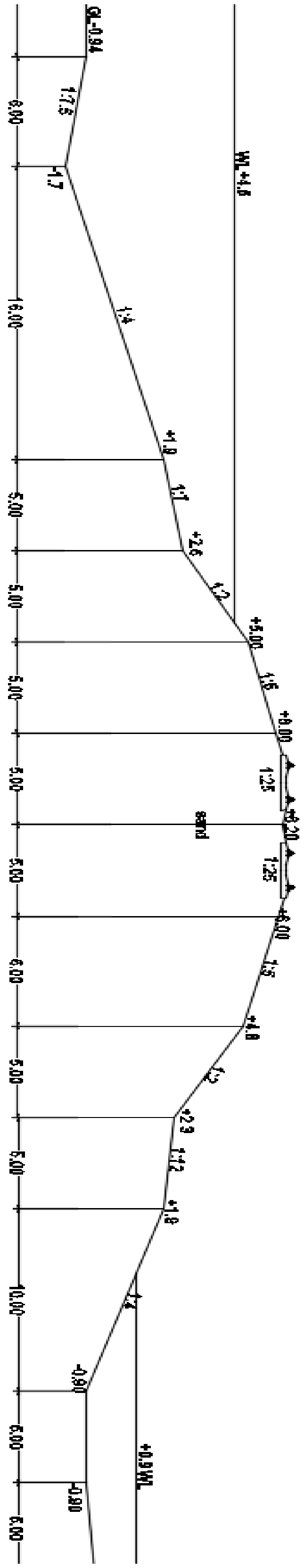
3. Location three



Before flood



During Flood



Appendix 7: D-Geo stability results

https://www.pdf.investintech.com/preview/4dbdd196-6a7e-11e8-b174-0cc47a792c0a/index.html

(See appendix 7 pdf file)

Appendix 8: settlements results

Location one

- Before flood:
    - One day: https://www.pdf.investintech.com/preview/b4e8a910-6a4a-11e8-b174-0cc47a792c0a/index.html
    - Two weeks: https://www.pdf.investintech.com/preview/ba3e1c24-6a4a-11e8-b174-0cc47a792c0a/index.html
    - One month: https://www.pdf.investintech.com/preview/38e061fe-6a4b-11e8-b174-0cc47a792c0a/index.html
    - Two months: https://www.pdf.investintech.com/preview/f51d0486-6a4a-11e8-b174-0cc47a792c0a/index.html
- During flood:
    - One day: https://www.pdf.investintech.com/preview/7bc3709c-6a4b-11e8-b174-0cc47a792c0a/index.html
    - Two weeks: https://www.pdf.investintech.com/preview/1d77629c-6a4a-11e8-b174-0cc47a792c0a/index.html
    - One month: https://www.pdf.investintech.com/preview/845f717e-6a4b-11e8-b174-0cc47a792c0a/index.html
    - Two months: https://www.pdf.investintech.com/preview/5e0dd61a-6a4a-11e8-b174-0cc47a792c0a/index.html
- After flood:
    - One day: https://www.pdf.investintech.com/preview/b7569b0c-6a4b-11e8-b174-0cc47a792c0a/index.html
    - Two weeks: https://www.pdf.investintech.com/preview/bf918bf6-6a4b-11e8-b174-0cc47a792c0a/index.html
    - One month: https://www.pdf.investintech.com/preview/6b8a9e90-6a4a-11e8-b174-0cc47a792c0a/index.html
    - Two months: https://www.pdf.investintech.com/preview/cb493fac-6a4b-11e8-b174-0cc47a792c0a/index.html

Location two

- Before flood:
  - One day: https://www.pdf.investintech.com/preview/21ccc7f4-6a4c-11e8-b174-0cc47a792c0a/index.html
  - Two weeks: https://www.pdf.investintech.com/preview/2554f82e-6a4c-11e8-b174-0cc47a792c0a/index.html
  - One month: https://www.pdf.investintech.com/preview/3e917dec-5d47-11e8-b174-0cc47a792c0a/index.html
  - Two months: https://www.pdf.investintech.com/preview/2e3e5228-6a4c-11e8-b174-0cc47a792c0a/index.html
- During flood:
  - One day: https://www.pdf.investintech.com/preview/7bbe1c72-6a4c-11e8-b174-0cc47a792c0a/index.html
  - Two weeks: https://www.pdf.investintech.com/preview/7f4a4474-6a4c-11e8-b174-0cc47a792c0a/index.html
  - One month: https://www.pdf.investintech.com/preview/81e421f0-6a4c-11e8-b174-0cc47a792c0a/index.html
  - Two months: https://www.pdf.investintech.com/preview/196d7182-5d48-11e8-b174-0cc47a792c0a/index.html
- After flood:
  - One day: https://www.pdf.investintech.com/preview/d373cf48-6a4c-11e8-b174-0cc47a792c0a/index.html
  - Two weeks: https://www.pdf.investintech.com/preview/93b0964a-5d48-11e8-b174-0cc47a792c0a/index.html
  - One month: https://www.pdf.investintech.com/preview/d72cf574-6a4c-11e8-b174-0cc47a792c0a/index.html
  - Two months: https://www.pdf.investintech.com/preview/dae73bc0-6a4c-11e8-b174-0cc47a792c0a/index.html

Location three

- Before flood:
  - One day: https://www.pdf.investintech.com/preview/1f0e6b52-6a4d-11e8-b174-0cc47a792c0a/index.html
  - Two weeks: https://www.pdf.investintech.com/preview/33d6b73a-5d49-11e8-b174-0cc47a792c0a/index.html
  - One month: https://www.pdf.investintech.com/preview/5474c3d8-5d49-11e8-b174-0cc47a792c0a/index.html
  - Two months: https://www.pdf.investintech.com/preview/24bf1ace-6a4d-11e8-b174-0cc47a792c0a/index.html
- During flood:
  - One day: https://www.pdf.investintech.com/preview/82ed0872-6a4d-11e8-b174-0cc47a792c0a/index.html
  - Two weeks: https://www.pdf.investintech.com/preview/a166835c-5d49-11e8-b174-0cc47a792c0a/index.html
  - One month: https://www.pdf.investintech.com/preview/87eedf08-6a4d-11e8-b174-0cc47a792c0a/index.html
  - Two months: https://www.pdf.investintech.com/preview/d5e39d86-5d49-11e8-b174-0cc47a792c0a/index.html
- After flood:
  - One day: https://www.pdf.investintech.com/preview/c47e8504-6a4d-11e8-b174-0cc47a792c0a/index.html
  - Two weeks: https://www.pdf.investintech.com/preview/c893a7dc-6a4d-11e8-b174-0cc47a792c0a/index.html
  - One month: https://www.pdf.investintech.com/preview/cdd20ac2-6a4d-11e8-b174-0cc47a792c0a/index.html
  - Two months: https://www.pdf.investintech.com/preview/702726ce-5d4a-11e8-b174-0cc47a792c0a/index.html