AFSLUITDIJK UPGRADING
NON TYPICAL DUTCH SOLUTIONS

Final Report

CIE 4061 Multidisciplinary Project

December 2013

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Challenge the future

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CIE4061 Multidisciplinary Project

Delft University of Technology

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Afsluitdijk Upgrading, Non-Typical Dutch Solutions

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PREFACE

This report is the result of the studies carried out for the course CIE4061 Multidisciplinary Project, which is part of the MSc. Civil Engineering at Delft University of Technology. The goal of this course is to solve a current and/or recent civil engineering problem in a multi-disciplinary team. It is also required to integrate multiple studies and designs into a coherent whole, based on knowledge, understanding and skills acquired in previous years.

The Multidisciplinary Project planning started in May 2013. The group members, all of them international students, contacted ir Henk Jan Verhagen looking for a possible topic. The objective was to find a project in the Netherlands to have better insights on Dutch Engineering. Afterwards, Ir Henk Jan Verhagen came with a proposal to study the Afsluitdijk Upgrading with Non-Typical Dutch Solutions. He provided information about this iconic construction and Rijkswaterstaat plans to upgrade the dike for future scenarios. Immediately, team members agreed to work on this exciting project along the coming months.

Therefore, the contact with Rijkswaterstaat, Dutch Ministry of Infrastructure and the Environment, was set throughout Ing. Eric Regeling, who together with Ir. Henk Jan Verhagen, have been the mentors and supervisors from Rijkswaterstaat and TU Delft respectively.

The students participating in this project are following Hydraulic Engineering track at Delft University of Technology. However, most of them have different background, which has become a key factor to enrich work processes and project results.

The main task committed to the group was to define the upgraded cross section of the Afsluitdijk; a landmark not only in the Netherland but worldwide. The focus of the project is the development of a design that fulfils the latest safety standards according to Dutch legislation.

This multidisciplinary approach resulted in plenty fruitful discussions on different topics. Along the project, synergy among group members significantly increased, resulting in a very enjoyable experience. It is also important to highlight that meetings and interaction with the Client enhanced the undertaking and outcome of the project.

This team wants to warmly thank ing Eric Regeling, for all his support and kindness during this four month process. Besides, team members want to express their gratitude to ir Henk Jan Verhagen, who made this adventure possible.

We started as four group members, but we ended as very good friends. Therefore, to conclude, we hope the reading of this report is as pleasant as it was for us working on it.

TU Delft, December 2013

Y. Li; M. J. Ruiz Fuentes; P. Arecco; C. Miranda Eguez

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SUMMARY

The Afsluitdijk (Enclosure Dam) is a major causeway in the Netherlands, which was constructed between 1927 and 1933, running from Den Oever on Wieringen in North Holland province, to the village of Zurich in Friesland province. The dam is 32 kilometers long and 90 m wide, with an initial height of 7.25 m above sea-level and a slope of 1:4 (original slope, now 1:3.6) on each side (Rijkswaterstaat, 2009).

After 80 years of successful performance, expected changes in boundary conditions and an increase of safety requirements make necessary to think of an adaptation of the structure, so it can perform its function in the future. Rijkwaterstaat has decided to adopt an overtopping resistant solution which provides the required protection until the year 2050.

This project is aiming to define and propose a new non-typical Dutch dike configuration which needs to comply with Employer's Requirements.

As a starting point, an existing cross section from the Afsluitdijk is used. Mean Waddenzee bottom elevation at the Afsluitdijk is between -4.0m to -5.0m, NAP referred. For every possible new configuration, -5.0m is adopted trying to perform a representative design. In the intermediate design, several non-typical Dutch solutions have been defined trying to cover a wide range of options. The following feasible alternatives have been evaluated during the Intermediate Design (slopes are noted Vertical:Horizontal; i.e. 2V:3H):

1. Rip-Rap without berm, slope 2:3
2. Rip-Rap without berm, slope 1:2
3. Xbloc®, slope 2:3
4. Xbloc®, slope 3:4
5. Berm breakwater, dynamically stable reshaped
6. Rip-Rap with berm
7. Acropode™ II slope 3:4 (up to the external limit)
8. Acropode™ II slope 3:4 (cutting slope)
9. Antifer cubes, slope 2:3
10. Rip-Rap without berm, slope 1:3.6, over layer on top of existing slope invading the Waddenzee
11. Xbloc®, slope 3:4, invading the Waddenzee
12. Berm breakwater, dynamically stable reshaped, invading the Waddenzee

Then, a comparison among them is done by means of a multi-criteria analysis, together with cost estimations. As a result, the two more favourable alternatives, design 4 and design 10, were selected.

In the final stage, further studies were done for both selected alternatives, which were contrasted with Rijkswaterstaat adopted solution (OverTopping resistant solution). Design 10 is the most advantageous of the proposed solutions.

However, current politics dominant way of thinking is directly influencing Rijkswaterstaat standards and procedures. Consequently, possible solutions should be the less expensive ones.

As a major conclusion, this report is proposing Rijkswaterstaat to think over the whole life cycle of the structures. This could lead to introduce more flexibility and adaptability into the designs (robust designs including future planned adaptation). Finally, is up to the Ministry of Infrastructure and the Environment to decide whether providing advantages to future generations is worth a larger investment.

1. INTRODUCTION

As part of the Master's Program of Hydraulic Engineering at Delft University of Technology, it is possible to start a Multidisciplinary project. The aim of this project is to solve an existing civil engineering problem, proposed by a Public Institution or a Company. Part of the project consists on developing a clear and precise solution based on a wide starting point, always taking into account a multidisciplinary perspective and satisfying Client needs.

In this case, the starting point is the Afsluitdijk, one of the most important infrastructures in the Netherlands. The Afsluitdijk was built aiming to protect the coast along the Zuiderzee against the North Sea, turning it into a fresh water lake at the same time. The old coastline configuration is shown in Figure 1-1. It is clearly visible that the Afsluitdijk protects central Netherlands from the effects of the North Sea (Merwe & Bezuidenhout, 2007). As it was mentioned in the Summary, after almost a century of successful performance, changes are expected.

Figure 1-1. Map of the Netherlands 1658, Source: Janssonius

2. OBJECTIVES

The Multidisciplinary Project *"Afsluitdijk upgrading, non-Typical Dutch solutions"* aims to define a new armour layer solution and dike configuration which is suitable for the Afsluitdijk upgrading that Rijswaterstaat is considering nowadays. The task given and purpose of this Multidisciplinary project is to define the upgraded cross section for the Afsluitdijk. The developed design will have to accomplish several goals:

- Provide the required safety level
- Respect the imposed conditions (keep roads operational while working, and any other requirements from the Client)
- Optimized construction cost (definition of the optimal cross section and construction methods according to the given conditions)

The project will focus on the development of a design that fulfils the given conditions, and a substantiation of the advantages of the chosen design. First, several non-typical Dutch solutions have been defined trying to cover a wide range of options. Then, a comparison among them is done by means of a multi-criteria analysis. Finally, the most advantageous solution proposed for the Afsluitdijk is chosen. The studies will be based also in a cost estimation analysis.

3. ISSUES BEING ADDRESSED

The Afsluitdijk was built up with boulder clay, clay and sand which were found in the bottom of former Zuiderzee. The dam is erected on top of a smaller closure made of boulder clay which was emplaced previously to separate both water masses. On the Ijsselmeer side of this dam, a wide body of sand which is covered with boulder clay and clay was built. The dam body below the waterline is protected with osier wood and reed mattresses, where Rip-Rap is placed on. Above waterline, the dike is protected with basalt blocks. The crest and inner slope are covered with grass. Furthermore a motorway stretches out at the top of the dam, enabling road traffic between the provinces of Noord Holland and Friesland.

For the current situation, the dike reaches a level of +7.8m NAP with an outside slope of 1:3.6 covered with basalt blocks as a revetment. There is also a permeable clay layer on top of the crest covered with grass with an inside slope of around 1:2.7. The total a width of the dike is between 80m to 100m. If the current structure faces these severe storm conditions it would mean that a wave overflow of approximately 366 ℓ/s/m will occur, rising Lake Ijssel's water level by 0.5m over storm duration of 12 hours (Liu, Huang, Rayo, & Lim, 2012).

An existing cross section from the Afsluitdijk will be used as starting point. Specifically, cross section 10a (referred to Legger Afsluitdijk document (Rijkswaterstaat, 2009)) shown in Figure 3-3, is chosen as the characteristic cross section and the proposed designs are based on it.

The mean sea bottom depth at the Afsluitdijk is around 4.0m to 5.0m, NAP referred. Therefore the adopted sea bottom elevation for this cross-section is -5.0m NAP. This value is used in every proposed new configuration trying to have a representative design for the whole dike length. However, it is important to mention that the actual existing depths at the area where cross section 10a is located are around -10.00m+NAP. In addition other cross sections are in shallower areas around -2.00m NAP.

On the following figures details about its layout and cross section can be found.

Figure 3-1. Map of the Northeast part of the Netherlands

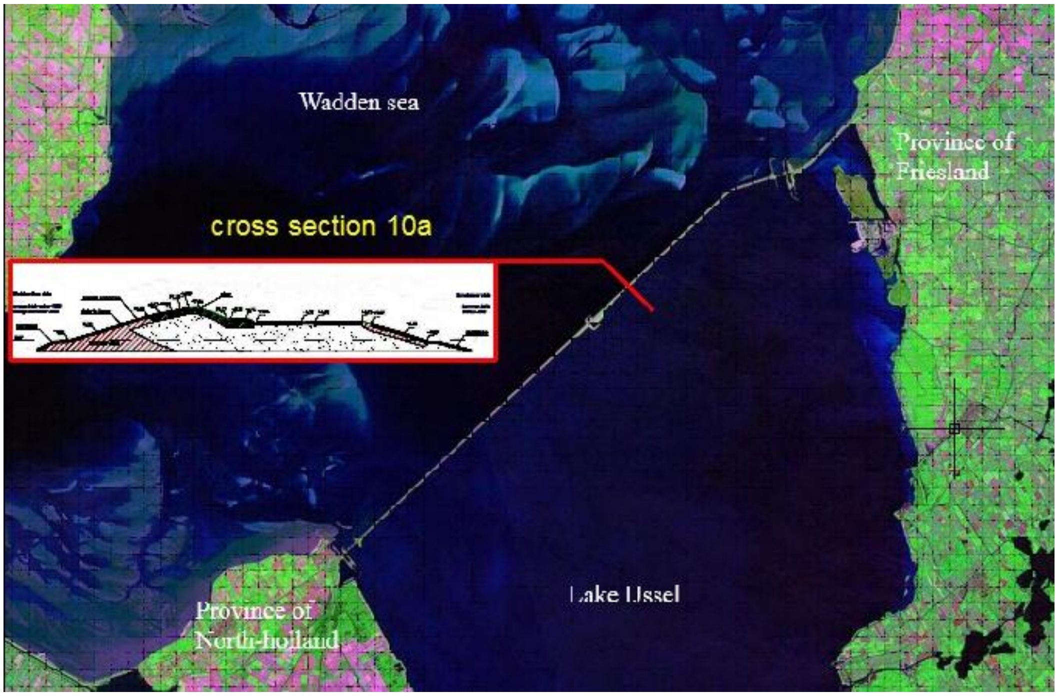


Figure 3-2. General Layout

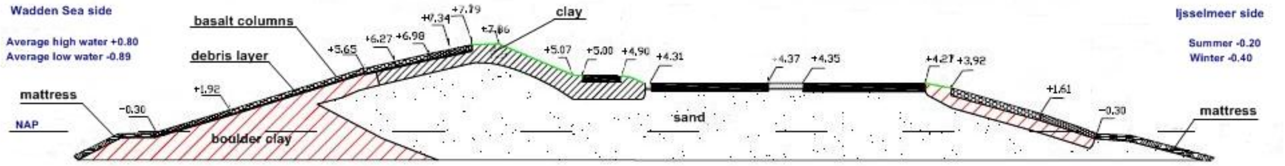


Figure 3-3. Characteristic Cross Section Afsluitdijk (Rijkswaterstaat, 2009)

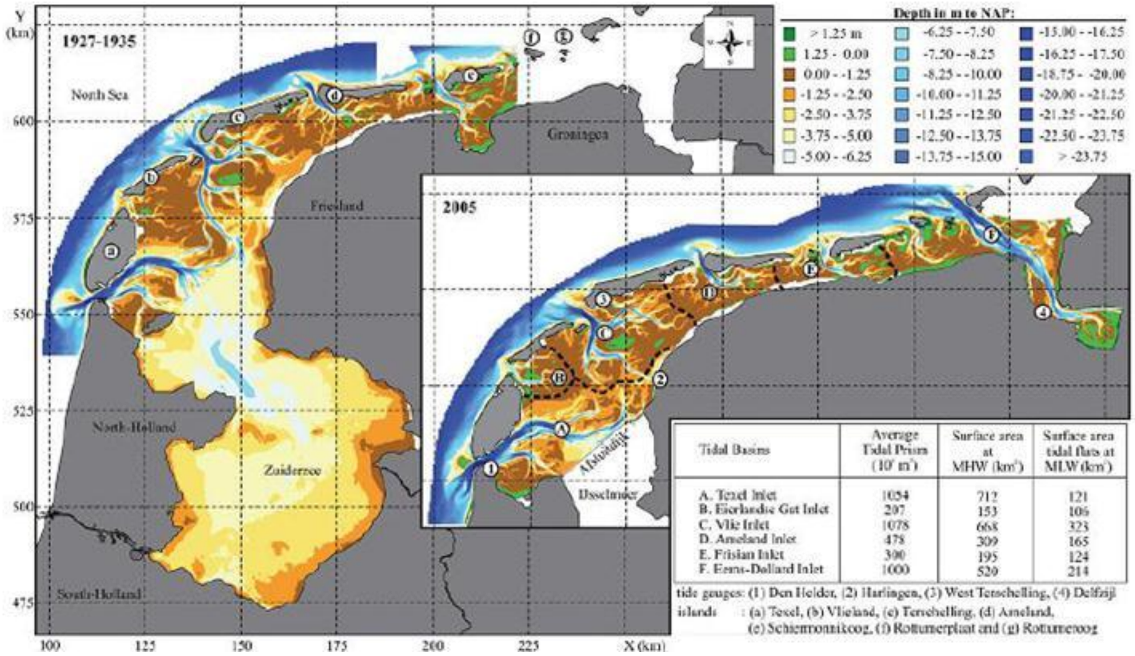


Figure 3-4. Bathymetry in 1927/35 and 2005 (Vroom, 2011)

4. SOURCE INFORMATION & DATA COLLECTION

In this section, references, documents and requirements used for the analysis and design of new alternatives for the Afsluitdijk are presented.

4.1. EMPLOYER'S REQUIREMENTS

It is essential to know and understand Employer's needs in order to design and offer a satisfactory solution. This design complies, not only the explicit requirements, but also other conditions that are not directly requested, but follow the general spirit of Employer's demands. These requirements are introduced in the following statements:

- Define a new armour layer solution and dike configuration, using non-typical Dutch solutions. The new design should be innovative and reliable for Dutch standards.
- Use different values of wave heights and wave periods to perform specific calculations for each proposed cross-section design, i.e. use "Golfklappen betonblokken-info" to compute concrete blocks and Rip-Rap armour units stability; on the other hand use "golfoverslag" values to design crest height for overtopping.
- Limit to the existing boundaries of the current dike situation (no extra space occupied, however some alternatives were developed superseding this constraint due to the fact of special request from the Client; also, keep roads operational while working, et cetera).
- Basalt columns should be reused or sold to the market, if they are removed from the Afsluitdijk. Alternatives without removing the basalt columns are also evaluated under request of the Client assuming there will be no benefit on it. .
- The increase in land availability provided by the crown wall is not essential. An optimization of concrete crown wall should be studied.

4.2. REFERENCE DOCUMENTS

Among others books, standards, papers that will be listed as reference at the end of this report, the documents listed in Table 1 will set the standards for this report. In case, there are not available codes regarding any parameter, recommendations from books will be followed.

Table 1. Documents Issued by the Client

No	ITEM NAME	TYPE	DESCRIPTION
1	Calculation Appendix	Word	Hydraulic boundary conditions of representative cross sections of Afsluitdijk. Provided by Rijkswaterstaat.
2	Closure Dam-Indonesia 13dec2012	PPT	General description of the Afsluitdijk, including details of the structure and definition of the Reconstruction Plan.
3	Dijkvakken_ontwerprvw_Waddenzeezijde_T10000	Excel	Detailed survey of Aflsuitdijk; wave climate at different locations of the dike; list of materials. Includes survey of year 2012 and extimation of the year 2050 and 2100.
4	Dikesections-Afsluitdijk	PDF	Cross sections of different locations of Afsluitdijk.
5	Legger Afsluitdijk	PDF	Information about Afsluitdijk. Contains layouts of plan views and cross sections of different locations of the dike, including The Monument location.
6	Loding BZD-FRL-scan-ER	PDF	A profile of one of the alternatives that was developed in the exploration phase of the project: A wider and higher dike (crest height ca. 10 m +NAP), where the amount of overtopping water was limited to about 10 l/s/m
7	LV963_Afsluitdijk	PDF	A draft drawing concerns different cross section profiles at different locations of Afsluitdijk.
8	memo-DGRW-verschil-HYDRA-HR-rekenbijlagen	Word	Technical memorandum that includes hydraulic calculations and results about wave climate and overtopping rate on the Aflsuitdijk. Includes calculations for the year 2006 and estimation of sea level rise to the year 2050.
9	dwp-altT2-def	JPEG	A scan of measured waterdepths at the stretch Breezanddijk, Frisian coast.
10	List of prices	Text File	A short list of some available prices, regarding sand, clay, quarry, asphalt, mattress

4.3. STANDARDS & GUIDELINES:

- PIANC PTC II - Analysis of rubble mound breakwaters (PIANC PTC II WG 12, 1992).
- PIANC MarCom Working Group 40 - State-of-the-art of designing and constructing berm breakwaters (PIANC MarCom WG 40, 2003).

- PIANC MarCom Working Group 56 - The application of geosynthetics in waterfront areas (PIANC MarCom WG 56, 2011).
- EN 1990 Eurocode - Basis of structural design (British Standards Institution, 2002).
- EN 1992 Eurocode Design of concrete structures (British Standards Institution, 2004).
- EurOtop – Wave Overtopping of Sea Defenses and Related Structures: Assessment Manual (Pullen, Allsop, & van der Meer, 2007).
- New safety standards for coastal flood defenses in the Netherlands (Jonkman, Jongejan, Maaskant, & Vrijling, 2011).
- The Rock Manual. The use of rock in hydraulic engineering (Martin, 1999).
- Wave run-up on dikes with shallow foreshores (van Gent, 2001).
- ROM 0.1-09 Guidelines and recommendations for design and construction of Breakwaters (Puertos del Estado, 2008).
- Chinese Code of Design and Construction of Breakwaters (Ministry of Transport of the People's Republic of China, 2012).
- Delta Marine Consultants, Guidelines for Xbloc Concept Designs (Delta Marine Consultants, 2011).
- Breakwaters and closure dams, 2nd Edition (Verhagen, d'Angremond, & van Roode, 2009).

4.4. SITE VISIT

On September 7, 2013 the group departed from Delft to recognize the project site with its particularities. As it was explained before, the Afluitsdijk is located in the Northeast of the Netherlands and it divides the Ijsselmeer at the SE from the Waddenzee and the Wadden Islands at the NW (Figure 3-1). The political border between the provinces of Noord Holland and Friesland is situated here.

Figure 4-1. Satellite image of the Afsluitdijk showing the site visit stops

The technical visit comprised four stops at key points of the 32 km long dike to have better insights. The mentioned stops are shown on Figure 4-1. It is important to mention that, A7 Highway runs on top of the dike as well as a bike lane. More details are shown in *Appendix C – Source information and data collection*.

4.5. MATERIALS PROPERTIES

4.5.1. DIKE MATERIALS

The properties of dike components have been collected from the report Toekomst Afsluitdijk (Vossen, Swinkels, Wichman, Dionisio Pires, & Meurs, 2010). This information is summarized in Table 2

Table 2. Materials Properties

	UNIT WEIGHT: SATURATED / DRY		INTERNAL FRICTION ANGLE	COHESION
	γ_s (kN/m^3)	γ (kN/m^3)	ϕ (º)	C (kPa)
Dike material	19.0	17.0	26.4	0.0
Loamy sand	19.0	17.0	30.1	0.0
Peat	11.0	11.0	15.0	2.0
Sandy clay	15.5	15.5	18.3	2.4
Sandy-organic clay	15.5	15.5	18.3	2.4
Sand	20.0	18.0	30.1	0.0
Clay -organic	14.0	14.0	14.8	2.0
Boulder clay	19.0	16.0	23.7	2.6
Cover clay	16.5	15.0	25.0	5.0

4.5.2. GRANULAR MATERIALS

It is necessary to set values for the properties of imported granular materials. Clay properties values come from "Geotechnische risico-evaluatie van vijf basisreferentievarianten voor versterking Afsluitdijk" (Deltares, 2008) and Toekomst Afsluitdijk (Vossen et al., 2010). Rockfill properties come from "Advanced Dam Engineering for Design, Construction, and Rehabilitation" (Jansen, 1988). This information is presented in Table 3.

Table 3. Granular Materials Properties

	UNIT WEIGHT: SATURATED / DRY		INTERNAL FRICTION ANGLE	COHESION
	γ_s (kN/m^3)	γ (kN/m^3)	ϕ (º)	C (kPa)
Rockfill	-	18.0	42.0	0.0

It is important to notice that rockfill properties are variable. Within the scope of this report conservative values have been selected.

4.5.3. CONCRETE

For concrete properties EN 1992 Eurocode Design of concrete structures is used (British Standards Institution, 2004). Concrete properties are shown in Table 4.

Table 4. Concrete properties

	UNIT WEIGHT	DEFORMATION MODULUS	POISSON'S RATIO	STRENGTH
	γ (kN/m^3)	E'_b (MPa)	υ	f'_{ck} (MPa)
Lean concrete C12/15	23	26000	0.15	15
Concrete C28/35	24	31000	0.15	35
Concrete C35/45	24	33500	0.15	45
Concrete C45/55	24	36000	0.15	55
Reinforced concrete	25	-	-	-

4.6. WAVE CLIMATE

The wave climate definition (return period 10,000 years) is obtained from reference documents “Dijkvakken_ontwerprvw_Waddenzeezijde_T10000” (Excel data sheet with wave climate design values, issued by the Client), which include several cross sections of the Afsluitdijk. The available information includes mean sea level elevation, significant wave height, mean wave period and peak period. For design purposes, the end of the structure service life is considered at 2050; therefore the wave climate data used will be the one corresponding to this year. The used wave climate data is shown in Table 5.

Table 5. Wave climate data for Afsluitdijk cross section 10a

	SEA LEVEL ELEVATION	SIGNIFICANT WAVE HEIGHT	MEAN WAVE PERIOD	PEAK PERIOD
	h (m + NAP)	$\mathbf{H_0}$ (m)	$\mathbf{T_{m1\text{-}0}}$ (s)	$\mathbf{T_p}$ (s)
2050 (overtopping)	5.31	3.83	6.2	7.6
2050 (concrete blocks)	1.00	2.63	4.9	5.9
2050 (concrete blocks)	5.00	3.72	6.1	7.5
2050 (overall stability)	5.52	-	-	-

Note: values indicated for concrete blocks are also used for Rip-Rap calculations.

4.7. CURRENTS

Current velocities are obtained from 3-D Model graphs collected from "Tidal Divides. A study of a simplified case and the Dutch Wadden Sea" (Vroom, 2011). Maximum current velocities are shown in Figure 4-2.

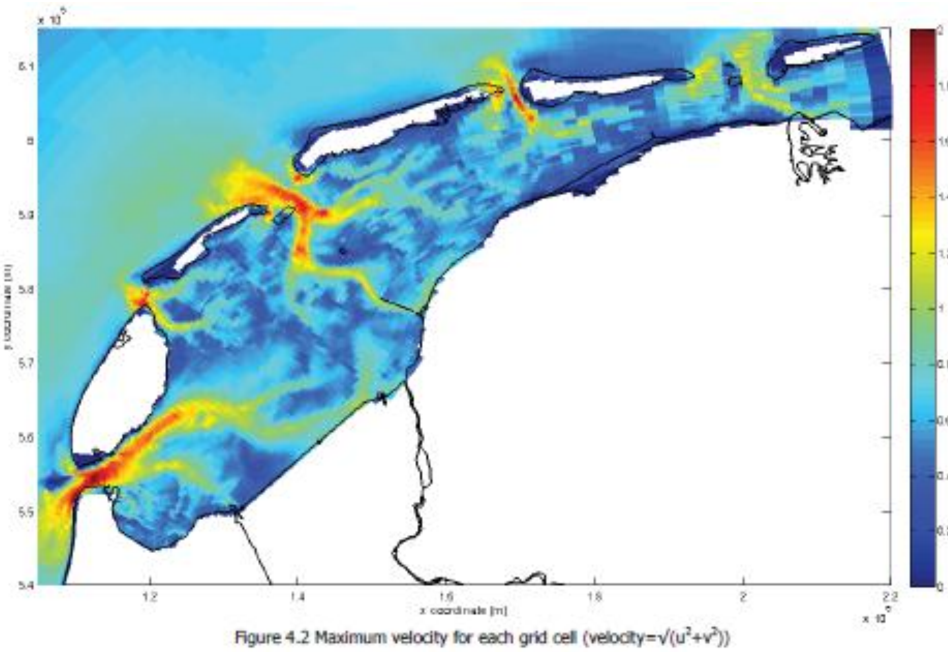


Figure 4-2. Currents velocities (Vroom, 2011)

Due to its low magnitude, within the scope of this report and studies currents are neglected.

5. DESIGN BASIS CRITERIA

The purpose of this Design Basis Criteria is to summarize the input information and the design criteria that will be the basis for the development of the Multidisciplinary project**.** The project framework and boundary conditions are defined in this part, setting the methodology to be followed.

5.1. DESIGN METHOD

This section addresses the methodology that is followed for the design of the Afsluitdijk cross section upgrading. The design procedure will be conditioned by the range of application of each method or formula.

Besides the calculation methods, it is necessary to set some limits. These are the project requirements. As mentioned in 4 *Source information & data collection*, there are two sources for those requirements: Employer's requirements and international standards and guidelines.

In principle, two non-typical Dutch design options will be proposed for the armour layer: Rip-Rap and concrete blocks revetment. Within these two possibilities, different variations will be studied and calculated, in order to see which one is more advantageous. While working in the alternatives, special attention will be paid to costs. Therefore, material costs and construction procedures will be considered in detail as well. By means of this study, the most favourable alternative will be found. Then, a complete definition of the chosen cross section will be made.

5.1.1. ARMOUR LAYER CALCULATION

To determine the required armour layer unit size, three calculation approaches would be performed. Firstly, the Classical or Deterministic method is used. Then in case it is possible the Partial Safety Coefficients method (consist in a level 1 probabilistic computation) and a Probabilistic Calculation (level 2 probabilistic computation) would be applied as well.

5.1.2. THE CLASSICAL OR DETERMINISTIC METOHD

This analysis can be done using Van der Meer or Hudson formula. Hudson and Van der Meer formulae have different applicability range. For the Afsluitdijk, only Van der Meer formula is applied, due to the limitations that Hudson formula has for non-permeable cores.

5.1.3. PARTIAL SAFETY COEFFICIENT METHOD

This second approach is the one developed by PIANC (PIANC PTC II WG 12, 1992), and it is based on the application of safety coefficients that are added to the Van der Meer design formula. Two safety coefficients are used, one for loads and another for strength.

5.1.4. PROBABILISTIC COMPUTATION

Using this methodology, the different parameters are treated as stochastic variables, each on them with its own probability distribution function. The equation for calculation of armour unit size is rewritten as a Z-function (reliability function) and then the full probabilistic calculation is carried out.

5.2. TOE PROTECTION

The toe is responsible for withstanding armour layer. Its stability is related to weight, level and damage level of the toe as it was proposed by Gerding in Toe Structure Stability of Rubble Mound Breakwater (Gerding, 1993) and confirmed latter by L. Docters Van Leeuwen (PIANC EnviCom, 2011). In this report, toe calculation is performed using their findings.

5.2.1. RUN-UP

Run up is the vertical distance measured from mean sea level to the highest point reached for a wave in a slope. The EurOtop Manual (Pullen et al., 2007) recommends make use of $\mathrm{R}_{2\%}$, which is the run-up level that is exceeded by 2% of the number of incident waves

5.2.2. OVERTOPPING

Overtopping can arise when run-up exceeds crest height. Its prediction will be performed using the guidelines from The EurOtop Manual (Pullen et al., 2007). The maximum allowed mean discharge is set at 10 l/s/m following the design rules from EurOtop Manual and extensive discussions with the Client.

5.3. MULTI-CRITERIA ANALYSIS (MCA)

A Multi-criteria Analysis is carried on, starting from individual assessment of each team member and ending up with a balanced and consented scoring and weighing for each relevant criterion. The process will be iterative and it will lead to the determination of the most favourable design alternatives. In addition individual assets from the Client are included.

The analysis will make meaningful use of stakeholder engagement; identifying win-win options during the construction process as well as during the dike life cycle. Recommendations from "Multi-criteria analysis: a manual" (Department for Communities and Local Government, 2009) will be addressed. Some of the topics that will be weighed are:

- *Technical factors.* This condition is divided in the following topics: Protection from waves, Construction process and Flexibility for future upgrading.
- *Operational factors.* Within this category Resilience and Land availability are considered.
- *Environment aspects.* Waddenzee protected area invasion, PIANC Working with Nature approach (PIANC EnviCom, 2011), Pollution during construction and Landscape are included.
- *Maintenance.* Essential to know and understand operation's Client needs in order to design for maintenance simplicity and easy adaptable solutions.
- *Third parties.* Incorporate the ambitions from third parties which can have an interest in developing their activities in the area, i.e. Recreation, Social considerations (economy boost, et cetera).

After the multi-criteria analysis the decision making stage will be addressed, during this process a cost-benefit analysis will be carried out in order to choose the most favorable design.

6. INTERMEDIATE DESIGN

As stated in Section 3 *Issues being addressed*, Afsluitdijk cross section 10a is used as the initial dike configuration. Therefore every alternative is based on this characteristic cross section.

As it was mentioned, a wide range of breakwater designs has been studied. To accomplish that, some conditions for the design process have been established:

- Definition of at least one design for each main typology of breakwater (considering different type of materials, one or two layer concrete armour units, with or without berm, et cetera).

- Definition of different cross section geometries within a defined intervention area, in which the outer end point of the cross section is fixed and it is not invading the Waddenzee. Different slopes, cross section, end point location in the defined intervention area and variation of some other parameters have been studied. However, due to Employer's Requirements some alternatives invading the Waddenzee were analyzed as well.
- Comparison between available Dutch and foreign technology for concrete armour layer units. This is based in several Reports and Catalogues; i.e. (PIANC MarCom WG 36, 2005).
- For some alternatives, existing basalt columns armour layer are assumed to be removed and new layers are placed on top of the boulder clay core which should be reshaped and protected. In addition, as these basalt columns are kind of unique in Europe, it is recommended to reuse them or at least try to place them into the market. However, after extensive discussions with the Client, it is considered a difficult procedure. Nevertheless, the team still believes those basalt blocks should be saved. Moreover, due to Employer's Requirements, other alternatives without removing the existing basalt columns armour layer are analyzed.
- It is assumed impermeable core for every proposed alternative, except for dynamically reshaping berm breakwaters where a permeability of P=0.5 was assumed due to the fact of having a sufficient thick armour and underlayers.
- A wave height of 3.72m is used for the armour layer calculations and a wave height of 3.83m has been used for the rest of the calculations based on the Employer's Requirements. These parameters are presented in Table 5, Section *4.6 Wave climate*.

Taking all these considerations into account, the following alternatives have been evaluated (slopes are noted Vertical:Horizontal; i.e. 2V:3H):

1. Rip-Rap without berm, slope 2:3
2. Rip-Rap without berm, slope 1:2
3. Xbloc®, slope 2:3
4. Xbloc®, slope 3:4
5. Berm breakwater, dynamically stable reshaped
6. Rip-Rap with berm
7. Acropode™ II slope 3:4 (up to the external limit)
8. Acropode™ II slope 3:4 (cutting slope)
9. Antifer cubes, slope 2:3
10. Rip-Rap without berm, slope 1:3.6, over layer on top of existing slope invading the Waddenzee
11. Xbloc®, slope 3:4, invading the Waddenzee
12. Berm breakwater, dynamically stable reshaped, invading the Waddenzee

Descriptions of the mentioned alternatives are included within next sections. Detailed calculations and final drawings of the analysed alternatives are in *Appendix A – Intermediate Design Drawings* and *Appendix E – Calculations*.

6.1. CROSS SECTION ALTERNATIVES

6.1.1. RIP-RAP

This design considers typical rubble mound cross section with Rip-Rap.

This type of cross section is defined as a breakwater without berm with two layer armour and underlayer (three d_{n50} thicknesses for easiness during construction). Underlayer rocks should be the first fraction of quarry yield curve.

Rubble mound breakwater examples are shown in Figure 6-1, Figure 6-2, Figure 6-3, and Figure 6-4.

Figure 6-1. Amador Causeway rubble mound breakwater, Panama city, Panama, 1913

Figure 6-2. Gau-ji Causeway rubble mound breakwater, Xiamen City, China, 1955

Figure 6-3. Improvement of an estuarine rubble mound breakwater at Port of Buenos Aires, Argentina, 2012

Figure 6-4. Rubble mound breakwater at Port of La Coruña, Spain

Two alternatives are presented here. The main difference between them is the armour layer slope. A 2:3 slope and 1:2 slope are studied.

6.1.1.1. CALCULATIONS

Main failure mechanisms are defined as overtopping and instability of armour layer. Run up is checked as well and the calculated value, according to Rock Manual (Ciria, Cur, & Cetmef, 2007), is 9.37m. Overtopping can arise when run up exceeds the crest height. Its prediction is performed using the guidelines from The EurOtop Manual (Pullen et al., 2007).

Determination of the required armour layer unit size is made according to Van de Meer (Verhagen et al., 2009). As it was mentioned, each alternative has two layers. The first alternative with slope 2:3 has a nominal diameter of 1.6m (d_{n50}=1.60m and W=11t) and the second alternative with slope 1:2 has a nominal diameter of 1.8m (d_{n50}=1.85m and W=17t). The rock size of the toe is calculated for both alternatives as well, giving a weight of 1.1t and 1.7t for each alternative respectively.

The calculations also have been performed for the crown wall in this Intermediate Design section.

6.1.1.2. RESULTS

It can be clearly seen which main differences between both alternatives are. Mainly, material availability would be significantly diverse, due to large d_{n50} for the alternative with slope 2:3.

Also as can be observed, making reference for the alternative with slope of 2:3; the main differences that can be found are:

- Smaller volumes of quarry run and underlayer, saving around 10m^3 per dike length meter of each type of material.
- Filter and toe rock volumes remain practically identical, however larger rocks are required for this alternative.
- Less excavation is required.
- Higher run-up with its consequent higher crest.

As a result of the Intermediate Design, it seems that is advisable to choose a slope 1:2 in case of a Rip-Rap cross section.

6.1.2. XBLOC®

Two cross section of breakwater with Xbloc® concrete units are studied. This type of cross section is defined as a rubble mound solution with a one layer armour which is achieved by using interlocking concrete blocks. Xbloc® design is considered of special interest since it is technology fully developed in The Netherlands.

The most significant variation that could be done in this type of design is a change in the armour layer slope. Hence, a 2:3 slope and a 3:4 slope solutions are calculated and implemented on the existing Characteristic dike cross section.

6.1.2.1. CALCULATIONS

For calculations, the Guidelines for Xbloc® Concept Designs (Delta Marine Consultants, 2011) are used. Some examples are shown in Figure 6-5. Moreover, the size of the armour layer is checked also with Van der Meer formula. Secondly, the dimensions of the toe rocks and the rocks in the underlayer are checked as well, according to the geometrical rules for filters in breakwater slopes.

Figure 6-5. Xbloc® developed by Delta Marine Consultants

For both slopes the calculations give an Xbloc® of 4t, with a height of 1.72m. This Xbloc® layer is supported by an underlayer of rocks between 300kg and 1t, and finally the core of the cross section is composed of quarry run. Also a concrete crown wall is defined at the top of the dike to give support to the blocks on the crest. However further variations for the crest are studied in the Final Design.Finally, the base of the armour layer is composed of a toe rock of 1t rocks and the transition between them is materialized with Xbase® because it is easy to place as a first row; and can be placed on relatively fine grading. Both Xbase® and toe rock are supported by a base made of 300kg rocks. Xbase® placement example is appreciated in Figure 6-6.

Figure 6-6. Xbase®

Calculations are completed by checking overtopping. An example is shown in Figure 6-8.

6.1.2.2. RESULTS

For both alternatives the upper part of the dike is removed in order to provide a platform as wide as possible (the new surface will be at the same elevation that the existing road). In addition, these alternatives introduce flexibility within the life cycle of the upgraded dike, resulting in robust solutions with adaptability for uncertain futures. As can be observed, making reference for the alternative with slope of 3:4 (steeper slope); the main differences between both alternatives are:

- Extra space gained maintaining the inner slope; dike available width is around 2.0m wider.
- Smaller volumes of quarry run, saving around $2m^2$ per dike length meter.
- Underlayer and toe Rock volumes remain practically identical.
- One less Xbloc® unit is required in the armour layer.

It seems that is advisable to choose a slope 3:4 in case of an Xbloc® cross section. However, these two alternatives are compared one to each other and with the other types of proposed cross sections in next sections. For environmental benefits, Eco Xbloc® is a very interesting alternative which can be applied for these designs. Eco Xbloc® is shown in Figure 6-7.

Figure 6-7. Eco Xbloc® mould and different concrete surfaces specifically prepared to enhance flora and fauna habitats

Figure 6-8. Dikkowita Fishery Harbour, Sri Lanka, 2011

6.1.3. DYNAMICALLY STABLE RESHAPED BERM BREAKWATER

This type of breakwater allows some rock movement (up and down, longshore transport should be restricted) causing the breakwater to reshape until a new reshaped equilibrium profile is achieved.

In this report the guidelines “State of the art of designing and constructing berm breakwaters” (Baird, Magoon, & Willis, 1987) ,“Berm Breakwaters Un-conventional Rubble-Mound” (van Gent, Smith, & van der Werf, 2012) are followed.

Berm breakwaters allow an easy construction method making use of only two different rock grading types; one for the armour layer and one for the core.

In this type of breakwaters the stability of the armour layer is checked in a different way from rubble mound breakwaters; mainly because rocks are allowed to move up and down. Therefore the existing profile is reshaped into a new one during storms. Armour layer stability is assured, if in every case there are at least two armour layers on top of the underlayer along the whole profile.

In addition berm breakwaters are less sensitive to scour than a rubble mound breakwater, mainly due to its flexibility. Thus, easy construction methodologies are applied. Those consist in dropping rocks and letting them find their own repose angle. Examples are shown in Figure 6-9, Figure 6-10 and Figure 6-11 .

Figure 6-9. Berm breakwater

Figure 6-10. South Breakwater , Hulushan Bay, Dalian City, China, 2012

Figure 6-11.South Breakwater of the Typhoon Shelter at Hei Ling Chau, Hong Kong, China, 1993

6.1.3.1. CALCULATIONS

Overtopping and run up calculations were performed with PcOverslag (Pullen et al.) on a first stage. As input, the reshaped profile and 0.55 as roughness factor is used this values were compared also with the formulae proposed by Burcharth et al (Andersen & Burcharth, 2005).

Two different profiles are proposed; one with berm elevation above design water level (El. +5.31+NAP) and another with berm below design water level (El. +2.54+NAP), with the same slope the two of them (4:7). For both cases the berm width was set to 7.5 m saving space landwards.

For material grading, a gradation factor D_{n85}/D_{n15} of 1.6 is used, to be consistent with recommendations from “State of the art of designing and constructing berm breakwaters” (PIANC MarCom WG 40, 2003).

6.1.3.2. RESULTS

The alternative with berm located below design water level, would experience a severe attack for the larger waves, primarily in the region above design water line. For this reason is needed to increase the thickness of the armour layer. Besides its efficiency against overtopping is less, which result in a higher crest (El. +10.81+NAP). For these reasons, the alternative with berm located below design water level is disregarded for further analysis.

With the proposed geometry; slope 4:7, berm width 7.5 m (El +5.31+NAP) and crest height El. +9.81+NAP, the berm breakwater fulfils the boundary conditions.

The dynamically reshaping character is one of the main advantages of this type of breakwaters; however it can become an important disadvantage too; particularly for the imposed boundary conditions of not intruding into the Waddenzee. After analysing future situations with reshaped profiles; is calculated that the Waddenzee is invaded approximately by 2 meters.

6.1.4. BREAKWATER WITH BERM

In practice, introduction of a berm into a sloped breakwater has shown a reduction of the overtopping and an increased stability in the armour layer.

This type of breakwater performs in similar manner than rubble mound breakwaters, no motion of rocks is allowed. The main difference appears in the inclusion of a berm. Due to the berm some energy dissipation is expected in the armour layer, reducing the run up and overtopping.

6.1.4.1. CALCULATIONS

For Intermediate Design, guidelines given by Stability of Rubble Mound Breakwater with a Berm (van Gent et al., 2012) are used in case of stability, to determine the d_{n50} needed. For overtopping Wave Run-up and Overtopping by van der Meer (1998) calculations are used.

Despite an even larger reduction of run up and overtopping can be achieved for wide berms, berm width was set at 7.5m and placed at El. +5.31+NAP (design water level). The reasoning behind, is the limited width on the existing dike, where a wider berm would lead into a reduction of the existing available width at the dike with a possible incursion into the road area.

The berm elevation is chosen in order to obtain the maximum position reduction factor (γ_{pos}).

The adopted slope is 1:2 in accordance with tests mentioned in the guidelines Wave Run-up and Overtopping in Seawalls, Dikes and Revetments(van der Meer, 1998; van Gent et al., 2012).

6.1.4.2. RESULTS

For this breakwater and the chosen geometry; slope 1:2, berm elevation +5.31+NAP, and berm width of 7.5 m; it is found a crest elevation of +9.31+NAP which fulfils overtopping boundary conditions.

Regarding stability two types of armour layer were determined, one for the region below design water elevation D_{n50}=1.56m and D_{n50}=0.75m for the region above the water elevation. The relation $D_{core\ n50}/D_{n50}$ is set to 0.5.

Due to the presence of its berm this alternative has the disadvantage of not bringing extra space on the road side; becoming a possible constraint in long term future scenarios, thus reducing future upgrading flexibility of the Afsluitdijk.

6.1.5. ACCROPODE™ II

The previously described characteristic cross section is designed also with Accropode™ II. This type of cross section is defined as a rubble mound solution with a 1-layer interlocking concrete armour blocks. The approach is quite similar to Xbloc®; however its design process is not explicit due to the lack of specialized guidelines. Although following existing bibliography armour layers with Accropode™ II (Figure 6-12) can be designed.

Figure 6-12. Accropode™ II developed by Sogreah, Artelia Group

Two preliminary alternatives have been studied. Both of them have same armour layer slope (3:4). Therefore, the main introduced difference is the location of the outer armour layer face, one is starting at the actual location of the Afsluitdijk toe with its consequent increasing of available land and the other one is designed maintaining the same existing inner slope and the current land available.

6.1.5.1. CALCULATIONS

The size of the armour layer has been checked with Van der Meer formula (Verhagen et al., 2009), where the slope is not part of the stability formula. Therefore the formula becomes simpler; $H_s / \Delta d_n$ equals to a given number that is developed on the basis of model experiments. For Accropode™ II, $H_s / \Delta d_n$ is equal to 2.5 (design value based on 2D-tests by Van der Meer and 2D-test by developers). It should be taken into account that Accropode™ II design assumes a permeable core, thus the calculated volume should be increased by a factor of 1.5 following the same criteria applied for Xbloc®. Hence the obtained Accropode™ II size is 4.4t with a height of H=1.62m.

The dimensions of the underlayer rock have been checked according to geometrical rules for filters in breakwater slopes. Furthermore, the toe rock grading was also designed following the same grading geometrical rules.

The armour layer will be supported by an underlayer of rocks between 180kg and 450kg; then quarry run will complete the grading.

A concrete crown wall is defined at the top, to give support to the blocks on the crest. However, after discussions with the Client, an alternative without crown wall may be studied in case this alternative is selected for the Final Design.

Calculations have been completed with a check for run-up and overtopping, and the design of the crown wall.

Examples of breakwaters that are already built or ongoing constructions with Accropode^{TM} II are shown in Figure 6-13 and Figure 6-14.

Figure 6-13. Breakwater reconstruction, Cerbere, France (maximum unit size 9m3 and water depth 10m), 2010

Figure 6-14. Breakwater extension, Port of Constanta, Romania, 2013

6.1.5.2. RESULTS

The main design criterion for the first alternative (up to the outer limit without invading the Waddenzee) was the cross section earth moving balance trying to compensate filling and removal areas. This assumption is valid if the removed material can be reused as filling material in the designed cross section. Supposing the removal material is suitable to be reused as filling material;

then removal areas are set to approximately 70% of the filling amounts leaving 30% of the filling zone for quarry run; which is an appropriate foundation material for the crown wall. The toe positioning of this design is set up to the outer limit of the available working area without invading the Waddenzee.

The second alternative (cutting slope) was developed in order to minimize the earth moving filling volumes and keeping the actual inner slope in its position. Therefore in comparison with the other introduced alternative, minor interventions would be required. Nevertheless larger excavation volumes are necessary, because the Accropode™ II armour layer should be placed cutting more than 60% of the existing slope of the dike.

Quarry run volumes required for the second alternative (cutting slope) are smaller, however in the first alternative same volumes can be achieved by cross-section earth moving balance, provided is possible to reuse the removed material.

In the first alternative (up to the outer limit without invading the Waddenzee), the added land is at least 15.5 meters per meter length of the dike.

For these alternatives also it is proposed the inclusion of specifically developed toe concrete blocks, the aim of these concrete blocks is to enhance the surrounding environment by promoting suitable habitats for flora and fauna present in the Waddenzee at the new toe of the dike.

In essence, it is proposed to adopt PIANC Working with Nature philosophy (PIANC EnviCom, 2011) which means doing things in a different order. Instead of developing a design and then assessing its environmental impacts (an approach which inevitably revolves around damage limitation and is ultimately not sustainable), Working with Nature advocates the following steps, which are highly recommended to be followed:

1. Establish project need and objectives (already accomplished for this Intermediate Design)
2. Understand the environment (recommended to be done with further studies)
3. Make meaningful use of stakeholder engagement; identify win-win options (on going throughout Rikjswaterstaat)
4. Prepare project proposals/design to benefit navigation and nature (introduced idea in this Intermediate Design).

This idea is taken from an existing project in the United States of America, developed by the US Army Corps of Engineers for the Great Lakes Restoration program, mainly for the Cleveland Harbour breakwaters where the design of the standard concrete toe blocks used for breakwater maintenance at the Cleveland Harbour east arrowhead was modified.

The proposed solution helps to enhance the habitat that exists or possible future scenarios, which consists of providing extra refuge to fauna and flora by creating substantially more habitat surface on the breakwater and also by modifying the shape and surface texture of the constructed blocks using textured liners or modified walls in the concrete block forms. Some solutions implemented in USA are shown in Figure 6-15.

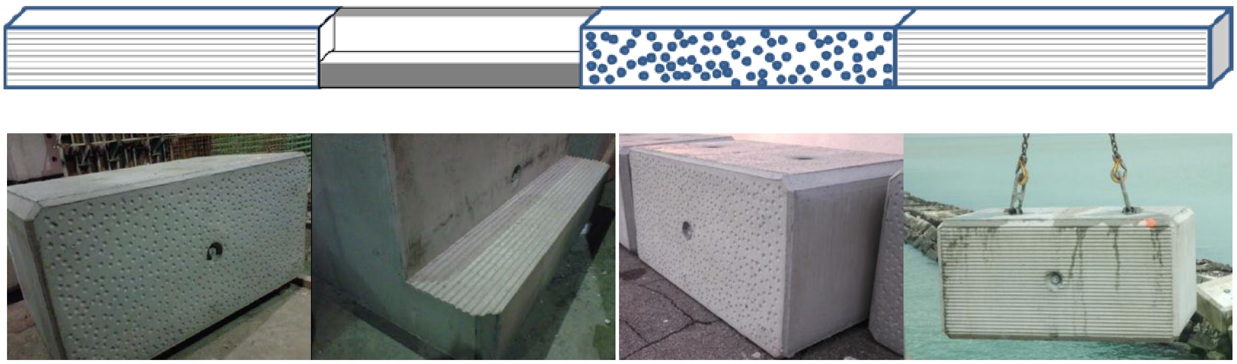


Figure 6-15. USACE designed green concrete toe units for Cleveland Harbour breakwater, Ohio, USA.

These proposed modifications can be applied also for Xbloc® or any other concrete armour unit solution. However further studies should be completed in order to design suitable concrete units for the Waddenzee habitats. Additional information is included in section *7.2.6 Innovative design approaches*.

6.1.6. CONCRETE CUBES

First the armour layer is estimated. Concrete and/or Antifer cubes should be displayed in two layers. To determine the required Concrete and/or Antifer Cube size Van der Meer formula is applied. A slope of 2:3 is used.

From calculations an antifer cube of 1.50m side is obtained. The weight of this concrete block is 8.8t leading to an amour layer thickness of 3.4m. This alternative, based on the weight of the each armour unit, can be compared with one of the rubble mound alternatives, however labour, production facilities (concrete plant, casting yard, et cetera) and consequently costs are much more important than the rubble mound alternative.

Therefore, from explanations given in previous paragraph it can be easily understood that this alternative would not be cost efficient. Hence no further calculations are done following this design.

Nevertheless, some of the major breakwaters under construction in the world are designed with concrete cubes as it is shown in Figure 6-16.

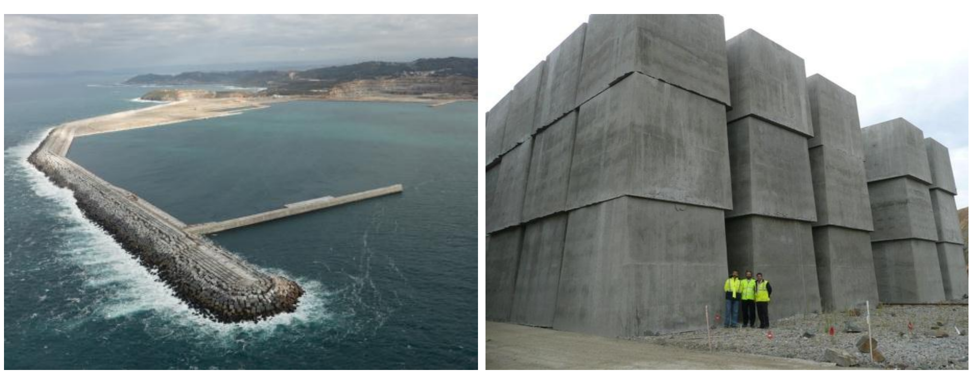


Figure 6-16. Breakwater heads with concrete cubes at Langosteira, Spain, 2011

Since this breakwater typology is widely used and there are a lot of experiences in the subject, some research has been done in order to find ideas that could be applied in the Afsluitdijk upgrading. For example, an aesthetic improvement of the breakwater was achieved in Llanes, Spain by means of commissioning it to a famous artist. This line of action has been very successful and the port is nowadays a tourist attraction (see Figure 6-17).

Figure 6-17. "Memory Cubes" by Agustín Ibarrola, Port of Llanes, Spain

6.1.7. RIP-RAP OVERLAYER INVADING WADDENZEE

A design based on a layer of Rip-Rap over the existing dike has been studied as a possible solution. This type of cross-section is considered of interest since it requires minimal intervention (no demolition or excavations and fewer materials).

For this design, it is considered that basalt columns will not be removed. Therefore a filter layer is not necessary to keep the core material in place, as this condition is already guaranteed by existing armour layer.

6.1.7.1. CALCULATIONS

Armour layer size has been calculated using Van der Meer formula, giving a d_{n50} of 3t. The base of the armour layer is composed by a toe rock of 0.75t stones (the size is calculated following Gerding and Van Leeuwen formula (Gerding, 1993) as it was done for every design, aside berm breakwater.

Calculations are completed by checking run-up and overtopping, being the last one the limiting factor to define the crest height.

Despite the severe boundary conditions used for calculating the upgraded cross-section, obtained crest elevation is very similar to the existing one. This is a consequence of Rip-Rap's higher capacity for dissipating wave energy compared to basalt columns, which results in lower run-up values and, consequently, smaller overtopping rates.

6.1.7.2. RESULTS

As stated before, this design requires minimal intervention. The upgrading consists on executing a Rip-Rap cover on the existing outer slope. Since crest elevation is increased around 1.2m height, no large modifications need to be done at the top of the dike. Of course, the main problem of this alternative is the invasion of the Waddenzee; however, this incursion is only around 10.0m.

6.1.8. XBLOC® INVADING WADDENZEE

An Xbloc® cross-section is studied too. In this case, the possibility of occupying an extra surface of the Waddenzee is considered. This would avoid excavations in order to place the toe inside the limits of the existing cross-section. As the existing dike remains untouched, there is no need to place a filter protection below the underlayer to retain core material.

6.1.8.1. CALCULATIONS

Calculations for armour layer unit size, dimensions, run-up and overtopping are the same as previous alternatives designed with Xbloc®. The only modification with regard to preceding designs is the change of position of the armour layer (moving towards the Waddenzee) which does not have any influence in the calculations, as boundary conditions remain the same.

6.1.8.2. RESULTS

This alternative has similar characteristics to the aforementioned Xbloc® cross section design with slope 3:4. Nevertheless, there are some differences between them. There is a significant increase on available land on top of the dike when occupying the Waddenzee. Removing the existing top of the dike leads to a final platform on top of the dike which is 4 meters wider than the widest alternative presented in section 6.1.2. Besides no excavation or demolition is needed, which can be considered a significant benefit as well.

However, a larger amount of filling materials is needed for this design. Filter layers and toe remain practically the same, but quarry run volume increases about 50m^3 per dike stretch meter, which means an increase of almost 75%.

At this stage, it is not possible to discern which Xbloc® cross section would be the most favourable. A cost study is needed to clarify the differences, as this alternative has strong and weak points that need to be quantified.

6.1.9. BERM BREAKWATER INVADING WADDENZEE

Following the criterion of introducing alternatives invading the Waddenzee, two more proposals for berm breakwater were analysed. The difference between both alternatives relies on different slopes.

6.1.9.1. CALCULATIONS

The calculation process is the same described before for berm breakwaters in section 6.1.3.

6.1.9.2. RESULTS

One alternative has a slope 4:7 trying to resemble the rock repose angle; meanwhile for the second alternative a gentler slope is chosen. In the second alternative, due its gentle slope, a shorter crest height is achieved reaching an elevation of +9.80+NAP. It is one meter shorter compared with the first alternative (slope 4:7) which its crest height is at an elevation of +10.85+NAP.

For the gentle sloped alternative (1:3.6), the amount of rock is almost equal to the alternative with steeper slope (4:7), nevertheless invasion into the Waddenzee is larger and land availability is limited to the present situation. In addition, the construction method for gentle sloped alternative, demands extra work mainly due to profiling works needed for reaching a specific slope. Therefore, only an overlayer berm breakwater alternative with a slope 4:7 is studied.

The selected alternative throughout the described considerations in the previous paragraph is exactly the same than the dynamically stable reshaped berm breakwater described beforehand within this report. However, it is shifted seawards invading the Waddenzee approximately 5.0 meters. An important difference is the reduced amount of materials and extra works needed for this alternative in comparison with the Berm Breakwater alternative without invading the Waddenzee.

6.2. MULTI-CRITERIA ANALYSIS

In this section a comparison between previously defined alternatives is carried out. Multi-Criteria Analysis is thought as the best way to find out which option; among the large number of alternatives, is the most favourable. Moreover, as it is known, there are a large number of factors of different importance that will influence the decision-making process. A general overview of those factors was introduced in section 5.3.

The relevant criteria are identified and assigned a level of performance and relative importance. In addition, team members (evaluation experts) have given their evaluation to avoid subjectivity, as well as the Employer. In this way, the design team is continuously tracking Employer’s interests, wills and certainly fulfilling the given requirements.

6.2.1. METHOD

There are different types of Multi-Criteria Analysis. In this report, Linear Additive Model is used. It is a method that is widely applied and has a sound theoretical basis (Department for Communities and Local Government, 2009). However extensive discussions were carried on, within the design team, before selecting this method. Mainly its simplicity and standardized mode for scoring alternatives are key differentiators to avoid subjectivity. Other methodologies were discarded because they use project references to contrast to the project under evaluation. Afsluitdijk uniqueness makes difficult to find similar examples in the world.

The Linear Additive Model method is based on applying a relative weight to each criterion that takes part on the comparison. This weight will multiply the score given to each factor. Therefore, the diverse importance of the studied criteria is taken into account. The weighed scores are added for each alternative. The ones with highest mark will be considered the best options.

As first step main objectives have to be identified, fulfilling relevant criteria which influence the analysis procedure. Once relevant factors are identified, the analysis is performed.

The analysed alternatives, which were intensively discussed before, are summarized in Table 6.

Table 6.Cross Section alternatives studied within Multi-criteria analysis

ALTERNATIVE	TYPE OF CROSS SECTION PROPOSED
Design 1	Rip-Rap without berm, slope 2:3
Design 2	Rip-Rap without berm, slope 1:2
Design 3	Xbloc® 2:3
Design 4	Xbloc® 3:4
Design 5	Berm breakwater
Design 6	Breakwater with berm
Design 7	AcropodeTM II 2:3 (up to the outer limit)
Design 8	AcropodeTM II 2:3 (cutting slope)
Design 9	Antifer cubes, slope 2:3
Design 10	Rip-Rap overlayer, slope 1:3.6
Design 11	Xbloc® invading Waddenzee, slope 3:4
Design 12	Berm breakwater invading Waddenzee

6.2.2. IDENTIFICATION OF RELEVANT CRITERIA

A number of criteria are selected to evaluate benefits for different design options. Every factor which can be considered relevant for the decision-making process is listed and clustered in different categories. In Table 7 a list with categories and relevant criteria for analysis can be found.

Table 7. Categories and criteria used in comparison of alternatives

TECHNICAL FACTORS	Protection from waves (i.e. wave number)
	Construction Process (duration; phasing; required area & equipment; et cetera)
	Flexibility future upgrading
OPERATIONAL FACTORS	Resilience (i.e. dike width; H_s for N_{od} = failure, et cetera)
	Land availability (possible future road & road safety improvements; new bike lanes; additional service lane; et cetera)
ENVIRONMENT	Incursion in protected area Waddenzee (from identified outer limit)
	Pollution during construction (currents/sedimentology; water turbidity; CO_2 emissions; noise, light and soil pollution; excavation volumes; et cetera)
	Landscape
	PIANC Working with Nature philosophy
MAINTENANCE	Frequency of maintenance and monitoring
	Accessibility for inspection of armour layer
	Accessibility for maintenance tasks (toe; berm; rolling surface for cranes; et cetera)
THIRD PARTIES	Recreation (available area for sightseeing; bike lane; sports; fishing, societal activities inclusion, et cetera)
	Social considerations (Dutch pride; economy boost; et cetera)

6.2.3. ASSIGNMENT OF SCORES

First, a range of scores is chosen. The defined range tries to describe in a simple and accurate way possible states that the performance level of an alternative can reach. The final score scale is:

Table 8.Score range Multi-criteria analysis

EXPECTED PERFORMANCE	SCORE
The alternative presents ideal conditions regarding the analysed factor	+4
The alternative presents good conditions, without significant problems	+3
The alternative presents some problems regarding studied factor, but they can be solved	+2
The alternative presents significant problems regarding the analysed factor, difficult to resolve	+1
The alternative presents challenging issues that could proscribe the design	0

Once the range is defined, each alternative design gets a score for each criterion (from Table 8). With the aim of eliminate subjectivity in this report, not a single evaluation but average values are used.

The design team has completed the score assignment individually; then an average of the results is calculated.

6.2.4. ASSIGNMENT OF WEIGHTS

After assigning scores, the next step is to give a relative weight to the different criteria parameters mentioned in section 6.2.2.

As the number of relevant factors is significant, the chosen method is to compare the criteria by pairs and choose which one is more important. To this end, when comparing between two factors, a numerical value from each expert is given. One, if the most important is the row parameter and zero, if the most important is the columns factor.

Finally the criterion with higher score turns out to be the most relevant. This step is significantly subjective, as assigning scores. In order to get rid of subjectivity for weighing, experts have also completed the evaluation on their own.

An average value of weights is used in the analysis the details are shown in Table 9.

Table 9. Average relative weights multi-criteria analysis

CRITERIA	WEIGHTS				
	Abby	Carlos	María José	Pablo	**Average**
Protection from waves	14,29%	14,29%	14,29%	12,09%	13,66
Construction Process	3,30%	2,20%	6,59%	3,30%	3,57
Flexibility future upgrading	12,09%	7,69%	12,09%	14,29%	11,35
Resilience	6,59%	4,40%	6,59%	5,49%	5,81
Land availability	7,69%	1,10%	6,59%	6,59%	5,54
Incursion in Waddenzee	5,49%	13,19%	13,19%	8,79%	10,42
Pollution during construction	5,49%	6,59%	7,69%	3,30%	5,34
Landscape	3,30%	1,10%	2,20%	2,20%	2,02
PIANC Working with Nature	9,89%	8,79%	7,69%	9,89%	9,07
Frequency maintenance & monitoring	8,79%	9,89%	4,40%	12,09%	8,52
Accessibility inspection armour layer	6,59%	9,89%	1,10%	9,89%	7,00
Accessibility for maintenance tasks	9,89%	12,09%	7,69%	7,69%	9,59
Recreation	2,20%	3,30%	1,10%	2,20%	2,26
Social considerations	4,40%	5,49%	8,79%	2,20%	5,86
Total	**100**	**100**	**100**	**100**	**100**

6.2.5. RESULTS

The results of the analysis are summarized in Table 10.

Table 10. Multi-Criteria Analysis results

CRITERIA			Relative weights [%]	WEIGHED SCORES for each Alternative											
				1	2	3	4	5	6	7	8	9	10	11	12
TECHNICAL FACTORS	1	Protection from waves	13,66	55	55	55	55	55	55	55	55	55	55	55	55
	2	Construction Process	3,57	6	11	7	7	10	9	7	7	5	11	11	13
	3	Flexibility future upgrading	11,35	26	26	31	31	37	20	31	20	17	14	31	28
OPERATIONAL FACTORS	4	Resilience	5,81	12	12	9	12	19	12	10	9	17	12	16	16
	5	Land availability	5,54	15	15	17	22	13	7	22	11	14	7	22	14
ENVIRONMENT	6	Incursion in Waddenzee	10,42	36	36	36	36	21	36	36	36	34	13	10	8
	7	Pollution during construction	5,34	17	17	12	12	17	17	12	12	7	19	12	19
	8	Landscape	2,02	6	6	5	6	6	7	5	5	5	6	6	5
	9	PIANC Working with Nature	9,07	25	25	27	27	20	27	30	27	25	23	23	23
MAINTENANCE	10	Frequency maintenance & monitoring	8,52	28	28	30	30	19	26	30	30	32	21	30	19
	11	Accessibility inspection armour layer	7,00	19	19	19	19	19	19	19	19	21	21	18	19
	12	Accessibility for maintenance tasks	9,59	29	26	31	31	31	26	31	26	24	19	31	26
THIRD PARTIES	13	Recreation	2,26	7	7	7	7	7	7	8	7	6	5	9	7
	14	Social considerations	5,86	15	15	23	23	17	13	13	13	15	15	23	15
TOTAL			**100**	**295**	**298**	**310**	**319**	**291**	**281**	**310**	**278**	**276**	**239**	**296**	**267**

The aim of this analysis is to make a first selection and rule out the most unfavourable options. According to the obtained results, the goal is to keep at least one concrete units design and one Rip-Rap design.

As can be seen, the alternatives that score better are:

1. Xbloc® slope 3:4
2. Accropode™ II (up to the outer limit)
3. Xbloc® slope 2:3
4. Rip-Rap without berm, slope 1:2
5. Xbloc® slope 2:3, invading Waddenzee
6. Rip-Rap without berm, slope 2:3
7. Berm breakwater
8. Breakwater with berm
9. Accropode™ II (cutting slope)
10. Antifer cubes
11. Berm breakwater invading Waddenzee
12. Rip-Rap overlayer, slope 1:3.6

It is important to point out that the majority of the proposed alternatives are focused not only on the improvement of the armour layer, but also on strengthening the dike for long term scenarios. The main concept shared among the team members is to think of robust solutions, flexibility and adaptability for the upgraded Afsluitdijk.

6.3. COST ANALYSIS

For all alternatives, major items are: armour layer and underlayer elements; ranging from 50% of total direct cost for Xbloc® alternatives, to 60% - 90% for berm breakwaters and Rip-Rap alternatives, reaching its maximum for berm breakwater over layer and Rip-Rap over layer. In these two cases, almost whole direct cost is represented by rock material used in armour and underlayer elements.

For the alternatives not invading the Waddenzee, one relevant item, is the use of a geotextile which represents 28% in the case of berm breakwater. For berm breakwater, this geotextile could be replaced by a better gradation in the core by designing it as a filter. For Xbloc®, geotextile could be limited to the place where the new slope meets with the old slope (basalt columns are not removed). This also can be applied in the situation of berm breakwater.

Another important item for Xbloc® alternatives is the crown wall, which reaches 12% of total direct cost. This cost could be reduced by improving the crown wall design or by designing a different type of dike crest.

In order to get rid of uncertainties for the mentioned two items (geotextile and crown wall), their prices are set to zero. As a direct consequence, results do not vary and are following the same trend shown in Figure 6-18 and Figure 6-19. Cost estimation details are shown in Table 11.

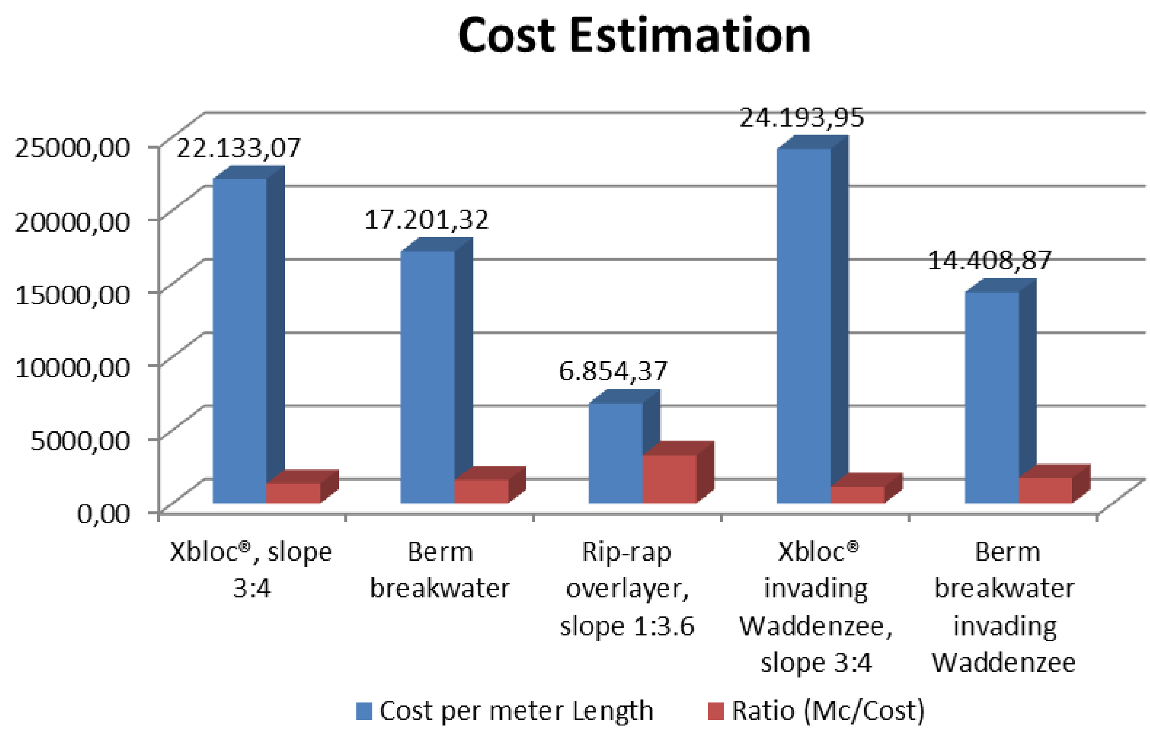


Figure 6-18. Cost estimation of alternatives per dike meter length of the dike

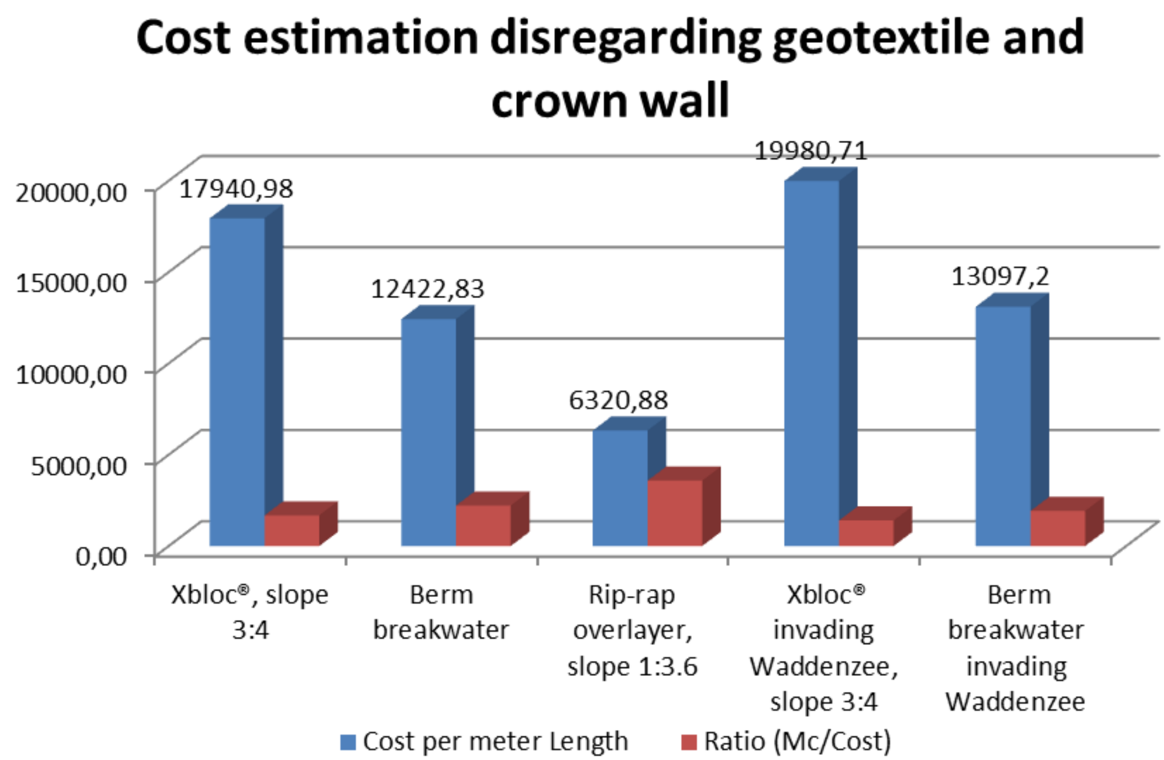


Figure 6-19. Cost estimation of alternatives per meter length of the dike (excluding geotextile and crown wall)

Table 11. Cost estimation

			COSTS PER METER														
			DESIGN 4			DESIGN 5			DESIGN 10			DESIGN 11			DESIGN 12		
		ESTIMATED COST	Xbloc®, slope 3:4			Berm breakwater			Rip-rap overlayer, slope 1:3.6			Xbloc® invading Waddenzee, slope 3:4			Berm breakwater invading Waddenzee		
ITEM	DESCRIPTION	RATE DC	QUANTITY	AMOUNT	%	QUANTITY	AMOUNT	%	QUANTITY	AMOUNT	%	QUANTITY	AMOUNT	%	QUANTITY	AMOUNT	%
1	Pavement demolition	20,24		0,00	0		0,00	0,0%		0	0,0%		0,00	0,0%		0	0,0%
2	Disposal	13,80	60,955	841,02	3,4%	39,45	544,31	3,2%		0	0,0%	38	524,30	2,2%	0	0	0,0%
3	Excavation land equipment inc. storage on	15,64	121,91	1906,31	7,7%	78,90	1233,76	7,2%		0,00	0,0%	76,00	1188,41	4,9%		0,00	0,0%
4	Quarry run	23,00	135,54	3116,83	12,6%		0,00	0,0%		0,00	0,0%	223,87	5148,03	21,3%		0,00	0,0%
5	Sand / selected material	15,00		0,00	0,0%		0,00	0,0%		0,00	0,0%		0,00	0,0%		0,00	0,0%
6	Clay	23,00		0,00	0,0%		0,00	0,0%		0,00	0,0%		0,00	0,0%		0,00	0,0%
7	Coarse gravel	30,00	10,94	328,20	1,3%		0,00	0,0%	4,25	127,50	1,9%	12,24	367,20	1,5%		0,00	0,0%
8	Quarry stone wider gradation >1 Tn	27,59		0,00	0,0%	182,10	5025,00	29,2%		0,00	0,0%		0,00	0,0%	222,72	6145,90	42,7%
9	Quarry stone wider gradation < 1Tn	25,76		0,00	0,0%	218,20	5619,76	32,7%		0,00	0,0%		0,00	0,0%	269,90	6951,30	48,2%
10	Quarry stone +250kg	28,00	10,90	305,20	1,2%		0,00	0,0%	4,25	119,00	1,7%	34,38	962,64	4,0%		0,00	0,0%
11	Quarry stone 600kg-1.5t	33,11	52,58	1741,12	7,1%		0,00	0,0%	22,14	733,14	10,7%	54,30	1798,07	7,4%		0,00	0,0%
12	Quarry stone 2-3t	36,79		0,00	0,0%		0,00	0,0%	145,17	5341,24	77,9%		0,00	0,0%		0,00	0,0%
13	Quarry stone 4t	36,79		0,00	0,0%		0,00	0,0%		0,00	0,0%		0,00	0,0%		0,00	0,0%
14	Production and stockpiling Xbloc 3.7t	289,74	18,00	5215,41	21,1%		0,00	0,0%		0,00	0,0%	19,00	5505,15	22,8%		0,00	0,0%
15	Transport and placement of Xbloc 3.7t	249,27	18,00	4486,90	18,2%		0,00	0,0%		0,00	0,0%	18,00	4486,90	18,5%		0,00	0,0%
16	Concrete C35/45 in	161,89	17,23	2789,35	11,3%		0,00	0,0%		0,00	0,0%	17,23	2789,35	11,5%		0,00	0,0%
17	Geotextile	91,98	42,76	3933,17	15,9%	51,95	4778,49	27,8%	5,80	533,50	7,8%	15,23	1400,89	5,8%	14,26	1311,67	9,1%
18	Drain	23,00	1,00	23,00	0,1%		0,00	0,0%		0,00	0,0%	1,00	23,00	0,1%		0,00	0,0%
19	Bituminous surface	1,20		0,00	0,0%		0,00	0,0%		0,00	0,0%		0,00	0,0%		0,00	0,0%
20	Bituminous pavement	70,00		0,00	0,0%		0,00	0,0%		0,00	0,0%		0,00	0,0%		0,00	0,0%
21	Mattress	18,00		0,00			0,00			0,00			0,00			0,00	
22	Other	0		0,00	0,0%		0,00	0,0%		0,00	0,0%		0,00	0,0%		0,00	0,0%
			TOTAL	**24686,50**	100%		**17201,32**	1,00		**6854,37**	100,0%		**24193,95**	100,0%		**14408,87**	100,0%
			MULTI-C.	**301**			**275,00**			**226**			**279**			**251**	
			RATIO	**1,22**			**1,60**			**3,30**			**1,15**			**1,74**	

Most expensive alternatives are Xbloc® designs, both of them with almost same cost (25,000 €/m). Their principal items are manufacturing and placement of the concrete units, which represents 40% of the direct cost. The amount of units per meter only differs in one extra unit in the alternative invading the Waddenzee. Excavation is almost the same in both cases. One main difference is the amount of stones, for the alternative invading the Waddenzee more material is needed to cover the bigger intervention area. The need for a geotextile in order to separate the underlayer from clay, which can fulfill filter functions (see filter section), increase the cost for the alternative invading the Waddenzee, taking in consideration the removal of the basalt columns. This extra cost almost equate with the extra cost for stone material in the alternative not invading the Waddenzee, making both options equal regarding costs.

More economical designs result to be the ones using random placing rocks. These solutions are more economical compared with options that make uses of prefabricated concrete elements, due to the lowest material, production and placement cost. From these alternatives the most economical is the "Rip-Rap Overlayer", owing the minimum amount of material to be used per meter length. Its cost is almost half of the cost of berm breakwater alternatives. This makes it the most economical alternative of all.

6.4. RESULTS

After the analysis carried on for the proposed alternatives for this Intermediate Design, two alternatives are selected as the best options, one based on concrete units and one based on a Rip-Rap solution. This decision is based on selecting the best alternative for each typology of armour layer solution. Hence, according to the Multi-Criteria Analysis and cost estimation, two final alternatives have been selected:

1. Xbloc®, slope 3:4
2. Rip-Rap overlayer, invading the Waddenzee

For these two alternatives together with Rikswaterstaat solution, a more comprehensive study is carried on for the Final Design. Cross sections are defined more in detail and other aspects, such as the optimization of the design or the construction process, are covered. Cost estimations are also adapted and together with a Final Multi-Criteria Analysis, are used for the final decision-making process.

7. FINAL DESIGN

In this section, extra considerations are analysed. In addition, detailed calculations for overall stability, crown wall optimization, and interfaces interaction are studied. In the following parts these topics are addressed.

7.1. EXISTING AFSLUITDIJK CROSS-SECTION OVERALL STABILITY

To compute overall stability, firstly, current studied Afsluitdijk cross section is modelled and analysed. Finite Elements Models are carried out to fulfil this task. First considered Finite Element

Model (FEM) is for the existing situation. Then; both best rated final designs' alternatives are studied and developed into two separate FEMs, which use this first FEM configuration as starting point. It is important to point out that every construction stage from present-day arrangement to the proposed alternatives is idealized and represented in both cases in order to represent critical situations during service life and during construction.

7.1.1. MATERIALS

The properties of dike materials have been collected from the report Toekomst Afsluitdijk (Vossen et al., 2010), as it is shown in section *4.5 Materials properties*. Those values are used for every material represented on the FEMs. Besides, the following porosities are adopted for different armour layers/materials:

- Quarry stones: $n_v = 0.40$
- Basalt columns: $n_v = 0.90$
- Xbloc®: $n_v = 0.50$

7.1.2. ANALYSIS & LOADS

The dimensions of the FEM are 320m by 60m. Model units are meter (m) for length, second (s) for time, KiloPascal (kPa) for stress and pressure, and KiloNewton (kN) for force. Current maximum crest elevation of the dike is set at +7.86m+NAP, the Waddenzee elevation is modelled at -10.00m+NAP and the IJselmeer elevation is represented -4.00m+NAP.

Dead loads considered within this FEM are soil and materials self-weight. Live loads included in the FEM are the highway and bike path service loads. For simplicity, previously mentioned live loads are assumed as static loads of 10kN/m^2 and 2kN/m^2 respectively and are introduced in accordance with the construction sequence defined which will be explained in the following sections. The facts introduced within the precedent paragraphs are graphically introduced in Figure 7-1.

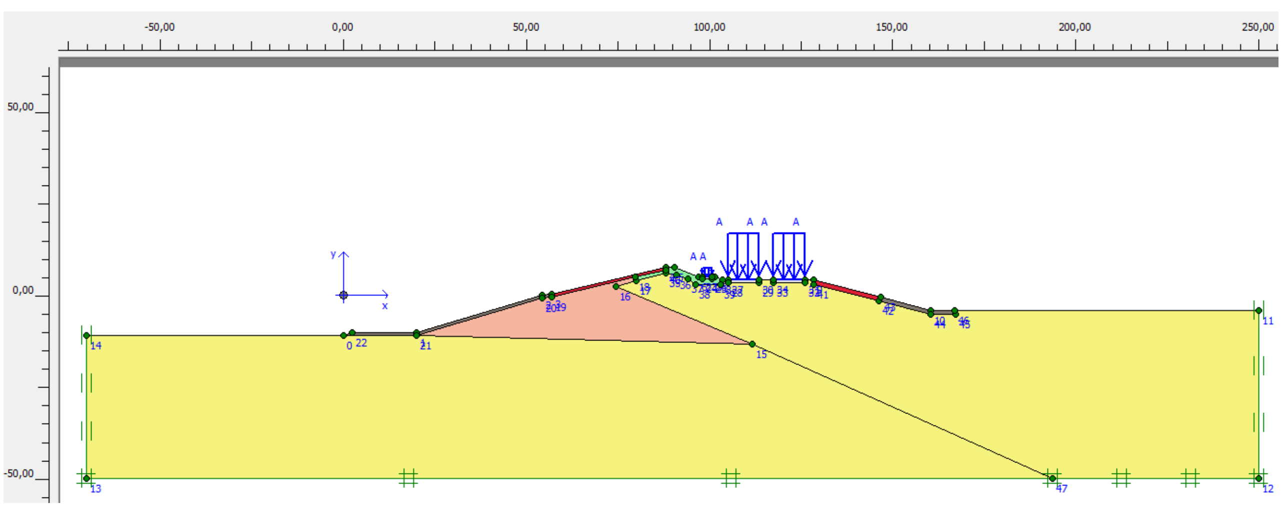


Figure 7-1. FEM geometry of the existing studied cross-section

In addition, Waddenzee and IJselmeer water levels are set at +0.00m+NAP for normal conditions, then according to different load combinations defined, Waddenzee water level will be modified up to the maximum elevation given for the year 2050 which is +5.52m+NAP to obtain the structural and geotechnical safety coefficient by the means of an internal strength reduction of the soil parameters in a process named phi/c reduction.

For the existing Afsluitdijk cross-section the following load combinations are studied:

1. Normal conditions; without live loads and Waddenzee water level at +0.00m+NAP.
2. Service loads are applied.
3. Waddenzee water level is increased up to +5.52m+NAP.
4. From Load Combination 2, a phi/c reduction process is started in order to obtain the existing Safety Factor under normal conditions for the Afsluitdijk.
5. From Load Combination 3, a phi/c reduction process is started in order to obtain the existing Safety Factor under storm conditions for the Afsluitdijk (2050).

As it was stated before, once this FEM is validated, it will be used as input for both alternatives developed and selected along the report.

7.1.3. FINITE ELEMENT MODEL

The Finite Element Models (FEMs) used in these cases are 2D non-linear plain strain models, where 15-node triangular elements are applied and it is shown in Figure 7-2.

Soil and rock behave in a highly non-linear way under loads. This stress-train behaviour is modelled with Mohr-Coulomb.

However, for pavement and concrete a linear elastic model, which is much more suitable for these types of materials, is used.

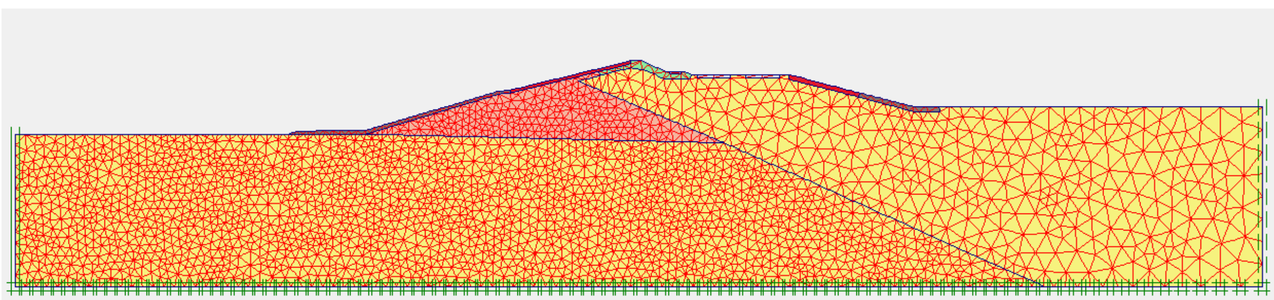


Figure 7-2. FEM coarseness mesh, which is refined in key zones for possible failure mechanisms

Active pore pressures for Waddenzee and IJselmeer normal conditions (+0.00m+NAP) are shown in Figure 7-3.

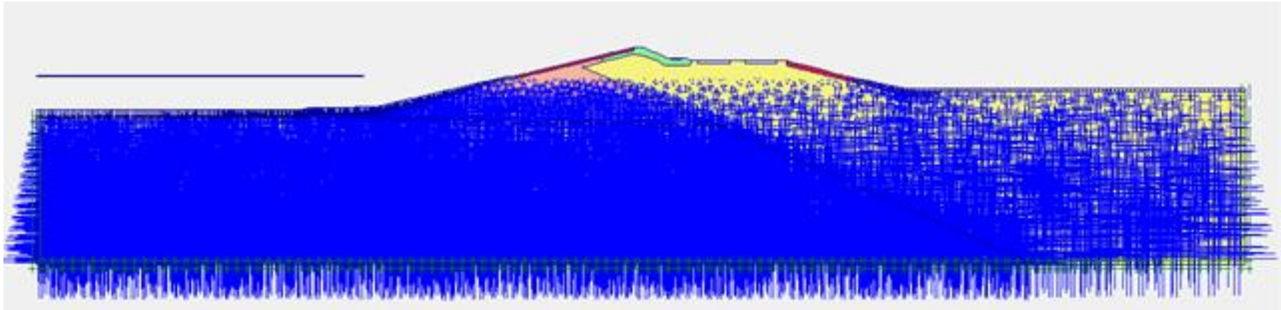


Figure 7-3. FEM active pore pressure. As a back check, the extreme active pore pressure at FEM bottom was read and it is 499.43kN/m^2, which is in accordance with FEM dimensions.

Besides, initial effective soil stresses were calculated (using k_0) and are presented in Figure 7-4.

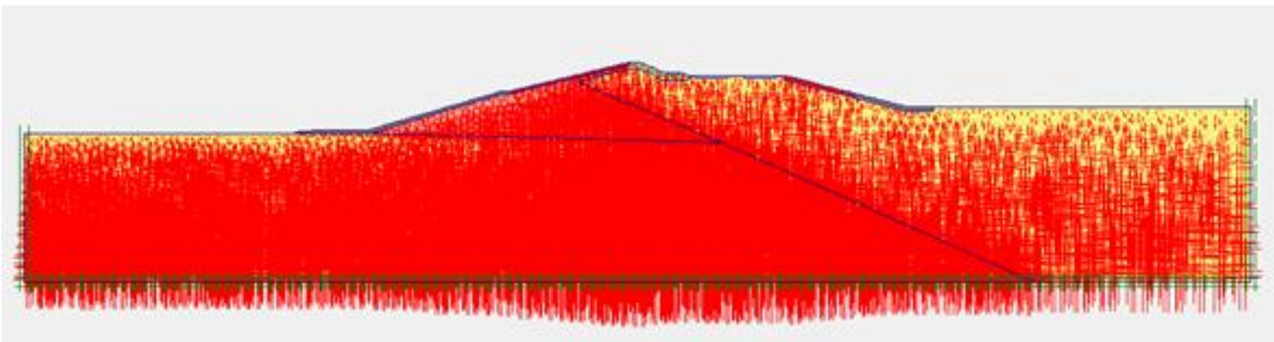


Figure 7-4. FEM Effective stresses with an extreme effective principal stress of -632.42kN/m^2 as expected at the bottom of the model (below dike crest)

7.1.4. RESULTS

As it is introduced in *7.1.2 Analysis & Loads*, different load combinations, following the idealized construction sequence are set.

These construction phases are shown also in Figure 7-5.

Identification	Phase no.	Start from	Calculation	Loading input	Time	Water	First	Last
Initial phase	0	0	N/A	N/A	0,00 ...	0	0	0
✓ Service Loads	1	0	Plastic	Staged construction	1,00 ...	1	1	11
✓ Waddenzee storm	2	1	Plastic	Staged construction	1,00 ...	2	12	14
✓ Normal conditions	3	2	Plastic	Staged construction	1,00 ...	3	15	16
✓ SF normal	4	3	Phi/c reduction	Incremental multipliers	0,00 ...	3	17	116
✓ SF storm	5	2	Phi/c reduction	Incremental multipliers	0,00 ...	2	117	216

Figure 7-5. FEM calculations phases

In Figure 7-6 are shown the active pore pressures originated during a storm (year 2050) in the Waddenzee. It is clearly visible that higher values are reached in the boulder clay and the deep sand layers below the Waddenzee, than the values obtained in the IJselmeer influence area.

It is assumed that the effect of a Waddenzee storm is influencing the ground water table on the Afsluitdijk up the diagonal geometry line crossing the dike geometry. Previous assumption is made based on boulder clay very low permeability.

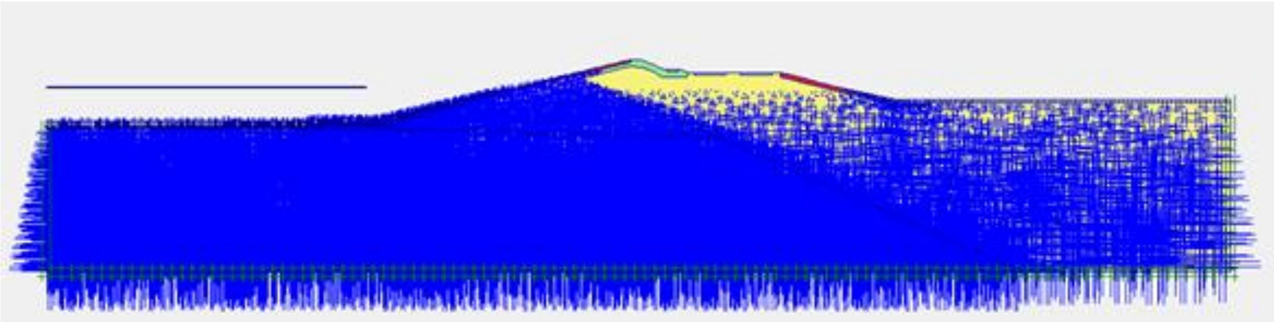


Figure 7-6. Active pore pressures due to Waddenzee water level during a storm +5.52m NAP. The extreme active pore pressure obtained is -554.43kN/m^2.

The main outcomes of this Finite Element Analysis are the geotechnical Safety Factors (SF) for the studied existing Afsluitdijk cross-section 10a.

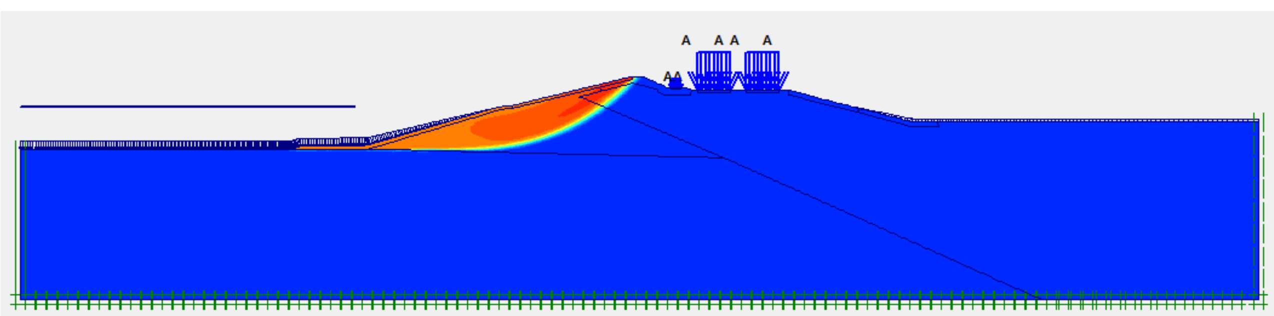
As it is explained before in this section, one of the Safety Factors is obtained for normal conditions; meanwhile the other Safety Factor is calculated for future Waddenzee water elevations during a design storm (2050).

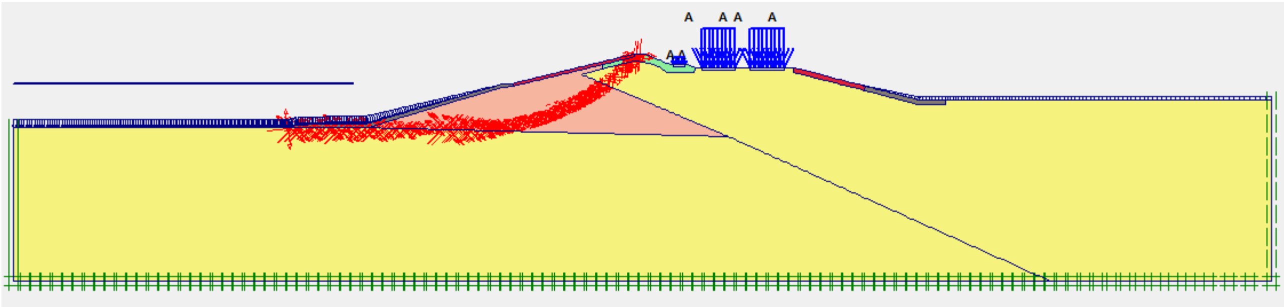
Both reached values are summarized in Table 12.

Table 12 Overall Stability Safety Factors for Afsluitdijk existing cross-section 10a

Geotechnical Safety Factors	
Normal Conditions	Waddenzee Storm 2050
1.82	1.73

In addition, each failure mechanisms are respectively shown in Figure 7-7 and Figure 7-8.





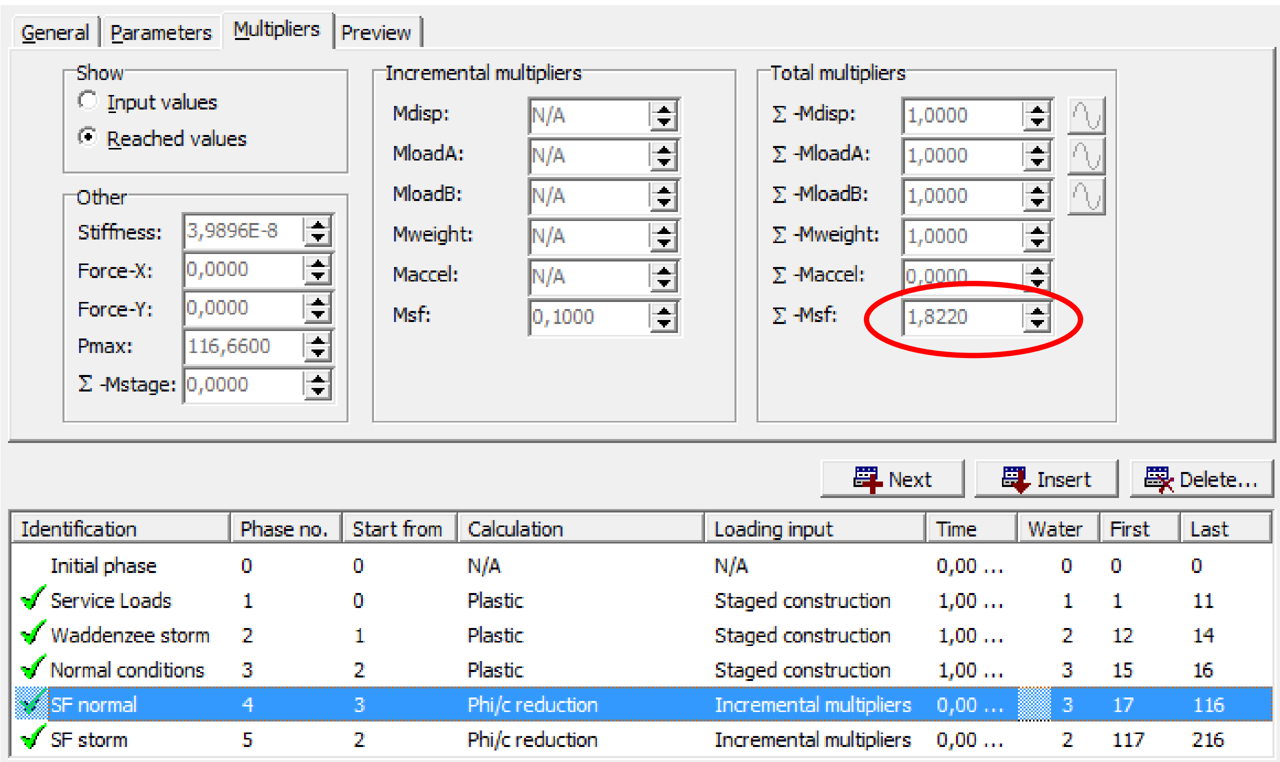
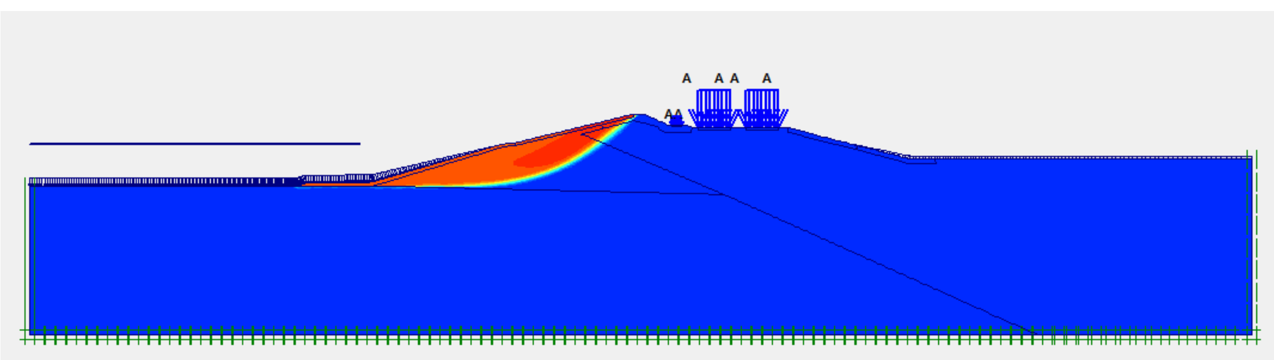


Figure 7-7. Geotechnical failure mechanism for normal conditions



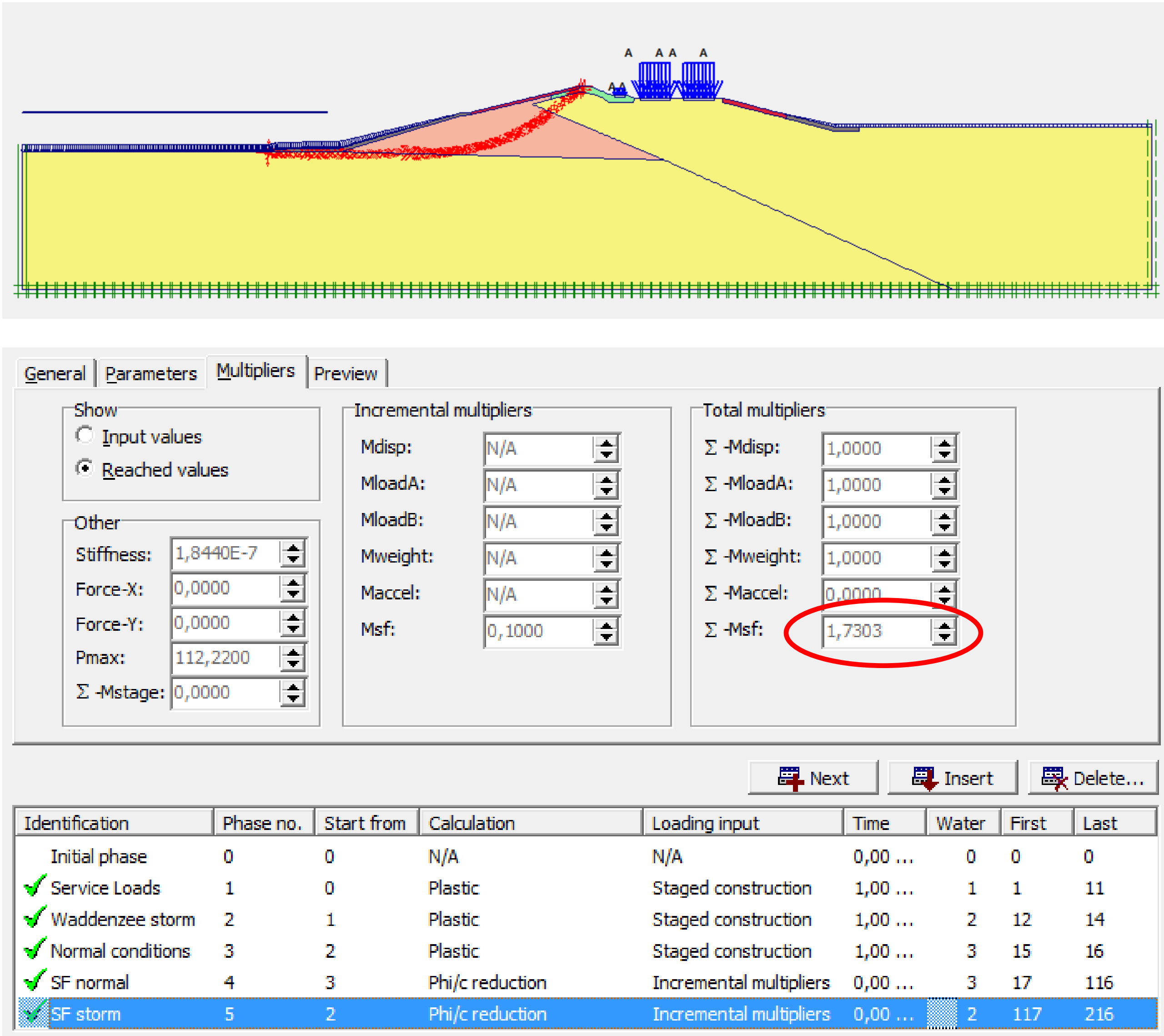


Figure 7-8. Geotechnical failure mechanism for Waddenzee design storm (2050)

Despite of the consistent results; it is advisable to recalibrate or repeat these calculations with more detailed material information in order to obtain even more reliable results.

7.2. XBLOC®

7.2.1. CROWN WALL

There are several reasons to place a crown wall on top of the cross section:

- To provide access to top of dike
- Working platform available for maintenance or repairs
- Reduction of rock and granular materials in core and underlayers

Crown walls have also some disadvantages, mainly the high cost of the massive concrete structure. Moreover, according to Employer's requirements, the increase in land availability provided by the crown wall is not essential. Therefore, a crest made from Xbloc® in addition to a new service lane for maintenance purposes is considered a good alternative and has been studied as well. The results for these two options are presented in this section, together with an estimation of costs associated to each alternative, in order to decide which one is to be preferred.

7.2.1.1. CROWN WALL OPTIMIZATION

The crown wall design has been studied in detail in order to optimize the dimensions. Several possibilities have been considered:

- Adding passive stresses to the calculation to help with sliding stability. This option is not feasible due to the existing platform low elevation. In order to place granular material on the inner surface of the crown wall, a large increment in core material would be necessary, which nullifies the possible advantages.
- Shear key at the base. A shear key to increase sliding stability has been considered and introduced in the calculations.
- Horizontal platform wide enough for the repairs crane to be able to position on the crown wall.
- Addition of holes in the base. This is an option to consider in case the crown wall is placed on top of a permeable layer, which is not the case here.
- Placement of a drain at the contact between dike core and permeable underlayer, in order to protect the core from erosion at this sensitive point. In case core material losses happen and sort of gullies appear, they would facilitate pressures transmission to the crown wall base.

Taking all these considerations into account, the crown wall has been calculated. The calculations details can be found in *Appendix E – Calculations* (Xbloc slope 4:3). The final cross-section can be found in *Appendix B – Final Design Drawings*.

7.2.1.2. DESIGN WITHOUT CROWN WALL

A dike crest without crown wall has been calculated, according to the Design guidelines for Xbloc® (Delta Marine Consultants, 2011). A minimum of three Xbloc® units need to be placed on the crest. These units are placed on top of an underlayer with equal characteristics to the existing one on the outer slope. Then, to complete the inner slope design, a minimum berm has been taken into account; see *Appendix B – Final Design Drawings* (Xbloc slope 4:3).

This alternative has been compared to the crown wall by means of a simplified cost study. For a complete analysis, not only construction cost, but also maintenance costs need to be taken into account. In this case, the two options will require different equipment for maintenance (crane, platform trucks, et cetera).

Table 13. Construction costs for Xbloc® design with and without crown wall

ITEM	DESCRIPTION	UNIT	RATE	COSTS PER METER				
				Crown Wall		Xbloc® crest		
				QUANTITY	AMOUNT	QUANTITY	AMOUNT	DIFFERENCE
1	Pavement demolition	m3	37.18		0		0	0
2	Disposal	m3	29.25		0		0	0
3	Excavation land equipment incl. storage on site	m3	33.15	121.91	4041.31	121.91	4041.31	0
4	Quarry run	t	48.75	80.68	3933.17	101.51	4948.63	1015.46
5	Sand / selected material	t	35.10		0		0	0
6	Clay	t	42.31		0		0	0
7	Coarse gravel	t	66.30	10.94	725.32	10.94	725.32	0
8	Quarry stone +250kg	t	66.30	14.04	930.85	14.04	930.85	0
9	Quarry stone 600kg-1.5t	t	70.20	52.58	3486.05	66.27	4393.70	907.64
10	Quarry stone 2-3t	t	78.00		0		0	0
11	Quarry stone 4t	t	78.00		0		0	0
12	Production & stock pilling Xbloc® 3.7t	ud	614.25	18	6177.6	21	7207.2	1029.6
13	Xbloc® 3.7t Transport & placement	ud	528.45	18	6177.6	21	7207.2	1029.6
14	Concrete C35/45 in structure	m3	343.20	13.65	4684.68	0	0	-4684.68
15	Geotextile	m2	195.00		0		0	0
16	Drain	m	48.75	1	48.75	1	48.75	0
17	Bituminous surface treatment	m2	2.53		0		0	0
18	Bituminous pavement	t	136.50		0		0	0
19	Overtopping revetment	m2	78.00	5	390	6.81	531.18	141.18
				TOTAL	**30595.34**		**30034.15**	**-561.19**

The results for construction cost differences are shown Table 13. Clearly, the alternative with a crest made from Xbloc® has lower construction cost, leading to savings around 562€ per meter of dike, which would mean savings around 17M€. In opposition to this, maintenance works will be more costly for this alternative, due to the absence of an auxiliary lane on top of the structure. A first estimation of these costs has been made for this analysis and is explained below.

For both cross sections, it is assumed that repairs will be carried out from land, using a crane. Therefore the crane needs to reach the end of the slope from its position. This means a working radius of 24m in case of having a crown wall and 37m in case of an Xbloc® crest (see Figure 7-9 a and Figure 7-9 b). Xbloc® units are supposed to move and occupy holes when damage occur (PIANC MarCom WG 56, 2011), therefore the expected gaps will be located at the upper part of the slope. Still, here the lowest part of the slope is considered the point to reach, doing a conservative assumption.

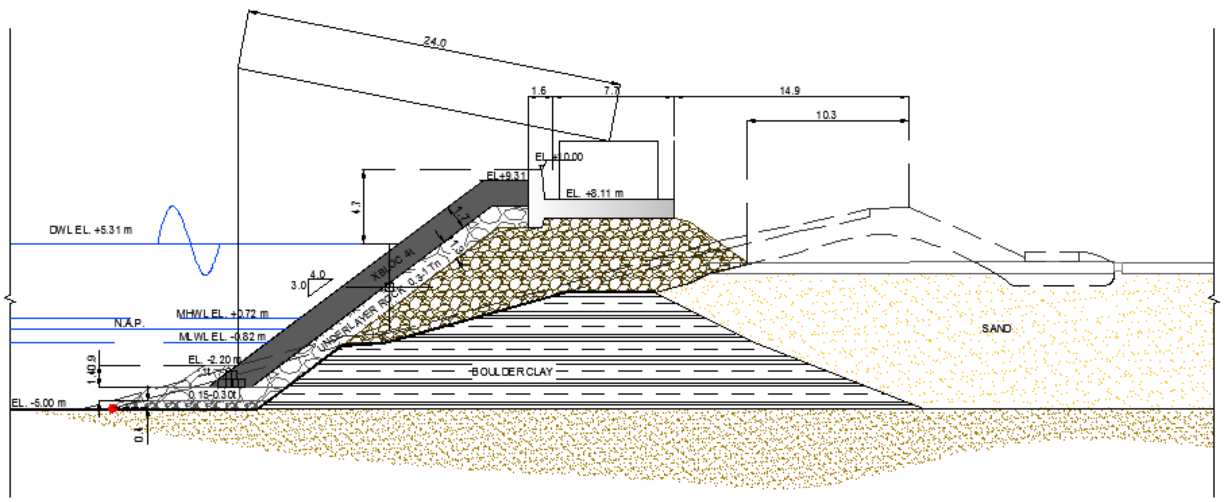


Figure 7-9 a. Cross Section Xbloc® with crown wall. Crane operations.

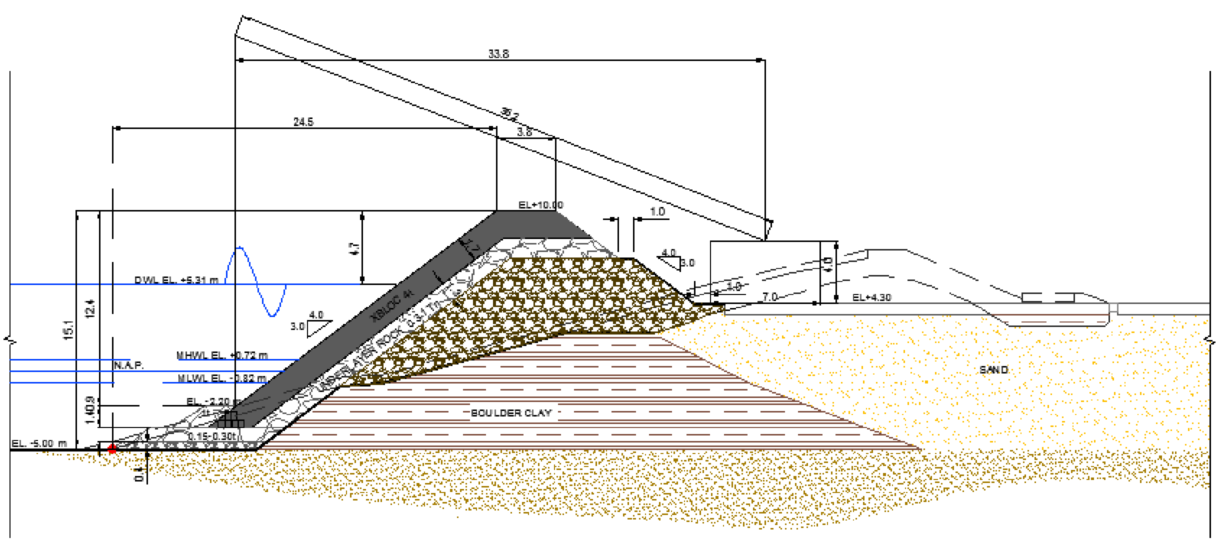


Figure 7-9 b. Cross Section Xbloc® without crown wall. Crane operations.

Besides that, each repair event is associated with the start of failure, which corresponds to a stability number of 3.5 Using the data available is not possible to calculate the associated return period and thus, with the help of Poisson distribution, to calculate the total probability of the event to occur. Due to this, only an estimation of one event costs is done and is compared with construction costs.

The surface to repair is assumed to be of 1 units per meter, which corresponds to start of damage according to (Rijkswaterstaat, Deltares, & EcoShape, 2013), along a 1% of the dike length, which is also an assumption. According to the information provided by DMC in the Xbloc® brochure, a minimum rate of 8 units per hour can be achieved in the placement process.

A summary with data and cost estimation can be found in Table 14.

Table 14. Estimation of crane repair costs in case of damage for Xbloc® designs

ALTERNATIVE	CRANE NEEDED	RATES INCL. MAN LABOR (€/h)	REPAIR LENGTH (m)	UNITS PER METER	TOTAL HOURS NEEDED	REPAIR COST (€)
Crown Wall	Loader 60t	200	300	0.6	45	8,999
Xbloc® Crest	Auto crane 100t	320	300	0.6	45	14,398

As can be seen, for the alternative without crown wall, construction savings far outweigh the difference in reparation costs (it would be necessary to have thousands start of damage events for the two alternatives to be comparable). In the light of this conclusion, it is considered that no more detailed cost analysis is needed. Clearly, Xbloc® crest is more favourable.

7.2.2. GEOTEXTILE

In the interface between first underlayer and natural soil, in this case consisting of quarry rock and boulder clay for the slope, rock and sand for the toe, large gradients are expected. For this reason the study of a filter becomes necessary. The analysis discerned into two different position of the filter. First, the filter is analyzed when is located on the slope, and in a second step the filter located on the toe is studied correspondingly. The following analysis is referred to Xbloc® alternatives; both of them have the same underlayer rock type.

Recommendations from Rock Manual (Ciria et al., 2007) endorse use of closed filters in case of breakwaters, no loss of material is allowed. This recommendation is based on granular material, owing that cohesion no is taken into account. In the case of the Afsluitdijk, the core consist of boulder clay, this would lead to a large number of filters if rules for open filters are followed. On the other hand, if clay is treated as sand its resistance against erosion will be underestimated, for these reasons a more detailed analysis is carried out, arriving to the conclusion that the best option is to make use of a geotextile which fulfil both separator and filter functions.

7.2.2.1. INTERFACE UNDERLAYER - QUARRY RUN

For designing this interface rules for open filters are used as it is stated on Introduction to Bed Bank and Shoreline Protection (Schiereck, 1995). From this approach the following gradation was found and is shown in Table 15:

Table 15 Underlayer: Class Limit 300-1000 kg

FILTER: UNDERLAYER CLASS LIMIT 300-1000 KG		
d_{n50}	0.60	m
d_{n85}	0.69	m
d_{n15}	0.44	m
W_{n50}	595	Kg
W_{n85}	900	Kg
W_{n15}	434	Kg

BASE: QUAARY RUN		
d_{n85}	150	mm
d_{n15}	15	mm

7.2.2.2. INTERFACE: UNDERLAYER - BOULDER CLAY

There is a lack of research regarding erosion on cohesive materials. Ven Te Chow, 1959 gives some critical values for clay, ranging from 0.1 m/s for no too dense clay till 1.8 m/s for dense packed clay. In the report "Large Scale Tests of Boulder Clay Erosion at the Wieringermeer Dike (Ijsselmeer) "(PIANC PTC II WG 12, 1992) it is mentioned that in recent studies it has been found boulder clay can withstand flow velocities up to 3.5 m/s without failure. This information should be used with care and some test should be necessary to validate the final design.

It is true that there is lack of information regarding this topic, but on the other hand it is known that during the construction of the Afsluitdijk a filter made of broken bricks was used in the slope and a fascine mattress on sandy bottom. The duration of this type of material over almost 80 years can give an estimation of the gradients on the bottom and resistance of the boulder clay.

In order to have an estimation of the water velocity trough the underlayer, considerations for porous flow as presented in *Introduction to bed bank shore protection; engineering the interface of soil and water* (Schiereck, 1995) are followed, using the following expression:

$$U_f = k(i)^{\frac{1}{p}}$$

With p=2 (for turbulent flow) and k=0.5 (Schiereck, 1995). In order to consider the gradient (i), the value for run up was taken into account as load parameter, and the thickness of the armour layer plus the underlayer, as the porous medium.

Table 16 Mean Velocity through Rock Layer

$R_{u2\%}$	**10.44**	**m**
Armour layer thickness	1.7	m
Underlayer thickness	1.3	m
I	3.48	m/m
U_f	0.93	m/s

From this first approach it can be seen that the velocity throughout the porous rock layer is less than the critical velocity mentioned on "Large Scale Tests of Boulder Clay Erosion at the Wieringermeer Dike (Ijsselmeer)" (PIANC PTC II WG 12, 1992) and Ven Te Chow, 1959. It could be concluded that a filter is not needed. Nevertheless, placing rocks of medium size (say bigger than 10 cm) directly on clay; can generate concentration of flow which leads to increasing velocity and its correspondent erosion. For this reason is highly recommended, to use some kind of separator between these two materials. This material will be a geotextile which will fulfil filter requirements; this will be explained in section *7.2.2.4 Geotextile*.

7.2.2.3. INTERFACE: QUARRY RUN - BOULDER CLAY

As mentioned before, boulder clay is strong enough to withstand load requirements below the underlayer. For the interface between quarry run and boulder clay, flow velocities are expected to be lower, than in the interface underlayer-boulder clay, due the additional layer of quarry run, which in some places reaches up to 4 meters. It can be conclude this interface is stable. Even tough, for the reasons mentioned in the previous section, a geotextile used as separator is needed. This geotextile will be the same for the whole slope.

7.2.2.4. GEOTEXTILE

As stated on the previous section a geotextile is needed for separation issues. For this reason, it has been decided to put a geotextile along the whole profile which will also fulfill filter's function. Besides, there is no further information about the size of the sand, for this approach medium sand is taken as reference (particle's size of 200 μm). Stability rule for geotextile can be written (Schiereck, 1995):

$$O_{90} < 2d_{90B}$$

Where O_{90} is a measure for the largest holes in the textile.

Taking d_{n50}=0.2 mm and assuming d_{n90}/d_{n50}=1.8, d_{n90}=0.36 mm is obtained. Following the stability rule O_{90}<0.72 mm, so a geotextile with O_{90} =0.1 mm is chosen, with a permeability of 1-5 1/s.

7.2.2.5. RESULTS

After the analysis, it has been concluded to use a geotextile all over the length of the interface between first-underlayer - boulder clay; in the interface quarry run - boulder clay; and in the interface quarry run - boulder clay; in every case for the slope and for the toe. This would facilitate the construction process. Quarry run gradation have been determined, d_{n85}=150 mm; d_{n15}=15 mm.

7.2.3. OVERALL STABILITY

To compute overall stability for the proposed Xbloc® alternative, a Finite Elements Model was done. As it was mentioned before, this is studied in a new FEM which uses as starting point the previously introduced FEM developed for the current Afsluitdijk configuration, shown in section *7.1 Existing Afsluitdijk cross-section overall stability*.

7.2.3.1. MATERIALS

The same criterion explained in *7.1 Existing Afsluitdijk cross-section overall stability* was applied.

7.2.3.2. ANALYSIS & LOADS

Xbloc® proposed alternative has it maximum crest elevation at +10.00m+NAP, the Waddenzee elevation is modelled at -10.00m+NAP and the IJselmeer elevation is represented -4.00m+NAP.

Dead loads and live loads included in the FEM are the exactly the same than the ones explained in *7.1 Existing Afsluitdijk cross-section overall stability*. Geometry definition is a very important modelling phase due to the fact that every step from the existing situation to the proposed alternative should be accomplished in a consistent way. This is shown in Figure 7-9.

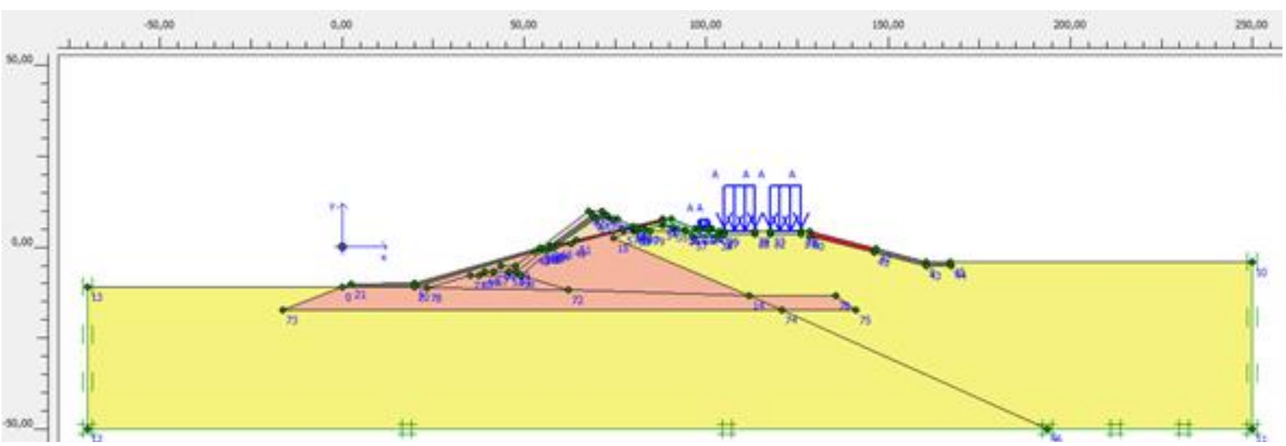


Figure 7-9. FEM geometry of the Xbloc® proposed cross-section

For the proposed Afsluitdijk Xbloc® cross-section the following load combinations are studied:

1. Excavation of the existing profile in order to build the new toe for Xbloc®; without live loads and Waddenzee water level at +0.00m+NAP.

2. Toe construction and partial underlayer and armour layer positioning (under water works).
3. New crest construction, removal of original crest and under later completion.
4. Armour layer completion.
5. Service loads are applied.
6. Waddenzee water level is increased up to +5.52m+NAP.
7. From Load Combination 5, a phi/c reduction process is started in order to obtain the existing Safety Factor under normal conditions for the Afsluitdijk.
8. From Load Combination 6, a phi/c reduction process is started in order to obtain the existing Safety Factor under storm conditions for the Afsluitdijk (2050).

7.2.3.3. FINITE ELEMENT MODEL

The FEM developed is shown in Figure 7-10.

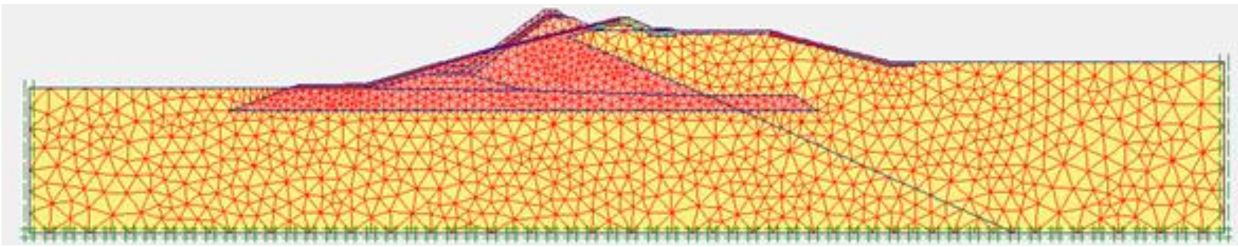


Figure 7-10. FEM coarseness mesh, which is refined in key zones for possible failure mechanisms

Active pore pressures for Waddenzee and IJselmeer normal conditions (+0.00m NAP) are shown in Figure 7-11.

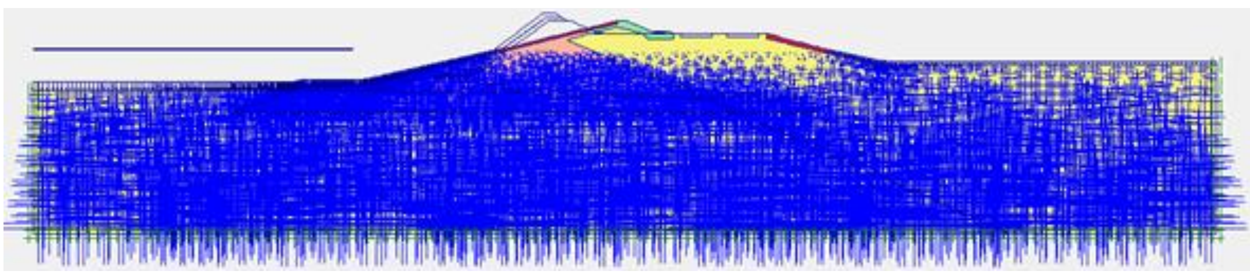


Figure 7-11. FEM active pore pressure. As a back check, the extreme active pore pressure at FEM bottom was read and it is 498.85kN/m^2, which is in accordance with FEM dimensions.

Besides, initial effective soil stresses were calculated (using k_0) and are presented in Figure 7-12.

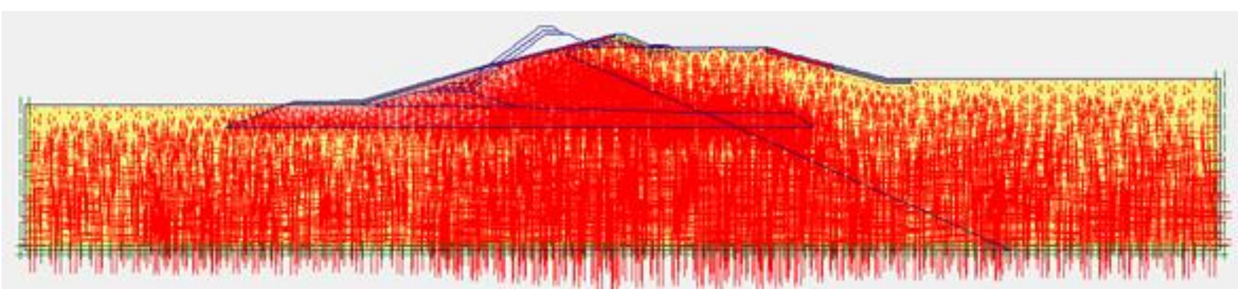


Figure 7-12. FEM Effective stresses with an extreme effective principal stress of -632.59kN/m^2 as expected at the bottom of the model (below dike crest)

7.2.3.4. RESULTS

The construction's phase list is shown in Figure 7-13.

Identification	Phase no.	Start from	Calculation	Loading input	Time	Water	First	Last
Initial phase	0	0	N/A	N/A	0,00 ...	0	0	0
✓ Excavation	1	0	Plastic	Staged construction	1,00 ...	1	1	9
✓ Toe & underwater construction	2	1	Plastic	Staged construction	1,00 ...	2	10	11
✓ Crest construction	3	2	Plastic	Staged construction	1,00 ...	3	12	17
✓ Armour layer	4	3	Plastic	Staged construction	1,00 ...	4	18	29
✓ Service loads	5	4	Plastic	Staged construction	1,00 ...	5	30	31
✓ Waddenzee storm	6	5	Plastic	Staged construction	1,00 ...	6	32	38
✓ SF Normal	7	5	Phi/c reduct...	Incremental multip...	0,00 ...	5	39	138
✓ SF Storm	8	6	Phi/c reduct...	Incremental multip...	0,00 ...	6	139	288

Figure 7-13. FEM calculations phases

In addition, each construction phase is detailed and shown in Figure 7-14, Figure 7-15, Figure 7-16, Figure 7-17 and Figure 7-18.

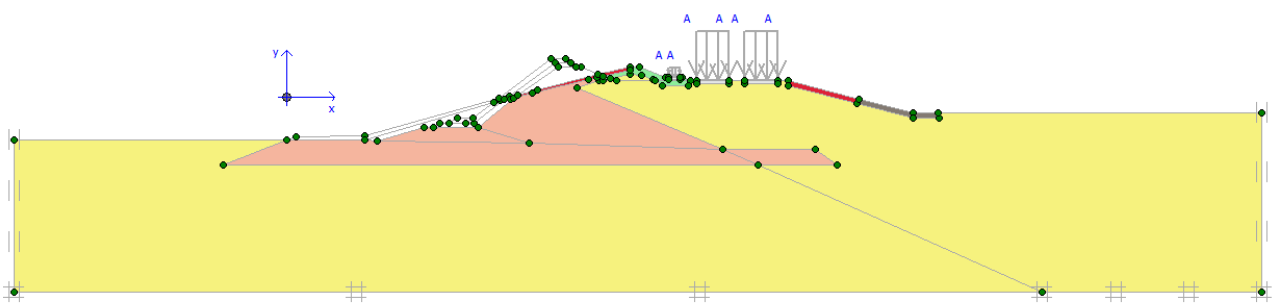


Figure 7-14. Excavation

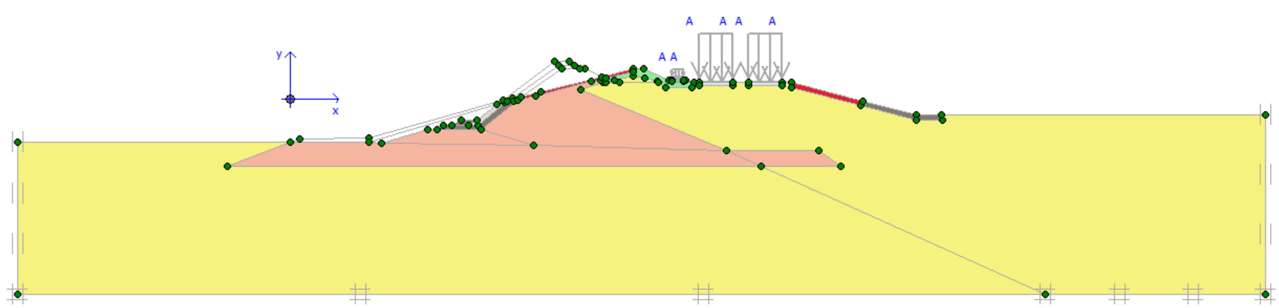


Figure 7-15. Toe & underwater construction

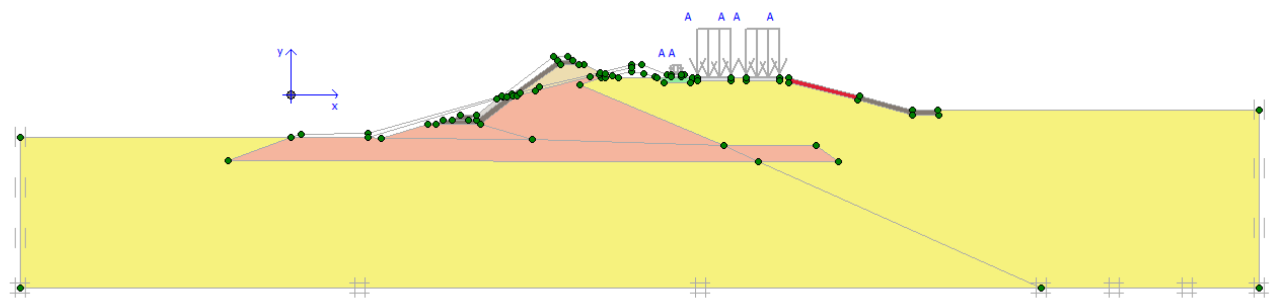


Figure 7-16. Crest construction

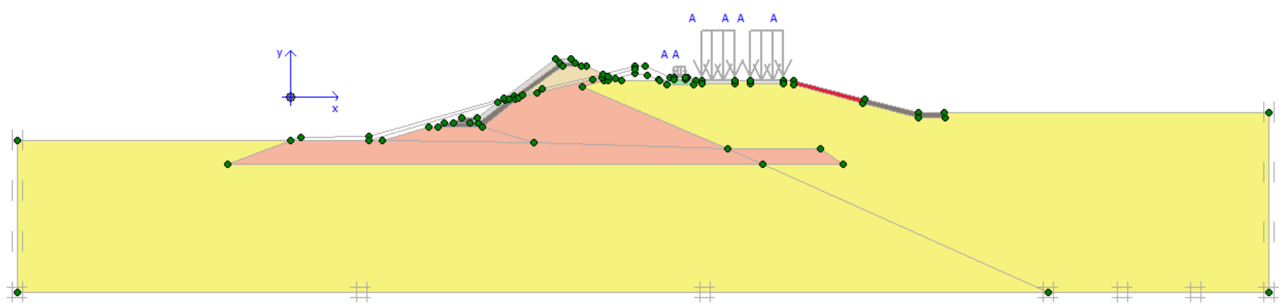


Figure 7-17. Armour layer construction

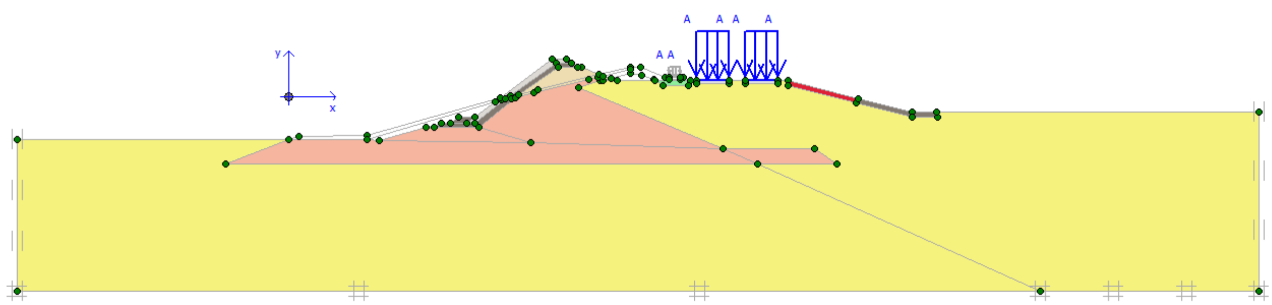


Figure 7-18. Service loads

In Figure 7-19 are shown the active pore pressures originated during a storm (year 2050) in the Waddenzee. It is clearly visible that higher values are reached in the boulder clay and the deep sand layers below the Waddenzee, than the values obtained in the IJselmeer influence area.

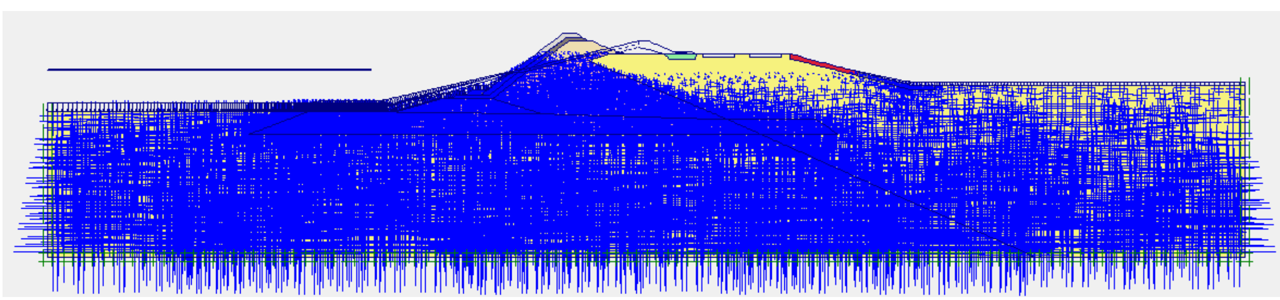


Figure 7-19. Active pore pressures due to Waddenzee water level during a storm +5.52m NAP. The extreme active pore pressure obtained is -553.85kN/m^2.

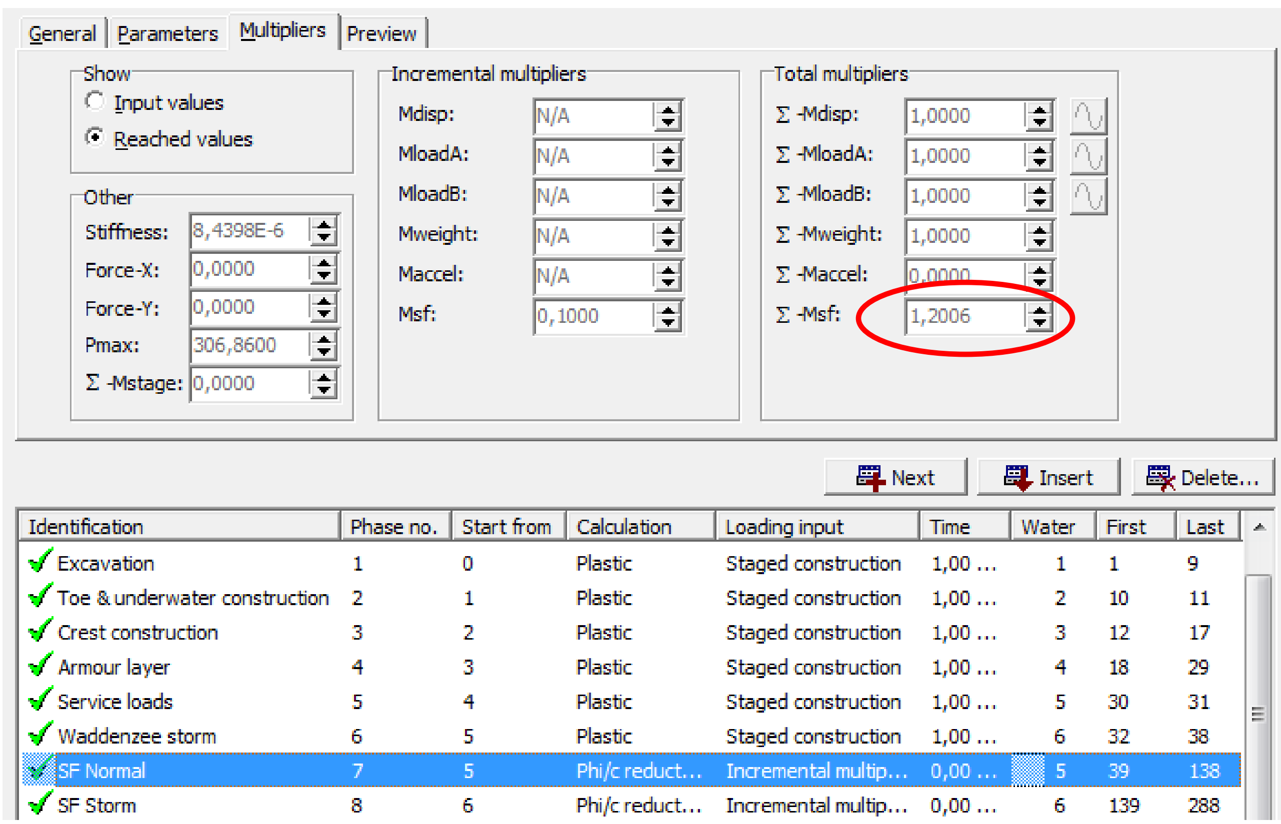
It is assumed that the effect of a Waddenzee storm is influencing the ground water table on the Afsluitdijk up the diagonal geometry line crossing the dike geometry. Previous assumption is made based on boulder clay very low permeability.

The geotechnical Safety Factors (SF) for the Xbloc® alternative are obtained throughout this Finite Element Analysis. In analogy with previous analysis, two Safety Factors are obtained, one for normal conditions and the other for future Waddenzee water elevations during a design storm (2050). Both reached values are summarized in Table 17.

Table 17 Overall Stability Safety Factors for Afsluitdijk existing cross-section 10

Geotechnical Safety Factors	
Normal Conditions	Waddenzee Storm 2050
1.20	1.12

The obtained values are rather small; therefore some measures to increase foundation's strength and geotechnical stability would be required. Also it is important to note that the modelled cross-section is the deeper one, hence higher values will be obtained for smaller depths in the Waddenzee zone. Each failure mechanisms is respectively shown in Figure 7-20 and Figure 7-21.



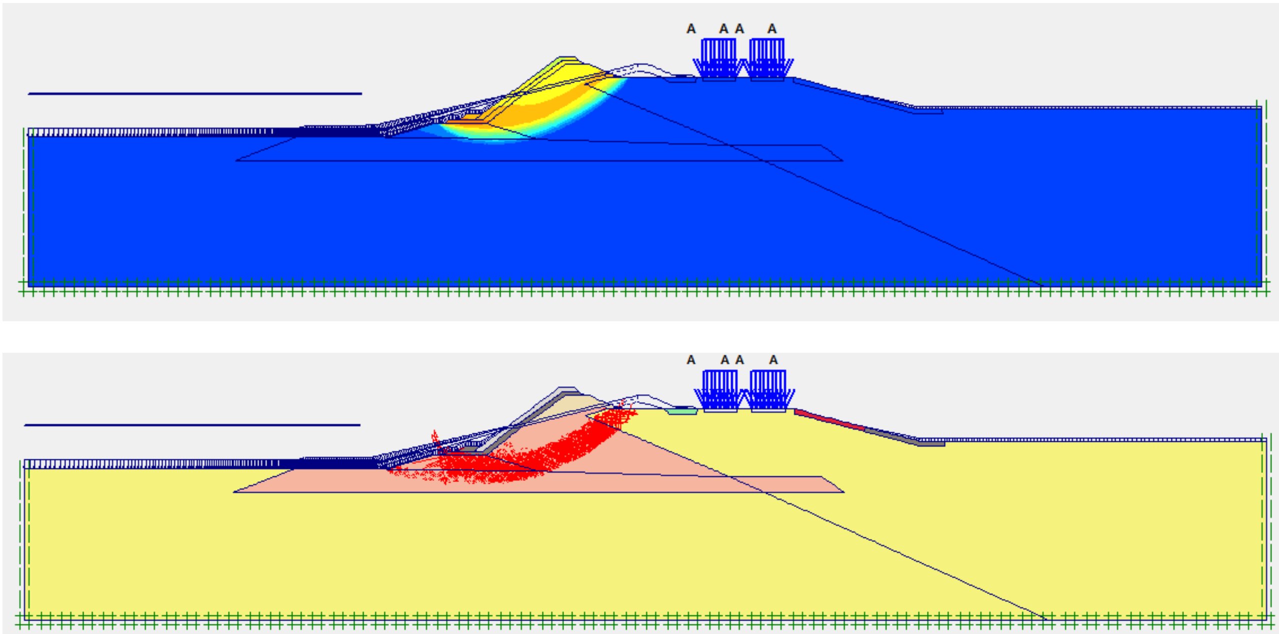
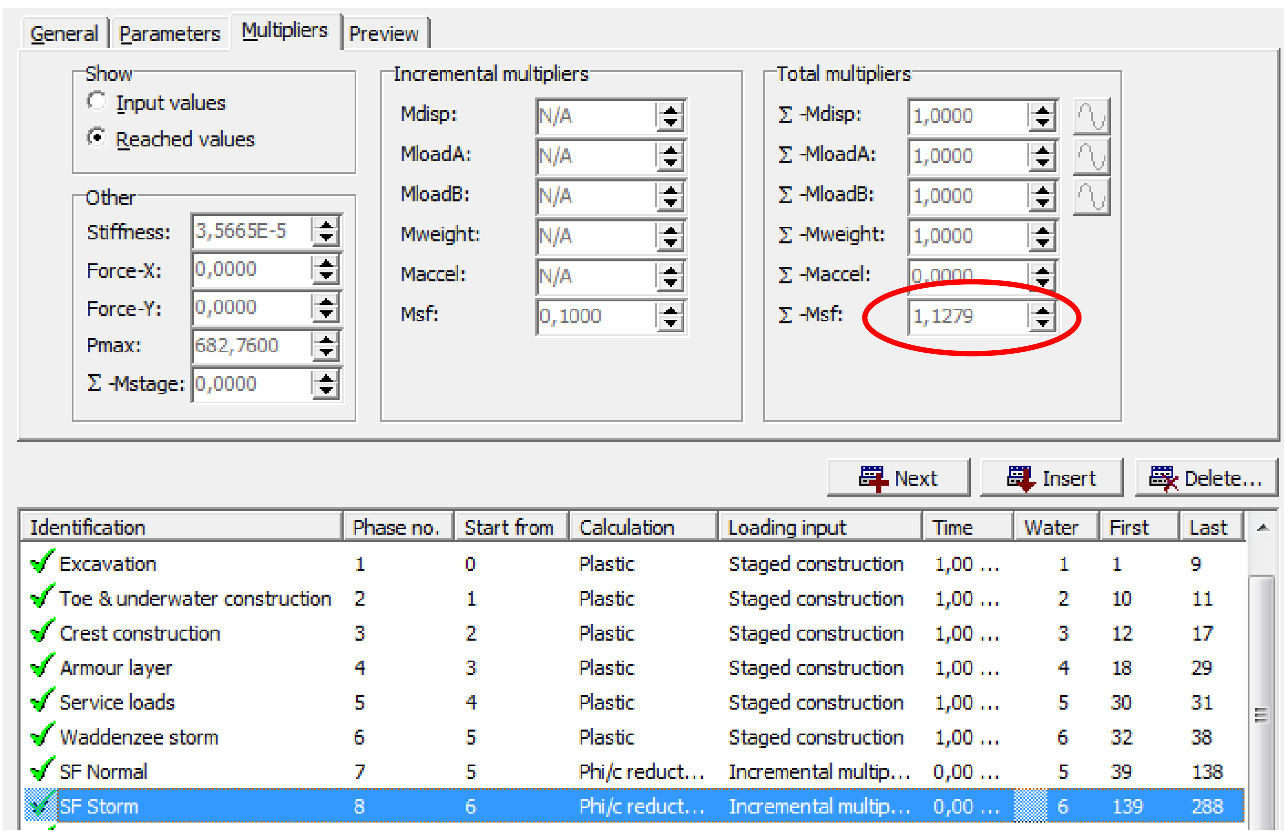


Figure 7-20. Geotechnical failure mechanism for normal conditions



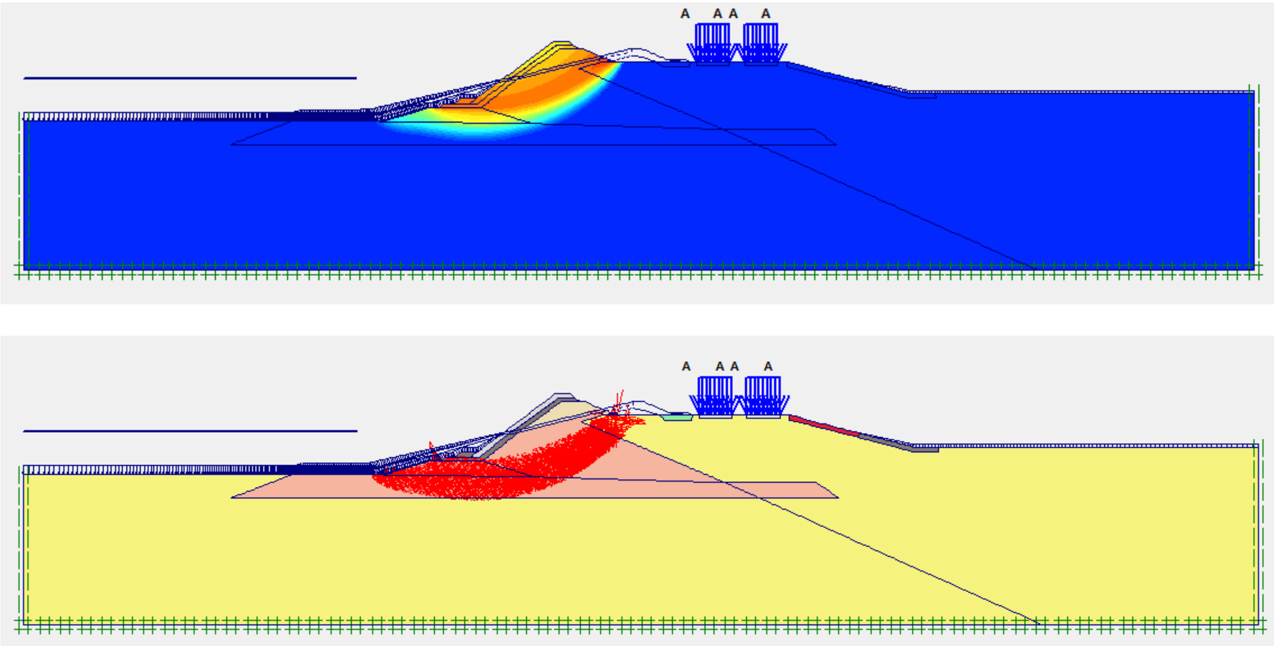


Figure 7-21. Geotechnical failure mechanism for Waddenzee design storm (2050)

With a detailed structural design of the toe, higher values can be achieved as well, thus the sliding surface can be incremented.

7.2.4. CONSTRUCTION PROCESS

The dimensions of the cross section and the water levels make possible to work with land based equipment. In section *7.2.1.2*, the reach of cranes was checked and no special lifting equipment seems to be needed, the whole slope is accessible from land.

Earth works can be executed with excavators. Different materials can be directly dropped with the help of land based earth work equipment.

Only the toe will be built submerged. The materials can be dropped with land based equipment too. The placement of geotextile can also be done from land. As there is part of the geotextile which should be placed under the toe (underwater), it will be necessary to ballast it.

After placement of geotextiles, toe and rock underlayers are built (also with land based equipment); Xbloc® units are placed with cranes as well.

7.2.5. LAND AVAILABILITY

Being the Netherlands, with 394 inhabitants per Km², one of densest populated countries in Europe, , it is definitely interesting to gain some extra land. Within the proposed alternatives for Afsluitdijk upgrading, regarding land availability: Xbloc® invading Waddenzee alternative (slope 3:4) is the most favourable. Twenty-four (24) meters are added to the current width of the

Afsluitdijk; extra 768.000 m² will be available. Unfortunately this area is limited by its short width compare to its length (24 meters vs. 32 Km).

Due to its shape, the first ideas that pop up are linear constructions (kind of tracks). It can be a maintenance lane, a new bike lane (fietspad) or a recreational lane (for slow velocities), among others. Nevertheless, such area can also be used to promote people's recreation, where some linear developments can be materialized. It is a fact that recreational areas could help to improve life quality by giving local communities some space for leisure. However, due to the fact of being a "risky" location, seasonality should be considered for the activities and ideas to be applied.

For the idea of public areas, car parking might be needed, and some places for services can be distributed along this new land. One main concept that have been considered, is the idea of a lineal park which account with public places for sports, as cycling, skateboarding, inline-skating (rollerblading), remote control cars track, green areas, acoustic shells, lineal forests with possible high line walking paths, et cetera. As reference some photos from the linear park at Manzanares River in Madrid are shown in Figure 7-22, as some other pictures from related topics can be appreciated in Figure 7-23, Figure 7-24 and Figure 7-25. In addition, some ideas can be taken from urban existing linear parks, as it is shown in Figure 7-26 and Figure 7-27.

Figure 7-22. Linear Park at Manzanares River in Madrid

Figure 7-23. Open Air Theatre (Acoustic Shell) parquet Miguel Hidalgo Mexico

Figure 7-24. Acoustic Shell, “Agua Azul” Park, Guadalajara, Mexico

Figure 7-25. Remote Control Cars Track

Figure 7-26. The High Line, New York City, USA (http://www.thehighline.org/)

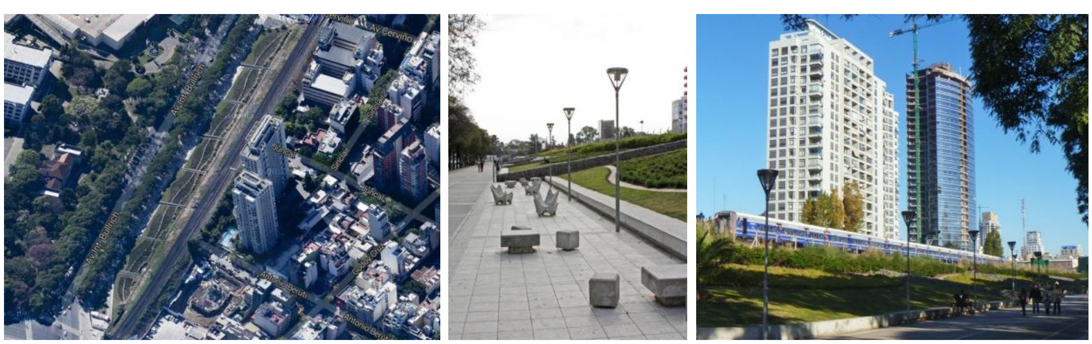


Figure 7-27. Bullrich Linear Park, Buenos Aires, Argentina

7.2.6. INNOVATIVE DESIGN APPROACHES

Due to the peculiar environmental situation constraining the Afsluitdijk, extensive research was carried out to find solutions out of the box. The main objective is to find environmental innovations to include within the design upgrading for the Afsluitdijk.

For this purpose as it is stated in section *6.1.5.2*, PIANC Working with Nature (WwN) approach (PIANC EnviCom, 2011) is followed and some reference projects were checked and used to have better insights about this philosophy. In addition, under the umbrella of WwN, at national scale in The Netherlands Building with Nature philosophy (BwN) is found. Furthermore with Dutch engineers working around the world, BwN also is helping to spread this design line, at least in organized ways.

"Eco-engineering in the Netherlands, Soft interventions with a solid impact" (Rijkswaterstaat et al., 2013) is a recently released comprehensive document, which provides useful information for these type of approaches that can be adopted in the Afsluitdijk. Some examples are shown in Figure 7-28 and Figure 7-29.

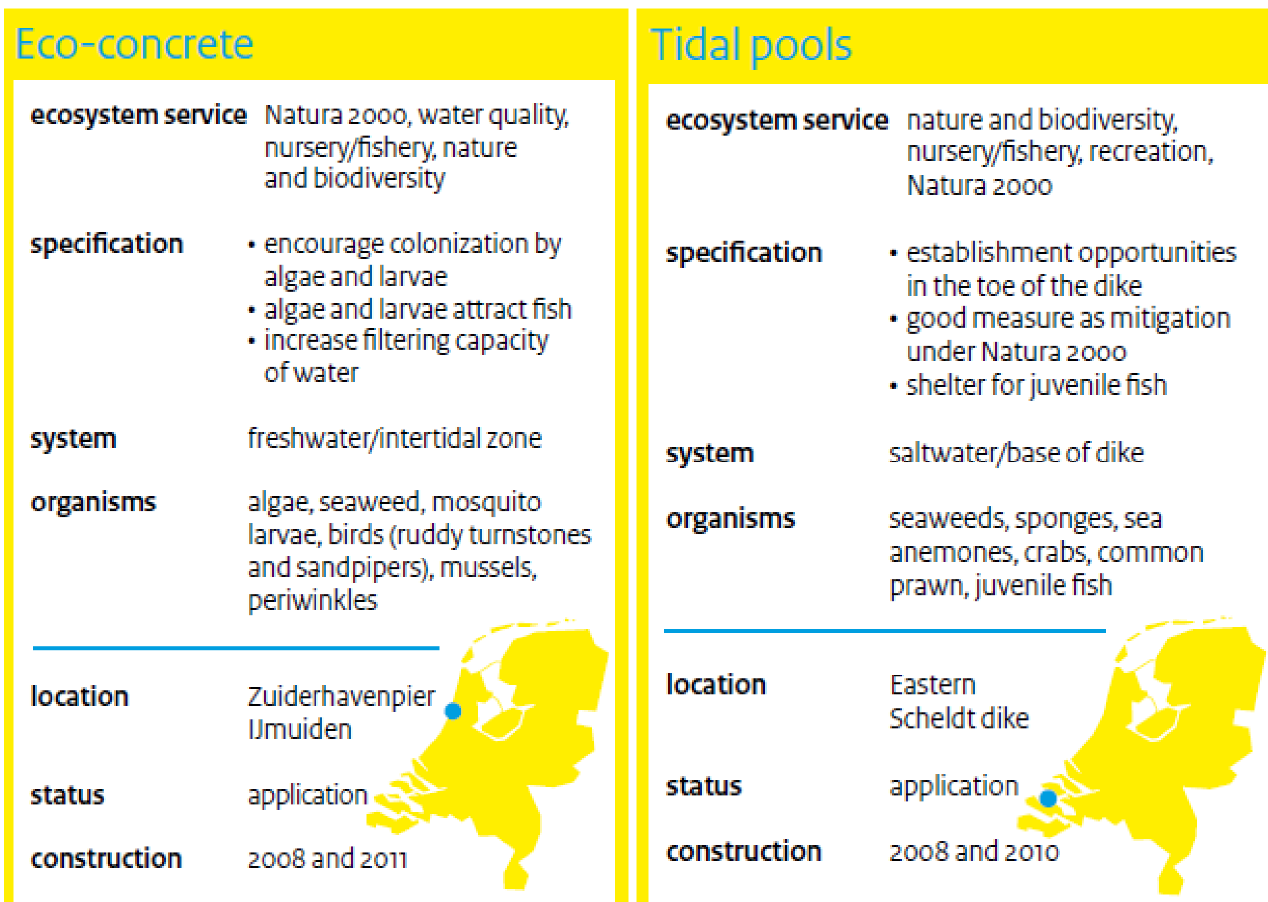


Figure 7-28. Related Eco-Engineering projects already built in the Netherlands

Figure 7-29. Eco-Concrete in Ijmuiden (left) and tidal pools in the Eastern Scheldt dike (right)

As it can be seen from previous figures, similar approach as the one constructed in the East Arrowhead Breakwaters of Cleveland Harbour in USA (section *6.1.5.2*), has already been built in the Netherlands. This concrete version in the Netherlands is called Eco-Concrete (interesting remark is that the name is in accordance with Eco Xbloc®). Eco-Concrete was developed to attract algae and larvae.

Moreover, tidal pools have been constructed at the toe of a dike (tidal zones in Zeeland) to attract crabs, common prawn, juvenile fish among others. The Afsluitdijk is not in a major tidal influence area, nevertheless something like these tidal pools would result interesting options to research and probably apply for the upgrading.

Therefore, the advice of this multi-disciplinary group is to include some of these improvements within the Afsluitdijk to promote and enhance nature and biodiversity. However further studies and discussions should be done to decide and implement particular solution. This studies are out of the scope of this report.

7.3. RIP-RAP OVERLAYER

7.3.1. OVERALL STABILITY

To compute overall stability for the proposed Rip-Rap over layer alternative, another Finite Elements Model was done. The same methodology explained in previous sections is followed.

7.3.1.1. MATERIALS

The same criterion explained in *7.1 Existing Afsluitdijk cross-section overall stability* was applied.

7.3.1.2. ANALYSIS & LOADS

This proposed alternative has it maximum crest elevation at +8.50m+NAP, Waddenzee and IJselmeer elevations are exactly the same introduced in *7.1 Existing Afsluitdijk cross-section* *overall stability*. Also dead loads and live loads are similar to mentioned section. FEM geometry is shown in Figure 7-30.

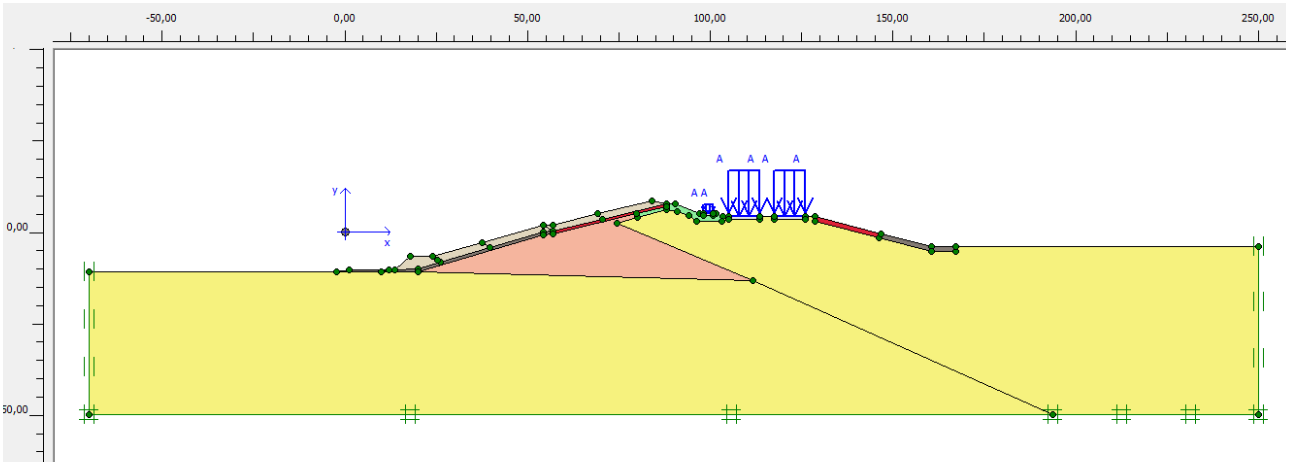


Figure 7-30. FEM geometry of the over-layer proposed cross-section

For the proposed Afsluitdijk over-layer cross-section the following load combinations are studied:

1. Excavation of the existing profile in order to build the new toe for Xbloc®; without live loads and Waddenzee water level at +0.00m+NAP.
2. Toe construction and partial underlayer and armour layer positioning (under water works).
3. New crest construction, removal of original crest and under later completion.
4. Armour layer completion.
5. Service loads are applied.
6. Waddenzee water level is increased up to +5.52m+NAP.
7. From Load Combination 5, a phi/c reduction process is started in order to obtain the existing Safety Factor under normal conditions for the Afsluitdijk.
8. From Load Combination 6, a phi/c reduction process is started in order to obtain the existing Safety Factor under storm conditions for the Afsluitdijk (2050).

7.3.1.3. FINITE ELEMENT MODEL

The FEM developed is shown in Figure 7-31.

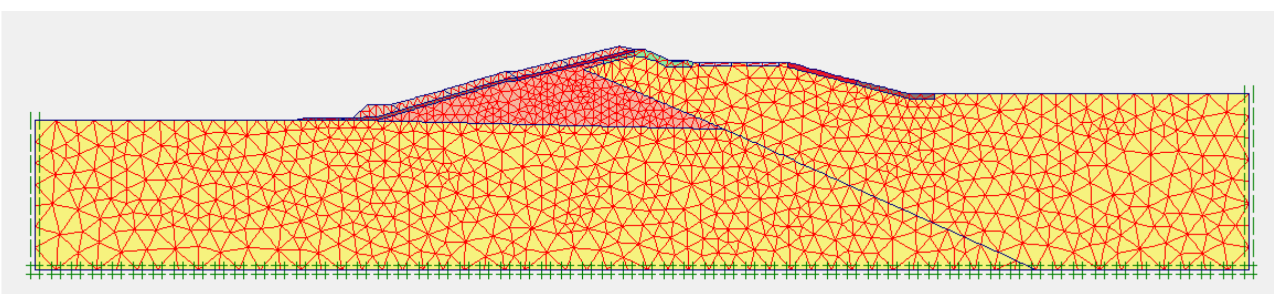


Figure 7-31. FEM coarseness mesh, which is refined in key zones for possible failure mechanisms

Active pore pressures for Waddenzee and IJselmeer normal conditions (+0.00m+NAP) are shown in Figure 7-32.

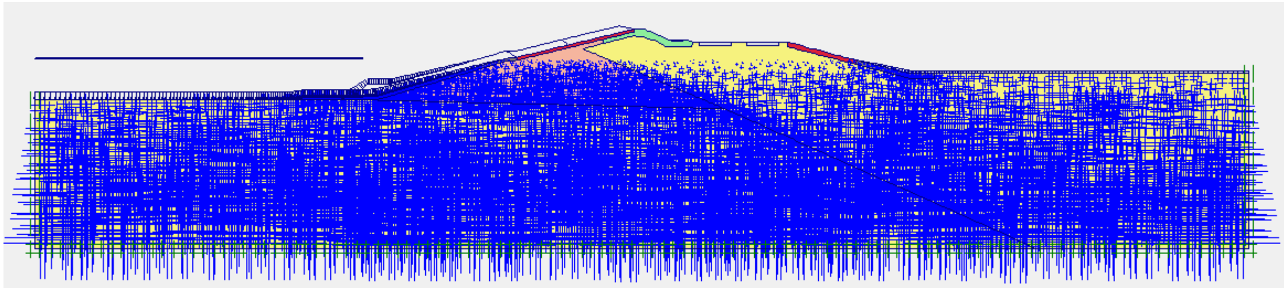


Figure 7-32. FEM active pore pressure. As a back check, the extreme active pore pressure at FEM bottom was read and it is 498.81kN/m^2, which is in accordance with FEM dimensions.

Besides, initial effective soil stresses were calculated (using k_0) and are presented in Figure 7-33.

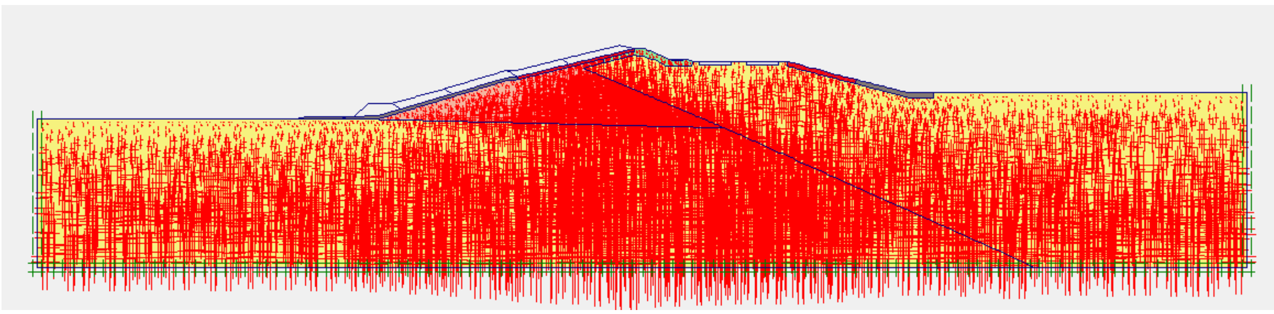


Figure 7-33. FEM Effective stresses with an extreme effective principal stress of -632.45kN/m^2 as expected at the bottom of the model (below dike crest)

7.3.1.4. RESULTS

The construction's phase list is shown in Figure 7-34.

Identification	Phase no.	Start from	Calculation	Loading input	Time	Water	First	Last
Initial phase	0	0	N/A	N/A	0,00 ...	0	0	0
✓ Existing condition - Service Loads	1	0	Plastic	Staged construction	1,00 ...	1	1	16
✓ Toe construction	2	1	Plastic	Staged construction	1,00 ...	2	17	18
✓ Armour layer 1st section	3	2	Plastic	Staged construction	1,00 ...	3	19	22
✓ Armour layer 2nd section	4	3	Plastic	Staged construction	1,00 ...	4	23	24
✓ Armour layer 3rd section	5	4	Plastic	Staged construction	1,00 ...	5	25	26
✓ Armour layer 4th section (crest)	6	5	Plastic	Staged construction	1,00 ...	6	27	29
✓ Waddenzee storm	7	6	Plastic	Staged construction	1,00 ...	7	30	33
✓ Normal conditions	8	7	Plastic	Staged construction	1,00 ...	8	34	35
✓ SF storm	9	7	Phi/c reduct...	Incremental multip...	0,00 ...	7	36	135
✓ SF normal	10	8	Phi/c reduct...	Incremental multip...	0,00 ...	8	136	235

Figure 7-34. FEM calculations phases

Each construction phase is detailed and shown in Figure 7-35, Figure 7-36, Figure 7-37, Figure 7-38, Figure 7-39 and Figure 7-40.

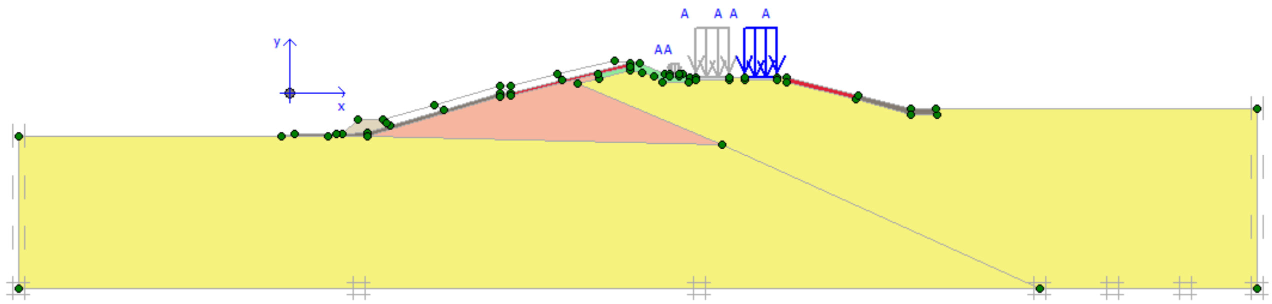


Figure 7-35. Toe construction

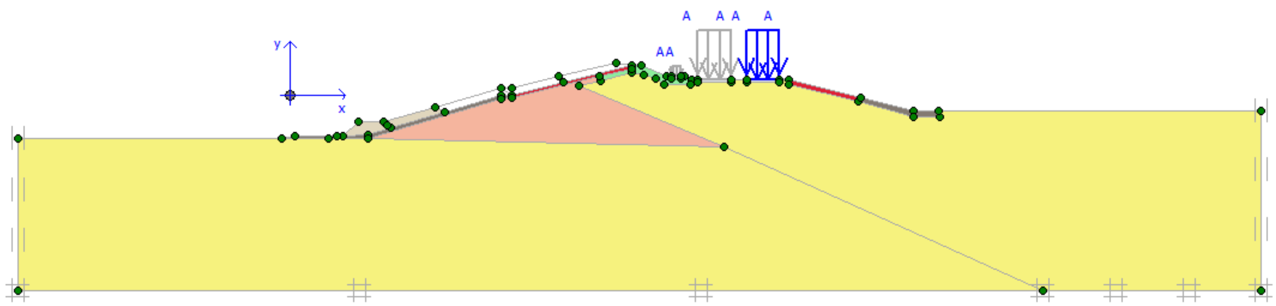


Figure 7-36. Armour layer, first stage

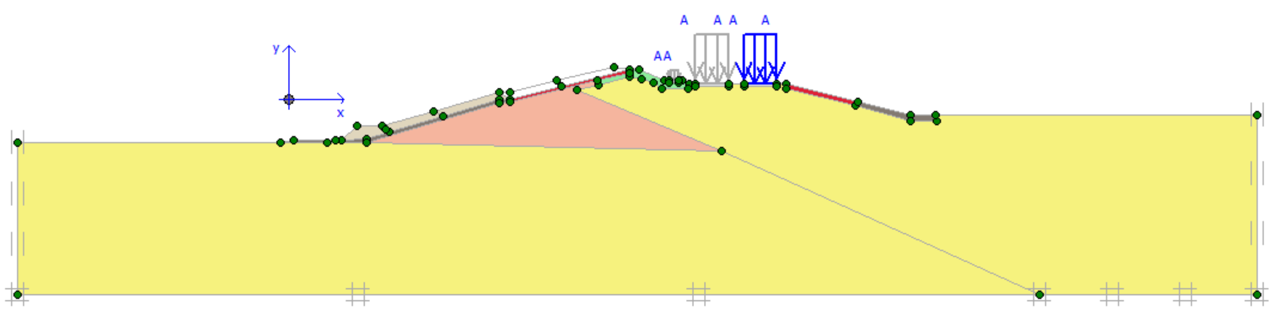


Figure 7-37. Armour layer, second stage

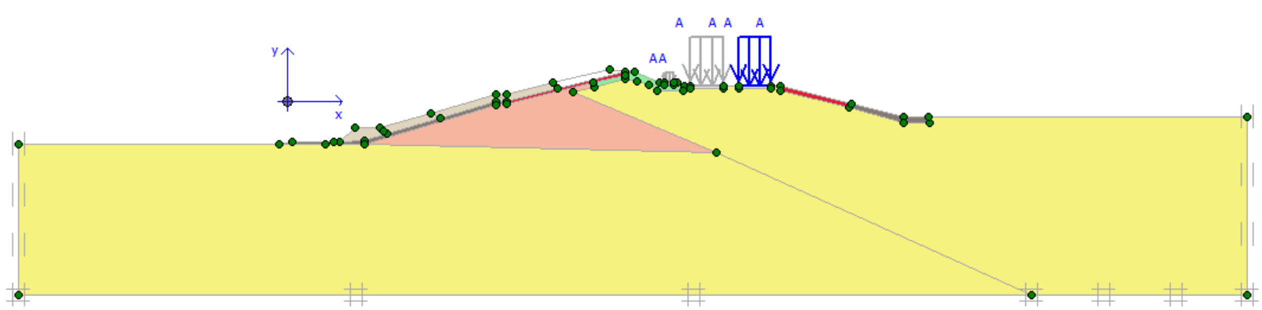


Figure 7-38. Armour layer, third stage

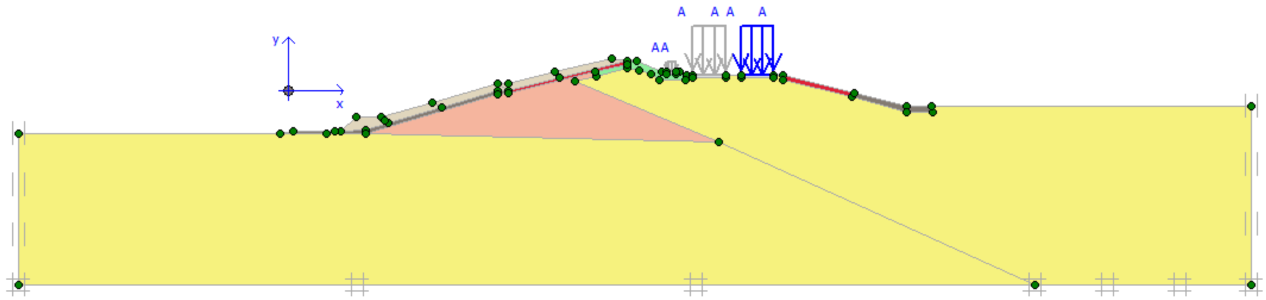


Figure 7-39. Armour layer, fourth stage (crest)

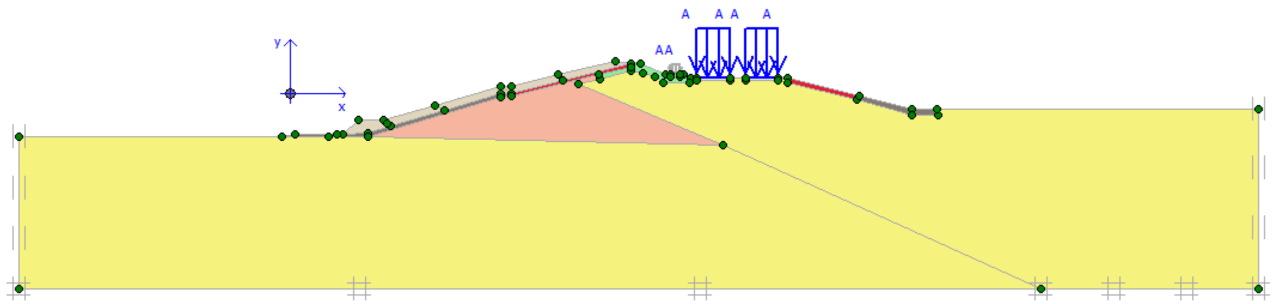


Figure 7-40. Service loads

In Figure 7-41 are shown the active pore pressures originated during a storm (year 2050) in the Waddenzee. It is clearly visible that higher values are reached in the boulder clay and the deep sand layers below the Waddenzee, than the values obtained in the IJselmeer influence area.

It is assumed that the effect of a Waddenzee storm is influencing the ground water table on the Afsluitdijk up the diagonal geometry line crossing the dike geometry.

Previous assumption is made based on boulder clay very low permeability.

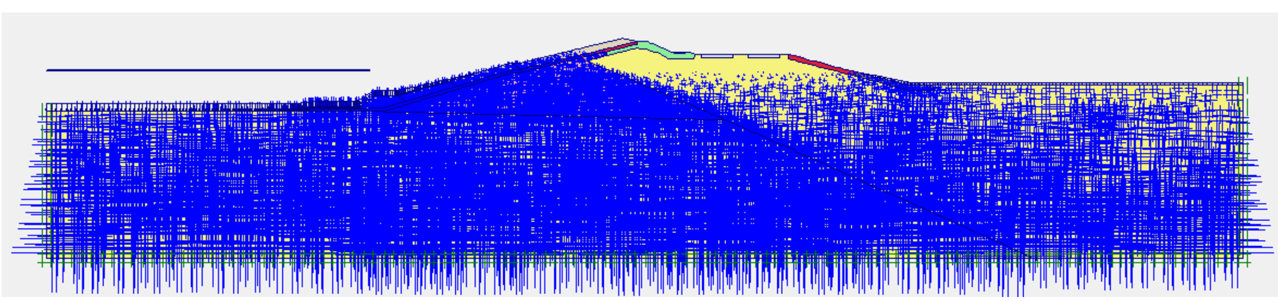


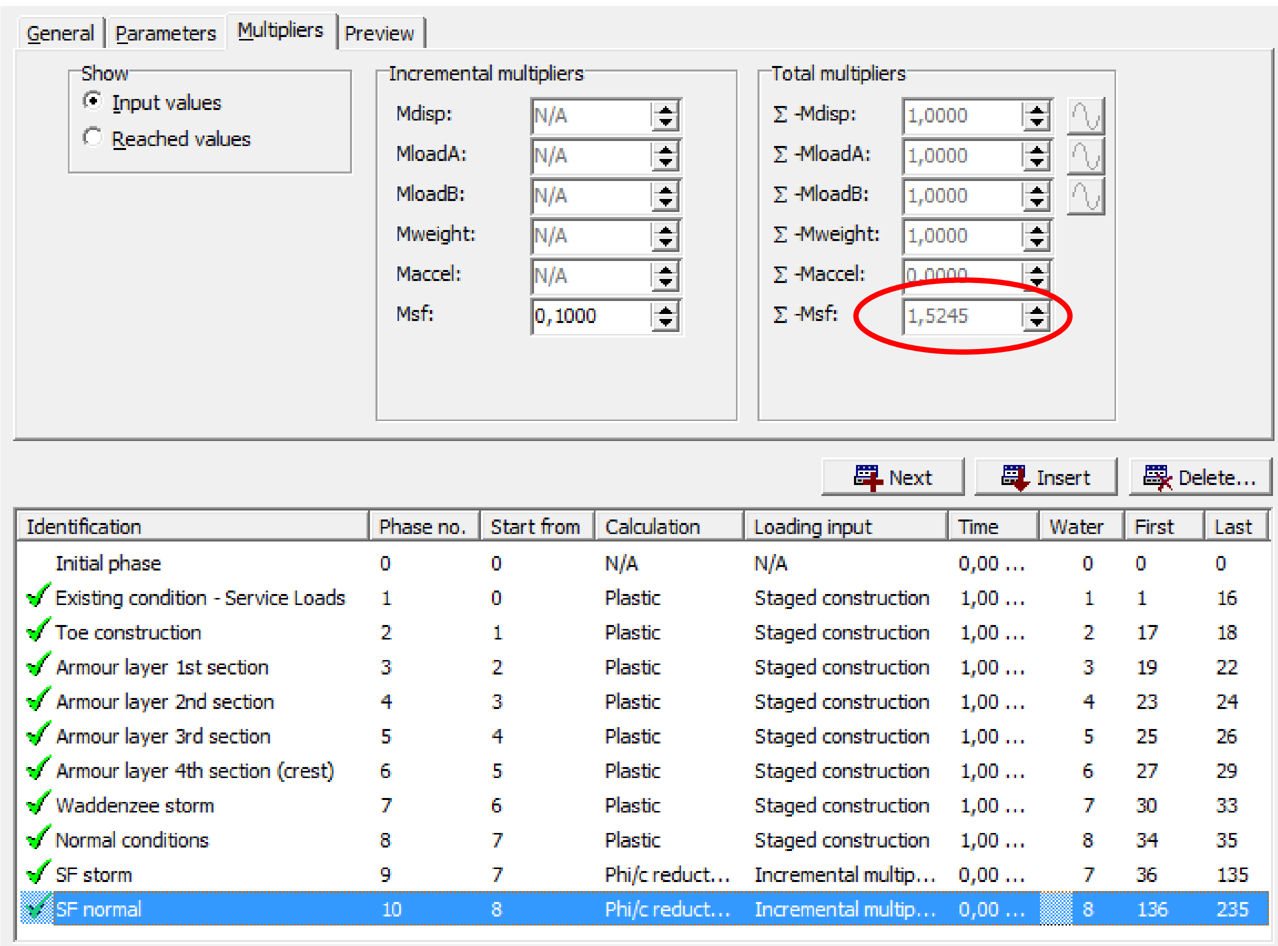
Figure 7-41. Active pore pressures due to Waddenzee water level during a storm +5.52m NAP. The extreme active pore pressure obtained is -553.85kN/m^2.

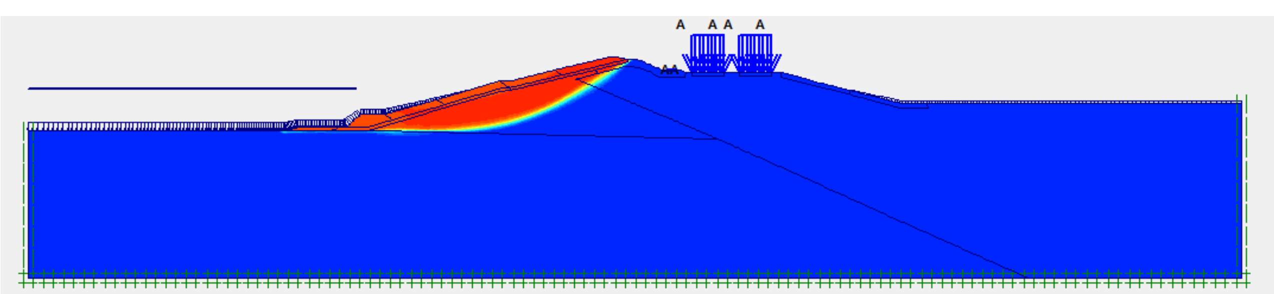
The geotechnical Safety Factors (SF) for the Rip-Rap over layer alternative are obtained throughout this Finite Element Analysis. In accordance with previous analysis, also both Safety Factors are obtained for this alternative. These are summarized in Table 17.

Table 18 Overall Stability Safety Factors for Afsluitdijk existing cross-section 10

Geotechnical Safety Factors	
Normal Conditions	Waddenzee Storm 2050
1.53	1.46

The obtained values are just accomplishing international standards, however further improvements can be done in a more extensive analysis in order to increase these values. Each failure mechanisms is respectively shown in Figure 7-42 and Figure 7-43.





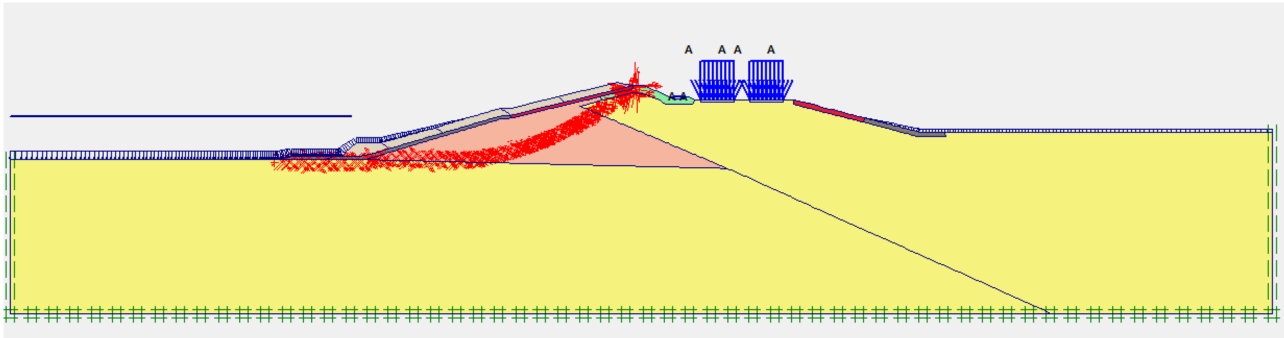
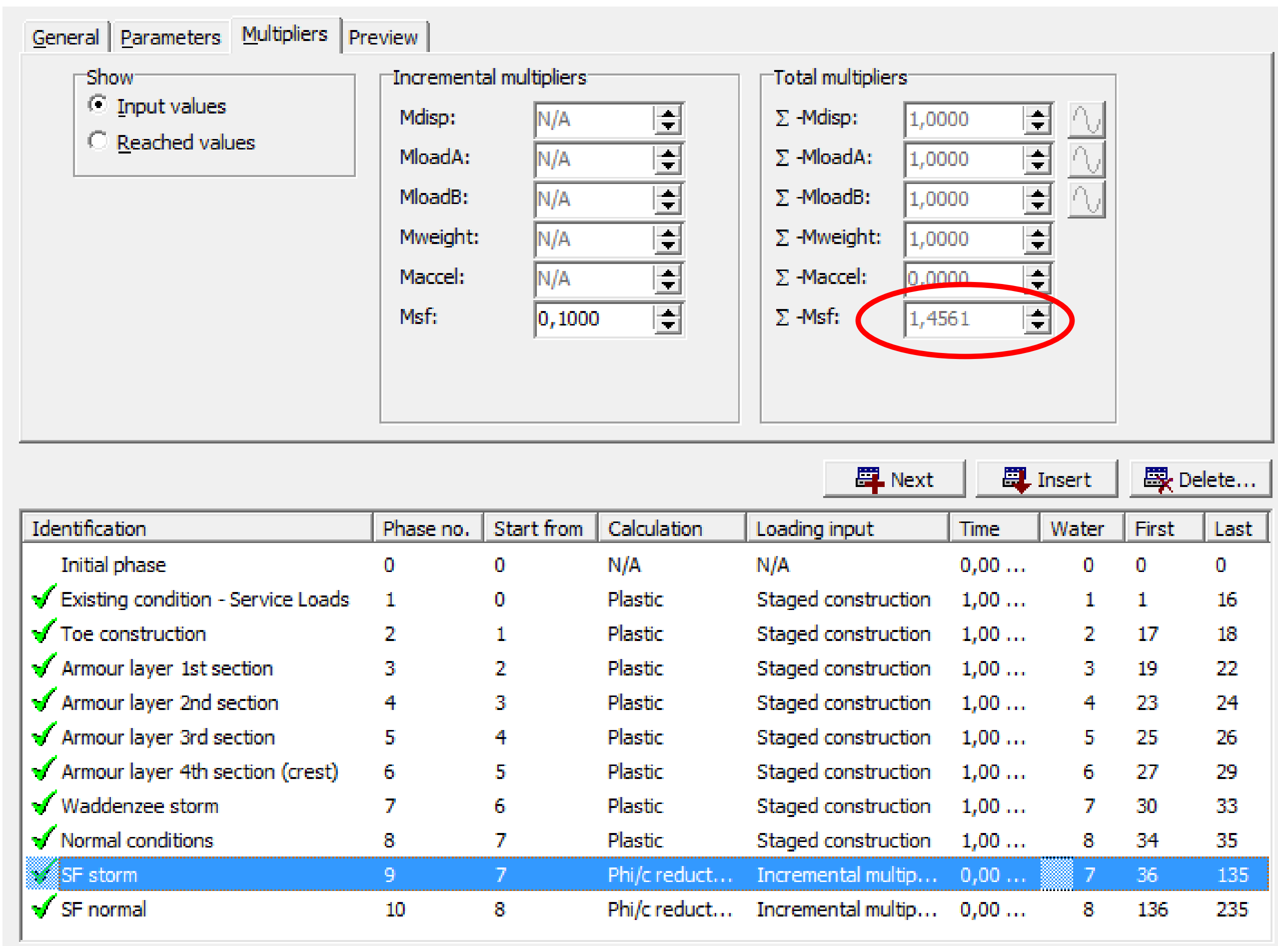
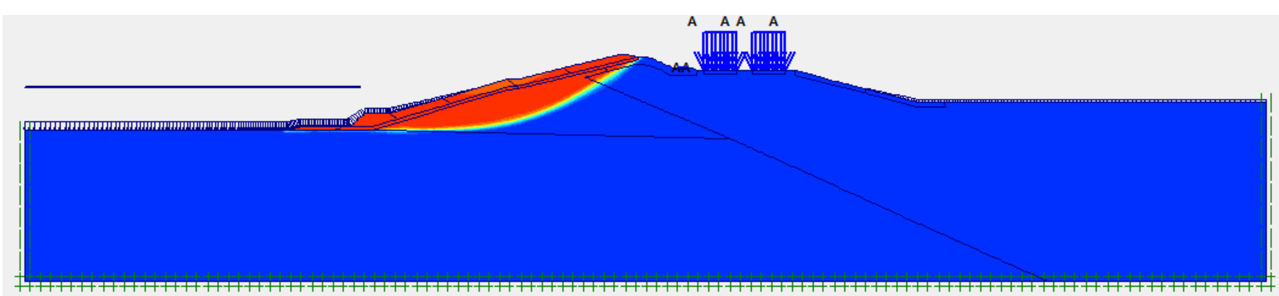


Figure 7-42. Geotechnical failure mechanism for normal conditions





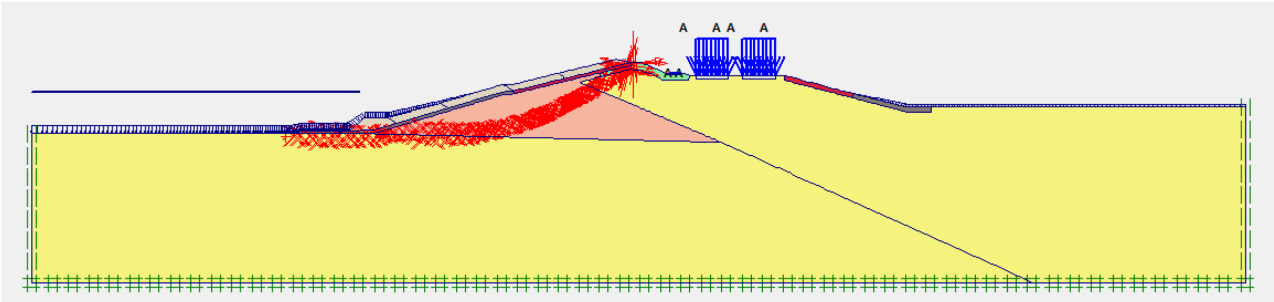


Figure 7-43. Geotechnical failure mechanism for Waddenzee design storm (2050)

It is clearly visible how the design was improved by doing a detailed design of the toe. The sliding surface was increase with its consequent safety factor's increase. Hence, as it was mentioned in the previous section and FEMs' descriptions, further studies are recommended. For recalibrating the FEM, more accurate data is needed; mainly that which is required for a proper representation of the materials constitutive models.

7.3.2. CONSTRUCTION PROCESS

In this case, there are not excavations or demolitions; only the placement of the toe and the Rip-Rap layer should be done. This can be materialized with land based equipment. The water only covers the lowest part of the cross section. The underwater toe can be built from land without significant difficulties.

Only the placement of geotextile can pose some difficulties, since it is placed submerged, under the toe. This operation can be done from land, as the final position of the geotextile is very close to the shoreline. It is possible that help from divers is needed for the submerged part. After placement of geotextiles, toe and Rip-Rap layer can be placed with land based equipment as well.

7.4. RIJKSWATERSTAAT ADOPTED SOLUTION (OVERTOPPING RESISTANT)

Rijkwaterstaat (RWS) has decided to opt for overtopping resistance improvement. An innovative method is carried out, being considerably cheaper as well. The inner slope of the dike which is made of sand, is built on boulder clay, topped of clay and covered with grass. However, when facing a big storm, this surface layer may be washed away while water breaks over the dike. As a result, armour layer materials may also be washed away, which weakens the dike. The solution is making the slope erosion resistance, by strengthening the top layer by concrete box or asphalting concrete. The slope is finished off with the layer of grass to maintain its natural look. This is called "overtopping prevention". The dike will protect the Dutch against the North sea until 2050 at least.

7.5. PROBABILISTIC DESIGN

Due to the type of data received from the Client, in which the boundary conditions are given for different design storms, obtained with a probabilistic approach. It was decided to apply only the Classical method in which a design storm is selected; then the armour is designed using the selected design storm input and a deterministic design formula. This methodology is reliable enough, besides for storm duration and number of waves during a storm; conservative values are adopted for the presented calculations.

The difference between the Classical method (Deterministic approach) and the other two approaches is mainly caused by the fact that the deterministic approach does not take into account the measurement errors, the short term variability, the corrections for "life time" and the corrections for statistical uncertainties. However due to the amount of data required and main scope of this report, both alternative methodologies to the Classical method are not computed.

7.6. FINAL MULTI-CRITERIA ANALYSIS

Once the two final alternatives have been completely defined, a comparison between them with the Rijkswaterstaat solution has been made using a multi-criteria analysis. The same criteria and weighing factors are used as which have been done in the intermediate design. The results, taking the average between the Employer's scoring and the group's, are shown as follows.

Table 19. Cross Section alternatives studied within Final Multi-Criteria Analysis

Design 1	Xbloc® 3:4
Design 2	Rip-Rap overlayer
Design 3	RWS solution

Table 20. Average relative weights Multi-Criteria Analysis

CRITERIA	WEIGHTS					
	Eric	Abby	Carlos	María José	Pablo	**Average**
Protection from waves	14.29	14.29	14.29	14.29	12.09	13.85
Construction Process	10.99	3.30	2.20	6.59	3.30	5.27
Flexibility future upgrading	4.40	12.09	7.69	12.09	14.29	10.11
Resilience	9.89	6.59	4.40	6.59	5.49	6.59
Land availability	8.79	7.69	1.10	6.59	6.59	6.15
Incursion in Waddenzee	6.59	5.49	13.19	13.19	8.79	9.45
Pollution during construction	13.19	5.49	6.59	7.69	3.30	7.25
Landscape	7.69	3.30	1.10	2.20	2.20	3.30

PIANC Working with Nature	3.30	9.89	8.79	7.69	9.89	7.91
Frequency maintenance & monitoring	7.69	8.79	9.89	4.40	12.09	8.57
Accessibility inspection armour layer	6.59	6.59	9.89	1.10	9.89	6.81
Accessibility for maintenance tasks	5.49	9.89	12.09	7.69	7.69	8.57
Recreation	0.00	2.20	3.30	1.10	2.20	1.76
Social considerations	1.10	4.40	5.49	8.79	2.20	4.40
Total	**100**	**100**	**100**	**100**	**100**	**100**

Table 21. Final Multi-Criteria Analysis results

CRITERIA			Relative weights [%]	WEIGHED SCORES		
				1	2	3
TECHNICAL FACTORS	1	Protection from waves	13.85	55	55	24
	2	Construction Process	5.27	11	16	11
	3	Flexibility future upgrading	10.11	26	16	18
OPERATIONAL FACTORS	4	Resilience	6.59	12	15	7
	5	Land availability	6.15	25	9	8
ENVIRONMENT	6	Incursion in Waddenzee	9.45	30	13	24
	7	Pollution during construction	7.25	16	23	18
	8	Landscape	3.30	8	9	8
	9	PIANC Working with Nature	7.91	22	19	8
MAINTENANCE	10	Frequency maintenance & monitoring	8.57	29	22	21
	11	Accessibility inspection armour layer	6.81	18	19	26
	12	Accessibility for maintenance tasks	8.57	24	15	28
THIRD PARTIES	13	Recreation	1.76	5	4	3
	14	Social considerations	4.40	17	11	9
TOTAL			100	299	246	211

As is shown in

Table 21, the Xbloc® design gets the highest score, followed by the Rip-Rap over layer and Rijkswaterstaat solution. The Xbloc® gets highest in “Flexibility future upgrading”, because the crown wall has been modified, that means the equipment can be positioned and it is needed only conventional equipment. Also more space is created in the Xbloc® design. In addition, the Xbloc® does not invade the Waddenzee, which leads to much higher grade in “Incursion in Waddenzee”. The RWS solution has the best accessibility for inspecting armour layer, due to its gentle slope so worker can easily walk on it.

7.7. FINAL COST ANALYSIS

From the cost estimation analysis it can be seen that the overtopping resistant alternative is the cheapest one, even though it does score last on the Multi-Criteria Analysis, its MCA/€ ratio is the highest, as it can be seen in Figure 7-44 and Table 22.

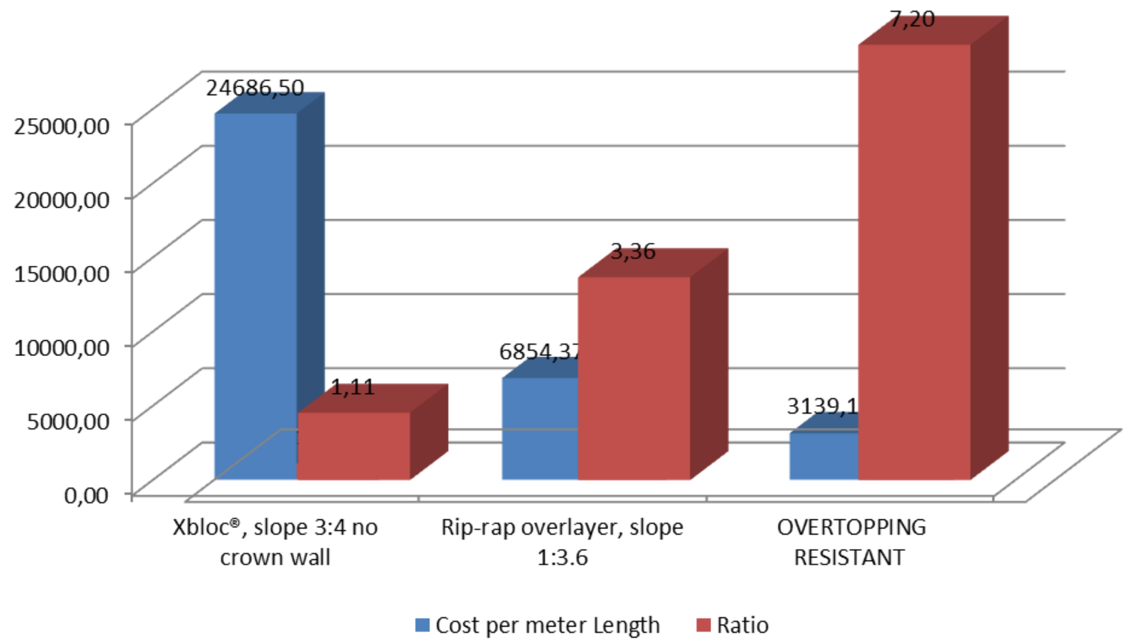


Figure 7-44. Cost per meter for three selected alternatives

Table 22 Cost Estimation for the three selected alternatives

				COSTS PER METER								
				DESIGN 4			DESIGN 10			OVERTOPPING		
			ESTIMATED COST	Xbloc®, slope 3:4 no crown wall			Rip-rap overlayer, slope 1:3.6			OVERTOPPING RESISTANT		
ITEM	DESCRIPTION	UNIT	RATE DC	QUANTITY	AMOUNT	%	QUANTITY	AMOUNT	%	QUANTITY	AMOUNT	%
1	Pavement demolition	m3	20,24		0,00	0		0	0,0%		0,00	0,0%
2	Disposal	m3	13,80	60,955	841,02	3,4%		0	0,0%		0,00	0,0%
3	Excavation land equipment inc. storage on site	m3	15,64	121,91	1906,31	7,7%		0,00	0,0%	3,39	53,01	1,7%
4	Quarry run	t	23,00	135,54	3116,83	12,6%		0,00	0,0%		0,00	0,0%
5	Sand / selected material	t	15,00		0,00	0,0%		0,00	0,0%		0,00	0,0%
6	Clay	t	23,00		0,00	0,0%		0,00	0,0%		0,00	0,0%
7	Coarse gravel	t	30,00	10,94	328,20	1,3%	4,25	127,50	1,9%		0,00	0,0%
8	Quarry stone wider gradation >1 Tn	t	27,59		0,00	0,0%		0,00	0,0%		0,00	0,0%
9	Quarry stone wider gradation < 1Tn	t	25,76		0,00	0,0%		0,00	0,0%		0,00	0,0%
10	Quarry stone +250kg	t	28,00	10,90	305,20	1,2%	4,25	119,00	1,7%		0,00	0,0%
11	Quarry stone 600kg-1.5t	t	33,11	52,58	1741,12	7,1%	22,14	733,14	10,7%		0,00	0,0%
12	Quarry stone 2-3t	t	36,79		0,00	0,0%	145,17	5341,24	77,9%		0,00	0,0%
13	Quarry stone 4t	t	36,79		0,00	0,0%		0,00	0,0%		0,00	0,0%
14	Production and stockpiling Xbloc 3.7t	u	289,74	18,00	5215,41	21,1%		0,00	0,0%		0,00	0,0%
15	Transport and placement of Xbloc 3.7t	u	249,27	18,00	4486,90	18,2%		0,00	0,0%		0,00	0,0%
16	Concrete C35/45 in	m3	161,89	17,23	2789,35	11,3%		0,00	0,0%		0,00	0,0%
17	Geotextile	m2	91,98	42,76	3933,17	15,9%	5,80	533,50	7,8%		0,00	0,0%
18	Drain	m	23,00	1,00	23,00	0,1%		0,00	0,0%		0,00	0,0%
19	Bituminous surface	m2	1,20		0,00	0,0%		0,00	0,0%	12,06	14,42	0,5%
20	Bituminous pavement	t	70,00		0,00	0,0%		0,00	0,0%	22,91	1603,98	51,9%
20	Open asphalt	t	78,19		0,00	0,0%		0,00	0,0%	3,72	291,16	9,4%
21	Mattress	m2	18,00		0,00			0,00			0,00	0,0%
22	Topsoil	t	11,04		0,00	0,0%		0,00	0,0%	9,61	106,02	3,4%
23	Planting grass	m2	9,20		0,00	0,0%		0,00	0,0%	11,30	103,94	3,4%
24	Sheet pile head/toe	m2	183,96		0,00	0,0%		0,00	0,0%	5,00	919,82	29,7%
				TOTAL	24686,50	100%		6854,37	100,0%		3092,35571	100,0%
				MULTI-C.	271			229			241	
				RATIO	1,10			3,34			7,79	

7.8. RESULTS

After an extensive analysis of the Final Design alternatives the following results are achieved:

- Best ratio solution: **Rip-Rap overlayer**.
- Among every proposed solution, Rip-Rap overlayer resulted the cheapest one.
- Safety level requirements are achieved.
- Rip-Rap overlayer solution is reducing run-up, consequently overtopping, compared to existing situation due to fact of increasing roughness on the armour layer.
- Minor invasion of the Waddenzee; however measures, within the Rip-Rap overlayer design, are carried on to enhance the environment (i.e. tidal pools).
- No extra land on top of the dike is added for Rip-Rap overlayer design.
- Rip-Rap overlayer alternative has limited flexibility for future upgrading.
- Basalt columns are preserved on the proposed solution.
- Rip-Rap overlayer is a very simple design, hence special attention should be paid when constructing the toe over the Waddenzee bottom.
- Geotextiles at the interface between the toe and the Waddenzee bottom are required.
- Construction methodology is not a key decision-making factor.
- Small traffic disruptions during construction.
- Maintenance accessibility is reduced compared to current situation.
- Crown wall for Rip-Rap overlayer alternative is not required.

8. FINAL REMARKS

Although under a purely economic point of view RWS solution is the most convenient, when considering the future performance of the dike it is not that favourable. It does not reduce run-up and overtopping, nor does it increase the dike crest height. It only provides more resistance to the slopes of the dike (asphalt over exiting basalt columns and inner slope).

On the other hand, being Rip-Rap overlayer the proposed alternative (within this report) which, according to MCA; it faces more inconveniences for future upgrading; it is worth to think in a different way to improve this alternative. Nevertheless, Rip-Rap overlayer is still better than RWS solution regarding dike upgrading because it would make the upgrading of the dike easier and less expensive along the life cycle of the structure. The following paragraphs are supporting this statement.

For current cross-section configuration and for the hydraulic boundary conditions of the year 2050, the overtopping resistant alternative has to cope with an overtopping of around 350l/m/s (Liu et al., 2012). Meanwhile, for the same situation, Rip-Rap overlayer proposed alternative reduces overtopping up to 10 l/m/s.

In addition, for the hydraulic boundary conditions of the year 2100, overtopping amounts will be around 700 l/m/s for RWS solution and approximately 50 l/m/s for Rip-Rap overlayer. These calculations are shown in *Appendix E.7 Computation of overtopping for the year 2100*.

Therefore, Rip-Rap overlayer solution would withstand hydraulic conditions of the year 2100 with minor interventions. These measures could be paving the inner slope, when required in the upcoming future. This would also allow to have a phased construction process, however to accomplish this, a monitoring program and planned adaptation are a must.

In contrary, RWS solution will not facilitate an upgrading because the slopes are covered in asphalt. Hence, a larger increase in crest height or implementing one of the proposed alternatives would be needed to reach the same level of protection.

To sum up this comparison between RWS solution and Rip-Rap overlayer alternative, the first one would be more expensive than second concerning life cycle costs, mainly due to the fact of the need to implement major overtopping preventive measures after the year 2050 for RWS solution.

Following PIANC Working with Nature (WwN) philosophy and The Netherlands Building with Nature (BwN) approach, environmental friendly measures are proposed. For Rip-Rap overlayer solution, tidal pools are suggested to be introduced in order to enhance nature and biodiversity. Nevertheless, Rip-Rap overlayer solution partly causes intervention on nature, as it invades the Waddenzee hence it is a very small area (10m). Compared to the previous sentence, RWS overtopping resistant solution is not invading the Waddenzee, but it is unable to adopt such eco-measures because it will be just an asphalt surface, which is not environmentally friendly at all.

The Xbloc® solution has also its advantages when it comes into environmental field. A new kind of concrete called Eco-Concrete which encourages colonization by algae and larvae is proposed to be implemented for Xbloc® solution. Besides, this solution would not invade the Waddenzee, helping to diminish the footprint on nature.

Xbloc® solution, apart from fulfilling the requirement regarding protection from waves, allows gaining some extra space on the dike. Despite that, the Employer has stated extra space is not needed from mid-term perspective (roads are far from reaching their capacity and traffic is not expected to increase enough to require an enlargement). Therefore, it appears that there is not a justification for larger investments, at least according to Employer’s Requirements, as the extra space would be used for recreational activities or maintenance tasks, in principle.

However, here a pause is compulsory to explain which one of the main concerns of this group is.

It is the understanding of this multidisciplinary team that Rijkswaterstaats’ selected alternative is a consequence of current standards, which seems to be set, at the moment, for short and/or mid-term solutions. On the one hand, this criterion can be understandable due to the fact of current economic situation.

Nonetheless, for further clarification it is important to mention that current dominant way of thinking within Rijkswaterstaat is not the same which was governing 80 years ago when the Afsluitdijk was built, nor 40 years ago when the Eastern Scheldt Barrier was built. It seems that spending the less possible amount of money is one of the main drivers, even though flexibility and efficiency are reduced, at least in the case of future upgrading.

Hence, one interesting question that popped up within the members of this multidisciplinary team is: *Why not apply a "new" approach for planning and design such hydraulic structures, like the one proposed in The Flexible Port (Taneja, 2013)?* This is an incipient discipline in some other fields, which can be easily reproduced for these types of projects. Instead of partially ignore future uncertainties, why not embracing them to be tackled by assuming the risk and improve possible future opportunities. Also, in contrary of having a static position, why not go for pro-active and dynamic position promoting planned adaptation for possible future scenarios. Therefore, it is the understanding of this group that the way to accomplish those issues is by introducing flexibility and adaptability in the designs. Exactly, that is the point which has led to have Xbloc® solution within the two best rated proposed alternatives, moreover it is the best MCA scored alternative. Xbloc® solution is a robust design which can be adapted to several future scenarios due to the fact of the increase of available land on top of the dike. In the meantime, some recreational activities have been proposed to be developed in these new lands while there is no need for major upgrading of the Afsluitdijk.

A final remark needs to be made about Rijkswaterstaat's choice of dike performance level and the consequent investment. The adopted investment is focused on solving a mid-term problem and not increasing the dike performance, the chosen design improves resistance while allowing larger amounts of overtopping. In case dike performance needs to be upgraded somewhere in the long term, this investment has not any contribution to this ulterior upgrading, compared to the designs in which an overtopping reduction is achieved. For these designs, a part of the future investment would already be done, and possibly at a smaller net present value, so the total final cost would be doubly reduced. Therefore, if the amount of overtopping needs to be limited at some point, a design that reduces overtopping would be better under a long term approach, which involves an intergenerational perspective. In order to do a proper comparison, it is essential to know which is the applicable intergenerational policy, together with a study of the possible limits allowable for overtopping and funds availability along the considered period.

Finally, shifting into a very important topic for every team member; communication is one of the most important keys to satisfactory accomplish a multidisciplinary project, whereas it was a challenge for this group as well. Thus, an Organization Chart was set up to push forward work and allow us to reach this point with success.

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Appendix A

INTERMEDIATE DESIGN DRAWINGS

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APPENDIX A – INTERMEDIATE DESIGN DRAWINGS

Drawings of the proposed alternatives are included in in this Appendix.

The drawing's numbers are in correlation with the numbers used for each design within the report.

Concrete or antifer cubes drawings are not included as it was ruled out during calculation processes.

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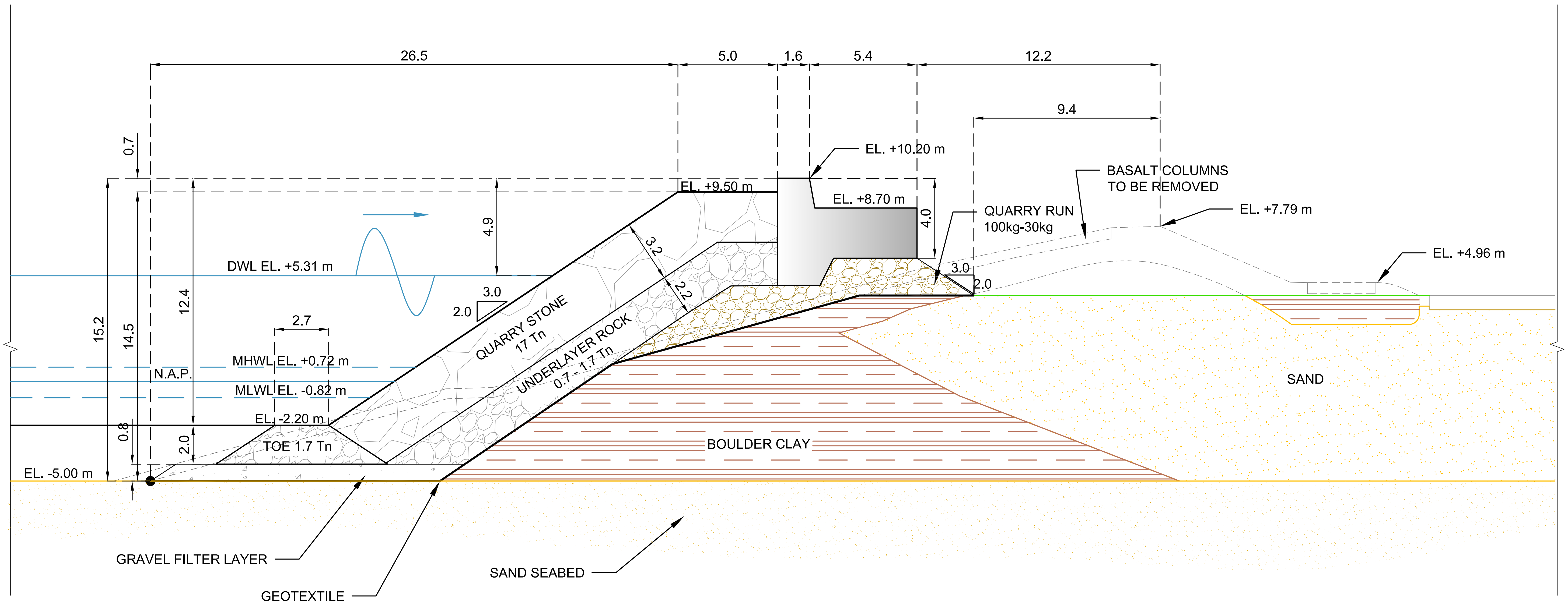
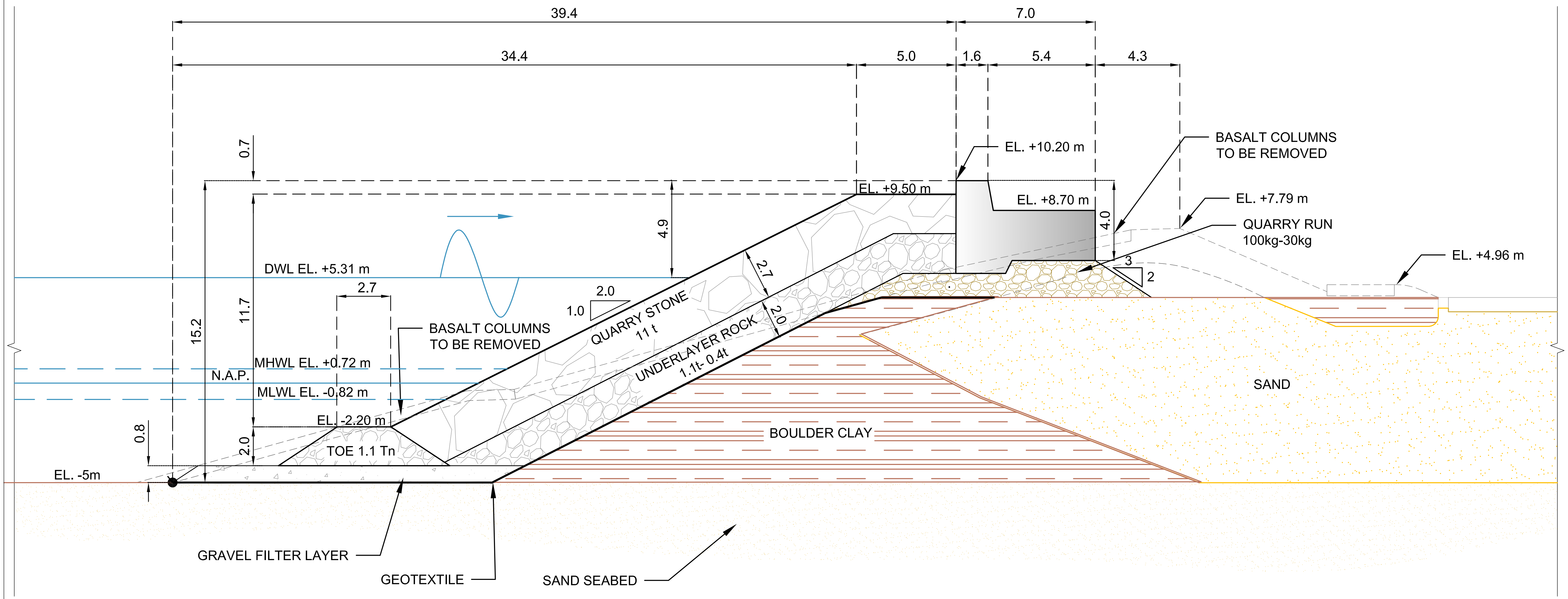
AFSLUITDIJK- CROSS SECTION 10
RIPRAP WITHOUT BERM- ALTERNATIVE I
SCALE 1:200



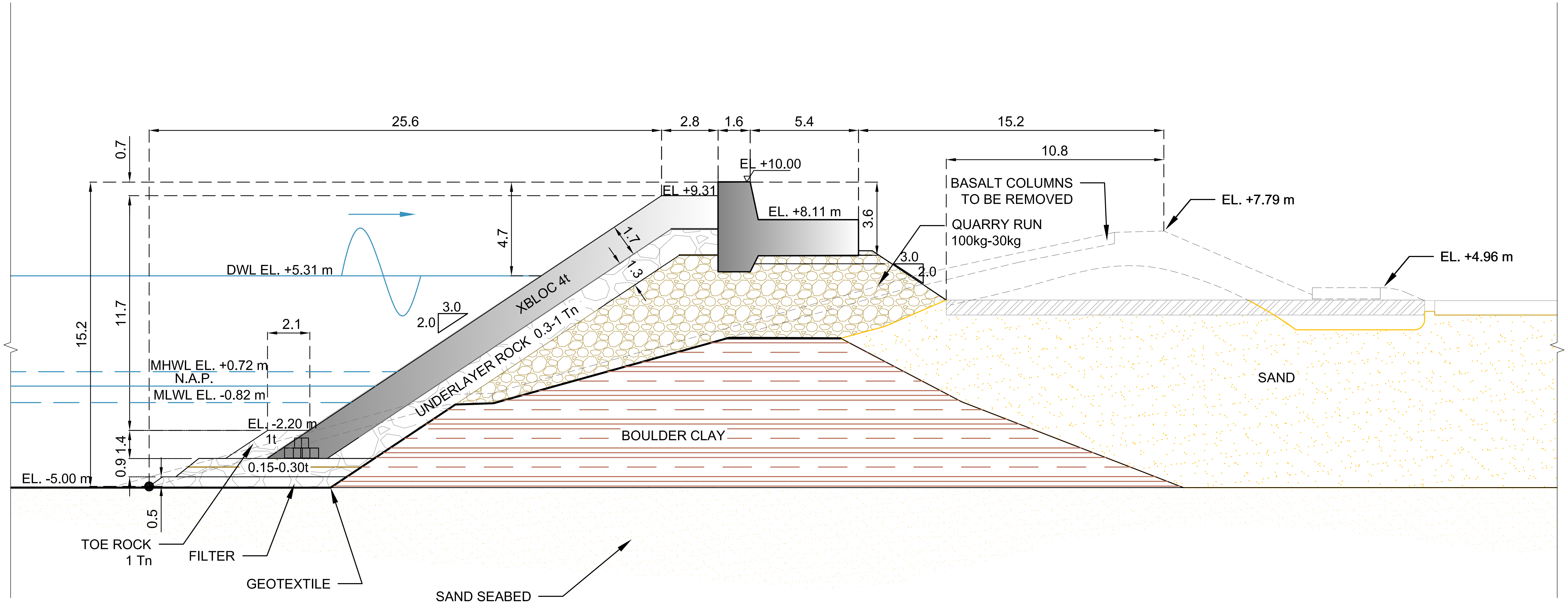
MATERIAL VOLUMES (M³) AND TONS PER METER OF BREAKWATER												
QUARRY STONE W50=17 Tn D50=1.85 M		UNDERLAYER ROCK 0.7-1.7 Tn		GRAVEL FILTER		TOE 1.7 Tn		QUARRY RUN		CONCRETE (CROWN WALL)		EXCAVATION
82 m³	156 Tn	47 m³	84.6 Tn	12.4 m³	23.80 Tn	12 m³	23,11 Tn	35.6 m³	68.7 Tn	25.1 m³	60.24 Tn	120 m³

AFSLUITDIJK- CROSS SECTION 10
RIPRAP WITHOUT BERM- ALTERNATIVE II (slope 1:2)
SCALE 1:200



MATERIAL VOLUMES (M³) AND TONS PER METER OF BREAKWATER												
QUARRY STONE W50=11 Tn D50=1.85 M		UNDERLAYER ROCK 0.4-1.1 Tn		GRAVEL FILTER		TOE 1.1 Tn		QUARRY RUN		CONCRETE (CROWN WALL)		EXCAVATION
85 m³	161.5 Tn	55.5 m³	105.5Tn	13.7 m³	26.9 Tn	12 m³	23,11 Tn³	29.8 m³	56.52 Tn	24.7 m³	59.3 Tn	136 m³

AFSLUITDIJK- CROSS SECTION 10
XBLOC® - ALTERNATIVE I (slope 2:3)
SCALE 1:200

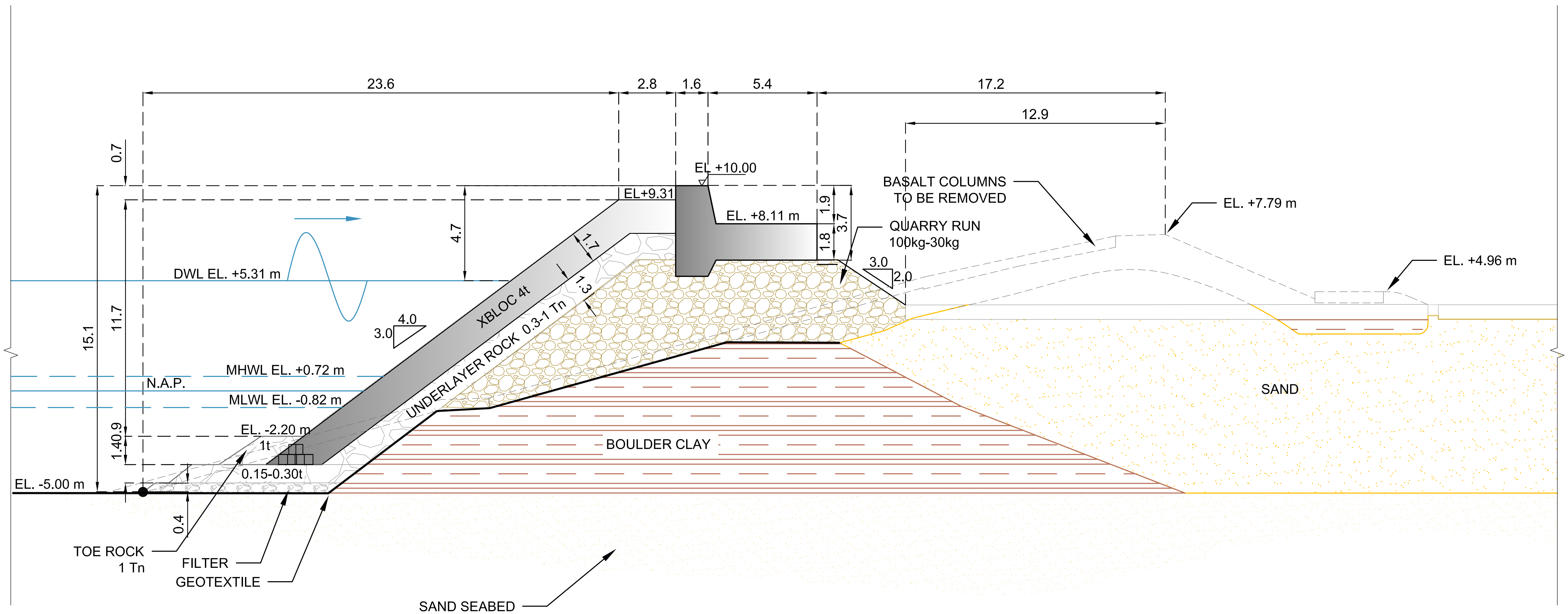


MATERIAL VOLUMES (M³) AND TONS PER METER OF BREAKWATER												
XBLOC 4t		UNDERLAYER ROCK 0.3-1t		GRAVEL FILTER		TOE 1 Tn		QUARRY RUN		CONCRETE (CROWN WALL)		EXCAVATION
40.3 m2	19 un	27.7 m³	54.3 Tn	5.67 m³	10.9Tn	2.94 m³	5.67 Tn	72.23 m³	130 Tn	17.23 m³	41.3Tn	122.56 m³

AFSLUITDIJK- CROSS SECTION 10

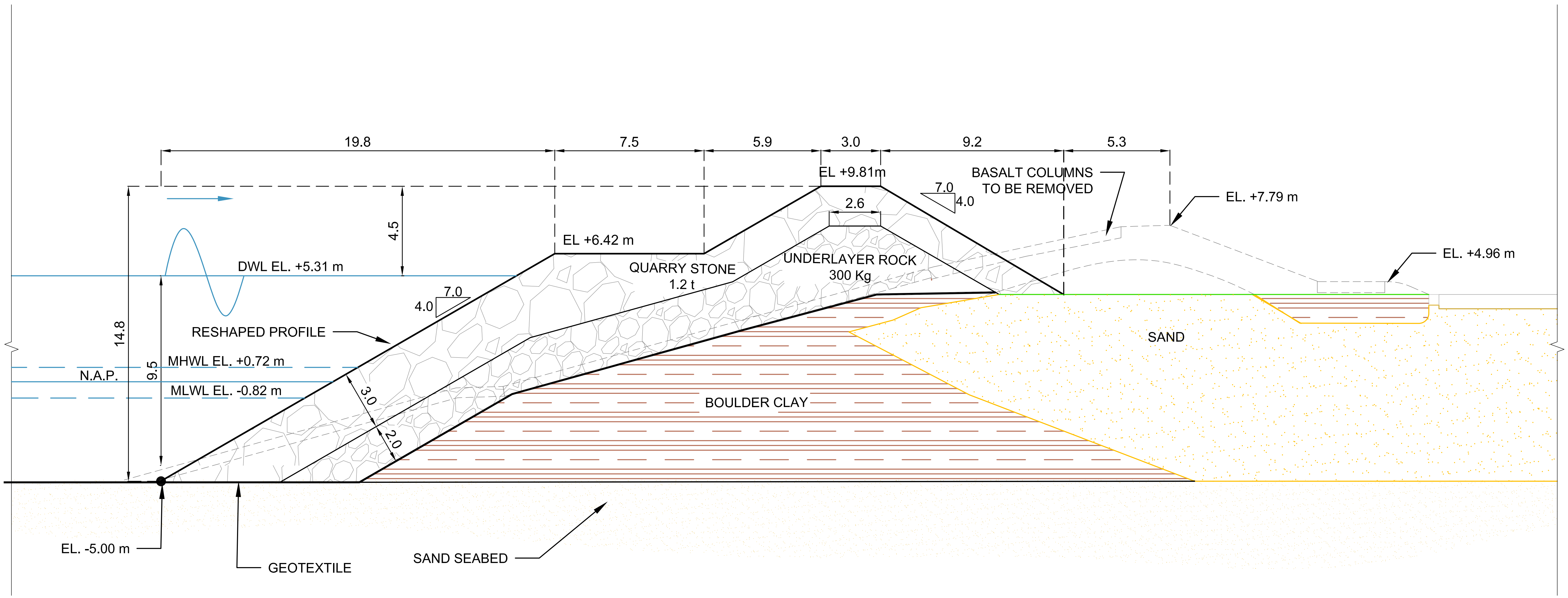
XBLOC® - ALTERNATIVE II (slope 3:4)

SCALE 1:200



MATERIAL VOLUMES (M³) AND TONS PER METER OF BREAKWATER												
XBLOC 4t		UNDERLAYER ROCK 0.3-1t		GRAVEL FILTER		TOE 1 Tn		QUARRY RUN		CONCRETE (CROWN WALL)		EXCAVATION
38.16 m2	18 un	26.06m³	46.91 Tn	5.67m³	10.9Tn	2.94 m³	5.67 Tn	75.35 m³	135.54Tn	17.23 m³	41.3Tn	127.91 m³

AFSLUITDIJK- CROSS SECTION 10
BERMBREAKWATER, DYNAMICALLY STABLE RESHAPED- ALTERNATIVE (Initial slope 4:7)
SCALE 1:200

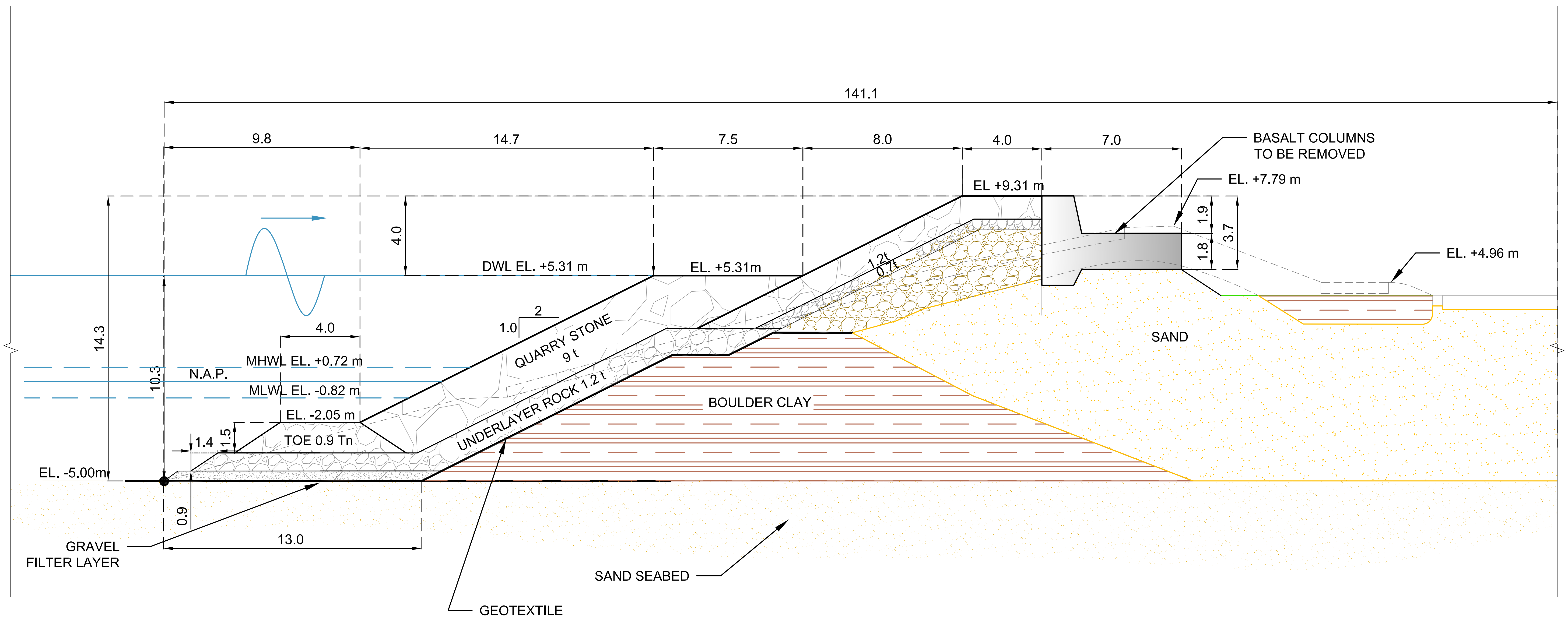


MATERIAL VOLUMES (M³) AND TONS PER METER OF BREAKWATER												
QUARRY STONE W50=1.2Tn D50=0.75M		UNDERLAYER ROCK 300kg		GRAVEL FILTER		TOE		QUARRY RUN		CONCRETE (CROWN WALL)		EXCAVATION
95 m³	182.1 Tn	121 m³	218.2 Tn									78.9 m³

AFSLUITDIJK- CROSS SECTION 10

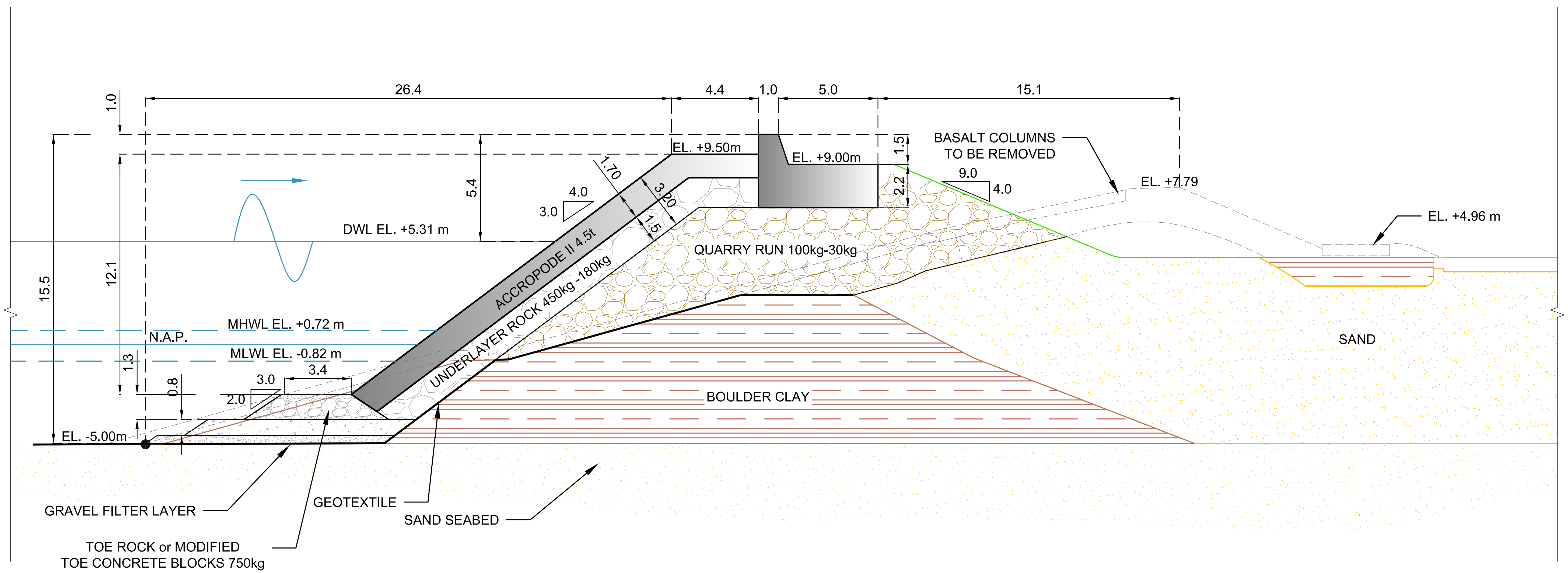
BREAKWATER WITH BERM - ALTERNATIVE (slope 1:2)

SCALE 1:200



MATERIAL VOLUMES (M^3) AND TONS PER METER OF BREAKWATER												
QUARRY STONE		UNDERLAYER ROCK		GRAVEL FILTER		TOE 0.9 Tn		QUARRY RUN		CONCRETE (CROWN WALL)		EXCAVATION
W50=9Tn D50=1.56M	W50=1.2Tn D50=0.75M	W50=1.2Tn D50=0.75M	W50=0.7Tn D50=0.36M	9M^3	17.1 Tn	15 M^3	28.9 Tn	30.2 M^3	84.3 Tn	25.7 M^3	61.68 Tn	91.8 M^3
53 M^3	22 M^3	23 M^3	9 M^3									
100 Tn	42 Tn	43 Tn	16 Tn									

AFSLUITDIJK- CROSS SECTION 10
ACCROPODES™ II - ALTERNATIVE I (slope 3:4)
SCALE 1:200

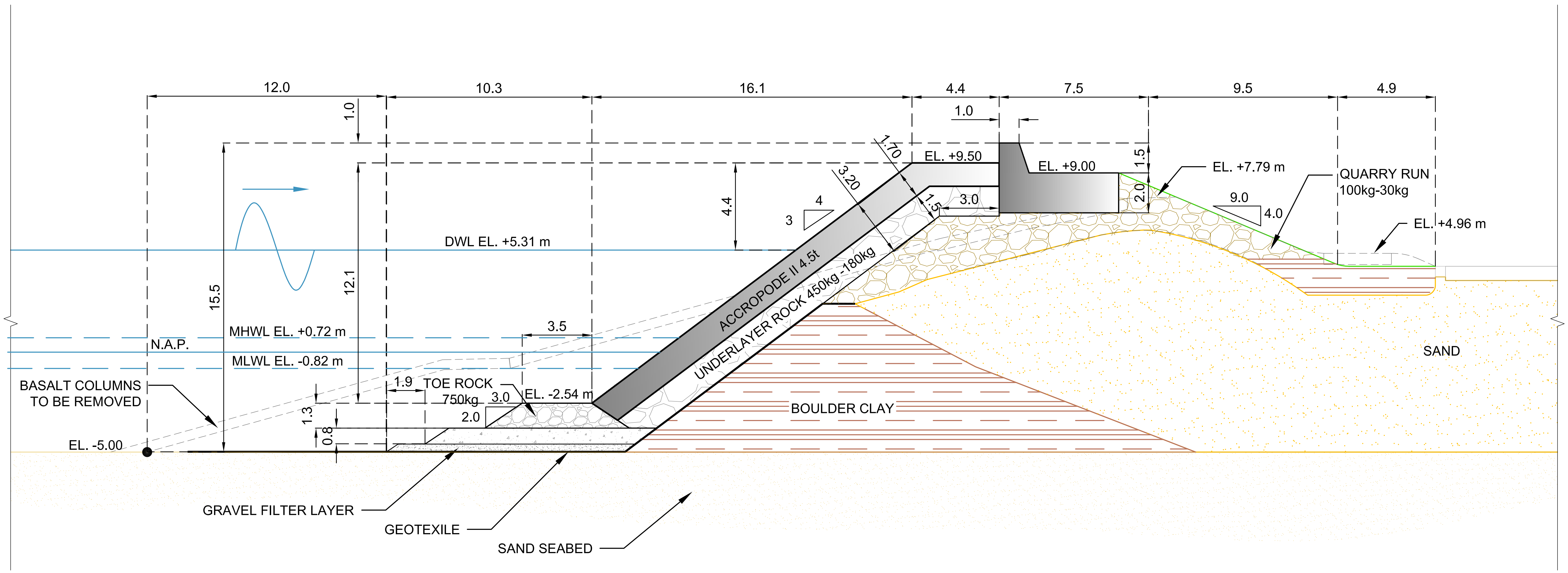


MATERIAL VOLUMES (M³) AND TONS PER METER OF BREAKWATER												
ACCROPODES II 3.0t		UNDERLAYER ROCK 300kg		GRAVEL FILTER		TOE		QUARRY RUN		CONCRETE (CROWN WALL)		EXCAVATION
28 m2	15 un	40 m³	77.2 Tn	7 m³	13.51 Tn	6.65 m³	12.8 Tn	100.1 m³	193 Tn	13.9 m³	33.6 Tn	108.4 m³

AFSLUITDIJK- CROSS SECTION 10

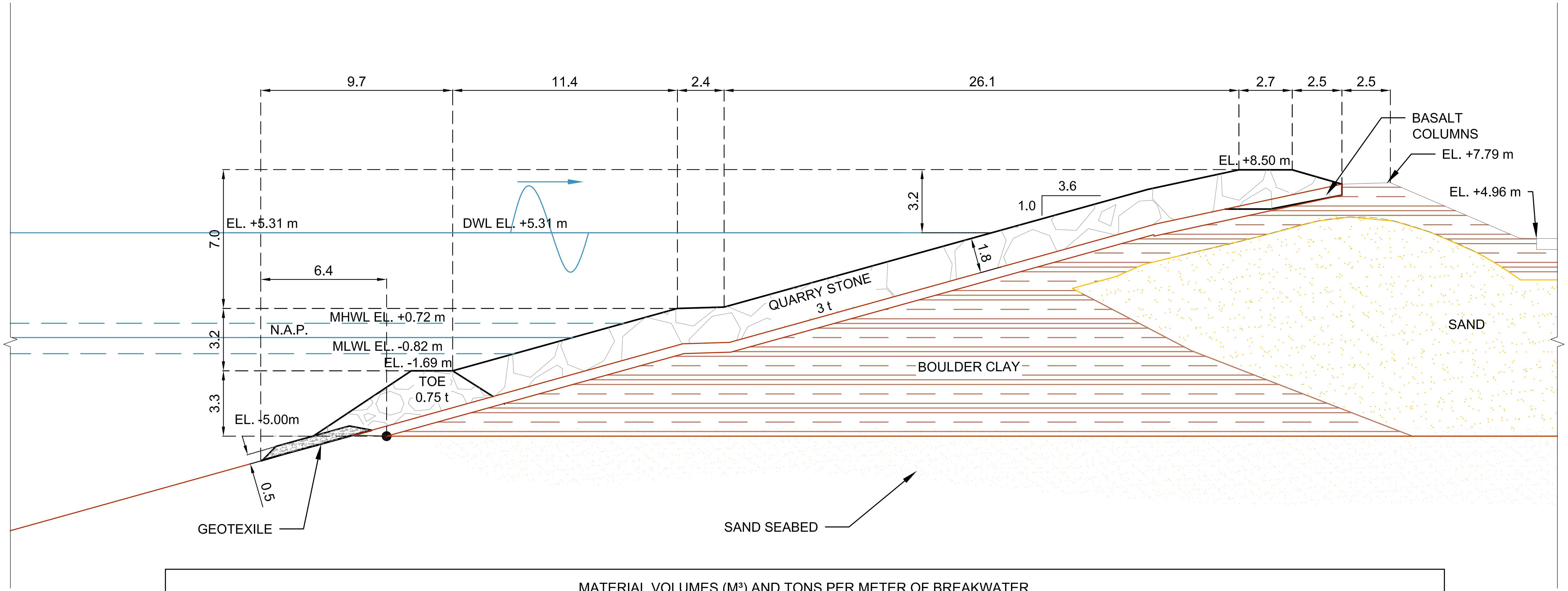
ACCROPODES™ II - ALTERNATIVE II (slope 3:4)

SCALE 1:200



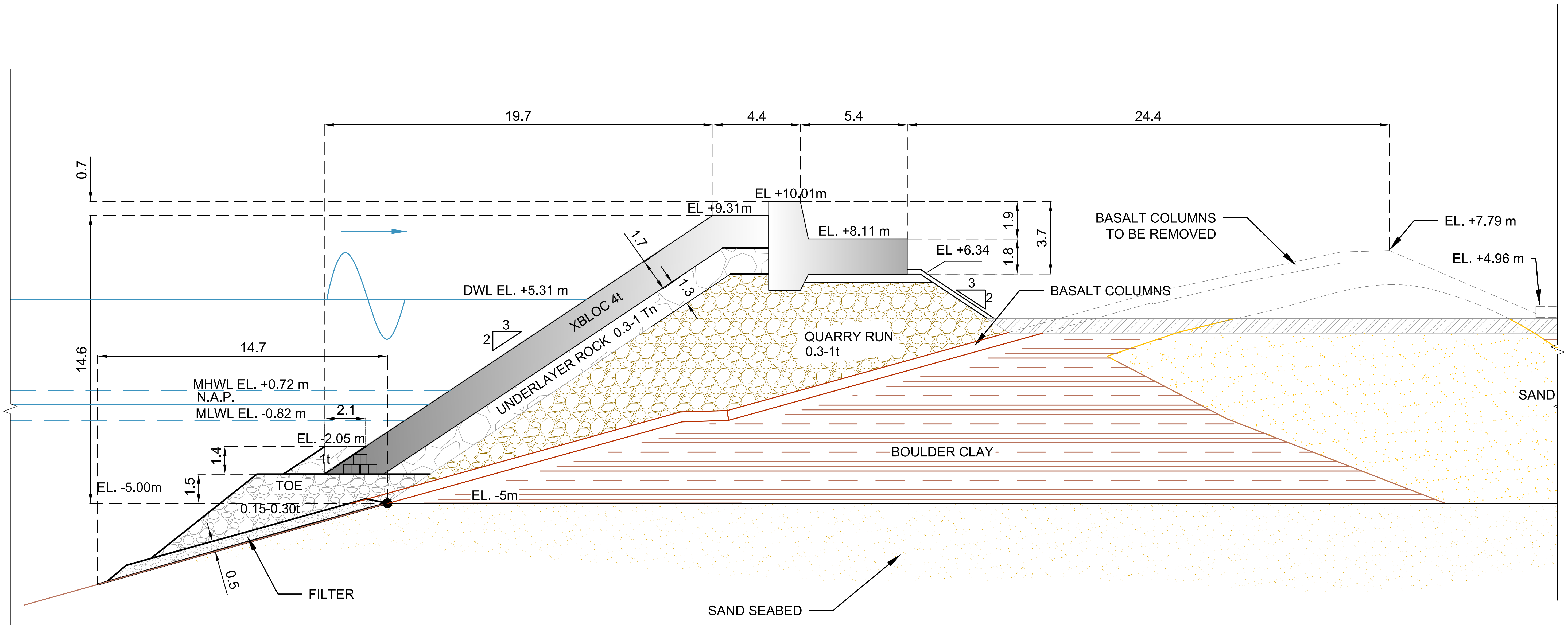
MATERIAL VOLUMES (M³) AND TONS PER METER OF BREAKWATER												
ACCROPODES II 4.5t		UNDERLAYER ROCK 300kg		GRAVEL FILTER		TOE		QUARRY RUN		CONCRETE (CROWN WALL)		EXCAVATION
28 m2	15 un	40 m³	77.2 Tn	7 m³	13.51 Tn	6.65 m³	12.8 Tn	43.7 m³	84.3 Tn	13.9 m³	33.6 Tn	134.7 m³

AFSLUITDIJK- CROSS SECTION 10
RIPRAP INVADING WADDENZEE- ALTERNATIVE (slope 1:3.6)
SCALE 1:200



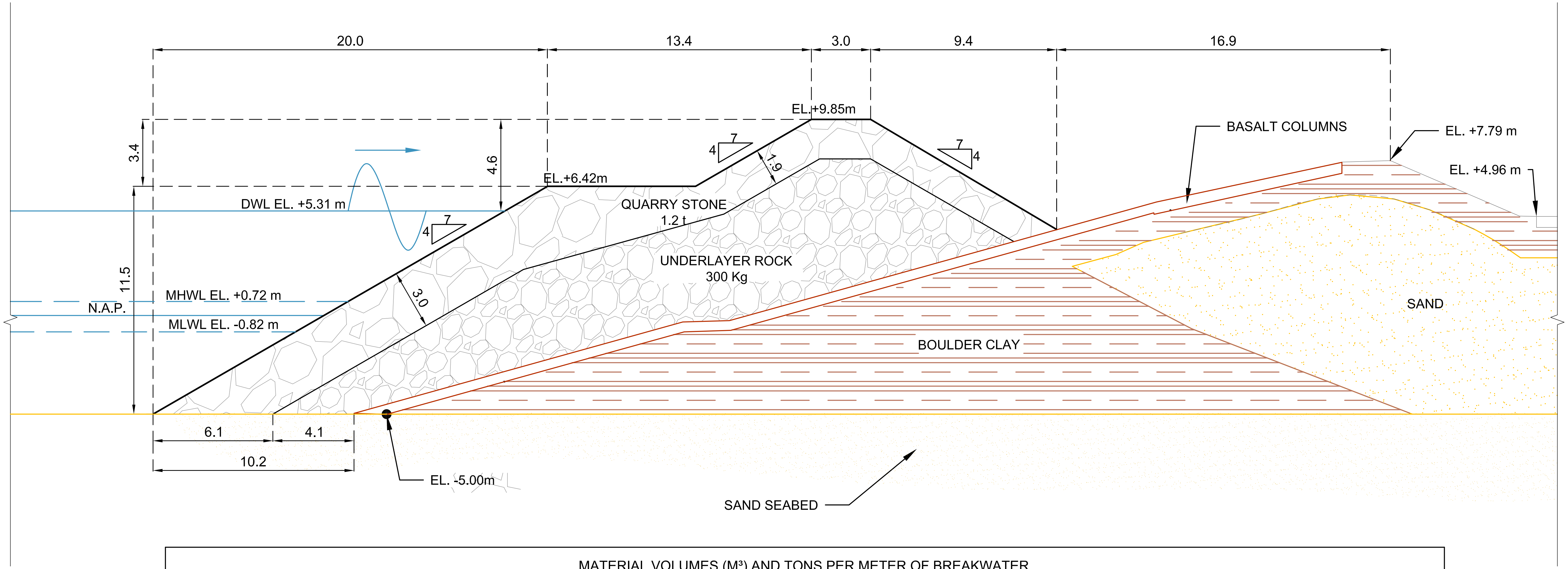
MATERIAL VOLUMES (M³) AND TONS PER METER OF BREAKWATER													
QUARRY STONE W50=3 Tn D50=1.05 m		UNDERLAYER ROCK		FILTER Protection 30 Kg		TOE		QUARRY RUN		CONCRETE (CROWN WALL)		EXCAVATION	
28 m2	15 un			2.36 m³	4.25 Tn	12.30m³	22.14 Tn						

AFSLUITDIJK- CROSS SECTION 10
XBLOC® INVADING WADDENZEE- ALTERNATIVE (slope 2:3)
SCALE 1:200



MATERIAL VOLUMES (M³) AND TONS PER METER OF BREAKWATER													
XBLOC 4t		UNDERLAYER ROCK		GRAVEL FILTER 150-300 Kg		TOE		QUARRY RUN		CONCRETE (CROWN WALL)		EXCAVATION
403 m2	19 un	27.70 m2	54.3 Tn	6.80 m³	12.24 Tn	12.30 m³	22.14 Tn	124.7 m³	223.87 Tn	17.23	41.3	

AFSLUITDIJK- CROSS SECTION 10
BERM BREAKWATER, DYNAMICALLY STABLE INVADING WADDENZEE- ALTERNATIVE I (Initial slope 4:7)
SCALE 1:200

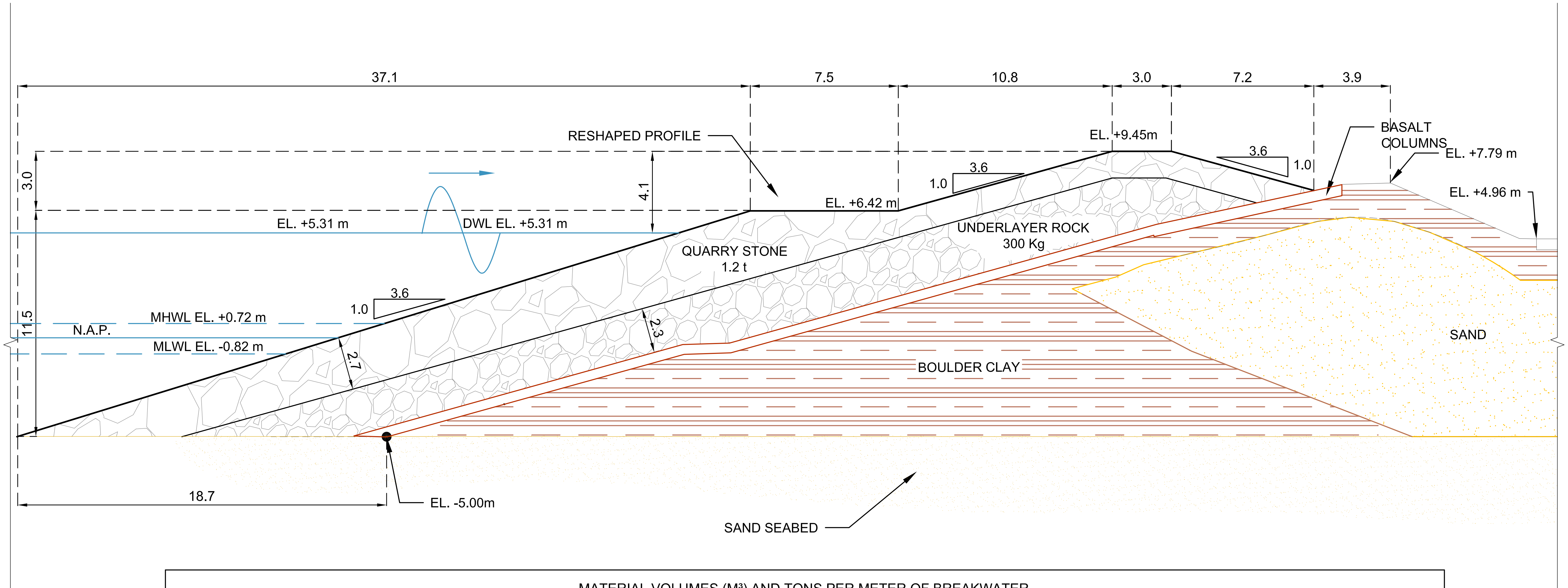


MATERIAL VOLUMES (M³) AND TONS PER METER OF BREAKWATER												
QUARRY STONE W50=1.2Tn D50=0.75M		UNDERLAYER ROCK 300kg		GRAVEL FILTER		TOE		QUARRY RUN		CONCRETE (CROWN WALL)		EXCAVATION
116 m³	222.72 Tn	156.27 m³	296.9 Tn									

AFSLUITDIJK- CROSS SECTION 10

BERM BREAKWATER, DYNAMICALLY STABLE INVADING WADDENZEE- ALTERNATIVE II (Initial slope 1:3.6)

SCALE 1:200



MATERIAL VOLUMES (M³) AND TONS PER METER OF BREAKWATER												
QUARRY STONE W50=1.2Tn D50=0.75M		UNDERLAYER ROCK 300kg		GRAVEL FILTER		TOE		QUARRY RUN		CONCRETE (CROWN WALL)		EXCAVATION
136 m³	262.4 Tn	136 m³	250.7 Tn									

Appendix B

FINAL DESIGN DRAWINGS

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APPENDIX B – FINAL DESIGN DRAWINGS

Drawings of both final proposed alternatives are included in in this Appendix.

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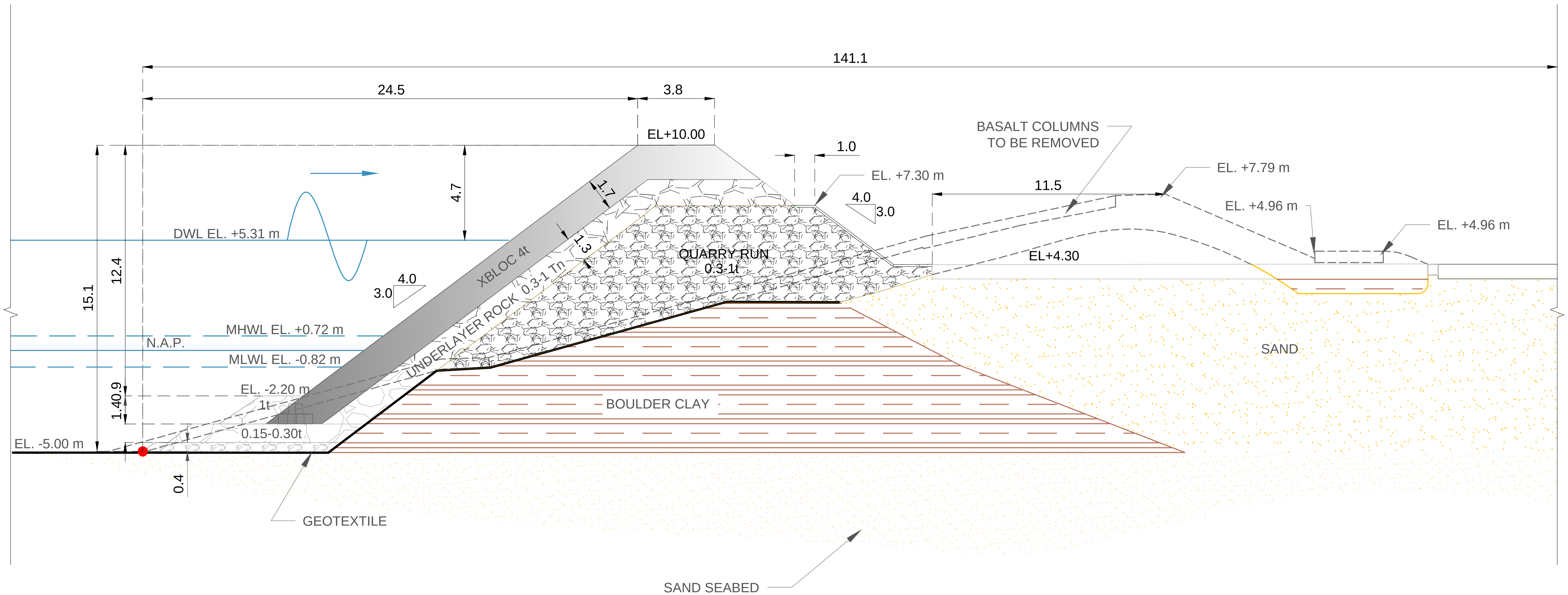
AFSLUITDIJK- CROSS SECTION 10
XBLOC® (slope 3:4)
SCALE 1:200

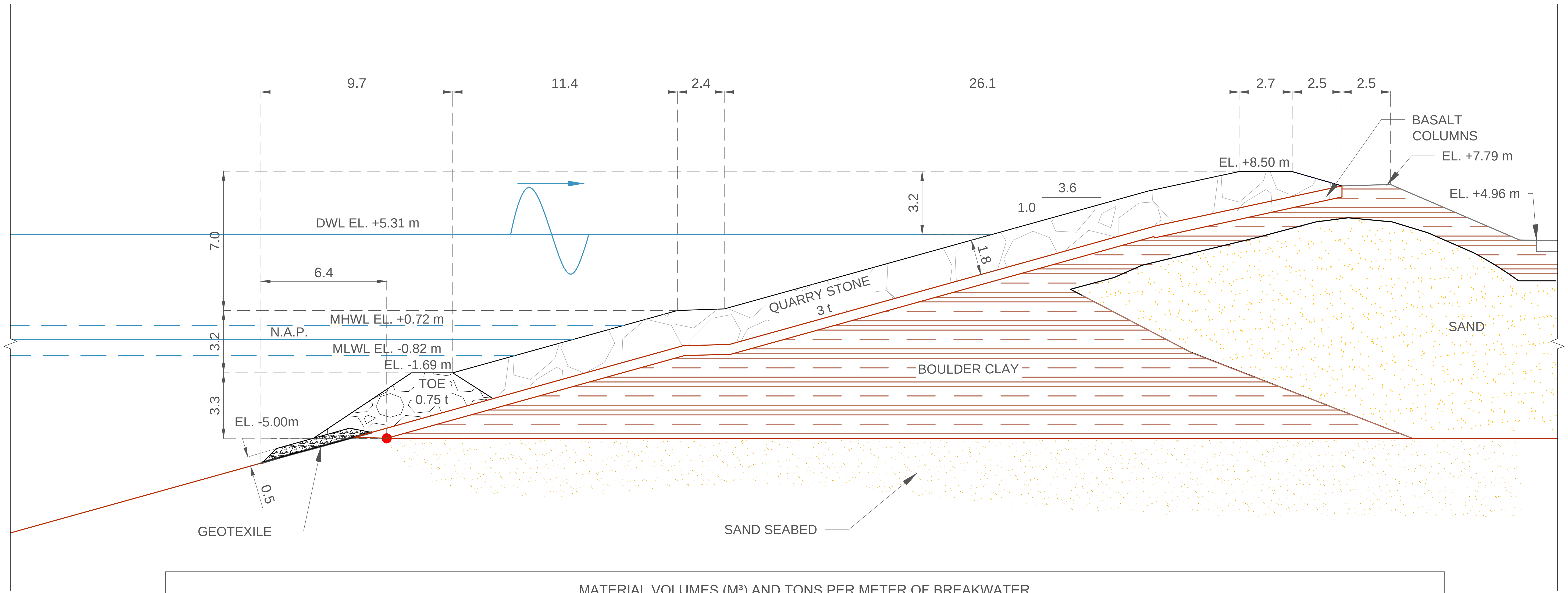


MATERIAL VOLUMES (M³) AND TONS PER METER OF BREAKWATER												
XBLOC 4t		UNDERLAYER 0.3-1t		GRAVEL FILTER 150-300 Kg		TOE		QUARRY RUN		CONCRETE (CROWN WALL)		EXCAVATION
43.84 m2	21 un	33.00 m2	59.4 Tn	5.67 m³	10.94 Tn	2.94 m³	5.67 Tn	86.87 m³	156.37 Tn	0 m³	0 Tn	121.91 m³

AFSLUITDIJK- CROSS SECTION 10

RIPRAP INVADING WADDENZEE (slope 1:3.6)

SCALE 1:200



MATERIAL VOLUMES (M³) AND TONS PER METER OF BREAKWATER												
QUARRY STONE W50=3 Tn D50=1.05 m		UNDERLAYER ROCK		FILTER Protection 30 Kg		TOE		QUARRY RUN		CONCRETE (CROWN WALL)		EXCAVATION
28 m2	15 un			2.36 m³	4.25 Tn	12.30m³	22.14 Tn					

Appendix C

SOURCE INFORMATION AND DATA COLLECTION

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APPENDIX C – SOURCE INFORMATION AND DATA COLLECTION

C.1 MEETING ON 18TH SEPTEMBER

Date: 18/09/2013

Place: Rijkswaterstaat

Participants:

- *Eric Regeling*
- *María José Ruiz Fuentes*
- *Yuting Li*
- *Carlos Miranda*
- *Pablo Arecco*

Content:

1. Introduction by the client

- History of the Enclosure Dam
- “South Sea- Project” development: improved flood protection; improved water management; ensure constant water level discharging sluices; improved road connections; gained space for new cities and villages.
- Design aspects of the dam: location and direction; reduction of tidal range; bottom profile and soil characteristics.
- As the enclosure dam is 80 years old, the dam and sluices do not meet strict safety standard, it should be prepared for future effects of climate change. Thus, a reconstruction plan was carried out to increase the safety of the dam and sluice, also the discharge capacity of outflow water.
- Additional goals are set to achieve the multifunctional use, like stimulating innovations, stimulating of recreation and tourism and of regional development, maximizing multifunctional use of the dam, and including pilots for the generation of sustainable energy.

2 Topics

- Do the roads/bike lane need to be operational the whole time while working on the upgrading?
  According to the client, part of the lane can be closed during the construction.

- Space for building a concrete plant close to the site?
  Yes, there is some space available for the plant.

- Do they have other use for the basalton?

- The existing basalt columns armour layer is removed and new layers are placed on top of the boulder clay core which should be reshaped and protected. In addition as these basalt columns are kind of unique in Europe, it is assumed and recommended to reuse them or to place them into the market.

- Any other restrictions?
  For RWS, the amount of traffic (existing and predicted) is too small to consider an increase of capacity of the road. For this project, they are considering a scope of 40 years.

3 Information needed from RWS

- Auto CAD files of Afsluitdijk section 8 and 10, and a general layout with the bathymetry (if possible);
- The wave climate at location of section 8 and 10;
- The digital copy of your presentation last meeting;
- Rijwaterstaat official list of prices, mainly for rock coat (EUR/ton), landfill/excavation equipment from landside and waterside (EUR/m3), and land transportation prices for soil and rock, reinforced concrete, pavement and subgrade construction.

C.2 MEETING ON 8TH NOVEMBER

Date: 08/11/2013

Place: Rijkswaterstaat

Participants:

- *Eric Regeling*
- *María José Ruiz Fuentes*
- *Yuting Li*
- *Carlos Miranda*
- *Pablo Arecco*

Content:

1 Introduction

Introduction of work the group have done in the past months.

2 Multi Criteria Analysis & Weighing

Explanation on how the group set the multi criteria analysis and decide weighing factors.

3 Alternatives Review & Scoring

Explanation on how the group score all the alternatives.

4 Selection of Final Alternatives

Consider which are the main interests for RWS, also taking into account ongoing studies in order to give valuable information for them.

5 Explain Final Design Report

Explanation about design details, selected cross section optimization (earth moving balance, crown wall, geotextile, terrain uses, WwN measures, construction methods and recommendations –i.e. underwater surveys, dike/mattresses samples-) and Cost analysis balanced with MCA.

6 Topics

- Explain assumptions for the reference point and sea bed elevation. According to Eric, the area close to the study cross section has a depth of about 10m, the average is 5m.
- Scour protection (Geotextile): can it be placed on the Waddenzee area although it is supposed to remain untouched? We can study options where there is some occupation of the Waddenzee area.
- RWS preference: land availability is one of the main drivers? It is not that important for them, they consider the capacity of the road is enough for the forecast they have for the lifetime of the project. Anyway, they see it as an advantage and suggest to think of ways to use the new land that we get in some solutions.
- Do they prefer to save materials and use it in the same cross section with earth moving balance? Or they would consider the possibility of elevating the dike platform in several phases for the long term future? They have doubts the quality of the boulder clay is going to be sufficient to build the new parts of the dike.
- List of prices: stones, concrete, excavation, dredging on sand, bituminous pavement. They will send it in a mail with the rest of information.
- Toe design: The existing matresses are damaged. It is possible to keep them in place so they help with filter function, for example. But probably a new filter has to be placed in certain areas.
- Keep two alternatives of berm breakwater at least: cutting the existing slope and keeping the slope untouched.
- Avoid crown wall if possible, study this option for the final design. Make a proposal for the uses of the new space that some alternatives provide. Also check if there is space for a bike lane to be placed.
- The actual project RWS is developing keeps the same dike profile. There is no heightening considered, they want to improve just the dike overtopping resistance. This overtopping profile RWS is studying should be included in the final multi criteria analysis, together with the final alternatives. (Blue energy is not a factor that affects the project and has to be removed.)
- Study in deep designs for long term, say 100 years. The overall stability has to be calculated for the two final alternatives, including both inner and outer slopes.

- Study two different options in the end: X-bloc and rock designs. Also check size of X-blocs and see if it is possible to reduce its size in the underwater area

7 Intermediate Report Modification

- Including following alternatives in the final report: overlayer; invading Waddenzee with: Xbloc, berm, rip-rap (slope 1:3).
- Study crown wall removal and replacement with rip rap or concrete units, and make cost estimation for final report.
- Add text explaining why we take -5m (mean water depth is 4-5m) as reference, as water depth differs from -2m to -15m.
- Clarify that existing mattress is of low quality. To reuse them, invading the Waddenzee is necessary.
- Clarify that all proposals are focused on strengthening the dike for the year 2100, we are thinking of more robust, long-term solutions.
- Take out blue energy from multi-criteria analysis.
- Check settlements of the profile due to added filling material (or crown wall).
- Check geotechnical stability of armour layer and inner slope.
- Check homogeneous structure for each alternative .

C.3 E-MAILING WITH THE CLIENT

1 Selection of Representative Cross Section

The group received a detailed survey of 21 cross sections of the existing Afsluitdijk from the client. To achieve a well-developed design, it is advisable to focus on only one and thus to choose a representative cross section. Cross section 10a is chosen for later calculations in this report. The choosing process could be explained as follows in Table 17

- The dike dividing in different stretches was analyzed, according to the significant wave height, in order to find the representative location for the data input, keeping in mind the future cost analysis.
- Analyzed the most representative section related to its length. Thus, some thresholds for Hs was established: Hs<3.00m; 3.00m<Hs<3.50m; 3.50m<Hs< 4.00m; Hs>4.00m.
- Associated the total length for each Hs range, the longest stretch of the dike is influenced by the range 3.50m<Hs<4.00m
- Used the maximum given Hs within the resulting range, leading to the chosen location 10a.

Table C- 1. Distance Between Sections

CROSS SECTION	Significant Wave Height	Distance Between Sections(m)
1	-	
2	-	
3	-	
4	2.57	
5	2.77	493.52
6a	3.08	1974.28
6b	3.23	2466.39
7	3.25	739.62
8a	3.74	3409.61
8b	4.06	3808.11
9	3.75	670.86
10a	3.83	2187.98
10b	3.67	1964.64
11a	3.57	1984.37
11b	3	2475.85
12	3.3	2197.51
13	3.17	230.85
14	2.93	228.71
15	2.81	228.48
16	2.96	952.81
17	3.2	497.14

Table C- 2. Total Length Each Stretch

Stretches Hs	Total Length Each Stretch(m)
>4m	3808.11
4m-3.5m	10217.46
3.5m-3m	8105.79
<3m	4379.37

2 Selection of Significant Wave Height Hs

This design is supposed to be made for the year 2050, however, on the excel sheet "Dijkvakken_ontwerprvw_Waddenzeezijde_T10000" which is given by the client, there are several values (overtopping, concrete blocks, general stability, etc.). The client helped the group with how to select the appropriate values for different calculations.

- Use the "Golfklappen betonblokken- info" for calculations of concrete blocks and rip-rap units (as long as it concerns the computations concerning the "failure mechanism of stability" of such elements).
- For the calculation of crest height, overtopping is the main failure mechanism. Thus, for this design all the "golfoverslag" values should be taken into account.
- In summary, for overtopping and crest height computations, another set of water level and wave data should be used, than for computation of stability of concrete blocks and rip-rap.

C.4 SITE VISIT

STOP 1

The first stop was 1 km from Den Oever, just crossing over Stevin Sluizen as it can be seen on Figure C- 1.

Figure C- 1. Stop 1 Location

The inner slope was surveyed, identifying the basalt columns displayed as armour layer, in addition the transition between those and the grass was analysed, as it is shown in Figure C- 2. Afsluitdijk inner slope and Stevin Sluizen

.

Figure C- 2. Afsluitdijk inner slope and Stevin Sluizen

STOP 2

The second stop was in a non-typical dike cross section, where a third lane is designed for recreational purposes, details and aerial view is shown in Figure C- 3.

Figure C- 3. Afsluitdijk stopover and recreational third lane

STOP 3

The third stop was where the dam closure was done in 1933, the existence of a pedestrian bridge allowed an inspection of the Afsluitdijk's outer slope too, furthermore an observer's point located at the top of a tower gives an excellent overview of the dike, as it is shown in Figure C- 4, Figure C- 5 and Figure C- 6.

Figure C- 4. Visitor centre and views of the dike to Friesland direction

Figure C- 5. Pedestrian bridge and views of the dike to Noord Holland direction

More images including some particular details can be appreciated in Figure C- 6.

Figure C- 6. Afsluitdijk outer slope and basalt columns details

STOP 4

The last stop of the field trip was almost at the end of the Afsluitdijk, reaching Friesland in order to take a closer view of the Kornwerderzand complex, the swing bridges (in Figure C- 7, Figure C- 8, **Figure C- 9**,

Figure C- 10 and Figure C- 11).

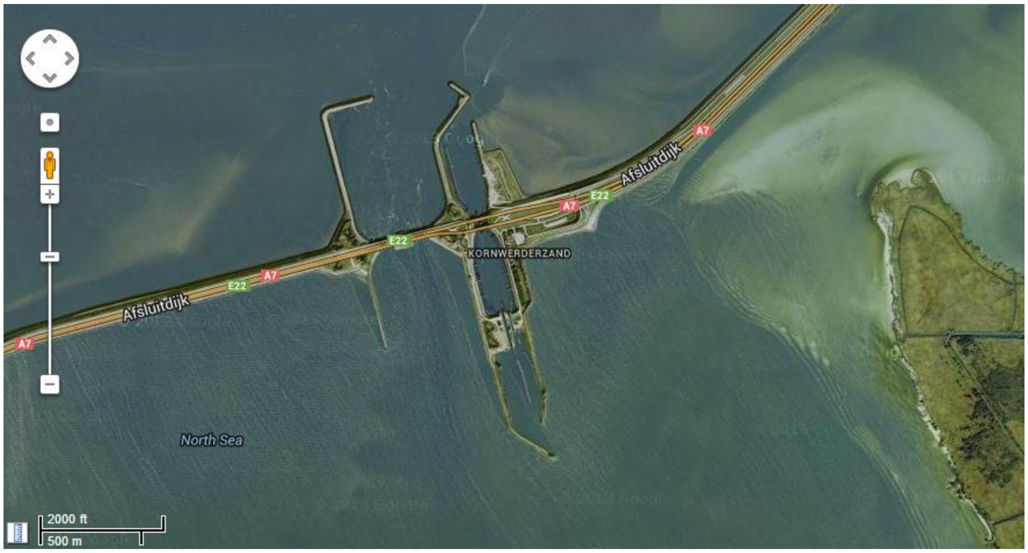

Figure C- 7. Kornwerderzand aerial view

The importance of this complex is remarkable because, with the Van Oeder lock complex, these are the only two connections between the North Sea and the Ijsselmeer. Also in the past its strategic position was noticed from the beginning, thing that can be easily recognized nowadays at the Kazematenmuseum.

Figure C- 8. Kornwerderzand swing bridge on the A7 highway

Figure C- 9. Lorenz sluizen

Figure C- 10. Lorenz Sluizen complex - Double set of lifting gates

Figure C- 11. Lorenz Sluizen complex - Lifting gates

Figure C- 12. Project team members

From leftt to right: Carlos Miranda Eguez, Yuting Li, María José Ruiz Fuentes and Pablo Arecco

Appendix D

MULTI CRITERIA ANYALYSIS

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APPENDIX D – MULTI-CRITERIA ANALYSIS

In this appendix, how the multi criteria analysis is carried by the group are described in detail, including how the group weighed the factors and scored the different cross sections in both intermediate and final design. Also, the client helped the MCA process, the results are also shown here.

Table D- 1. Weighing Factors

TECHNICAL FACTORS	A	1	Protection from waves (i.e. wave number)
	B	2	Construction Process (duration; phasing; required area & equipment; et cetera)
	C	3	Flexibility future upgrading
OPERATIONAL FACTORS	D	4	Resilience (i.e. dike width; H_s for N_{od} = failure, et cetera)
	E	5	Land availability (possible future road & road safety improvements; new bike lanes; additional service lane; et cetera)
ENVIRONMENT	F	6	Incursion in protected area Waddenzee (from identified outer limit)
	G	7	Pollution during construction (currents/sedimentology; water turbidity; CO_2 emissions; noise, light and soil pollution; excavation volumes; et cetera)
	H	8	Landscape
	I	9	PIANC Working with Nature philosophy
MAINTENANCE	J	10	Frequency of maintenance and monitoring
	K	11	Accessibility for inspection of armour layer
	L	12	Accessibility for maintenance tasks (toe; berm; rolling surface for cranes; et cetera)
THIRD PARTIES	M	13	Recreation (available area for sightseeing; bike lane; sports; fishing, societal activities inclusion, et cetera)
	N	14	Social considerations (Dutch pride; economy boost; et cetera)

D.1 WEIGHING JUSTIFICATION

D.1.1 WEIGHING JUSTIFICATION FROM MARÍA JOSÉ

Table D- 2. Weighing Justification from Maria Jose

CRITERIA	1	2	3	4	5	6	7	8	9	10	11	12	13	14	RELATIVE WEIGHT (%)
A		1	1	1	1	1	1	1	1	1	1	1	1	1	14,29%
B	0		0	0	1	0	0	1	0	1	1	1	1	0	6,59%
C	0	1		1	1	0	1	1	1	1	1	1	1	1	12,09%
D	0	1	0		0	0	0	1	0	1	1	1	0	1	6,59%
E	0	0	0	1		0	0	1	0	1	1	1	1	0	6,59%
F	0	1	1	1	1		1	1	1	1	1	1	1	1	13,19%
G	0	1	0	1	1	0		1	0	1	1	0	1	0	7,69%
H	0	0	0	0	0	0	0		0	0	1	0	1	0	2,20%
I	0	1	0	1	1	0	1	1		0	1	0	1	0	7,69%
J	0	0	0	0	0	0	0	1	1		1	0	1	0	4,40%
K	0	0	0	0	0	0	0	0	0	0		0	1	0	1,10%
L	0	0	0	0	0	0	1	1	1	1	1		1	1	7,69%
M	0	0	0	1	0	0	0	0	0	0	0	0		0	1,10%
N	0	1	0	0	1	0	1	1	1	1	1	0	1		8,79%
														TOTAL	100

PROTECTION FROM WAVES VS.

Protection from waves is the main objective. This has to be fulfilled in any case and other requirements might be changed so they allow the required protection from waves:

Table D- 3. Protection form Waves VS. Other Factors

Criteria	Weighing
Construction Process	1
Flexibility future upgrading	1
Resilience	1
Land availability	1
Incursion in protected area Waddenzee	1
Pollution during construction	1
Landscape	1
PIANC Working with Nature philosophy	1
Frequency of maintenance and monitoring	1
Accessibility for inspection of armour layer	1
Accessibility for maintenance tasks	1
Recreation	1
Social considerations (also Dutch pride, economy boost)	1

CONSTRUCTION PROCESS VS.

Construction process will be modified to satisfy other criteria if the benefits of doing it are bigger than keeping the original construction process.

Table D- 4. Construction Process VS. other Factors

Criteria	Weighing
Protection from waves	0
Flexibility future upgrading	0
Resilience	0
Land availability	1
Incursion in protected area Waddenzee	0
Pollution during construction	0
Landscape	1
PIANC Working with Nature philosophy	0
Frequency of maintenance and monitoring	1
Accessibility for inspection of armour layer	1
Accessibility for maintenance tasks	1

Recreation	1
Social considerations (also Dutch pride, economy boost)	0

- Flexibility future upgrading. Here, it is considered that facilitate future upgrading can save more money than changing equipment or construction procedures, once the works are ongoing.
- Resilience. High resilience means less maintenance costs in case of damage due to a storm, it could be worth changing construction process
- Land availability. It is an upgrading collateral benefit, it is not clear how much land is wanted or needed, so savings in the construction process can be worth reducing new land.
- Incursion in protected area Waddenzee. Not allowed.
- Pollution during construction. Construction process can be changed in order to avoid pollution.
- Landscape. As construction is a short phase, landscape does not influence the chosen methods.
- PIANC Working with Nature philosophy. Construction process can be modified to help.
- Frequency of maintenance and monitoring. Usually, the costs of construction will be larger than the costs of monitoring and maintenance, so it is worth to optimize the construction even if later the infrastructure needs more monitoring
- Accessibility for inspection of armour layer. Construction more important, accessibility is going to be more or less the same no matter what construction method is used.
- Accessibility for maintenance tasks. Same as for accessibility for inspection of armour layer.
- Recreation. Recreation is a secondary use that could be modified if there are important advantages for the construction process.
- Social considerations. Construction process needs to adapt to be accepted by society (environmentally friendly, labor rights…).

FLEXIBILITY FUTURE UPGRADING VS.

Flexibility can allow important savings in next upgrading.

Table D- 5. Flexibility Future Upgrading VS. other Factors

Criteria	Weighing
Protection from waves	0
Construction Process	1
Resilience	1
Land availability	1
Incursion in protected area Waddenzee	0
Pollution during construction	1
Landscape	1
PIANC Working with Nature philosophy	1

Frequency of maintenance and monitoring	1
Accessibility for inspection of armour layer	1
Accessibility for maintenance tasks	1
Recreation	1
Social considerations (also Dutch pride, economy boost)	1

- Resilience. High resilience means less maintenance costs in case of damage, but a flexible design can save more money.
- Land availability. This is a collateral benefit of the upgrading, it is not clear how much land is wanted or needed, so savings in the construction when upgrading can be worth reducing new land.
- Incursion in protected area Waddenzee. Not allowed.
- Pollution during construction. The control measures to take for having a lot of pollution will be probably cheaper compared with the savings allowed by a flexible design.
- Landscape. The advantages of flexibility can justify some design less favorable with respect to landscape, compensatory measures can be taken and will be cheaper.
- PIANC Working with Nature philosophy. It can be adapted to fulfill the flexibility requirements.
- Frequency of maintenance and monitoring. Usually, the costs of construction will be larger than the costs of monitoring and maintenance, so it is worth to optimize the construction (via upgrading) even if later the infrastructure needs more monitoring.
- Accessibility for inspection of armour layer. Construction more important, accessibility is going to be more or less the same no matter what construction method is used.
- Accessibility for maintenance tasks. The same as accessibility for inspection of armour layer.
- Recreation. Recreation is a secondary use that could be modified if there are important advantages for the construction of future upgrading.
- Social considerations. The disadvantages that flexibility could have (poor landscape quality, etc) can be understood by society (there will be compensation by the advantages).

RESILIENCE VS.

Resilience is a good quality that can provide extra safety and savings in maintenance tasks. But extra resilience is secondary and only allowed if there is no big modification in other criteria. The benefits of it are some savings in case of damage that can be small in the lifecycle of the structure.

Table D- 6. Resilience VS. Other Factors

Criteria	Weighing
Protection from waves	0
Construction Process	1
Flexibility future upgrading	0
Land availability	0

Incursion in protected area Waddenzee	0
Pollution during construction	0
Landscape	1
PIANC Working with Nature philosophy	0
Frequency of maintenance and monitoring	1
Accessibility for inspection of armour layer	1
Accessibility for maintenance tasks	1
Recreation	0
Social considerations (also Dutch pride, economy boost)	1

- Land availability. It is preferred to have more land available.
- Incursion in protected area Waddenzee. Not allowed.
- Pollution during construction. Extra resilience would not justify more pollution.
- Landscape. The advantages of resilience can justify some design less favorable with respect to landscape, compensatory measures can be taken and will be cheaper
- PIANC Working with Nature philosophy. There is no need to sacrifice an environmental friendly measures (which is an objective itself) to give more resilience.
- Frequency of maintenance and monitoring. Usually, the costs of repairing will be larger than the costs of monitoring and maintenance, so it is worth to have extra safety margins even if later the infrastructure needs more monitoring.
- Accessibility for inspection of armour layer. Resilience is more important, accessibility is going to be more or less the same no matter what construction method is used.
- Accessibility for maintenance tasks. The same as accessibility for inspection.
- Recreation. Recreation is a secondary objective but resilience will give only small advantage so the first one is considered more important
- Social considerations. The disadvantages that resilience could have (poor landscape quality, etc) can be understood by society (there will be compensation by the advantages)

LAND AVAILABILITY VS.

Land availability is a benefit but a secondary one, flood protection is more important.

Table D- 7. Land availability VS. Other Factors

Criteria	Weighing
Protection from waves	0
Construction Process	0
Flexibility future upgrading	0
Resilience	1
Incursion in protected area Waddenzee	0
Pollution during construction	0

Landscape	1
PIANC Working with Nature philosophy	1
Frequency of maintenance and monitoring	1
Accessibility for inspection of armour layer	1
Accessibility for maintenance tasks	1
Recreation	0
Social considerations (also Dutch pride, economy boost)	0

- Incursion in protected area Waddenzee. Not allowed.
- Pollution during construction. Extra land would not justify more pollution.
- Landscape. The advantages of having more land available can justify some design less favorable with respect to landscape, compensatory measures can be taken and will be cheaper.
- PIANC Working with Nature philosophy. There is no need to sacrifice environmental friendly measures (that is an objective by itself) to get more land.
- Frequency of maintenance and monitoring. Maintenance aspects are important but as the cost of monitoring the structure is going to be low compared with other aspects of the project, getting more land available is considered more important.
- Accessibility for inspection of armour layer. Few inspections, not so important, accessibility is going to be more or less the same no matter what construction method is used.
- Accessibility for maintenance tasks. The same as accessibility for inspection.
- Recreation. Recreation is a secondary objective and it is depending on land availability.
- Social considerations. Land availability will satisfy some social needs, so if society has other priorities (environmental protection, etc) they would be more important than getting extra land

INCURSION IN PROTECTED AREA WADDENZEE VS.

Table D- 8. Incursion in Protection Area Waddenzee VS. Other Factors

Criteria	Weighing
Protection from waves	0
Construction Process	1
Flexibility future upgrading	1
Resilience	1
Land availability	1
Pollution during construction	1
Landscape	1
PIANC Working with Nature philosophy	1
Frequency of maintenance and monitoring	1
Accessibility for inspection of armour layer	1
Accessibility for maintenance tasks	1

Recreation	1
Social considerations (also Dutch pride, economy boost)	1

POLLUTION DURING CONSTRUCTION VS.

Table D- 9. Pollution during Construction VS. other Factors

Criteria	Weighing
Protection from waves	0
Construction Process	1
Flexibility future upgrading	0
Resilience	1
Land availability	1
Pollution during construction	0
Landscape	1
PIANC Working with Nature philosophy	0
Frequency of maintenance and monitoring	1
Accessibility for inspection of armour layer	1
Accessibility for maintenance tasks	0
Recreation	1
Social considerations (also Dutch pride, economy boost)	0

It is an important factor, but control and compensating measures can be implemented if the price is worth the benefits for other aspects:

- Landscape. Compensating measures for landscape (trees, screens…) are preferred than a lot of pollution to be controlled.
- PIANC Working with Nature philosophy. The benefits for the project along the whole life of the structure can be larger than the cost of control measures for more pollution.
- Frequency of maintenance and monitoring. It will not be very expensive, does not justify more pollution.
- Accessibility for inspection of armour layer, It will not be very expensive, does not justify more pollution.
- Accessibility for maintenance tasks. Maintenance equipment can be expensive and generate itself more pollution, some control measures would be preferred in construction phase.
- Recreation. This is a secondary use, does not justify more pollution.
- Social considerations. Pollution control is determined by social exigencies so social considerations will go first.

LANDSCAPE VS.

Table D- 10. Landscape VS. other Factors

Criteria	Weighing
Protection from waves	0
Construction Process	0
Flexibility future upgrading	0
Resilience	0
Land availability	0
Incursion in protected area Waddenzee	0
Pollution during construction	0
PIANC Working with Nature philosophy	0
Frequency of maintenance and monitoring	0
Accessibility for inspection of armour layer	1
Accessibility for maintenance tasks	0
Recreation	1
Social considerations (also Dutch pride, economy boost)	0

It is an aspect that has to be taken care of. But compensation measures are relatively cheap and easy to take, unless there is an extraordinary affection to landscape.

- PIANC Working with Nature philosophy. This will help landscape and other aspects, it is considered to be more important.
- Frequency of maintenance and monitoring. Compensation measures would be preferred to have a low frequency of maintenance.
- Accessibility for inspection of armour layer. It is not very expensive, so does not justify changes in landscape.
- Accessibility for maintenance tasks. Maintenance equipment can be expensive, some compensation measures for landscape would be preferred.
- Recreation. This is a secondary use, and it is related to a good quality landscape, which would come first.
- Social considerations. They determine the requirements for landscape therefore are more important.

PIANC WORKING WITH NATURE PHILOSOPHY VS.

Table D- 11. PIANC Working with Nature Philosophy VS. Other Factors

Criteria	Weighing
Protection from waves	0
Construction Process	1
Flexibility future upgrading	0

Resilience	1
Land availability	1
Incursion in protected area Waddenzee	0
Pollution during construction	1
Landscape	1
Frequency of maintenance and monitoring	0
Accessibility for inspection of armour layer	1
Accessibility for maintenance tasks	0
Recreation	1
Social considerations (also Dutch pride, economy boost)	0

It is a plus, but secondary compared with main objectives and costs.

- Frequency of maintenance and monitoring. Compensation measures would be preferred to have a low frequency of maintenance.
- Accessibility for inspection of armour layer. It is not very expensive, does not justify changes.
- Accessibility for maintenance tasks. Maintenance equipment can be expensive, some adaptation in the environmental measures would be preferred.
- Recreation. This is a secondary use, and it is related to a good quality environment, which would come first.
- Social considerations. They determine the requirements for environmental action therefore are more important.

FREQUENCY OF MAINTENANCE AND MONITORING VS.

Table D- 12. Frequency of Maintenance and Monitoring VS. Other Factors

Criteria	Weighing
Protection from waves	0
Construction Process	0
Flexibility future upgrading	0
Resilience	0
Land availability	0
Incursion in protected area Waddenzee	0
Pollution during construction	0
Landscape	1
PIANC Working with Nature philosophy	1
Accessibility for inspection of armour layer	1
Accessibility for maintenance tasks	0
Recreation	1

Social considerations (also Dutch pride, economy boost)	0

Small cost compared to other parts of the project.

- Accessibility for inspection of armour layer. It is not very expensive, so it does not justify changes.
- Accessibility for maintenance tasks. Maintenance equipment can be expensive, some adaptation in the environmental measures would be preferred.
- Recreation. Recreation is a secondary use, can be modified to satisfy other requirements related to the main function.
- Social considerations. Even if it is expensive, it will be seen as a positive thing that the structure is being surveyed (essential for safety in the country). So social considerations would come first here.

ACCESSIBILITY FOR INSPECTION OF ARMOUR LAYER VS.

Table D- 13. Accessibility for Inspection of Armour Layer VS. Other Factors

Criteria	Weighing
Protection from waves	0
Construction Process	0
Flexibility future upgrading	0
Resilience	0
Land availability	0
Incursion in protected area Waddenzee	0
Pollution during construction	0
Landscape	0
PIANC Working with Nature philosophy	0
Frequency of maintenance and monitoring	0
Accessibility for maintenance tasks	0
Recreation	1
Social considerations (also Dutch pride, economy boost)	0

Small cost compared to other parts of the project.

- Accessibility for maintenance tasks. Maintenance equipment can be expensive compared to inspections.
- Recreation. Recreation is a secondary use, can be modified to satisfy other requirements related to the main function.
- Social considerations. Even if it is expensive, it will be seen as a positive thing that the structure is being surveyed (essential for safety in the country). So social considerations come first here.

ACCESSIBILITY FOR MAINTENANCE TASKS VS.

Table D- 14. Accessibility for Maintenance Tasks VS. Other Factors

Criteria	Weighing
Protection from waves	0
Construction Process	0
Flexibility future upgrading	0
Resilience	0
Land availability	0
Incursion in protected area Waddenzee	0
Pollution during construction	1
Landscape	1
PIANC Working with Nature philosophy	1
Frequency of maintenance and monitoring	1
Accessibility for inspection of armour layer	1
Recreation	1
Social considerations (also Dutch pride, economy boost)	1

It will determine the equipment that can be used.

- Recreation. Recreation is a secondary use, can be modified to satisfy other requirements related to the main function.
- Social considerations. The social aspects that could be involved here are of small importance (landscape quality, etc), it is considered more important to facilitate maintenance.

RECREATION VS.

It is a secondary benefit.

Table D- 15. Recreation VS. Other Factors

Criteria	Weighing
Protection from waves	0
Construction Process	0
Flexibility future upgrading	0
Resilience	1
Land availability	0
Incursion in protected area Waddenzee	0
Pollution during construction	0
Landscape	0
PIANC Working with Nature philosophy	0

Frequency of maintenance and monitoring	0
Accessibility for inspection of armour layer	0
Accessibility for maintenance tasks	0
Social considerations (also Dutch pride, economy boost)	0

SOCIAL CONSIDERATIONS VS.

It is a secondary benefit.

- Social considerations. Recreation is part of the social dimension of the project and will be subject to other social aspects.

Table D- 16. Social Consideration VS. other Factors

Criteria	Weighing
Protection from waves	0
Construction Process	1
Flexibility future upgrading	0
Resilience	0
Land availability	1
Incursion in protected area Waddenzee	0
Pollution during construction	1
Landscape	1
PIANC Working with Nature philosophy	1
Frequency of maintenance and monitoring	1
Accessibility for inspection of armour layer	1
Accessibility for maintenance tasks	0
Recreation	1

D.1.2 WEIGHING JUSTIFICATION FROM YUTING

Table D- 17. Weighing Justification from Yuting

CRITERIA	1	2	3	4	5	6	7	8	9	10	11	12	13	14	RELATIVE WEIGHT (%)
A		1	1	1	1	1	1	1	1	1	1	1	1	1	14,29%
B	0		0	0	0	1	1	0	0	0	0	0	1	0	3,30%
C	0	1		1	1	1	1	1	1	1	1	0	1	1	12,09%
D	0	1	0		0	0	1	1	0	1	0	0	1	1	6,59%
E	0	1	0	1		1	1	1	0	0	0	0	1	1	7,69%
F	0	0	0	1	0		0	1	0	0	1	0	1	1	5,49%
G	0	0	0	0	0	1		1	0	0	1	0	1	1	5,49%
H	0	1	0	0	0	0	0		0	0	1	0	0	1	3,30%
I	0	1	0	1	1	1	1	1		0	0	1	1	1	9,89%
J	0	1	0	0	1	1	1	1	1		1	0	1	0	8,79%
K	0	1	0	1	1	0	0	0	1	0		1	1	0	6,59%
L	0	1	1	1	1	1	1	1	0	1	0		0	1	9,89%
M	0	0	0	0	0	0	0	1	0	0	0	1		0	2,20%
N	0	1	0	0	0	0	0	0	0	1	1	0	1		4,40%
														TOTAL	100

PROTECTION FROM WAVES VS.

Protection from wave is the main function for the structure. Therefore, it is regarded as the most important requirements.

Table D- 18. Protection form Waves VS. other Factors

Criteria	Weighing
Construction Process	1
Flexibility future upgrading	1
Resilience	1
Land availability	1
Incursion in protected area Waddenzee	1
Pollution during construction	1
Landscape	1
PIANC Working with Nature philosophy	1
Frequency of maintenance and monitoring	1
Accessibility for inspection of armour layer	1
Accessibility for maintenance tasks	1
Recreation	1
Social considerations (also Dutch pride, economy boost)	1

CONSTRUCTION PROCESS VS.

Construction process does influence the feasible and operational feature of the closure dam, not the function. It would be modified during the execution process.

Table D- 19. Construction Process VS. other Factors

Criteria	Weighing
Protection from waves	0
Flexibility future upgrading	0
Resilience	0
Land availability	0
Incursion in protected area Waddenzee	1
Pollution during construction	1
Landscape	0
PIANC Working with Nature philosophy	0
Frequency of maintenance and monitoring	0
Accessibility for inspection of armour layer	0
Accessibility for maintenance tasks	0
Recreation	1

Social considerations (also Dutch pride, economy boost)	0

FLEXIBILITY FUTURE UPGRADING VS.

Flexibility is of importance due to the unpredictable future conditions. The structure itself should be easy to adapt to changing conditions.

Table D- 20. Flexibility Future Upgrading VS. other Factors

Criteria	Weighing
Protection from waves	0
Construction Process	0
Resilience	0
Land availability	0
Incursion in protected area Waddenzee	1
Pollution during construction	1
Landscape	0
PIANC Working with Nature philosophy	0
Frequency of maintenance and monitoring	0
Accessibility for inspection of armour layer	0
Accessibility for maintenance tasks	0
Recreation	1
Social considerations (also Dutch pride, economy boost)	0

RESILIENCE VS.

Resilience is the capacity to recover quickly from extreme conditions. It is considered in the design stage, more important in the maintenance and inspection tasks.

Table D- 21. Resilience VS. other Factors

Criteria	Weighing
Protection from waves	0
Construction Process	1
Flexibility future upgrading	1
Land availability	1
Incursion in protected area Waddenzee	1
Pollution during construction	1
Landscape	1
PIANC Working with Nature philosophy	1
Frequency of maintenance and monitoring	1

Accessibility for inspection of armour layer	1
Accessibility for maintenance tasks	0
Recreation	1
Social considerations (also Dutch pride, economy boost)	1

LAND AVAILABILITY VS.

The advantages of having more land available can justify some designs with respect to landscape and recreation.

Table D- 22. Land availability VS. other Factors

Criteria	Weighing
Protection from waves	0
Construction Process	1
Flexibility future upgrading	0
Resilience	1
Incursion in protected area Waddenzee	0
Pollution during construction	1
Landscape	1
PIANC Working with Nature philosophy	0
Frequency of maintenance and monitoring	1
Accessibility for inspection of armour layer	0
Accessibility for maintenance tasks	0
Recreation	1
Social considerations (also Dutch pride, economy boost)	1

INCURSION IN PROTECTED AREA WADDENZEE VS.

It is a tendency not to disturb the nature as not invading the Waddenzee.

Table D- 23. Incursion in Protection Area Waddenzee VS. other Factors

Criteria	Weighing
Protection from waves	0
Construction Process	0
Flexibility future upgrading	0
Resilience	1
Land availability	0
Pollution during construction	0
Landscape	1

PIANC Working with Nature philosophy	0
Frequency of maintenance and monitoring	0
Accessibility for inspection of armour layer	1
Accessibility for maintenance tasks	0
Recreation	1
Social considerations (also Dutch pride, economy boost)	1

POLLUTION DURING CONSTRUCTION VS.

It is an important factor, but control and compensating measures can be implemented. Compensating measures for landscape are preferred than a lot of pollution to be controlled.

Table D- 24. Pollution during Construction VS. other Factors

Criteria	Weighing
Protection from waves	0
Construction Process	0
Flexibility future upgrading	0
Resilience	0
Land availability	0
Pollution during construction	1
Landscape	1
PIANC Working with Nature philosophy	0
Frequency of maintenance and monitoring	0
Accessibility for inspection of armour layer	1
Accessibility for maintenance tasks	0
Recreation	1
Social considerations (also Dutch pride, economy boost)	1

LANDSCAPE VS.

As a tourist point, it is essential to keep its natural landscape, and the construction foot print should be as small as possible. But it is not a main function, so it gets lower scores.

Table D- 25. Landscape VS. other Factors

Criteria	Weighing
Protection from waves	0
Construction Process	1
Flexibility future upgrading	0
Resilience	0

Land availability	0
Incursion in protected area Waddenzee	0
Pollution during construction	0
PIANC Working with Nature philosophy	0
Frequency of maintenance and monitoring	0
Accessibility for inspection of armour layer	1
Accessibility for maintenance tasks	0
Recreation	0
Social considerations (also Dutch pride, economy boost)	1

PIANC WORKING WITH NATURE PHILOSOPHY VS.

Working with Nature considers the project objectives firstly from the perspective of the natural system rather than from the perspective of technical design. However, Working with Nature does not mean that we no longer achieve our development objectives: rather it ensures that these objectives are satisfied in a way which maximizes opportunities and – importantly – reduces frustrations, delays and associated extra costs.

Table D- 26. PIANC Working with Nature Philosophy VS. other Factors

Criteria	Weighing
Protection from waves	0
Construction Process	1
Flexibility future upgrading	0
Resilience	1
Land availability	1
Incursion in protected area Waddenzee	1
Pollution during construction	1
Landscape	1
Frequency of maintenance and monitoring	0
Accessibility for inspection of armour layer	0
Accessibility for maintenance tasks	1
Recreation	1
Social considerations (also Dutch pride, economy boost)	1

FREQUENCY OF MAINTENANCE AND MONITORING VS.

Maintenance task can be costly and complicated during the life cycle. Attention should be paid in the design phase.

Table D- 27. Frequency of Maintenance and Monitoring VS. other Factors

Criteria	Weighing
Protection from waves	0
Construction Process	1
Flexibility future upgrading	0
Resilience	0
Land availability	1
Incursion in protected area Waddenzee	1
Pollution during construction	1
Landscape	1
PIANC Working with Nature philosophy	1
Accessibility for inspection of armour layer	1
Accessibility for maintenance tasks	0
Recreation	1
Social considerations (also Dutch pride, economy boost)	0

ACCESSIBILITY FOR INSPECTION OF ARMOUR LAYER VS.

Table D- 28. Accessibility for Inspection of Armour Layer VS. other Factors

Criteria	Weighing
Protection from waves	0
Construction Process	1
Flexibility future upgrading	0
Resilience	1
Land availability	1
Incursion in protected area Waddenzee	0
Pollution during construction	0
Landscape	0
PIANC Working with Nature philosophy	1
Frequency of maintenance and monitoring	0
Accessibility for maintenance tasks	1
Recreation	1
Social considerations (also Dutch pride, economy boost)	0

ACCESSIBILITY FOR MAINTENANCE TASKS VS.

Table D- 29. Accessibility for Inspection of Armour Layer VS. other Factors

Criteria	Weighing
Protection from waves	0

Construction Process	1
Flexibility future upgrading	1
Resilience	1
Land availability	1
Incursion in protected area Waddenzee	1
Pollution during construction	1
Landscape	1
PIANC Working with Nature philosophy	0
Frequency of maintenance and monitoring	1
Accessibility for inspection of armour layer	0
Recreation	0
Social considerations (also Dutch pride, economy boost)	1

RECREATION VS.

It is a secondary benefit. Recreation is part of the social dimension of the project and will be subject to other social aspects.

Table D- 30. Recreation VS. other Factors

Criteria	Weighing
Protection from waves	0
Construction Process	0
Flexibility future upgrading	0
Resilience	0
Land availability	0
Incursion in protected area Waddenzee	0
Pollution during construction	0
Landscape	1
PIANC Working with Nature philosophy	0
Frequency of maintenance and monitoring	0
Accessibility for inspection of armour layer	0
Accessibility for maintenance tasks	1
Social considerations (also Dutch pride, economy boost)	0

SOCIAL CONSIDERATIONS VS.

Upgrading the structure catches high social consideration.

Table D- 31. Social Consideration VS. other Factors

Criteria	Weighing
Protection from waves	0
Construction Process	1
Flexibility future upgrading	0
Resilience	0
Land availability	0
Incursion in protected area Waddenzee	0
Pollution during construction	0
Landscape	0
PIANC Working with Nature philosophy	0
Frequency of maintenance and monitoring	1
Accessibility for inspection of armour layer	1
Accessibility for maintenance tasks	0
Recreation	1

D.1.3 WEIGHING JUSTIFICATION FROM CARLOS

Table D- 32. Weighing Justification from Carlos

CRITERIA	1	2	3	4	5	6	7	8	9	10	11	12	13	14	RELATIVE WEIGHT (%)
A		1	1	1	1	1	1	1	1	1	1	1	1	1	14,29%
B	0		0	0	1	0	0	0	0	0	0	0	1	0	2,20%
C	0	1		0	1	0	1	1	0	1	0	0	1	1	7,69%
D	0	1	1		1	0	0	1	0	0	0	0	0	0	4,40%
E	0	0	0	1		0	0	1	0	0	0	0	0	0	1,10%
F	0	1	1	1	1		1	1	1	1	1	1	1	1	13,19%
G	0	1	1	1	1	1		1	1	1	1	1	1	1	6,59%
H	0	1	0	0	0	0	0		0	0	0	0	0	0	1,10%
I	0	1	1	1	1	0	1	1		0	0	0	1	1	8,79%
J	0	1	0	1	1	0	1	1	1		1	0	1	1	9,89%
K	0	1	1	1	1	0	1	1	1	0		0	1	1	9,89%
L	0	1	1	1	1	0	1	1	1	1	1		1	1	12,09%
M	0	0	0	1	1	0	0	1	0	0	0	0		0	3,30%
N	0	1	0	1	1	0	0	1	0	0	0	0	1		5,49%
														TOTAL	100

PROTECTION FROM WAVES VS.

Is the main function of the structures therefore have been weighted as the most important.

Table D- 33. Protection form Waves VS. other Factors

Criteria	Weighing
Construction Process	1
Flexibility future upgrading	1
Resilience	1
Land availability	1
Incursion in protected area Waddenzee	1
Pollution during construction	1
Landscape	1
PIANC Working with Nature philosophy	1
Frequency of maintenance and monitoring	1
Accessibility for inspection of armour layer	1
Accessibility for maintenance tasks	1
Recreation	1
Social considerations (also Dutch pride, economy boost)	1

CONSTRUCTION PROCESS VS.

Construction process can be managed during execution of Works, it won't change closure dam functions, its influence lies on operational features while construction. For it has been given a relative low weight.

Table D- 34. Construction Process VS. other Factors

Criteria	Weighing
Protection from waves	0
Flexibility future upgrading	0
Resilience	0
Land availability	1
Incursion in protected area Waddenzee	0
Pollution during construction	0
Landscape	0
PIANC Working with Nature philosophy	0
Frequency of maintenance and monitoring	0
Accessibility for inspection of armour layer	0
Accessibility for maintenance tasks	0
Recreation	1

Social considerations (also Dutch pride, economy boost)	0

FLEXIBILITY FUTURE UPGRADING VS.

Flexibility for upgrading is important due the fact that the design conditions might change (e.g. sea level rise, wind speed) for this reason some relevance among others criteria have been given.

Table D- 35. Flexibility Future Upgrading VS. other Factors

Criteria	**Weighing**
Protection from waves	0
Construction Process	1
Resilience	0
Land availability	1
Incursion in protected area Waddenzee	0
Pollution during construction	1
Landscape	1
PIANC Working with Nature philosophy	0
Frequency of maintenance and monitoring	1
Accessibility for inspection of armour layer	0
Accessibility for maintenance tasks	0
Recreation	1
Social considerations (also Dutch pride, economy boost)	1

RESILIENCE VS.

Resilience could be needed during extreme cases. In the other hand is considered that during the design stage safety margin are taken, for this reason; resilience has been graded low during weighing.

Table D- 36. Resilience VS. other Factors

Criteria	**Weighing**
Protection from waves	0
Construction Process	1
Flexibility future upgrading	1
Land availability	1
Incursion in protected area Waddenzee	0
Pollution during construction	0
Landscape	1
PIANC Working with Nature philosophy	0

Frequency of maintenance and monitoring	0
Accessibility for inspection of armour layer	0
Accessibility for maintenance tasks	0
Recreation	0
Social considerations (also Dutch pride, economy boost)	0

LAND AVAILABILITY VS.

Land availability can be seen as an added benefit from the main function of the structure, for this reason it had scored low during weighing.

Table D- 37. Land availability VS. other Factors

Criteria	Weighing
Protection from waves	0
Construction Process	0
Flexibility future upgrading	0
Resilience	0
Incursion in protected area Waddenzee	0
Pollution during construction	0
Landscape	1
PIANC Working with Nature philosophy	0
Frequency of maintenance and monitoring	0
Accessibility for inspection of armour layer	0
Accessibility for maintenance tasks	0
Recreation	0
Social considerations (also Dutch pride, economy boost)	0

INCURSION IN PROTECTED AREA WADDENZEE VS.

Waddenzee is considered a protected area, for this reason has been graded as the second most important criteria after protection from waves.

Table D- 38. Incursion in Protection Area Waddenzee VS. other Factors

Criteria	Weighing
Protection from waves	0
Construction Process	1
Flexibility future upgrading	1
Resilience	1
Land availability	1

Pollution during construction	1
Landscape	1
PIANC Working with Nature philosophy	1
Frequency of maintenance and monitoring	1
Accessibility for inspection of armour layer	1
Accessibility for maintenance tasks	1
Recreation	1
Social considerations (also Dutch pride, economy boost)	1

POLLUTION DURING CONSTRUCTION VS.

Environmental rules are taking an increasingly prominent role during construction projects this is why a relative importance has been provided.

Table D- 39. Pollution during Construction VS. other Factors

Criteria	Weighing
Protection from waves	0
Construction Process	1
Flexibility future upgrading	0
Resilience	1
Land availability	1
Pollution during construction	0
Landscape	1
PIANC Working with Nature philosophy	0
Frequency of maintenance and monitoring	0
Accessibility for inspection of armour layer	0
Accessibility for maintenance tasks	0
Recreation	1
Social considerations (also Dutch pride, economy boost)	1

LANDSCAPE VS.

It is important to keep the project's panorama, for this reason landscape has been taken into account as criterion for this multicriteria analysis. Nevertheless a minimal intervention is expected trying to keep its "natural" rocky landscape. As tourism is not the main function for this project, landscape has scored the lowest weighing.

Table D- 40. Landscape VS. other Factors

Criteria	Weighing
Protection from waves	0

Construction Process	1
Flexibility future upgrading	0
Resilience	0
Land availability	0
Incursion in protected area Waddenzee	0
Pollution during construction	0
PIANC Working with Nature philosophy	0
Frequency of maintenance and monitoring	0
Accessibility for inspection of armour layer	0
Accessibility for maintenance tasks	0
Recreation	0
Social considerations (also Dutch pride, economy boost)	0

PIANC WORKING WITH NATURE PHILOSOPHY VS.

Conservation of nature is worldwide issue and it cannot be threated separated from the others function of the structure, for this an ecological approach is highly recommended.

Table D- 41. PIANC Working with Nature Philosophy VS. other Factors

Criteria	**Weighing**
Protection from waves	0
Construction Process	1
Flexibility future upgrading	1
Resilience	1
Land availability	1
Incursion in protected area Waddenzee	0
Pollution during construction	1
Landscape	1
Frequency of maintenance and monitoring	0
Accessibility for inspection of armour layer	0
Accessibility for maintenance tasks	0
Recreation	1
Social considerations (also Dutch pride, economy boost)	1

FREQUENCY OF MAINTENANCE AND MONITORING VS.

Maintenance can be costly and monitoring can be a really complicated task, for this reason, some stress has been underline by given relative importance to this criteria.

Table D- 42. Frequency of Maintenance and Monitoring VS. other Factors

Criteria	**Weighing**

Protection from waves	0
Construction Process	1
Flexibility future upgrading	0
Resilience	1
Land availability	1
Incursion in protected area Waddenzee	0
Pollution during construction	1
Landscape	1
PIANC Working with Nature philosophy	1
Accessibility for inspection of armour layer	1
Accessibility for maintenance tasks	0
Recreation	1
Social considerations (also Dutch pride, economy boost)	1

ACCESSIBILITY FOR INSPECTION OF ARMOUR LAYER VS.

This was one of the client’s solicitations for this reason graded high during weighing.

Table D- 43. Accessibility for Inspection of Armour Layer VS. other Factors

Criteria	**Weighing**
Protection from waves	0
Construction Process	1
Flexibility future upgrading	1
Resilience	1
Land availability	1
Incursion in protected area Waddenzee	0
Pollution during construction	1
Landscape	1
PIANC Working with Nature philosophy	1
Frequency of maintenance and monitoring	0
Accessibility for maintenance tasks	0
Recreation	1
Social considerations (also Dutch pride, economy boost)	1

ACCESIBILITY FOR MAINTENANCE TASKS VS.

This was another of the client’s solicitations.

Table D- 44. Accessibility for Maintenance Tasks VS. other Factors

Criteria	Weighing
Protection from waves	0
Construction Process	1
Flexibility future upgrading	1
Resilience	1
Land availability	1
Incursion in protected area Waddenzee	0
Pollution during construction	1
Landscape	1
PIANC Working with Nature philosophy	1
Frequency of maintenance and monitoring	1
Accessibility for inspection of armour layer	1
Recreation	1
Social considerations (also Dutch pride, economy boost)	1

RECREATION VS.

Recreation is an added value, important for improving life style.

Table D- 45. Recreation VS. other Factors

Criteria	Weighing
Protection from waves	0
Construction Process	0
Flexibility future upgrading	0
Resilience	1
Land availability	1
Incursion in protected area Waddenzee	0
Pollution during construction	0
Landscape	1
PIANC Working with Nature philosophy	0
Frequency of maintenance and monitoring	0
Accessibility for inspection of armour layer	0
Accessibility for maintenance tasks	0
Social considerations (also Dutch pride, economy boost)	0

SOCIAL CONSIDERATIONS VS.

Construction of such work can mean higher development in society, which will generate welfare in it. For this is why this criterion is rated as relatively important.

Table D- 46. Social Consideration VS. other Factors

Criteria	Weighing
Protection from waves	0
Construction Process	1
Flexibility future upgrading	0
Resilience	1
Land availability	1
Incursion in protected area Waddenzee	0
Pollution during construction	0
Landscape	1
PIANC Working with Nature philosophy	0
Frequency of maintenance and monitoring	0
Accessibility for inspection of armour layer	0
Accessibility for maintenance tasks	0
Recreation	1

D.1.4 WEIGHING JUSTIFICATION FROM PABLO

Table D- 47. Weighing Justification from Pablo

CRITERIA	1	2	3	4	5	6	7	8	9	10	11	12	13	14	RELATIVE WEIGHT (%)
A		1	0	1	1	1	1	1	1	0	1	1	1	1	12,09%
B	0		0	0	0	1	1	0	0	0	0	0	1	0	3,30%
C	1	1		1	1	1	1	1	1	1	1	1	1	1	14,29%
D	0	1	0		0	0	1	1	0	0	0	0	1	1	5,49%
E	0	1	0	1		0	1	1	0	0	0	0	1	1	6,59%
F	0	0	0	1	1		1	1	0	0	1	1	1	1	8,79%
G	0	0	0	0	0	0		1	0	0	0	0	1	1	3,30%
H	0	1	0	0	0	0	0		0	0	0	0	0	1	2,20%
I	0	1	0	1	1	1	1	1		0	0	1	1	1	9,89%
J	1	1	0	1	1	1	1	1	1		1	0	1	1	12,09%
K	0	1	0	1	1	0	1	1	1	0		1	1	1	9,89%
L	0	1	0	1	1	0	1	1	0	1	0		0	1	7,69%
M	0	0	0	0	0	0	0	1	0	0	0	1		0	2,20%
N	0	1	0	0	0	0	0	0	0	0	0	0	1		2,20%
														TOTAL	100.00

PROTECTION FROM WAVES VS.

One of the most important functions of this structure is the protection against waves. It is the only purpose of the Afsluitdijk when it was built several years ago and remains in the same way until now. Therefore it was weighted as the second prevalent category. However flexibility for future upgrading is considered the most important criteria, because every design has to accomplish with protection against waves, nevertheless not every design will introduce flexibility into the system.

Table D- 48. Protection form Waves VS. other Factors

Criteria	Weighing
Construction Process	1
Flexibility future upgrading	0
Resilience	1
Land availability	1
Incursion in protected area Waddenzee	1
Pollution during construction	1
Landscape	1
PIANC Working with Nature philosophy	1
Frequency of maintenance and monitoring	0
Accessibility for inspection of armour layer	1
Accessibility for maintenance tasks	1
Recreation	1
Social considerations (also Dutch pride, economy boost)	1

CONSTRUCTION PROCESS VS.

As the construction process is only during a short period of time compared with the life cycle of the dike, there are only a few categories in which it would be considered more relevant than other aspects. These are identified in the following table with 1.Table D- 49. Construction Process VS. other Factors

Criteria	Weighing
Protection from waves	0
Flexibility future upgrading	0
Resilience	0
Land availability	0
Incursion in protected area Waddenzee	1
Pollution during construction	1
Landscape	0
PIANC Working with Nature philosophy	0
Frequency of maintenance and monitoring	0
Accessibility for inspection of armour layer	0

Accessibility for maintenance tasks	0
Recreation	1
Social considerations (also Dutch pride, economy boost)	0

FLEXIBILITY FUTURE UPGRADING VS.

Flexibility for future upgrading is considered the most important characteristic to be considered within this project. Due to the fact of its uniqueness and functional concept, Afsluitdijk probably will remain for centuries protecting the Netherlands from the North Sea. It is known that future uncertainties are a lot. Therefore it is considered very valuable to embrace those uncertainties and have a robust and adaptable design to cope with those possible future scenarios.

Table D- 50. Flexibility Future Upgrading VS. other Factors

Criteria	Weighing
Protection from waves	1
Construction Process	1
Resilience	1
Land availability	1
Incursion in protected area Waddenzee	1
Pollution during construction	1
Landscape	1
PIANC Working with Nature philosophy	1
Frequency of maintenance and monitoring	1
Accessibility for inspection of armour layer	1
Accessibility for maintenance tasks	1
Recreation	1
Social considerations (also Dutch pride, economy boost)	1

RESILIENCE VS.

Resilience for extreme conditions can become an important characteristic to be analyzed and evaluated, however only it is considered more relevant than transient situations (like construction) or than aesthetic parameters, because it is partially part of Dutch additional safety.

Table D- 51. Resilience VS. other Factors

Criteria	Weighing
Protection from waves	0
Construction Process	1
Flexibility future upgrading	0
Land availability	0
Incursion in protected area Waddenzee	0
Pollution during construction	1

Landscape	1
PIANC Working with Nature philosophy	0
Frequency of maintenance and monitoring	0
Accessibility for inspection of armour layer	0
Accessibility for maintenance tasks	0
Recreation	1
Social considerations (also Dutch pride, economy boost)	1

LAND AVAILABILITY VS.

This particular topic can be considered in two different ways. On the one hand, land availability is an added benefit to the main function of the structure, but on the other hand also it is directly linked for flexibility on the design and possibilities for future upgrading of the dike. However as the second part was considered within some other topics the relative weighing it was not that relevant.

Table D- 52. Land availability VS. other Factors

Criteria	**Weighing**
Protection from waves	0
Construction Process	1
Flexibility future upgrading	0
Resilience	1
Incursion in protected area Waddenzee	0
Pollution during construction	1
Landscape	1
PIANC Working with Nature philosophy	0
Frequency of maintenance and monitoring	0
Accessibility for inspection of armour layer	0
Accessibility for maintenance tasks	0
Recreation	1
Social considerations (also Dutch pride, economy boost)	1

INCURSION IN PROTECTED AREA WADDENZEE VS.

Waddenzee is a protected area, therefore this importance is considered; however when contrasting with some main parameters such as Flexibility for future upgrading or Frequency of maintenance and monitoring, certain incursion into the Waddenzee is allowed.

Table D- 53. Incursion in Protection Area Waddenzee VS. other Factors

Criteria	**Weighing**
Protection from waves	0
Construction Process	0
Flexibility future upgrading	0

Resilience	1
Land availability	1
Pollution during construction	1
Landscape	1
PIANC Working with Nature philosophy	0
Frequency of maintenance and monitoring	0
Accessibility for inspection of armour layer	1
Accessibility for maintenance tasks	1
Recreation	1
Social considerations (also Dutch pride, economy boost)	1

POLLUTION DURING CONSTRUCTION VS.

Even though environmental regulations are becoming stronger during construction phases, this characteristic influences only during the construction period, hence it is not weighed as much relevant as some other parameters that will influence the whole life cycle of the structure.

Table D- 54. Pollution during Construction VS. other Factors

Criteria	**Weighing**
Protection from waves	0
Construction Process	0
Flexibility future upgrading	0
Resilience	0
Land availability	0
Pollution during construction	0
Landscape	1
PIANC Working with Nature philosophy	0
Frequency of maintenance and monitoring	0
Accessibility for inspection of armour layer	0
Accessibility for maintenance tasks	0
Recreation	1
Social considerations (also Dutch pride, economy boost)	1

LANDSCAPE VS.

Afsluitdijk is a one of the Civil Engineering landmark in the Netherlands and probably in the world, thus its aesthetic design is important. In addition, it is one of the main connections between North Holland and Friesland, which is used on daily basis for local people, therefore landscape is and added value for the project. Nevertheless the weight given is not that relevant because certain technical aspects are more essential.

Table D- 55. Landscape VS. other Factors

Criteria	Weighing
Protection from waves	0
Construction Process	1
Flexibility future upgrading	0
Resilience	0
Land availability	0
Incursion in protected area Waddenzee	0
Pollution during construction	0
PIANC Working with Nature philosophy	0
Frequency of maintenance and monitoring	0
Accessibility for inspection of armour layer	0
Accessibility for maintenance tasks	0
Recreation	0
Social considerations (also Dutch pride, economy boost)	1

PIANC WORKING WITH NATURE PHILOSOPHY VS.

In essence, adopting the Working with Nature philosophy means doing things in a different order at least from the environmental point of view and this is considered within this category. It is weighed as one of the important characteristics due to the relevance of this approach for the whole life cycle of the structure and its interaction with the surrounding environment.

Table D- 56. PIANC Working with Nature Philosophy VS. other Factors

Criteria	Weighing
Protection from waves	0
Construction Process	1
Flexibility future upgrading	0
Resilience	1
Land availability	1
Incursion in protected area Waddenzee	1
Pollution during construction	1
Landscape	1
Frequency of maintenance and monitoring	0
Accessibility for inspection of armour layer	0
Accessibility for maintenance tasks	1
Recreation	1
Social considerations (also Dutch pride, economy boost)	1

FREQUENCY OF MAINTENANCE AND MONITORING VS.

The frequency of these activities is crucial for future operation of the dike, hence it is weighed as one of the most relevant aspects to be considered and evaluated for alternative's selection.

Table D- 57. Frequency of Maintenance and Monitoring VS. other Factors

Criteria	Weighing
Protection from waves	1
Construction Process	1
Flexibility future upgrading	0
Resilience	1
Land availability	1
Incursion in protected area Waddenzee	1
Pollution during construction	1
Landscape	1
PIANC Working with Nature philosophy	1
Accessibility for inspection of armour layer	1
Accessibility for maintenance tasks	0
Recreation	1
Social considerations (also Dutch pride, economy boost)	1

ACCESIBILITY FOR INSPECTION OF ARMOUR LAYER VS.

Rijkswaterstaat enquired to analyze and consider this specific topic, therefore it is high weighed.

Table D- 58. Accessibility for Inspection of Armour Layer VS. other Factors

Criteria	Weighing
Protection from waves	0
Construction Process	1
Flexibility future upgrading	0
Resilience	1
Land availability	1
Incursion in protected area Waddenzee	0
Pollution during construction	1
Landscape	1
PIANC Working with Nature philosophy	1
Frequency of maintenance and monitoring	0
Accessibility for maintenance tasks	1
Recreation	1
Social considerations (also Dutch pride, economy boost)	1

ACCESIBILITY FOR MAINTENANCE TASKS VS.

This particular aspect is also one of the Employer's Requirements, thus it is taken into account for the alternative's evaluation. Besides it is weighed as one of the intermediate parameters for the selection process.

Table D- 59. Accessibility for Maintenance Tasks VS. other Factors

Criteria	Weighing
Protection from waves	0
Construction Process	1
Flexibility future upgrading	0
Resilience	1
Land availability	1
Incursion in protected area Waddenzee	0
Pollution during construction	1
Landscape	1
PIANC Working with Nature philosophy	0
Frequency of maintenance and monitoring	1
Accessibility for inspection of armour layer	0
Recreation	0
Social considerations (also Dutch pride, economy boost)	1

RECREATION VS.

This topic is considered as an additional value for the project. This area is also used for recreation activities (Sightseeing, Bike lane, Sports, Fishing, et cetera) that can be improved within the dike, but as it is stated is something complementary, thus the weight is not very high.

Table D- 60. Recreation VS. other Factors

Criteria	Weighing
Protection from waves	0
Construction Process	0
Flexibility future upgrading	0
Resilience	0
Land availability	0
Incursion in protected area Waddenzee	0
Pollution during construction	0
Landscape	1
PIANC Working with Nature philosophy	0
Frequency of maintenance and monitoring	0
Accessibility for inspection of armour layer	0

Accessibility for maintenance tasks	1
Social considerations (also Dutch pride, economy boost)	0

SOCIAL CONSIDERATIONS VS.

Afsluitdijk is one of the major projects in the Netherlands and directly linked to Dutch self-worth, besides the upgrading of the dike can be a social-economic boost during the construction period. Despite the mentioned issues, it is considered as one the lowest ranked characteristic for the alternative's selection process.

Table D- 61. Social Consideration VS. other Factors

Criteria	Weighing
Protection from waves	0
Construction Process	1
Flexibility future upgrading	0
Resilience	0
Land availability	0
Incursion in protected area Waddenzee	0
Pollution during construction	0
Landscape	0
PIANC Working with Nature philosophy	0
Frequency of maintenance and monitoring	0
Accessibility for inspection of armour layer	0
Accessibility for maintenance tasks	0
Recreation	1

D.1.5 WEIGHING FROM THE CLIENT

Table D- 62. Weighing Justification from the Client

CRITERIA	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Relative Weight (%)
A		1	1	1	1	1	1	1	1	1	1	1	1	1	13,66
B	0		1	1	1	0	0	1	1	1	1	1	1	1	3,57
C	0	0		0	1	0	0	1	0	0	0	0	1	1	11,35
D	0	0	1		1	0	0	1	1	1	1	1	1	1	5,81
E	0	0	0	0		1	0	1	1	1	1	1	1	1	5,54
F	0	1	1	1	0		0	0	1	0	0	0	1	1	10,42
G	0	1	1	1	1	1		1	1	1	1	1	1	1	5,34
H	0	0	0	0	0	1	0		1	1	1	1	1	1	2,02
I	0	0	1	0	0	0	0	0		0	0	0	1	1	9,07
J	0	0	1	0	0	1	0	0	1		1	1	1	1	8,52
K	0	0	1	0	0	1	0	0	1	0		1	1	1	7,00
L	0	0	1	0	0	1	0	0	1	0	0		1	1	9,59
M	0	0	0	0	0	0	0	0	0	0	0	0		0	2,26
N	0	0	0	0	0	0	0	0	0	0	0	0	1		5,86
														TOTAL	100

D.2 SCORING JUSTIFICATION IN INTERMEDIATE DESIGN

In this part, how the group give scores to the intermediate designs are illustrated here. The analysed alternatives are summarized in the following table.

Table D- 63. Alternatives of Cross Sections

ALTERNATIVE	TYPE OF CROSS SECTION PROPOSED
Design 1	Rip-rap without berm, slope 2:3
Design 2	Rip-rap without berm, slope 1:2
Design 3	Xbloc® 2:3
Design 4	Xbloc® 3:4
Design 5	Berm breakwater
Design 6	Breakwater with berm
Design 7	AcropodeTM II 2:3 (up to the outer limit)
Design 8	AcropodeTM II 2:3 (cutting slope)
Design 9	Antifer cubes, slope 2:3
Design 10	Rip-rap overlayer, slope 1:3.6
Design 11	Xbloc® invading Waddenzee, slope 3:4
Design 12	Berm breakwater invading Waddenzee

First, a range of scores is chosen. The defined range tries to describe in a simple and accurate way possible states that the performance level of an alternative can reach. The final score scale is:

Table D- 64. Sores Set of Multi Criteria Analysis

EXPECTED PERFORMANCE	SCORE
The alternative presents ideal conditions regarding the analysed factor	+4
The alternative presents good conditions, without significant problems	+3
The alternative presents some problems regarding studied factor, but they can be solved	+2
The alternative presents significant problems regarding the analysed factor, difficult to resolve	+1
The alternative presents challenging issues that could proscribe the design	0

Once the range is defined, each alternative design gets a score for each criterion. With the aim of eliminate subjectivity in this report, not a single evaluation but average values are used. The design team has completed the score assignment individually; then an average of the result is calculated.

D.2.1 SCORING JUSTIFICATION FROM MARÍA JOSÉ

Table D- 65. Scoring Results from Maria Jose

CRITERIA			SCORES for each previous introduced DESIGN											
			1	2	3	4	5	6	7	8	9	10	11	12
TECHNICAL FACTORS	1	Protection from waves	+4	+4	+4	+4	+4	+4	+4	+4	+4	+4	+4	+4
	2	Construction Process	+2	+2	+2	+2	+2	+2	+2	+2	+2	**+3**	+3	+3
	3	Flexibility future upgrading	+2	+2	+2	+2	+3	+2	+2	+2	+2	+1	+2	+3
OPERATIONAL FACTORS	4	Resilience	+2	+2	+1	+1	+4	+2	+1	+1	+3	+2	+1	+4
	5	Land availability	+3	+4	+3	+4	+2	+2	+4	+2	+4	+2	+4	+3
ENVIRONMENT	6	Incursion in Waddenzee	+3	+3	+3	+3	+2	+3	+3	+2	+4	+1	+1	+1
	7	Pollution during construction	+3	+3	+2	+2	+3	+3	+2	+2	+1	+4	+2	+3
	8	Landscape	+3	+3	+2	+2	+3	+4	+2	+2	+2	+3	+2	+3
	9	PIANC Working with Nature	+3	+3	+3	+3	+2	+4	+3	+3	+3	+3	+3	+2
MAINTENANCE	10	Frequency maintenance &monitoring	+3	+3	+3	+3	+3	+3	+3	+3	+3	+3	+3	+3
	11	Accessibility inspection of armour layer	+3	+3	+3	+3	+3	+3	+3	+3	+3	+3	+3	+3
	12	Accessibility for maintenance tasks	+3	+3	+3	+3	+3	+3	+3	+3	+3	+2	+2	+2
THIRD PARTIES	13	Recreation	+4	+4	+4	+4	+3	+4	+4	+4	+4	+3	+4	+3
	14	Social considerations	+3	+3	+4	+4	+3	+3	+2	+2	+2	+3	+4	+3

Table D- 66. Weighed Scoring Results from Maria Jose

CRITERIA			WEIGHED SCORES for each previous introduced DESIGN												
			Relative weights [%]	1	2	3	4	5	6	7	8	9	10	11	12
TECHNICAL FACTORS	1	Protection from waves	13.85	55	55	55	55	55	55	55	55	55	55	55	55
	2	Construction Process	5.27	5	11	11	11	11	11	11	11	11	16	16	16
	3	Flexibility future upgrading	10.11	20	20	20	20	30	20	20	20	20	10	20	30
OPERATIONAL FACTORS	4	Resilience	6.59	13	13	7	7	26	13	7	7	20	13	7	26
	5	Land availability	6.15	18	25	18	25	12	12	25	12	25	12	25	18
ENVIRONMENT	6	Incursion in Waddenzee	9.45	28	28	28	28	19	28	28	28	28	9	9	9
	7	Pollution during construction	7.25	22	22	15	15	22	22	15	15	7	29	15	22
	8	Landscape	3.30	10	10	7	7	10	13	7	7	7	10	7	10
	9	PIANC Working with Nature	7.91	24	24	24	24	16	32	24	24	24	24	24	16
MAINTENANCE	10	Frequency maintenance &monitoring	8.57	26	26	26	26	26	26	26	26	26	26	26	26
	11	Accessibility inspection of armourlayer	6.81	20	20	20	20	20	20	20	20	20	20	20	20
	12	Accessibility for maintenance tasks	8.57	26	26	26	26	26	26	26	26	26	17	17	17
THIRD PARTIES	13	Recreation	1.76	7	7	7	7	5	7	7	7	7	7	7	5
	14	Social considerations	4.40	13	13	18	18	13	13	9	9	9	13	18	13
TOTAL			288	300	281	287	292	299	278	266	284	262	265	285	288

RIP RAP SLOPE 2:3

Protection from waves: +4. Ideal conditions, no problems.

Construction Process: +2. No stones in The Netherlands, expensive import (some problems that can be solved).

Flexibility future upgrading: +2. Crown wall should be modified or demolished if the structure is upgraded again (some problems that can be solved).

Resilience: +2. Loss of material in armour layer can lead to significant damage (problem that can be solved).

Land availability: +3. Significant increase in surface, but this is not optimized to the maximum (good conditions but not ideal).

Incursion in protected area Waddenzee: +3. No interference.

Pollution during construction: +3. Only caused by equipment and trucks or barges (not ideal but good).

Landscape: +3. Good conditions, stones look natural.

PIANC Working with Nature philosophy: +3. Rip rap slope is favourable for wildlife development (good conditions but not ideal).

Frequency of maintenance and monitoring: +3. After storms a check is needed (good but not ideal).

Accessibility for inspection of armour layer: +3. Good conditions: inspection can be done from crow wall and with a boat, but the slope can't be walked on.

Accessibility for maintenance tasks: +3. Good as the equipment can be positioned on the crown wall and it is needed only conventional equipment .

Recreation: +4. Good for fishing.

Social considerations (also Dutch pride, economy boost): +3. Good conditions, but not ideal (due to import of stones part of business is done abroad)

RIP RAP SLOPE 1:2

Protection from waves: +4. Ideal conditions, no problems.

Construction Process: +2. No stones in The Netherlands, expensive import (some problems that can be solved)

Flexibility future upgrading: +2. Crown wall should be modified or demolished if the structure is upgraded again (some problems that can be solved).

Resilience: +2. Loss of material in armour layer can lead to significant damage (problem that can be solved).

Land availability: +4. Optimal increase in surface, ideal conditions.

Incursion in protected area Waddenzee: +3. No interference.

Pollution during construction: +3. Produced by equipment, like trucks or barges (not ideal but good).

Landscape: +3. Good conditions, stones look natural.

PIANC Working with Nature philosophy: +3. Rip rap slope is favourable for wildlife growth (good conditions but not ideal)..

Frequency of maintenance and monitoring: +3. After storms a check is needed (good but not ideal)

Accessibility for inspection of armour layer: +3. Good conditions: inspection can be done from the top or a boat but the slope can't be walked on.

Accessibility for maintenance tasks: +3. Good as the equipment can be positioned on the top part and only conventional equipment is needed.

Recreation: +4. Good for fishing.

Social considerations (also Dutch pride, economy boost): +3. Good conditions but not ideal (import of stones: part of business is done abroad).

XBLOC® SLOPE 2:3

Protection from waves: +4. Ideal conditions, no problems.

Construction Process: +2. Due to concrete blocks use, a concrete plant is needed, as well as building area and storage surface for a long period (some problems).

Flexibility future upgrading:+2. Crown wall should be modified (or the XBloc® units removed at the top) if the structure is upgraded again (some problems that can be solved).

Resilience: +1. Loss of material in armour layer can lead to significant damage and the loss of interlocking will make the problem worse and facilitate more losses (problem difficult to solve).

Land availability: +3. Significant increase in surface but it is not optimized to the maximum (good conditions but not ideal).

Incursion in protected area Waddenzee: +3. No interference.

Pollution during construction: +2. Trucks and excavators or other equipment, concrete plant (problems that can be solved).

Landscape: +2. Block units can be considered to look unnatural or too aggressive (problems that can be solved).

PIANC Working with Nature philosophy: +3. Block units slope is favourable for wildlife to develop, the block units can be modified to add some roughness and this way they can facilitate wildlife growth (good conditions but not ideal).

Frequency of maintenance and monitoring: +3. After storms a check is needed (good but not ideal)

Accessibility for inspection of armour layer: +3. Good conditions: inspection can be done from the top part or a boat, but the slope cannot be walked on.

Accessibility for maintenance tasks: +3. Good as the equipment can be positioned on the top part and only conventional equipment is needed.

Recreation: +4. Good for fishing.

Social considerations (also Dutch pride, economy boost): +4. Ideal conditions (work developed in the Netherlands and use of Xbloc® helping promotion of Dutch technology)

XBLOC® SLOPE 3:4

Protection from waves: +4. Ideal conditions, no problems.

Construction Process: +2. Concrete plant needed, building area and storage surface for a long period (some problems).

Flexibility future upgrading: +2. Crown wall should be modified or demolished (or the XBloc® units removed at the top) in case the structure is upgraded again (some problems that can be solved).

Resilience: +1. Material losses in armour layer can lead to significant damage and the weakening of interlocking will make the problem worse, facilitating more losses (problem difficult to solve).

Land availability: +4. Optimal increase in surface, ideal conditions.

Incursion in protected area Waddenzee: +3. No interference.

Pollution during construction: +2. Trucks and excavators or other equipment, concrete plant (problems that can be solved).

Landscape: +2. Block units can be considered to look unnatural, too aggressive (problems that can be solved).

PIANC Working with Nature philosophy: +3. Block units slope favourable for wildlife development, the block units surface can be modified to include some roughness (good conditions but not ideal).

Frequency of maintenance and monitoring: +3. After storms a check is needed (good but not ideal).

Accessibility for inspection of armour layer. +3. Good conditions: inspection can be done from the top or a boat but the slope can't be walked on.

Accessibility for maintenance tasks: +3. Good as the equipment can be positioned on the top part and only conventional equipment is needed.

Recreation: +4. Good for fishing.

Social considerations (also Dutch pride, economy boost): +4. Ideal conditions (work developed in the Netherlands and use of Xbloc® helping promotion of Dutch technology).

BERM BREAKWATER

Protection from waves: +4. Ideal conditions, no problems.

Construction Process: +2. No stones in The Netherlands, expensive import (some problems that can be solved).

Flexibility future upgrading: +3. No crown wall so it is easier to upgrade using the same type of cross section (good conditions but not ideal)

Resilience: +4. Material displacement and losses are expected, the damage is more gradual in this type of breakwater (good conditions).

Land availability: +2. Due to the berm, less available space (some problems).

Incursion in protected area Waddenzee: +2. Dynamic structure, the stones are supposed to move, so it can't be assured that the Waddenzee space won't be invaded.

Pollution during construction: +3. Only trucks or barges and other equipment (not ideal but good)

Landscape: +3. Good conditions, stones look natural.

PIANC Working with Nature philosophy: +2. Rip rap slope favourable for wildlife development but the stones will move so it will be not a stable environment (some problems).

Frequency of maintenance and monitoring: +3. After storms a check is needed (good but not ideal).

Accessibility for inspection of armour layer: +3. Good conditions: inspection can be done from the top part or a boat, but the slope can't be walked on.

Accessibility for maintenance tasks: +3. Good as the equipment can be positioned on the top part and only conventional equipment is needed.

Recreation: +4. Good for fishing.

Social considerations (also Dutch pride, economy boost): +3. Good conditions but not ideal (import of stones: part of business is done abroad)

BREAKWATER WITH BERM

Protection from waves: +4. Ideal conditions, no problems.

Construction Process. +2. No stones in The Netherlands, expensive import (some problems that can be solved).

Flexibility future upgrading: +2. Crown wall should be modified or demolished if the structure is upgraded again (some problems that can be solved)

Resilience: +2. Material loss in armour layer can lead to significant damage (problem that can be solved)

Land availability: +2. No significant increase in surface since the berm will consume part of the space (good conditions but not ideal)

Incursion in protected area Waddenzee: +3. No interference

Pollution during construction: +3. Only equipment and trucks or barges (not ideal but good)

Landscape: +4. Ideal conditions, lower elevation

PIANC Working with Nature philosophy: +4. Ideal conditions, stable stones and horizontal stable berm is a good place for wildlife to develop

Frequency of maintenance and monitoring: +3. Only after storm check needed (good but not ideal)

Accessibility for inspection of armour layer: +3. Good conditions: inspection can be done from crow wall and with a boat but the slope can't be walked on

Accessibility for maintenance tasks: +3. Good conditions as the equipment can be positioned on the crown wall and it is needed only conventional equipment

Recreation: +4. Good for fishing

Social considerations (also Dutch pride, economy boost):+3. Good conditions but not ideal (import of stones: part of business is done abroad and no help to Dutch pride)

ACCROPODE II^{TM} (UP TO THE OUTER LIMIT)

Protection from waves: +4. Ideal conditions, no problems

Construction Process: +2. Needed concrete plant and building and storage surface for a long period (some problems)

Flexibility future upgrading: +2. Crown wall should be modified or demolished (or the concrete units removed at the top) if the structure is upgraded again (some problems that can be solved)

Resilience: +1. Material losses in armour layer can lead to significant damage and the loss of interlocking will make the problem worse and facilitate more losses (problem difficult to solve)

Land availability: +4. Optimum increase in surface, ideal conditions

Incursion in protected area Waddenzee: +3. No interference

Pollution during construction: +2. Equipment and trucks or barges, concrete plant (problems that can be solved)

Landscape: +2. Concrete units can be considered to look unnatural, too aggressive (problems that can be solved)

PIANC Working with Nature philosophy: +3. Concrete blocks slope favorable for wildlife to develop, the bloc can be modified? (good conditions but not ideal)

Frequency of maintenance and monitoring: +3. Only after storm check needed (good but not ideal)

Accessibility for inspection of armour layer: +3. Good conditions: inspection can be done from crow wall and with a boat but the slope can't be walked on

Accessibility for maintenance tasks: +3. Good as the equipment can be positioned on the crown wall and it is needed only conventional equipment

Recreation: +4. Good for fishing

Social considerations (also Dutch pride, economy boost): +2. Small problems (use of Accropode™ which is French technology is not so good regarding this aspect)

ACCROPODE II™ (CUTTING SLOPE)

Protection from waves: +4. Ideal conditions, no problems

Construction Process: +2. Concrete plant needed and building and storage surface for a long period (some problems)

Flexibility future upgrading: +1. Crown wall should be modified or demolished if the structure is upgraded again (some problems that can be solved)

Resilience: +2. Material losses in armour layer can lead to significant damage and the loss of interlocking will make the problem worse and facilitate more losses (problem difficult to solve)

Land availability: +2. Almost no increase in surface (problems)

Incursion in protected area Waddenzee: +2. No interference

Pollution during construction: +2. Equipment and trucks or barges, concrete plant (problems that can be solved)

Landscape: +2. Concrete units can be considered to look unnatural, too aggressive (problems that can be solved)

PIANC Working with Nature philosophy: +3. Concrete units slope is favorable for wildlife to develop, concrete surface can be modified to give it some roughness (good conditions but not ideal)

Frequency of maintenance and monitoring: +3. Only after storm check needed (good but not ideal)

Accessibility for inspection of armour layer: +3. Good conditions: inspection can be done from crow wall and with a boat but the slope can't be walked on

Accessibility for maintenance tasks: +3. Good as the equipment can be positioned on the crown wall and it is needed only conventional equipment.

Recreation: +4. Good for fishing.

Social considerations (also Dutch pride, economy boost): +2. Small problems (use of Accropode™ which is French technology is not so good regarding this aspect)

ANTIFER CUBES

Protection from waves: +4. Ideal conditions, no problems

Construction Process: +2. Concrete plant needed and building and storage surface for a long period (some problems)

Flexibility future upgrading: +2. Crown wall should be modified or demolished if the structure is upgraded again (some problems that can be solved)

Resilience: +3. Two layers of blocks, when there are some losses, the slope can continue resisting (good conditions)

Land availability: +4. Optimal increase in surface , ideal conditions

Incursion in protected area Waddenzee: +4. No interference

Pollution during construction: +1. Trucks, barges and other equipment, concrete plant increase in concrete volume (significant problems)

Landscape: +2. Concrete units can be considered to look unnatural, too aggressive (problems that can be solved)

PIANC Working with Nature philosophy: +3. Concrete units slope favorable for wildlife to develop, the bloc can be modified? (good conditions but not ideal)

Frequency of maintenance and monitoring: +3. Only after storm check needed (good but not ideal)

Accessibility for inspection of armour layer: +3. Good conditions: inspection can be done from crow wall and with a boat but the slope can't be walked on

Accessibility for maintenance tasks: +3. Good as the equipment can be positioned on the crown wall and it is needed only conventional equipment

Recreation: +4. Good for fishing

Social considerations (also Dutch pride, economy boost): +2. Small problems (work developed in the Netherlands and use of Accropode^{TM} which is French technology is not so good)

D.2.2 SCORING JUSTIFICATION FROM YUTING

Table D- 67. Scoring Results from Yuting

CRITERIA			SCORES for each previous introduced DESIGN											
			1	2	3	4	5	6	7	8	9	10	11	12
TECHNICAL FACTORS	1	Protection from waves	+4	+4	+4	+4	+4	+4	+4	+4	+4	+4	+4	+4
	2	Construction Process	+4	+4	+2	+2	+2	+2	+2	+2	+1	+3	+3	+4
	3	Flexibility future upgrading	+2	+2	+3	+2	+3	+2	+2	+2	+1	+1	+4	+2
OPERATIONAL FACTORS	4	Resilience	+2	+2	+1	+1	+3	+2	+1	+1	+3	+2	+4	+2
	5	Land availability	+3	+3	+3	+4	+2	+2	+2	+4	+3	+1	+4	+2
ENVIRONMENT	6	Incursion in Waddenzee	+4	+4	+4	+4	+3	+4	+4	+4	+3	+2	+1	+1
	7	Pollution during construction	+3	+3	+2	+2	+3	+3	+2	+2	+1	+4	+3	+4
	8	Landscape	+3	+3	+2	+3	+3	+4	+2	+2	+2	+3	+3	+2
	9	PIANC Working with Nature	+3	+3	+3	+2	+2	+3	+3	+3	+3	+3	+2	+3
MAINTENANCE	10	Frequency maintenance &monitoring	+3	+3	+3	+3	+3	+3	+3	+3	+4	+2	+4	+2
	11	Accessibility inspection of armour layer	+3	+3	+3	+3	+3	+3	+3	+3	+3	+3	+2	+3
	12	Accessibility for maintenance tasks	+3	+3	+3	+3	+4	+4	+3	+3	+2	+2	+4	+3
THIRD PARTIES	13	Recreation	+3	+4	+3	+3	+3	+4	+4	+4	+2	+1	+4	+3
	14	Social considerations	+3	+3	+4	+4	+3	+3	+2	+2	+3	+2	+4	+2

Table D- 68. Weighed Scoring Results from Yuting

CRITERIA			WEIGHED SCORES for each previous introduced DESIGN												
			Relative weights [%]	1	2	3	4	5	6	7	8	9	10	11	12
TECHNICAL FACTORS	1	Protection from waves	13.85	55	55	55	55	55	55	55	55	55	55	55	55
	2	Construction Process	5.27	11	21	11	11	11	11	11	11	5	16	16	21
	3	Flexibility future upgrading	10.11	20	20	30	30	30	20	30	20	10	10	40	20
OPERATIONAL FACTORS	4	Resilience	6.59	13	13	7	7	20	13	7	7	20	13	26	13
	5	Land availability	6.15	18	18	18	25	12	12	25	12	18	6	25	12
ENVIRONMENT	6	Incursion in Waddenzee	9.45	38	38	38	38	28	38	38	38	28	19	9	9
	7	Pollution during construction	7.25	22	22	15	15	22	22	15	15	7	29	22	29
	8	Landscape	3.30	10	10	7	10	10	13	7	7	7	10	10	7
	9	PIANC Working with Nature	7.91	24	24	24	24	16	24	24	24	24	24	16	24
MAINTENANCE	10	Frequency maintenance &monitoring	8.57	26	26	26	26	26	26	26	26	34	17	34	17
	11	Accessibility inspection of armour layer	6.81	20	20	20	20	20	20	20	20	20	20	14	20
	12	Accessibility for maintenance tasks	8.57	26	26	26	26	34	34	26	26	17	17	34	26
THIRD PARTIES	13	Recreation	1.76	5	7	5	5	5	7	7	7	4	2	7	5
	14	Social considerations	4.40	13	13	18	18	13	13	9	9	13	9	18	9
TOTAL			301	314	299	308	303	309	298	275	264	247	326	268	301

Protection from waves

For all designs, this criterion are rated the highest score +4 because all of them fulfil this requirement.

Construction Process

For those with stones rated with +4. Although no stone in the Netherland, this problem can be solved by importing rocks from neighboring countries. For those alternatives with concrete, lower scores are given, because they need concrete plant and building and storage surface for a long period, and also more labor consuming.

Flexibility future upgrading

For future upgrading, the space is considered. Then crown wall should be modified or demolished if the structure is upgraded again.

Resilience

The capacity of resilience depends on the layers of armour. Lose of material in armour layer can lead to significant damage and the loss of interlocking will make the problem worse and facilitate more losses. This problem is easier to be solved for berm breakwater type.

Land availability

For land availability the maximum space gained from the crest of the actual protection to the end of the new possible crest was taking into consideration. Due to the berm, less space is available. For Acropode^{TM} II, almost no increase in surface. For other designs, optimum increase in surface, ideal conditions.

Incursion in protected area Waddenzee

All alternatives fulfill with the condition of no incursion in the Waddenzee, nevertheless the berm breakwater will experienced some rock moving, which will eventually incuse into the Waddenzee, and for this reason it is scored lower.

Pollution during construction

Composite materials (i.e. concrete) will generated more pollution during its production and placing. Alternative with rocks are more eco-friendly.

Landscape

Stones look natural; while the concrete blocks can be considered to look unnatural.

PIANC Working with Nature philosophy

Alternatives with composite material have special bases in order to help some species to grow.

Frequency of maintenance and monitoring

Alternatives with composite materials have a better interlocking. Berm breakwater only needs to be checked after extreme storms, because its profile will be shifting for different storms, which makes that this type of structure required a more frequent inspection.

Accessibility for inspection of armour layer

All proposed alternatives have some difficulty for accessing the armour layer, due to their irregular surface. Stones in the berm breakwater are placed almost on their repose angle, making more difficult inspection labor.

Accessibility for maintenance tasks

In all alternatives is possible to place a crane on the land side to be able to perform maintenance task, as the equipment can be positioned on the crown wall and it is needed only conventional equipment

Recreation

The more gentle slopes are better for recreation activities.

Social considerations (also Dutch pride, economy boost)

Alternatives labor intensive (composite material) will generate a more dynamic economy in the region. Xbloc alternatives have the advantage of being a Dutch technology; riprap needs to be imported from other countries, which means part of work are done out of the Netherlands.

D.2.3 SCORING JUSTIFICATION FROM CARLOS

Table D- 69. Scoring Results from Carlos

CRITERIA			SCORES for each previous introduced DESIGN											
			1	2	3	4	5	6	7	8	9	10	11	12
TECHNICAL FACTORS	1	Protection from waves	+4	+4	+4	+4	+4	+4	+4	+4	+4	+4	+4	+4
	2	Construction Process	+3	+3	+2	+2	+4	+3	+2	+2	+2	+3	+3	+4
	3	Flexibility future upgrading	+3	+3	+2	+2	+4	+3	+2	+2	+2	+2	+1	+3
OPERATIONAL FACTORS	4	Resilience	+3	+2	+2	+3	+3	+3	+2	+2	+3	+2	+2	+3
	5	Land availability	+3	+2	+4	+3	+3	+1	+4	+2	+0	+2	+4	+3
ENVIRONMENT	6	Incursion in Waddenzee	+4	+4	+4	+3	+1	+4	+4	+4	+4	+1	+1	+0
	7	Pollution during construction	+3	+3	+2	+2	+3	+3	+2	+2	+2	+2	+1	+3
	8	Landscape	+3	+3	+3	+3	+3	+3	+3	+3	+3	+3	+3	+3
	9	PIANC Working with Nature	+2	+2	+3	+3	+3	+2	+3	+3	+2	+2	+3	+3
MAINTENANCE	10	Frequency maintenance & monitoring	+3	+3	+4	+4	+2	+3	+4	+4	+4	+3	+3	+3
	11	Accessibility inspection of armour layer	+3	+3	+3	+3	+2	+3	+3	+3	+3	+3	+3	+2
	12	Accessibility for maintenance tasks	+3	+3	+3	+3	+3	+3	+3	+3	+3	+3	+3	+3
THIRD PARTIES	13	Recreation	+3	+3	+3	+3	+3	+3	+3	+3	+3	+3	+3	+3
	14	Social considerations	+2	+2	+4	+4	+4	+2	+2	+2	+2	+3	+4	+3

Table D- 70. Weighed Scoring Results from Carlos

CRITERIA			WEIGHED SCORES for each previous introduced DESIGN												
			Relative weights [%]	1	2	3	4	5	6	7	8	9	10	11	12
TECHNICAL FACTORS	1	Protection from waves	13.85	55	55	55	55	55	55	55	55	55	55	55	55
	2	Construction Process	5.27	16	16	11	11	21	16	11	11	11	16	16	21
	3	Flexibility future upgrading	10.11	30	30	20	20	40	20	20	20	20	20	10	30
OPERATIONAL FACTORS	4	Resilience	6.59	13	13	13	20	20	13	13	13	20	13	13	20
	5	Land availability	6.15	18	12	18	25	18	6	25	12	0	12	25	18
ENVIRONMENT	6	Incursion in Waddenzee	9.45	38	38	38	38	9	38	38	38	38	9	9	0
	7	Pollution during construction	7.25	22	22	15	15	22	22	15	15	15	15	7	22
	8	Landscape	3.30	10	10	10	10	10	10	10	10	10	10	10	10
	9	PIANC Working with Nature	7.91	16	16	24	24	24	16	24	24	16	16	24	24
MAINTENANCE	10	Frequency maintenance & monitoring	8.57	26	26	34	34	17	26	34	34	34	26	26	26
	11	Accessibility inspection of armourlayer	6.81	20	20	20	20	14	20	20	20	20	20	20	14
	12	Accessibility for maintenance tasks	8.57	26	26	26	26	26	26	26	26	26	26	26	26
THIRD PARTIES	13	Recreation	1.76	5	5	5	5	5	5	5	5	5	5	5	5
	14	Social considerations	4.40	9	9	18	18	18	9	9	9	9	13	18	13
TOTAL			304	298	307	320	299	282	304	292	278	257	264	284	304

Protection from waves

For this criterion all alternatives were rated +4 due the fact that every one of them fulfil with hydraulics boundary conditions.

Construction Process

For Construction Process alternatives with stones scored (Riprap alternatives) +3. Alternatives using composites materials (i.e. concrete) scored +2, due to the fact that its production and placing the units is more labor demanding. Berm breakwater scored +4 due the fact that it doesn't need to satisfy a specific slope; they are just dumped stones, expediting the construction process.

Flexibility future upgrading

For scoring future upgrading, the same reasoning than for construction process was adopted, besides the space availability for future upgrading.

Resilience

For resilience, alternatives with only one layer of armour were graded with +2. Alternatives with more than one layer scored +3.

Land availability

For land availability the maximum space gained from the crest of the actual protection to the end of the new possible crest was taking into consideration, setting as maximum +4 for Xbloc® and AcropodeTM II both of them with a gained distance of 15.2 m and 15.1 m respectively.

Incursion in protected area Waddenzee

All alternatives fulfil with the condition of no incursion in the Waddenzee, nevertheless the berm breakwater will experienced some rock moving, which will eventually incuse into the Waddenzee, and for this reason it scored +1.

Pollution during construction

All construction process generates some pollution, for this reason the maximum scored given is +3, however composite materials (i.e. concrete) will generated more pollution during its production and placing, for this reason these alternatives scored +2.

Landscape

Every engineering work has its own beauty; anyhow this criterion can be subjective. Due to this motive all alternatives scored +3*.

* +3 good conditions, stones look natural

PIANC Working with Nature philosophy

Alternatives with composite material have special bases in order to help some species to grow, these have scored +3, others alternatives have scored +2.

Frequency of maintenance and monitoring

Alternatives with composite materials have a better interlocking, for this reason have scored +4 in Frequency of maintenance and monitoring. In the case of berm breakwater, its profile will be shifting for different storms, which makes that this type of structure required a more frequent inspection, for this motive berm breakwater have scored +2.

Accessibility for inspection of armour layer

All proposed alternatives have some difficulty for accessing the armour layer, due to their irregular surface. Stones in the berm breakwater are placed almost on their repose angle, making more difficult inspection labor.

Accessibility for maintenance tasks

In all alternatives is possible to place a crane on the land side to be able to perform maintenance task, for this reason all alternatives have scored +3.

Recreation

It has been considered that all alternatives present good conditions to propose some recreation features, reason why all have scored +3.

Social considerations (also Dutch pride, economy boost)

Alternatives labor intensive (composite material) will generate a more dynamic economy in the region. Xbloc alternatives have the advantage of being a Dutch technology; which can be which could be appreciated in a representative Dutch work, which would promote national pride, for this reason has been described with +4.

D.2.4 SCORING JUSTIFICATION FROM PABLO

Table D- 71. Scoring Results from Pablo

CRITERIA			SCORES for each previous introduced DESIGN											
			1	2	3	4	5	6	7	8	9	10	11	12
TECHNICAL FACTORS	1	Protection from waves	+4	+4	+4	+4	+4	+4	+4	+4	+4	+4	+4	+4
	2	Construction Process	+1	+3	+2	+2	+3	+3	+2	+2	+1	+3	+3	+4
	3	Flexibility future upgrading	+2	+2	+4	+4	+3	+1	+4	+1	+1	+1	+4	+2
OPERATIONAL FACTORS	4	Resilience	+2	+2	+2	+3	+3	+2	+3	+2	+3	+2	+4	+2
	5	Land availability	+2	+2	+3	+4	+2	+0	+4	+2	+3	+0	+4	+2
ENVIRONMENT	6	Incursion in Waddenzee	+3	+3	+3	+3	+2	+3	+3	+3	+3	+1	+1	+1
	7	Pollution during construction	+4	+4	+3	+3	+4	+4	+3	+3	+1	+4	+3	+4
	8	Landscape	+2	+3	+3	+3	+3	+2	+3	+2	+2	+2	+3	+2
	9	PIANC Working with Nature	+3	+3	+3	+3	+2	+3	+4	+3	+3	+2	+2	+2
MAINTENANCE	10	Frequency maintenance& monitoring	+4	+4	+4	+4	+1	+3	+4	+4	+4	+2	+4	+1
	11	Accessibility inspection armour layer	+2	+2	+2	+2	+3	+2	+2	+2	+3	+3	+2	+3
	12	Accessibility maintenance tasks	+3	+2	+4	+4	+3	+1	+4	+2	+2	+1	+4	+3
THIRD PARTIES	13	Recreation	+3	+2	+3	+3	+3	+1	+3	+2	+2	+1	+4	+3
	14	Social considerations	+2	+2	+4	+4	+2	+1	+3	+3	+3	+2	+4	+2

Table D- 72. Weighed Scoring Results from Pablo

CRITERIA			WEIGHED SCORES for each previous introduced DESIGN												
			Relative weights [%]	1	2	3	4	5	6	7	8	9	10	11	12
TECHNICAL FACTORS	1	Protection from waves	13.85	55	55	55	55	55	55	55	55	55	55	55	55
	2	Construction Process	5.27	5	16	11	11	16	16	11	11	5	16	16	21
	3	Flexibility future upgrading	10.11	20	20	40	40	30	10	40	10	10	10	40	20
OPERATIONAL FACTORS	4	Resilience	6.59	13	13	13	20	20	13	20	13	20	13	26	13
	5	Land availability	6.15	12	12	18	25	12	0	25	12	18	0	25	12
ENVIRONMENT	6	Incursion in Waddenzee	9.45	28	28	28	28	19	28	28	28	28	9	9	9
	7	Pollution during construction	7.25	29	29	22	22	29	29	22	22	7	29	22	29
	8	Landscape	3.30	7	10	10	10	10	7	10	7	7	7	10	7
	9	PIANC Working with Nature	7.91	24	24	24	24	16	24	32	24	24	16	16	16
MAINTENANCE	10	Frequency maintenance &monitoring	8.57	34	34	34	34	9	26	34	34	34	17	34	9
	11	Accessibility inspection of armour layer	6.81	14	14	14	14	20	14	14	14	20	20	14	20
	12	Accessibility maintenance tasks	8.57	26	17	34	34	26	9	34	17	17	9	34	26
THIRD PARTIES	13	Recreation	1.76	5	4	5	5	5	2	5	4	4	2	7	5
	14	Social considerations	4.40	9	9	18	18	9	4	13	13	13	9	18	9
TOTAL			282	285	327	340	276	236	343	264	264	212	326	252	282

Protection from waves

Every proposed alternative is fulfilling this requirement because is the main purpose of the dike. At the beginning, it was meant to distinguish the reliability of the designs for extreme conditions (failure), however the differences resulted not to be significant enough to make an alteration on the scoring. Therefore every alternative was scored in the same way.

Construction Process

To evaluate and score this particular topic, the following characteristic were taken into account: construction time, possibility of construction phasing, stockpiles required areas (Rock or concrete blocks), required equipment and road traffic intensity during construction (heavy equipment on the road) considering when the road is partially blocked.

RipRap alternative with slope 2:3 and antifer cubes alternative were considered the worst. The first one due to the large size of the required rocks for the armour layer (rarely available on the market) and the second one, mainly due to similar reasons concerning the size, but additionally these large antifer cubes should be built, transported and placed as a two-layer armour units in the dike and certainly is not the most favourable alternative.

Then every alternative which implies cutting the existing armour layer slope was scored between +2 and +3. On the one hand, the first value was given to those which requires concrete blocks casting and on the other hand, the second value was given to those alternatives which do not imply concrete elaboration, such us RipRap 1:2 and berm breakwater alternatives. However between berm breakwater alternatives there is a clear difference in favour of the dynamically reshaped breakwater, but it cannot be clearly pointed out with this methodology.

Finally, the alternatives which are placed on top of the existing basalt columns were ranked between +3 and +4 and that is due to their construction simplicity. Nevertheless, an over layer berm breakwater was scored the best alternative due to the fact that is directly dumping stones and shaping the berm.

Flexibility future upgrading

This parameter is considered a crucial characteristic for the future of the Afsluitdijk. The best scored alternatives are those with single-armour layer concrete units with an slope 3:4, due to the fact that these alternatives are much more robust and are creating extra room on the dike. These solutions are including flexibility on its design for future upgrading.

The alternatives that were scored the less are those which are setting even stronger boundary conditions for future upgrading or those that are keeping exactly the same dike width. These alternatives are considered restricted alternatives in the long-term. Rijkswaterstaat overtopping solution is within this group of solutions.

Resilience

The best scored alternative is the Xbloc® over layer due to the fact that is the one which is keeping the existing dike on its actual shape completely covered for a new solution, which in addition, it increases the dike width.

Mainly the other alternatives were scored between +2 and +3 and those scores are function of the dike width, because it is assumed that reliability between single-layer units and double-layer units is rather similar.

Land availability

Solutions with a front slope 3:4 and that are not completely cutting off the existing slope are scored +4. Among the best ranked alternatives the single-layer concrete units alternatives are the dominant. Then according to the possible added width the other alternatives were ranked. The alternatives which were scored the lowest are those who are not adding any surface to the Afsluitdijk.

Incursion in protected area Waddenzee

Three scores are identified within this category. The higher of those scores is given to those alternatives with are not invading the Waddenzee, unless a failure mechanism occurs.

An intermediate value of +2 is given to the dynamically reshaped berm breakwater, because its design's behavior. As its name states, this type of breakwater is naturally reshaped, thus some rock movements will occur and a possible invasion into the Waddenzee is expected, nonetheless the amount of invasion is almost negligible.

The lowest scores were given to the alternatives which were designed, from the very beginning, as solutions invading the Waddenzee. Nevertheless the amount of invasion compared with the size of the Waddenzee is insignificant, however it is clearly understood the consequences of this kind of decisions.

Pollution during construction

If construction is required certain level of pollution will occur. Nevertheless, keeping previous statement on mind, the alternatives with less impact were scored +4 and those are the alternatives which are not including concrete elaboration on their construction process.

The alternatives which require concrete elaboration were scored +3. This is not an environmental driver to obtain a "no go".

Nonetheless, Antifer cubes alternative was scored +1 and this is due to the large amount of concrete required.

Landscape

Every alternative is scored between +2 and +3. This is a very subjective category, but the criterion used to define the scores is the following. Those alternatives which has a natural component like rocks or belongs to a Dutch developed technology, like Xbloc® were scored higher than the others.

PIANC Working with Nature philosophy

Alternatives are scored between +2 and +4. The lowest rated alternatives are those invading the Waddenzee. Despite this, applying some measures and using PIANC WwN approach, these alternatives can be scored higher. Also, the dynamically reshaped berm breakwater is scored +2 because is continuously moving and with high chances to invade the Waddenzee.

On the other hand, only one alternative was scored +4. This alternative is the one which introduced the concept of using a special developed toe to enhance sea life in accordance with PIANC WwN Philosophy. Of course, this concept can be extrapolated to other alternatives.

The remaining alternatives were scored +3.

Frequency of maintenance and monitoring

The lowest scored alternatives are the dynamically reshaped berm breakwater. These alternatives are very simple to construct, however frequent inspections are required and probably extra provision of materials would be needed.

The RipRap over layer alternative was scored only +2, because as it is placed directly on top of the existent basalt columns, therefore it is considered that some extra monitoring and maintenance should be required.

It is assumed that the breakwater with berm would need some extra monitoring due to the fact that is a rarely studied type of breakwater. Mainly at the berm location some extra maintenance would be required.

Finally the other alternatives were scored +4.

Accessibility for inspection of armour layer

Every alternative has certain degree of difficulty for inspecting the armour layer. However some benefits can be found on the alternatives with smaller rocks such us the berm breakwater and the RipRap over layer. In addition, the antifer cubes alternative presents an interesting option concerning this category. Therefore the mentioned alternatives were scored +3.

The remaining alternatives were scored +2.

Accessibility for maintenance tasks

This is intrinsically related with Land Availability. Hence, those alternatives which include some extra areas are better scored than the ones that are leading to keep the current dike dimensions.

Recreation

As the previous category, this parameter depends on the available land. Hence, those alternatives, which include some extra areas, are better scored than the ones that are leading to keep the current dike dimensions. Nevertheless, recreation is also connected to water front accessibility, thus those alternatives which has a smooth armour layer surface are scored better than those like Xbloc® which leads to rather rough surfaces.

Social considerations (also Dutch pride, economy boost)

Here two main considerations are taken into account for the scoring, as it is well known basalt columns are highly appreciated in the Netherlands, therefore these issues should be carefully managed. Following this idea Xbloc® are highly scored as it is a Dutch developed technology. Besides, the regional/national economy boost due to the future Afsluitdijk upgrading are estimated and here again, concrete blocks armour layer lead to much larger amount of workers in the Netherlands than natural rock armour layer alternatives, hence are scored higher.

D.2.5 SCORING FROM THE CLIENT

Table D- 73. Scoring Results from the Client

CRITERIA			SCORES for each previous introduced DESIGN											
			1	2	3	4	5	6	7	8	9	10	11	12
TECHNICAL FACTORS	1	Protection from waves	+4	+4	+4	+4	+4	+4	+4	+4	+4	+4	+4	+3
	2	Construction Process	+3	+3	+2	+2	+3	+3	+2	+2	+2	+3	+2	+3
	3	Flexibility future upgrading	+3	+3	+2	+2	+3	+3	+2	+2	+2	+3	+2	+3
OPERATIONAL FACTORS	4	Resilience	+3	+3	+1	+1	+3	+3	+1	+1	+2	+3	+2	+3
	5	Land availability	+3	+3	+3	+4	+3	+3	+4	+3	+3	+2	+3	+3
ENVIRONMENT	6	Incursion in Waddenzee	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2	+1	+1
	7	Pollution during construction	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2
	8	Landscape	+2	+2	+1	+1	+2	+2	+1	+1	+1	+2	+1	+2
	9	PIANC Working with Nature	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2
MAINTENANCE	10	Frequency maintenance & monitoring	+3	+3	+3	+3	+2	+3	+3	+3	+3	+3	+3	+2
	11	Accessibility inspection of armour layer	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2
	12	Accessibility for maintenance tasks	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1
THIRD PARTIES	13	Recreation	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2
	14	Social considerations	+2	+2	+3	+3	+2	+2	+2	+2	+2	+2	+3	+2

Table D- 74. Weighed Scoring Results from the Client

CRITERIA			WEIGHED SCORES for each previous introduced DESIGN												
			Relative weights [%]	1	2	3	4	5	6	7	8	9	10	11	12
TECHNICAL FACTORS	1	Protection from waves	13.85	55	55	55	55	55	55	55	55	55	55	55	42
	2	Construction Process	5.27	16	16	11	11	16	16	11	11	11	16	11	16
	3	Flexibility future upgrading	10.11	30	30	20	20	30	30	20	20	20	30	20	30
OPERATIONAL FACTORS	4	Resilience	6.59	20	20	7	7	20	20	7	7	13	20	13	20
	5	Land availability	6.15	18	18	18	25	18	18	25	18	18	12	18	18
ENVIRONMENT	6	Incursion in Waddenzee	9.45	19	19	19	19	19	19	19	19	19	19	9	9
	7	Pollution during construction	7.25	15	15	15	15	15	15	15	15	15	15	15	15
	8	Landscape	3.30	7	7	3	3	7	7	3	3	3	7	3	7
	9	PIANC Working with Nature	7.91	16	16	16	16	16	16	16	16	16	16	16	16
MAINTENANCE	10	Frequency maintenance &monitoring	8.57	26	26	26	26	17	26	26	26	26	26	26	17
	11	Accessibility inspection armour layer	6.81	14	14	14	14	14	14	14	14	14	14	14	14
	12	Accessibility for maintenance tasks	8.57	9	9	9	9	9	9	9	9	9	9	9	9
THIRD PARTIES	13	Recreation	1.76	4	4	4	4	4	4	4	4	4	4	4	4
	14	Social considerations	4.40	9	9	13	13	9	9	9	9	9	9	13	9
TOTAL			256	256	228	235	247	256	230	224	231	250	225	224	256

D.3 SCORING JUSTIFICTION IN FINAL DESIGN (OVERTOPPING RESISTANT SOLUTION)

In the final design, a solution from RWS is included in the MCA (Overtopping resistant solution). The group also do MCA of this solution.

D.3.1 SCORING JUSTIFICATION FROM MARÍA JOSÉ

Table D- 75. Scoring Justification for Overtopping Resistant Solution from Maria Jose

Criterion	Score	Comments
Protection from waves	+2	Problems (overtopping) that are dealt with (protecting inner slope)
Construction Process	+2	Most of it is a bituminous pavement, production is polluting
Flexibility future upgrading	+3	For a possible upgrading not much work is needed but some demolitions would have to be done (can be considered as problems that can be solved)
Resilience	+2	No increase in surface, no extra space (good conditions but not ideal)
Land availability	+1	Lose of asphalt or grass layer can lead to significant damage (problem that can be solved)
Incursion in Waddenzee	+1	The design occupies protected area (difficult to resolve)
Pollution during construction	+3	Only trucks, excavators and other equipment (not ideal but good)
Landscape	+3	Small problems, asphalt does not look natural, but the dike height remains the same
PIANC Working with Nature philosophy	+2	Asphalt is not good for wildlife development (problems that can be solved)
Frequency maintenance& monitoring	+2	Grass needs maintenance (problems that can be solved)
Accessibility inspection armourlayer	+4	Ideal conditions: accessibility is good, it is possible to walk on the slopes
Accessibility for maintenance	+4	Ideal conditions: accessibility is good, it is possible to walk on the slopes, equipment can access the slopes too
Recreation	+3	Good conditions but not ideal (asphalt is not appealing for people or wildlife)
Social considerations	+3	Good conditions but not ideal (the economic impact is lower due to the lower investment, but it is a typical Dutch solution, an example of Dutch technology)

D.3.2 SCORING JUSTIFICATION FROM YUTING

Table D- 76. Scoring Justification for Overtopping Resistant Solution from Yuting

Criterion	Score	Comments
Protection from waves	+2	The main function is to deal with overtopping problem.
Construction Process	+1	Construction process is simple but interpretation would be raised.
Flexibility future upgrading	+3	Enough space for future upgrading. Less work is needed.
Resilience	+1	Not good condition for resilience due to limited function.
Land availability	+2	This alternative does not supply extra land.
Incursion in Waddenzee	+1	The design occupies protected area.
Pollution during construction	+1	The composite material plants would generate considerable pollution.
Landscape	+3	The dike would be covered with grass.
PIANC Working with Nature philosophy	+2	Asphalt is not good for wildlife development.
Frequency maintenance& monitoring	+2	It does not need so much maintenance.
Accessibility inspection armourlayer	+3	It is possible to walk on the slope, so as the equipment.
Accessibility for maintenance	+3	It is possible to walk on the slope, so as the equipment.
Recreation	+2	The cross section would look like 'natural' and the gentle slopes are good.
Social considerations	+2	Typical Dutch solution

D.3.3 SCORING JUSTIFICATION FROM CARLOS

Table D- 77. Scoring Justification for Overtopping Resistant Solution from Carlos

Criterion	Score	Comments
Protection from waves	+1	This alternative focus on overtopping resistant.
Construction Process	+3	Construction is land based. It is pretty simple compared with others alternatives.
Flexibility future upgrading	+0	Its functionality is limited to the resistant of the material (asphalt, 200 l/s/m)
Resilience	+1	Its functionality is limited to the resistant of the material (asphalt, 200 l/s/m)
Land availability	+0	This alternative does not modify the present land availability
Incursion in Waddenzee	+4	All the work is done in land.
Pollution during construction	+1	Asphalt plants generate an important quantity of pollutants
Landscape	+3	This alternative propose to keep a ' green' look, by placing grass on top of the asphalt
PIANC Working with Nature philosophy	+0	This alternative does not modify the current status.
Frequency maintenance& monitoring	+4	Does not need any frequent maintenance.
Accessibility inspection armourlayer	+4	This alternative does not modify the actual conditions, which are good.
Accessibility for maintenance	+4	This alternative does not modify the actual conditions, which are good.
Recreation	+0	No intervention regarding this criterion
Social considerations	+1	No mayor intervention on economy or national pride

D.3.4 SCORING JUSTIFICATION FROM PABLO

Table D- 78. Scoring Justification for Overtopping Resistant Solution from Pablo

Criterion	Score	Comments
Protection from waves	+2	This alternative is dealing to protect the existing shape of the Afsluitdijk, however it has very low flexibility for future protection against waves.
Construction Process	+2	It is like the construction of a massive road and everything it is land based equipment, but not the simplest alternative (at least comparing with RipRap overlayer).
Flexibility future upgrading	+0	This alternative presents very low flexibility for future upgrading and it is considered not the best temporary solution at least comparing with the other alternatives introduced in this analysis.
Resilience	+1	Resilience comparing with the presented alternatives is rather low, in addition if future scenarios are different this dike solutions is not the stronger one
Land availability	+0	The current Afsluitdijk area is maintained.
Incursion in Waddenzee	+4	As this solution is keeping Afsluitdijk original shape, there is no incursion into the Waddenzee.
Pollution during construction	+2	The production of bituminous pavement is highly pollutant
Landscape	+2	The inner slope will not change as it is going to be covered with a new grass layer, but the basalt columns will be covered with pavement. That is not nice.
PIANC Working with Nature philosophy	+0	With a pavement surface there is not exchange between the Waddenzee fauna and Afsluitdijk. Therefore any kind of win win situation is not possible.
Frequency maintenance& monitoring	+1	Large surfaces to check and maintain. Inner slope should be carefully monitored, because the general stability of the dike is relying on this. Loads are not reduced.
Accessibility inspection armour layer	+4	It will become almost an inclined road. Hence regarding this topic is the best solution.
Accessibility for maintenance	+4	It will become almost an inclined road. Hence regarding this topic is the best solution.
Recreation	+2	The same area for the dike is kept. In addition it can be said that accessibility to the waterfront will be easy.
Social considerations	+2	There will be a labour boost due to the large amount of people required to build this solution. However there will be 30km pavement dike (outer face).

Appendix E

CALCULATIONS

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APPENDIX E – CALCULATIONS

E.1 RIP-RAP

E1.1 STABILITY

Using Van der Meer.

For plunging waves:

$$\frac{H_s}{\Delta * D_{n50}} = 6.2 * P^{0.18} * \left(\frac{S}{\sqrt{N}}\right)^{0.2} * \frac{1}{\sqrt{\xi_{m0}}}$$

For surging waves:

$$\frac{H_s}{\Delta * D_{n50}} = 1 * P^{-0.13} * \left(\frac{S}{\sqrt{N}}\right)^{0.2} * \sqrt{\cot\alpha} * \xi_m^P$$

Table E- 1 Rock Stability Rip Rap

Size stone armour layer (Van der Meer)			
slope 1:	1.5	2	Units
N	7200	7200	
ρr	2,70	2,70	T/m3
S	3,00	3,00	
	1,50	2,00	
α	0,59	0,46	rad
s	0,06	0,06	
ξ	2,78	2,09	
ξcr	4,54	3,57	
Δ	1,65	1,65	
P	0,10	0,10	
Tm	6,00	6,00	sec
Tp	7,30	7,30	sec
Hsoffshore	4,78	4,78	m
Hss	3,83	3,83	m
d_{n50}	1,84	1,60	M
W	17,02	11,05	Tn

E1.2 ARMOUR LAYER THICKNESS

Using Shore Protection Manual [1984] recommendations.

The thickness of a layer t (in m) is calculated as:

$$t = n * k_t * D_{n50}$$

Number of Units;

$$N = n * k_t * A * (1 - N_v) * D_{n50}^{-2}$$

Table E- 2. (Taken from Breakwaters and closure dams [2004])[1]

Type and shape of units	Layer thickness n	Placement	Layer coefficient k_t	Porosity n_v	Source
Smooth quarry stone	2	Random	1.02	0.38	SPM
Very round quarry stone		Random	0.80	0.36	Cur/Ciria
Very round quarry stone		Special	1.05 – 1.20	0.35	Cur/Ciria
Semi-round quarry stone		Random	0.75	0.37	Cur/Ciria
Semi-round quarry stone		Special	1.10 – 1.25	0.36	Cur/Ciria
Rough quarry stone	2	Random	1.00	0.37	SPM
Rough quarry stone	> 3	Random	1.00	0.40	SPM
Irregular quarry stone		Random	0.75	0.40	Cur/Ciria
Irregular quarry stone		Special	1.05 – 1.20	0.39	Cur/Ciria
Graded quarry stone		Random	-	0.37	SPM
Cubes	2	Random	1.10	0.47	SPM
Tetrapods	2	Random	1.04	0.50	SPM
Dolosse	2	Random	0.94	0.56	SPM
Accropode	1	Special	1.3	0.52	Sogreah
Akmon	2	Random	0.94	0.50	WL

For the under layer thickness *Breakwaters and closure dams [2004]* recommendations are followed, weight ratio should be kept between 1/10 and 1/25.

Table E- 3. Rip Rap Armour Layer Thickness

Armour layer thickness			
slope 1:	**1.5**	**2**	Units
n	2,00	2,00	
kt	0,87	0,87	T/m3
dn50	1,85	1,60	
W	17,03	11,06	T
nv	0,48	0,48	rad
A	19,83	19,83	m²/m
t	3,21	2,78	m
N	33,46	28,98	units/m

Table E- 4. Under layer thickness Rip Rap

Under layer thickness			
slope 1:	**1.5**	**2**	Units
n	2,00	2,00	
kt	0,87	0,87	
dn50	0,86	0,74	
W	1,70	1,10	T
nv	0,48	0,48	rad
t	2,24	1,94	m

E1.3 TOE STABILITY

For toe stability findings from L. Docters Van Leeuwen [1996] as presented in *Breakwaters and closure dams [2004]* are followed.

$$\frac{H_s}{\Delta * D_{n50}} = \left(0.24 * \frac{h_t}{D_{n50}} + 1.6\right) * N_{od}^{0.15}$$

Table E- 5. Toe Stability Rip Rap

Toe Stability			
slope 1:	1.5	2	Units
Actual water depth	5,00	5,00	
Design sea level	5,31	5,31	
Hs =	3,83	3,83	m
Δ=	1,65	1,65	
h =	10,31	10,31	m
filter layer	0,20	0,20	
armour layer thickness	3,21	2,78	m
maximum ht =	7,44	7,62	m
ht =	7,500	7,500	m
Nod	0,50	0,50	
ρrock=	2700,00	2700,00	kg/m3
ρwater=	1030,00	1030,00	kg/m3
Dn50, calculated=	0,56	0,56	m
Wcalculated=	0,47	0,47	T

Wrounded=	1,700	1,700	T
dn50, rounded =	0,900	0,900	m
Wminimum=	1,70	1,11	T
ht=	7,50	7,50	
dn50, rounded =	0,90	0,90	m
number stones=	3,00	3,00	
head width=	2,70	2,70	m
head height=	1,98	1,98	m

E1.4 WAVE RUN-UP, RUN-DOWN AND OVERTOPPING

For this section Van der Meer formulae are used.

$$\frac{Ru_{2\%}}{H_{mo}} = \{1.6 * \gamma_B * \gamma_r * \gamma_\beta * \xi_0 \}$$

$$\frac{q}{\sqrt{g * H_s^3}} = \frac{0.06}{\sqrt{\tan\alpha}} * \gamma_B * \xi_0 * exp\left(-4.7 * \frac{R_c}{H_s} * \frac{1}{\xi_0 * \gamma_B * \gamma_r * \gamma_\beta * \xi_0 * \gamma_v}\right)$$

Table E- 6. Run-Up Rip Rap

Run-up			
slope 1:	**1.5**	**2**	Units
Hs=	3,83	3,83	m
Tp=	7,30	7,30	s
α=	0,59	0,46	rad
A=	1,75	1,75	
γb=	1,00	1,00	
γf=	0,45	0,45	
β=	0,00	0,00	º
γβ=	1,00	1,00	
sop=	0,05	0,05	
ξop=	3,11	2,33	
Ru2%=	9,37	7,03	m

Table E- 7Run-Down Rip Rap

Run-down			
Case: NAP+1, Hs=2.63,Tm=4.9, Tp=5.9m			
slope 1:	**1.5**	**2**	Units
Hs=	3.83	3.83	m
α=	0,59	0,59	rad
P=	0,10	0,10	
Tm=	6.20	6.20	sec
som=	0,06	0,06	
Rd2%	3.48	2.56	m

Run-down			
Case: NAP+1, Hs=2.63,Tm=4.9, Tp=5.9m			
slope 1:	**1.5**	**2**	Units
Hs=	2,63	2,63	m
α=	0,59	0,46	rad
P=	0,10	0,10	
Tm=	4,90	4,90	sec
som=	0,07	0,07	
Rd2%	2.33	1.73	m

Table E- 8. Overtopping Rip Rap

Overtopping			
slope 1:	**1.5**	**2**	Units
g=	9,81	9,81	m/s²
Hs=	3,83	3,83	m
Hm0=	4,14	4,14	m
Tm=	6,00	6,00	s
Tz=	7,30	7,30	s
α=	0,59	0,46	rad
Ba=	3,01	2,61	
Dn50=	1,85	1,60	m
Ba/Hs=	0,73	0,63	
Rc=	4,50	4,50	m
som=	0,07	0,07	
ξ=	2,46	1,84	
C=	0,20	0,20	
D=	2,30	2,30	
γf=	0,72	0,69	
γβ=	1,00	1,00	
q=	0,16	0,144	l/s/m

E.2 XBLOC®

E.2.1 STABILITY

XBLOC® guidelines propose;

$$V = \left[\frac{H_s}{2.77 * \Delta}\right]^3$$

E.2.2 ARMOUR LAYER THICKNESS

Using Shore Protection Manual [1984] recommendations.

Table E- 9. Armour layer thickness Xbloc®

Size stone armour layer (XBloc® guidelines)				
slope 1:	**1.5**	**1.33**	**Units**	
Hss	3,72	3,72	m	
α=	0,59	0,64	rad	
ρconcrete=	2,40	2,40	T/m3	
ρwaterr=	1,03	1,03	T/m3	
Δ =	1,33	1,33		
Correction factors:				
Low core permeability	1,50	1,50		
V=	1,54	1,54	m3	
D=	1,67	1,67	m	
Dy=	1,05	1,05	m	Length per block unit along slope
Max. Slope length=	20,76	20,76	m	This means 19 units along the slope
W=	3,70	3,70	T	
D=	1,66	1,66	m	
hmax=	11,51	12,45	m	Maximum slope height

Armour layer thickness (XBloc® guidelines)			
slope 1:	**1.5**	**1.33**	**Units**
n	1,00	1,00	
kt	0,87	0,87	T/m3
dn50	1.67	1,67	
nv	0,48	0,48	rad
A	40.3	38.16	m²/m
t	1.62	1.62	m
N	19	18	units/m

Table E- 10. Under layer thickness Xbloc®

Under layer thickness check				
slope 1:	**1.5**	**1.33**	**Units**	
n	2,00	2,00		Number of layers
kt	0,87	0,87		For rock
dn50	0,75	0,75	m	
W	1,00	1,00	T	From design guidelines
nv	0,48	0,48	rad	
t (calculated)	1.30	1.30	m	1.30m according to design guidelines

E.2.3 TOE STABILITY

For toe stability findings from L. Docters Van Leeuwen [1996] as presented in *Breakwaters and closure dams [2004]* are followed.

Table E- 11. Toe Stability Xbloc®

Toe Stability				
slope 1:	**1.5**	**1.33**	**Units**	
Actual water depth	5,00	5,00		
Design sea level	5,31	5,31		
Hs =	3,83	3,83	m	
Δ=	1,33	1,33		
h =	10,31	10,31	m	Total water depth
filter layer	1,30	1,30		
armour layer thickness	1,66	1,66	m	
maximum ht =	8,61	8,61	m	Compatible with geometry
ht =	7,500	7,500	m	Water depth above the toe
Nod	0,50	0,50		Start of damage
ρrock=	2700,00	2700,00	kg/m3	
ρwater=	1030,00	1030,00	kg/m3	
Dn50, calculated=	0,69	0,69	m	
Wcalculated=	0,89	0,89	T	
Wrounded=	0,900	0,90	T	From design guidelines
dn50, rounded =	0,700	0,70	m	
Wminimum=			T	
ht=	7,50	7,50		
dn50, rounded =	0,70	0,70	m	
number stones=	3,00	3,00		
head width=	2,10	2,10	m	From design guidelines
head height=	1,40	1,40	m	

E.2.4 WAVE RUN-UP, RUN-DOWN AND OVERTOPPING

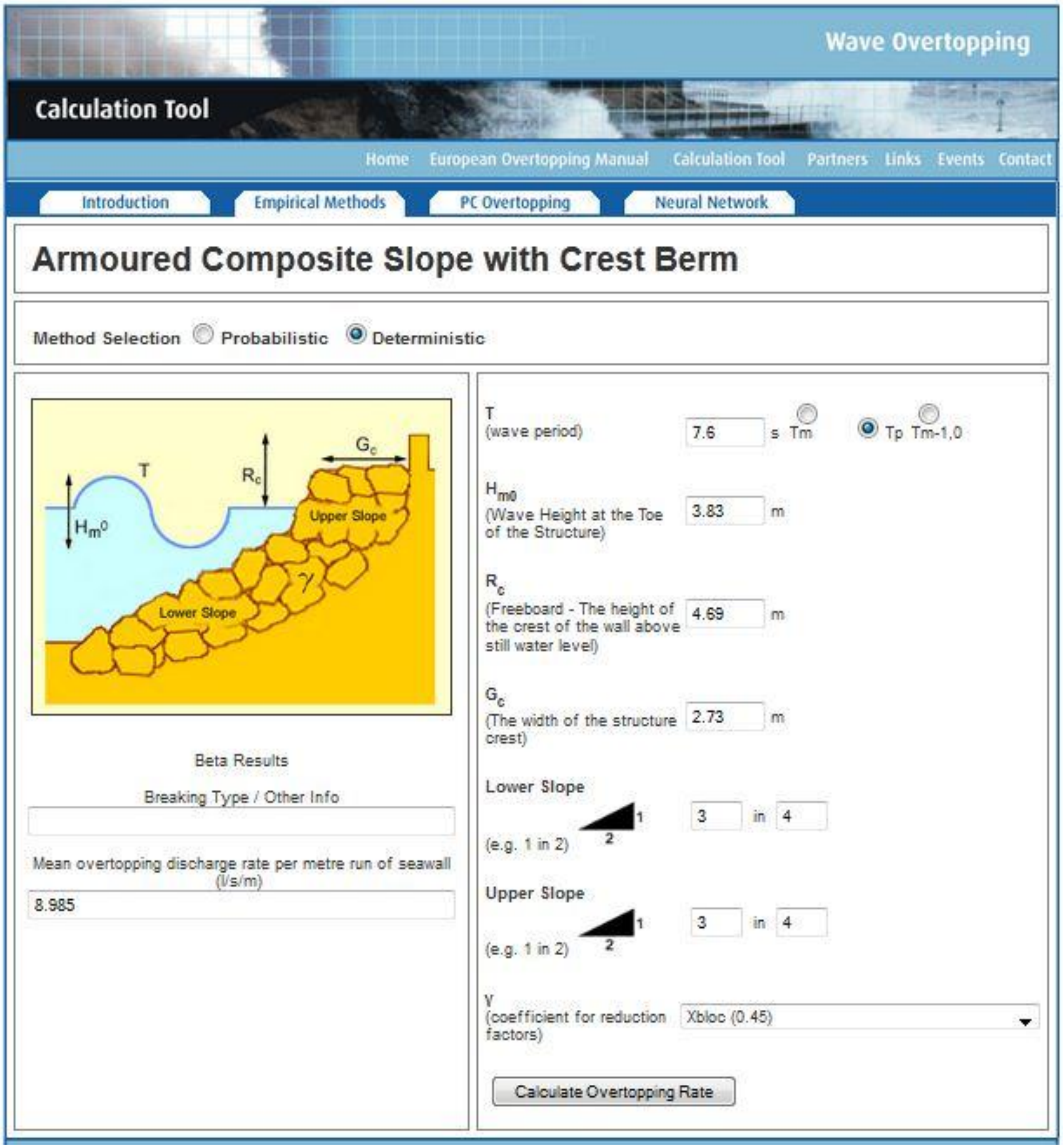
Table E- 12. Run-Up and Run-down Xbloc®

Run-up				
slope 1:	**1.50**	**1.33**	**Units**	
Hs=	3,83	3,83	m	
Tp=	7,30	7,30	s	
α=	0,59	0,64	rad	
A=	1,75	1,75		
γb=	1,00	1,00		No berm reduction
γf=	0,44	0,44		
β=	0,00	0,00	º	
γβ=	1,00	1,00		
sop=	0,05	0,05		
ξop=	3,11	3,50		
Ru2%=	9,16	10,312	m	

Run-down			
Case: NAP+5.31, Hs=3.72,Tm=6.1, Tp=7.5m			
slope 1:	**1.50**	**1.33**	Units
Hs=	3,72	3,72	m
α=	0,59	0,64	rad
P=	0,10	0,10	
Tm=	6,10	6,10	sec
som=	0,06	0,06	
Rd2%=	3,34	3,72	m

Run-down			
Case: NAP+1, Hs=2.63,Tm=4.9, Tp=5.9m			
slope 1:	1.50	1.33	Units
Hs=	2,63	2,63	m
α=	0,64	0,64	rad
P=	0,10	0,10	
Tm=	4,90	4,90	sec
som=	0,07	0,07	
Rd2%=	2,33	2,61	m

Table E- 13.Overtopping Xbloc®



E.2.5 CROWN WALL

The theoretical method proposed by F.L Martin in the report "Experimental study of wave forces on rubble mound breakwater crown walls" (Martin, 1999), is followed.

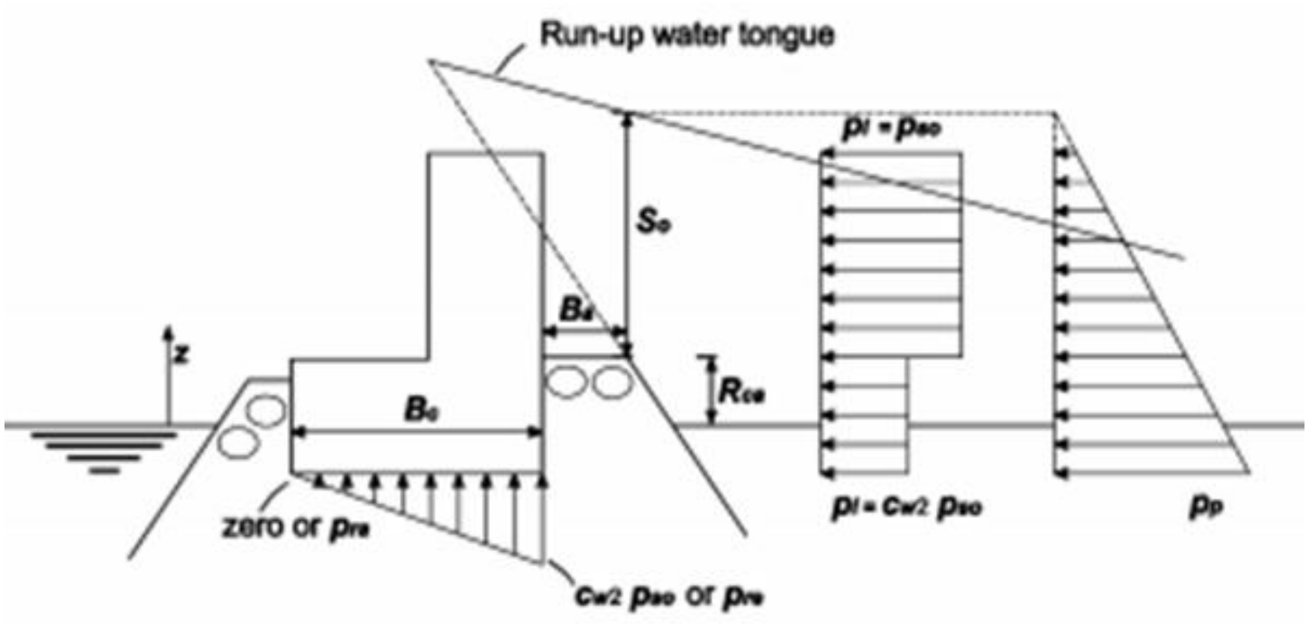


Figure E- 1.Pressure distribution (Martin 1999)

$$P_i(z) = C_{w1} * \rho_w * g * S_o$$

$$S_o = H * \left(1 - \frac{R_{ca}}{R_u}\right)$$

$$C_{w1} = 2.9 * \left[\left(\frac{R_u}{H}\right) * \cos\alpha\right]^2$$

For $0.030<H/L_p<0.075$

$$P_i(z) = C_{w2} * C_{w1} * \rho_w * g * S_o$$

$$C_{w2} = 0.8 * exp\left(\frac{-10.9 * B_a}{L_p}\right)$$

$$\frac{R_u}{H} = A_u * (1 - \exp(B_a * \xi))$$

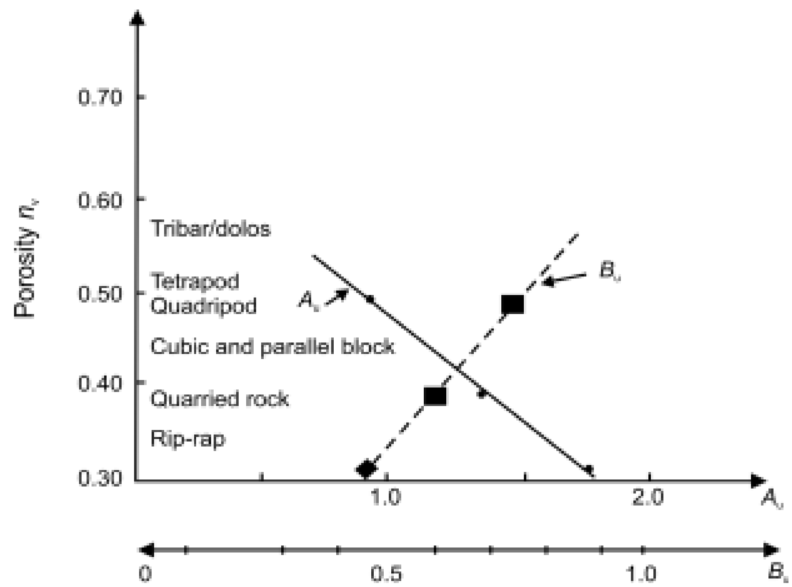


Figure E- 2. Run-up Parameters (Martin 1999)

$$P_p(z) = C_{w3} * \rho_w * g * (S_o + R_{cu} - z)$$

$$C_{w3} = a * exp(C_o)$$

$$C_o = C * \left(\frac{H}{L_p} - b\right)^2$$

B_e/D_{n50}	a	b	c
1	0.446	0.068	259.0
2	0.362	0.069	357.1
3	0.296	0.073	383.1

Figure E- 3.Empirical Coefficients for pulsating pressures (Martin 1999)

Table E- 14. Crown wall pre-dimensioning

Crown wall pre-dimensioning (Martin)			
General data		Units	
g=	9.81	m/s^2	
ρw=	1030.00	kg/m^3	
ρconcrete=	2400.00	kg/m^3	
ρsoil=	1800.00	kg/m^3	
Hs=	3.72	m	
H99.8%=	6.70	m	Estimation: 1.8Hs (always <0.75d)
Tp=	7.50		
L0p=	87.82	m	local wave length corresponding Tp
Bc=	**7.00**	**m**	Width crown wall base (SET THEN CHECKED)
dc=	**3.80**	**m**	Total height of crown wall (SET THEN CHECKED)
slab thickness=	**2.00**	**m**	Dimensions slab (SET THEN CHECKED)
wall thickness=	**1.80**	**m**	Dimensions vertical wall (SET THEN CHECKED)
wall height=	1.20	m	Measured at the inner part
shear key (soil)=	**0.60**	**m**	Included in total wall height dc (SET THEN CHECKED)
Ba=	2.73	m	Horizontal crest width of armour layer
Rca=	4.00	m	Armour layer freeboard
α=	0.64	rad	Slope
n=	0.587		
Au=	0.60		From figure 5.88 Rock Manual
Bu=	0.90		From figure 5.88 Rock Manual
ξ=	3.65		
Ru=	10.44	m	
Unprotected area			
So=	4.13	m	Coefficient figure 5.85 Rock Manual
cw1=	2.89	m	Coefficient figure 5.85 Rock Manual
pi=	119617.88	N/m^2	Impact pressure along unprotected area
Protected area			
cw2=	0.03	m	Coefficient figure 5.85 Rock Manual
pi=	3588.54	N/m^2	Impact pressure along protected area
Pulsating pressure			
a=	0.45		From table 5.51 Rock Manual
b=	0.07		From table 5.51 Rock Manual
c=	259.00		From table 5.51 Rock Manual
co=	0.017601		Eq. 5.217 Rock Manual
cw3=	0.45		Eq. 5.216 Rock Manual
zmin=	**0.20**	**m**	Crown wall is assumed to be above design water level
p_p=	36021.38	N/m^2	Pulsating pressure

Underpressure			
Bc/L=	0.08		
pui=	3588.54		uplift impact pressure
pre=	36021.38		uplift pulsating pressure
pra=	18010.69		coeff. 0.5 (n=0.4, Fig. 5.87 Rock Manual)
Passive stresses soil			
ϕ'=	0.56		**No passive stresses in this case**
β=	1.57		(there is not a wide enough soil layer
δ=	0.00		supporting the back of the crown wall slab)
i=	0.00		
ρsoil=	1800.00	kg/m^3	
kp=	3.84		
h=	0.00	m	
Fp=	0.00	N	
Safety check			**Separated checks for impact and pulsating pressure**
SLIDING			
Fg'=	405898.56	N	(no stresses on crown wall from Xbloc® units)
Fgsoil=	65687.76	N	
Fgtot=	471586.32	N	
Fui=	**12559.88**	**N**	Uplift impact force
Fup=	**189112.24**	**N**	Uplift pulsating force
Fhi=	**13636.44**	**N**	Horizontal impact force
Fhp=	**68440.62**	**N**	Horizontal pulsating force
f=	0.65		friction factor (0.5, 0.65 if the base is made of stones)
f(Fgtot-Fui)=	**255670.144**	**>Fhi-Fp**	
Safety coeff=	**18.75**		**Ok!**
f(Fgtot-Fup)=	**140911.111**	**>Fhp-Fp**	
Safety coeff=	**2.05**		**Ok! SLIDING IS THE LIMITING FACTOR**
TURNING			
Mg=	1542697.06	Nm	Crown wall weight moment
Mui=	**58026.63**	**Nm**	Uplift impact moment
Mup=	**1023727.57**	**Nm**	Uplift pulsating moment
Mp=	0.00	Nm	Passive stress moment
Mh=	25909.23	Nm	Horizontal forces moment (destabilizing)
Mg+Mp-Mui=	**1484670.424**	**>Mh**	OK!
Safety coeff=	**57.30**		**Ok!**
Mg+Mp-Mup=	**518969.489**	**>Mh**	OK!
Safety coeff=	**20.03**		**Ok!**

Sliding is the limiting factor for the crown wall calculation here, but the other safety coefficients are quite high. This indicates that there is room for design improvement. As the substitution of the crown wall for concrete units has been chosen as preferred solution, no more refinement on the crown wall calculations has been done.

E.3 DYNAMICALLY STABLE RESHAPED BERM BREAKWATER

This type of breakwater allows some rock movement (up and down, longshore transport should be restricted) causing the breakwater to reshape until a new reshaped equilibrium profile is achieved.

Berm breakwaters allow an easy construction method making use of only two different rock grading types; one for the armour layer and one for the core.

E.3.1 STABILITY

Guidelines "State of the art of designing and constructing berm breakwaters" (PIANC MarCom WG 40, 2003) and "Berm Breakwaters Un-conventional Rubble-Mound" (Baird et al., 1987; van Gent et al., 2012) are followed.

$$N_s = H_o = \frac{H_s}{\Delta * D_{n50}}$$

$$T_o = \sqrt{\frac{g}{D_{n50}}} * T_z$$

Regime	Ns≡Ho or N_s**	H_0T_0	Ns*
Little movement	<1.5-2	<20-40	<3.4 – 5.4
Limited movement during reshaping, statically stable	1.5-2.7	40-70	5.4 – 7.8
Relevant movement, dynamically stable	>2.7	>70	>7.8

Figure E- 4. Mobility criterion Bermbreakwaters "State of the art of designing and constructing berm breakwaters"

Table E- 15. Stability Bermbreakwater

H_s	**3,83**	**m**
D_{n50}	0,75	m
T_z	7.6	s
ρ_s	2,7	t/m3
ρ_w	1,025	t/m3
Δ	1,63	
Ns=Ho	3,12	
To	27,49	
HoTo	85,89	

In order to predict the reshaped profile, the dynamic profile is expressed in terms of wave parameters according, Van der Meer proposed on Berm Breakwaters Un-conventional Rubble-Mound" (Baird et al., 1987; van Gent et al., 2012):\

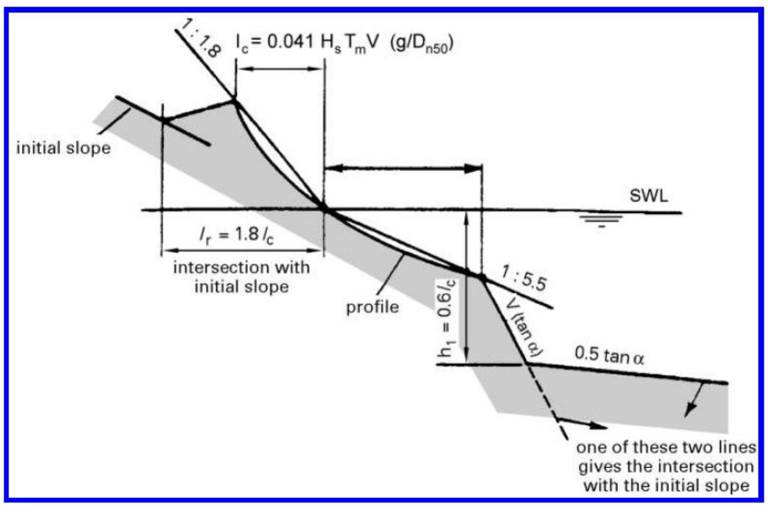


Figure E- 5. Schematized Profile dimensions for sand gravel beaches

Table E- 16.Profile parameters Bermbrerakwater

L_c	**4,32**	**m**
L_s	7,77	m
h_t	2,59	m
α	33.33	°

After some curve fitting the final profile as presented on drawings is obtained

E.3.2 ARMOUR LAYER THICKNESS

Table E- 17. Armour layer thickness Bermbreakwater

Armour layer thickness			
n	2,00	2,00	
kt	0,87	0,87	T/m3
D_{n50}	0,75	1,60	
W	1,14	11,06	T
nv	0,48	0,48	rad
A	134,23	19,83	m²/m
t	1,305	2,78	m
N	91,964	28,98	units/m

Table E- 18. Under layer thickness

Under layer thickness			
slope 1:	**1.5**	**1.33**	**Units**
n	2,00	2,00	
kt	0,87	0,87	
D_{n50}	0,75	0,75	m
W	1,00	1,00	T
nv	0,48	0,48	rad
t	1.30	1.30	m

E.3.3 WAVE RUN-UP AND OVERTOPPING

Van der Meer approach is used with the following parameters in order to stimate the run up;

Table E- 19. Run-up Bermbreakwater

Run-up		
slope 1:	**1.5**	**Units**
Hs=	3,83	m
Tp=	7,30	s
α=	0,59	rad
A=	1,6	
γb=	0.72	
γf=	0,55	
β=	0,00	º
γβ=	1,00	
sop=	0,042	
ξop=	3,23	
Ru2%=	7.88	m

$$\frac{Ru_{2\%(\max)}}{H_{mo}} = \left\{3.2 * \gamma_r * \gamma_\beta \right\}$$

$Ru_{2\%(max)}$=6.74 m

In order to get an appreciation of the amount of overtopping, to different approach were carried out, one using the reshape profile on PcOverslag (Pullen et al.), and the formulae proposed by Burcharth (Andersen & Burcharth, 2005)

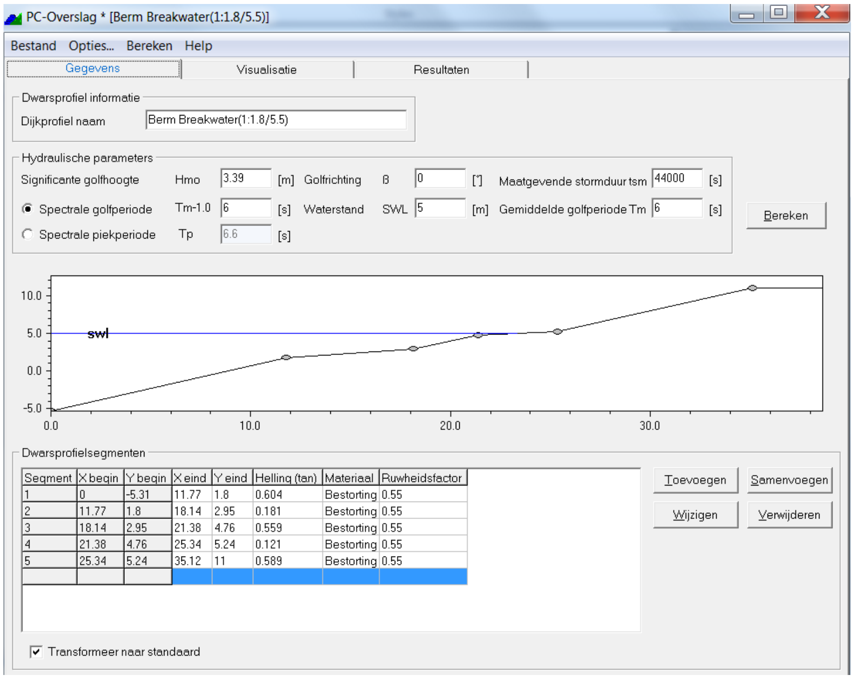


Figure E- 6. Input PcOverslag for bermbreakwater

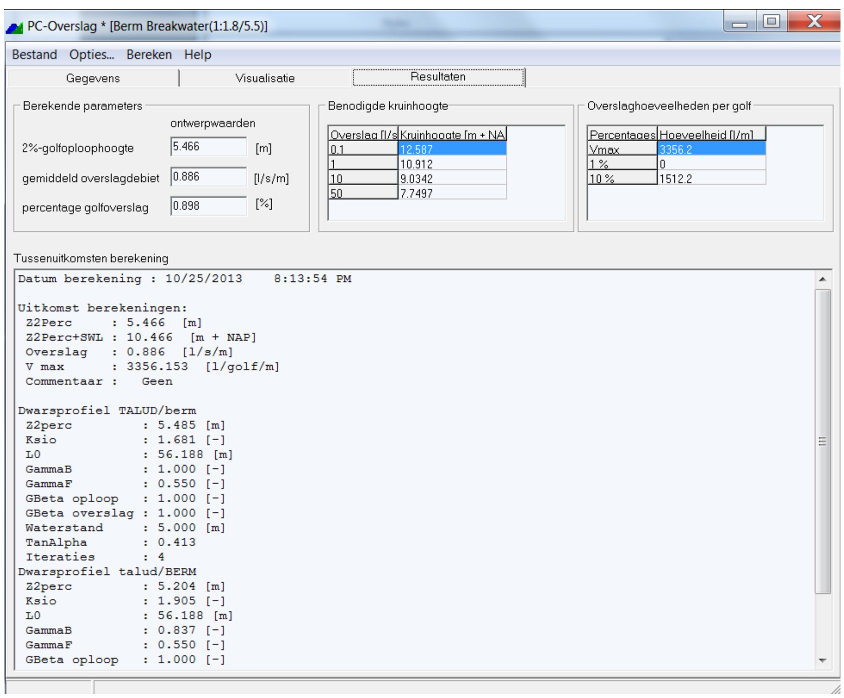


Figure E- 7. Output PcOverslag for bermbreakwater

Burcharth et al proposed the following formula;

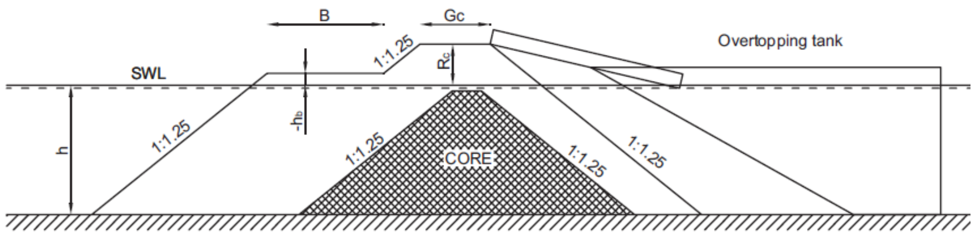


Figure E- 8. Initial Geometry Bermbreakwater

$$Q_* = 1.79 * 10^{-5} * \left(f_{HO}{}^{1.34} + 9.22\right) * S_{op}{}^{-2.52} * exp\left[-5.63 * R_*^{0.92} - 0.61 * G_*^{1.39} - 0.55 * h_b^{1.48} * B_*^{1.39}\right]$$

$$Q_* = \frac{Q}{\sqrt{g * H_{m0}^3}}$$

$$R_* = \frac{R_c}{H_{m0}}$$

$$G_* = \frac{G_c}{H_{m0}}$$

$$B_* = \frac{B}{H_{m0}}$$

$$h_{b*} = \frac{3 * H_{m0} - h_b}{3 * H_{m0} + R_c}$$

$$T_0^* = \frac{19.8 * exp\left(\frac{-708}{H_{m0}}\right) * S_{op}{}^{-0.5} - 11}{0.07 * H_0}$$

$T_0 > T_0^*$

$$f_{H0} = 19.8 * exp\left(-\frac{7.08}{H_0}\right) * S_{op}{}^{-0.5}$$

$T_0 . < T_0^*$

$$f_{H0} = 0.07 * H_0 * T_0 + 11$$

Table E- 20. Overtopping Bermbreakwater

Overtopping		
slope 1:	**1.5**	**Units**
D_{n50}	3,83	m
ρ_s	7,30	s
ρ_w	0,59	rad
R_c	1,6	m
H_{m0}	0.72	kg/m3
G_c	0,55	kg/m3
B	0,00	m
h_b	1,00	m
R*	1,17	
G*	0,78	
B*	1,96	
hb*	0,79	
Sop	0,04	
Δ	1,63	
Ho	3,12	
To	27,49	
HoTo	85,89	
To*	-4,71	
fho	9,97	
Q*	0,0005619	
q	13,19	l/s/m

E.4 BREAKWATER WITH BERM

E.4.1 STABILITY

For this type of breakwater the same formulation for Rip-Rap is used, the only difference is that for the case of the upper slope(above the berm) a reduction is used as propose by Van Gent et al (van Gent et al., 2012)

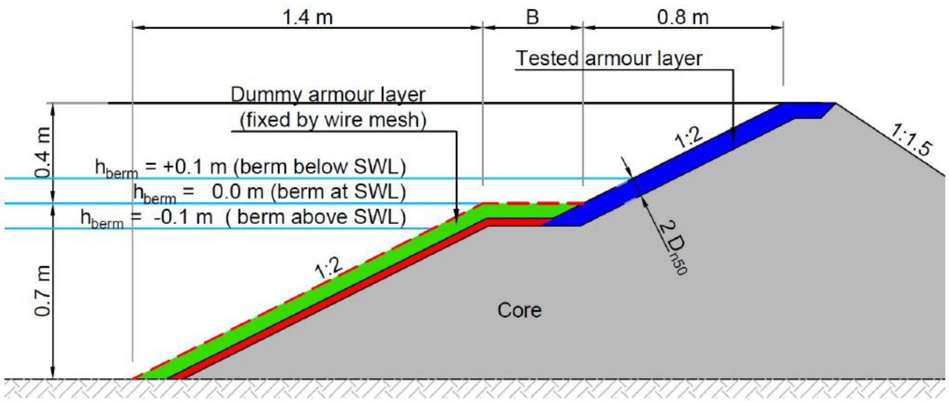


Figure 1. Configuration of tested structures with a berm (for stability of upper slope).

Figure E- 9. Configuration of tested structures (Van Gent et al [7])

$$S = \gamma_{berm} * \gamma_{pos} * \left(0.57 * \frac{H_s}{\Delta * D_{n50}} * (\tan\alpha)^{0.5} * \left(1 + \frac{D_{n50core}}{Dn50}\right)^{-\frac{2}{3}} * N^{0.1}\right)^5$$

$$\gamma_{pos} = \left(\frac{2 * H_s + h_b}{4 * H_s}\right)^5$$

$$\gamma_{berm} = 1 - C_1 * S_{m-1,0}{}^{C_2}\left(\frac{B}{H_s}\right)^{C_3}$$

Table E- 21. Stability Upper Slope Breakwater with Berm

Stability Upper Slope Breakwater with Berm		
slope 1:	**2**	**Units**
S	2	m
N	7500	s
Hs =	3,83	rad
ρr=	2,7	m
ρw=	1,025	kg/m3
Tm =	7,6	kg/m3
β =	0	m
Hb=	0	m
B=	7.5	
α =	0,46	rad
s =	1,96	
ξ=	0,79	

Δ =	0,04	
D_{core}/D_{n50}	0.5	
D_{n50}	0.75	
γpos =	0,03	
γberm =	0,91	
C1	0,08	
C2	-0,05	

E.4.2 ARMOUR LAYER THICKNESS

Table E- 22. Armour layer upper slope breakwater with berm

Armour layer thickness	
n	2,00
kt	0,87
D_{n50}	0,75
W	1.21
nv	0,48
t	1,33

E.4.3 WAVE RUN-UP, OVERTOPPING

Table E- 23. Run-Up and Overtopping Breakwater with Berm

Run-up and Overtopping		
β =	0	rad
dh =	0	m
Hs =	3,83	m
Tm =	7,6	s
B =	7,5	m
α =	0.46	rad
γb =	0.75	
γβ =	1	
γv=	0.65	
γf=	0.8	
Ru2%=	8.96	m
Rc =	4	m
q =	2.05	l/s/m

E.5 ACCROPODE™ II

E.5.1 STABILITY

For the computation of stability for ACCROPODE™ II Breakwaters and Closure Damns (Verhagen et al., 2009) propose:

$$\frac{H_s}{\Delta * d_n} = 2.5$$

Table E- 24. Stability Accropode™ II

rho =	**2400**	**kg/m3**
Nod =	0,0	Start of Damage
Δ =	1,35	
Hss	3,83	m
Ns = Hss / Δ d_n =	2,5	for Accropode II, design value
d_n =	1,13	m
H =	1,62	m

E.5.2 ARMOUR LAYER THICKNESS

Table E- 25. Armour layer Thickness Accropode™

Armour layer thickness		
n	1,00	
kt	1,30	
D_{n50}	1,33	m
W	4,46	t
nv	0,52	
t	1,73	m

Table E- 26. Under layer thickness Accropode^{TM}

Under layer thickness		
n	3,00	
kt	0,87	
D_{n50}	0,67	m
W	0,446	t
nv	0,44	
t	1,16	m

E.5.3 WAVE RUN-UP, RUN DOWN AND OVERTOPPING

Table E- 27. Run-up Accropode^{TM}

Run-up		
slope 1:	**1.33**	**Units**
Hs=	3,83	m
Tp=	7,60	s
α=	0,64	rad
A=	1,75	
γb=	1,00	
γf=	0,46	
β=	0,00	º
γβ=	1,00	
sop=	0,04	
ξop=	3,65	
Ru2%=	11,252	m

Table E- 28. Run down Accropode^{TM}

Run-down		
Case: NAP+5.31, Hs=3.83,Tm=6.2, Tp=7.6m		
slope 1:	**1.33**	Units
Hs=	3,83	m
α=	0,64	rad
P=	0,10	
Tm=	6,20	sec
som=	0,06	
Rd2%=	3,846	m

Run-down		
Case: NAP+1, Hs=2.63,Tm=4.9, Tp=5.9m		
slope 1:	1.33	Units
Hs=	2,63	m
α=	0,64	rad
P=	0,10	
Tm=	4,90	sec
som=	0,07	
Rd2%=	3,84	m

In order to compute overtopping PcOverslag (Pullen et al.) was used.

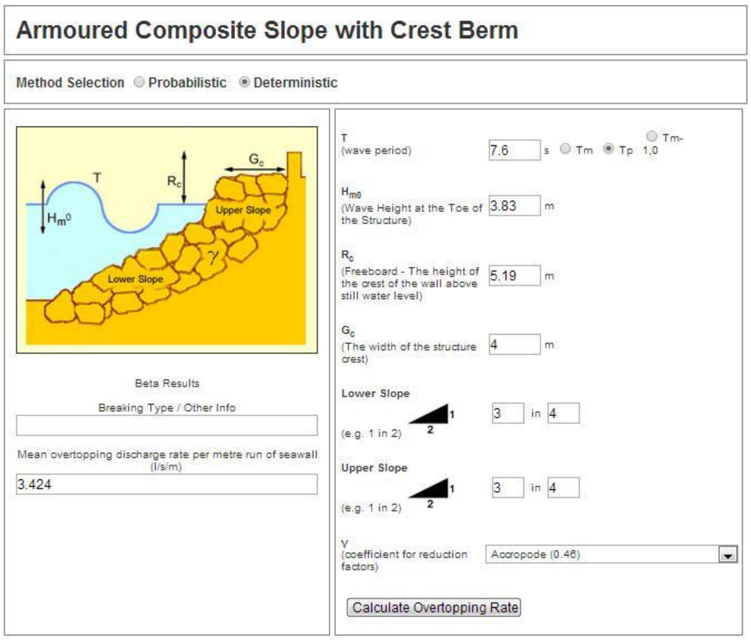


Figure E- 10. Overtopping Accropode™

E.6 RIP-RAP OVERLAYER

E.6.1 STABILITY

Table E- 29. Stability Rip Rap Overlayer

Size stone armour layer (Van der Meer)		
slope 1:	3.6	Units
N	7200	
ρr	2,70	T/m3
S	8,00	
	3,60	
α	0,27	rad
s	0,04	
ξ	1,35	
ξcr	2,19	
Δ	1,65	
P	0,10	
Tm	6,10	sec
Tp	7,50	sec
Hsoffshore	3,72	m
Hss	7200	m
d_{n50}	1,027	M
W	2,928	Tn

E.6.2 ARMOUR LAYER THICKNESS

Table E- 30. Armour layer thickness

Armour layer thickness		
slope 1:	**3.6**	Units
n	2,00	
kt	0,87	T/m3
dn50	1,03	
W	2.93	T
nv	0,48	rad
A	19,83	m²/m
t	1,78	m
N	18,61	units/m

Table E- 31. Under layer thickness Rip Rap Overlayer

Under layer thickness		
slope 1:	**1.33**	Units
n	3,00	
kt	0,87	
dn50	0,48	
W	0.30	T
nv	0,48	rad
t	1.26	m

E.6.3 TOE STABILITY

Table E- 32. Toe Stability Rip Rap overlayer

Toe Stability		
slope 1:	3.6	Units
Actual water depth	5,00	
Design sea level	5,31	
Hs =	3,72	m
Δ=	1,65	
h =	10,31	m
filter layer	1,26	
armour layer thickness	1,79	m
maximum ht =	1,00	m
	0,74	
ht =	5,05	m
	7,32	
Nod		
ρrock=	7,000	kg/m3
ρwater=		kg/m3
Dn50, calculated=	0,50	m
Wcalculated=	2700,00	T
	1030,00	
Wrounded=	0,60	T
dn50, rounded =	0,58	m

Wminimum=		T
ht=	0,750	
dn50, rounded =	0,700	m
number stones=	0,29	
	7,00	
head width=	0,70	m
head height=	3,00	m

E.6.4 WAVE RUN-UP, RUN DOWN AND OVERTOPPING

Table E- 33. Run-up Rip Rap overlayer

Run-up		
slope 1:	**1.33**	Units
Hs=	3,72	m
Tp=	7,30	s
α=	0,27	rad
A=	1,75	
γb=	1,00	
γf=	0,55	
β=	0,00	º
γβ=	1,00	
sop=	0,04	
ξop=	1,31	
Ru2%=	4,70	m
Run-down		
Case: NAP+1, Hs=2.63,Tm=4.9, Tp=5.9m		
slope 1:	**3.6**	Units
Hs=	3.83	m
α=	0,27	rad
P=	0,10	
Tm=	6,10	sec
som=	0,06	
Rd2%	1.07	m

Run-down		
Case: NAP+1, Hs=2.63,Tm=4.9, Tp=5.9m		
slope 1:	**3.6**	Units
Hs=	2,63	m
α=	0,27	rad
P=	0,10	
Tm=	4,90	sec
som=	0,07	
Rd2%	0.735	m

For the computation of overtopping Taw method have been used;

$$\frac{q}{\sqrt{g * H_{m0}{}^{3}}} = \frac{A}{\sqrt{\tan\alpha}} * \gamma_b * \xi_{m-1,0} * exp\left(-B * \frac{R_c}{H_{m0} * \xi_{m-1,0} * \gamma_b * \gamma_f * \gamma_\beta}\right)$$

Table E- 34. Overtopping Rip Rap overlayer

Overtopping		
slope 1:	**1.33**	Units
g=	9,81	m/s²
Hs=	3,83	m
Tm-1,0=	6,20	s
α=	0,27	rad
Ba=	2,68	
Dn50=	1,03	m
Ba/Hs=	0,70	
Rc=	3,00	m
som=	0,06	
ξm-1,0=	1,10	
A=	0,06	
C=	0,20	
D=	2,30	
B=	4,70	
γb=	1,00	
γf=	0,55	
γβ=	1,00	
q=	6,68	l/s/m

E.7 COMPUTATION OF OVERTOPPING FOR THE YEAR 2100

E.7.1 OVERTOPPING ESTIMATION FOR RWS SOLUTION FOR THE YEAR 2100

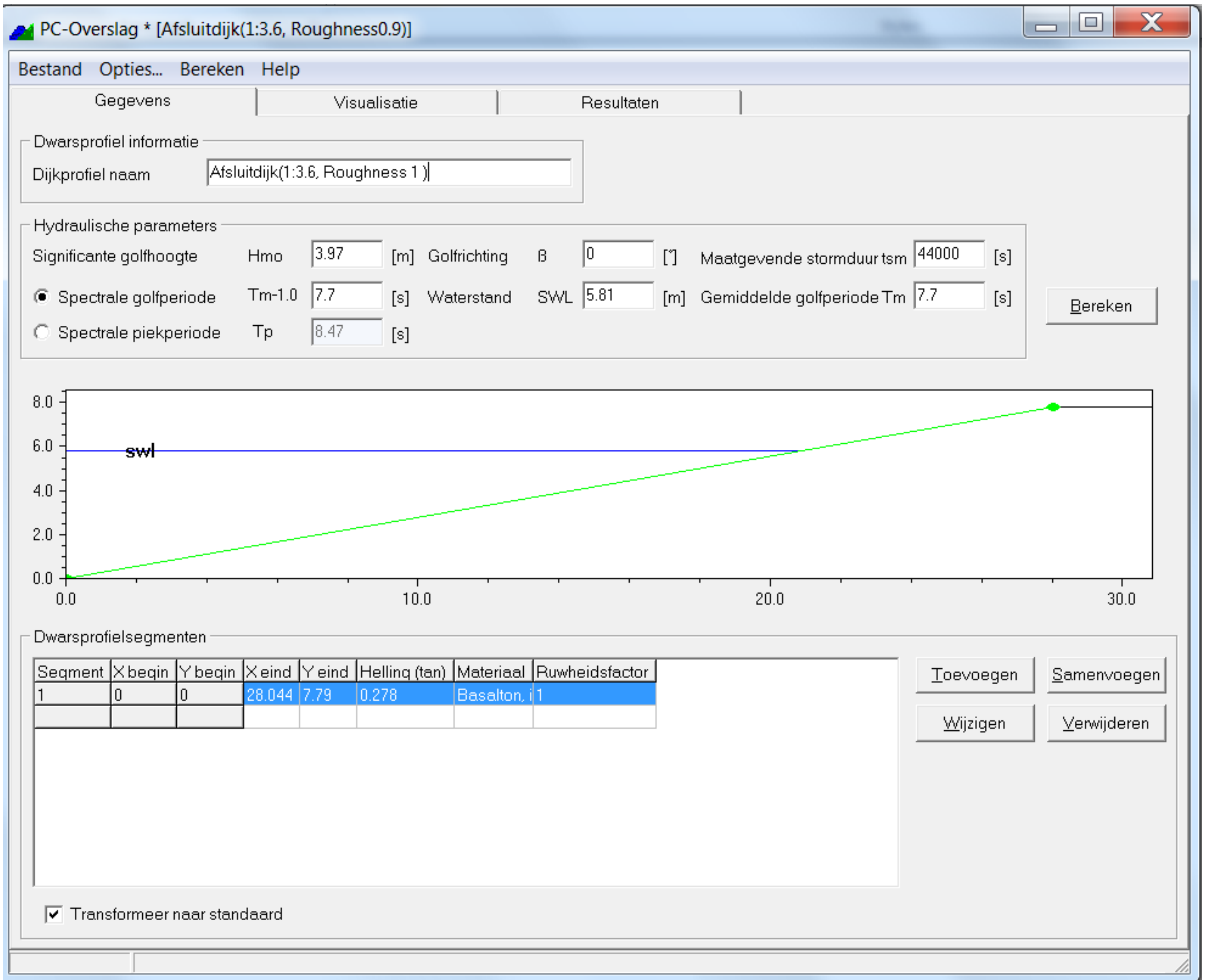


Figure E-11. Input for overtopping estimation RWS solution for the year 2100

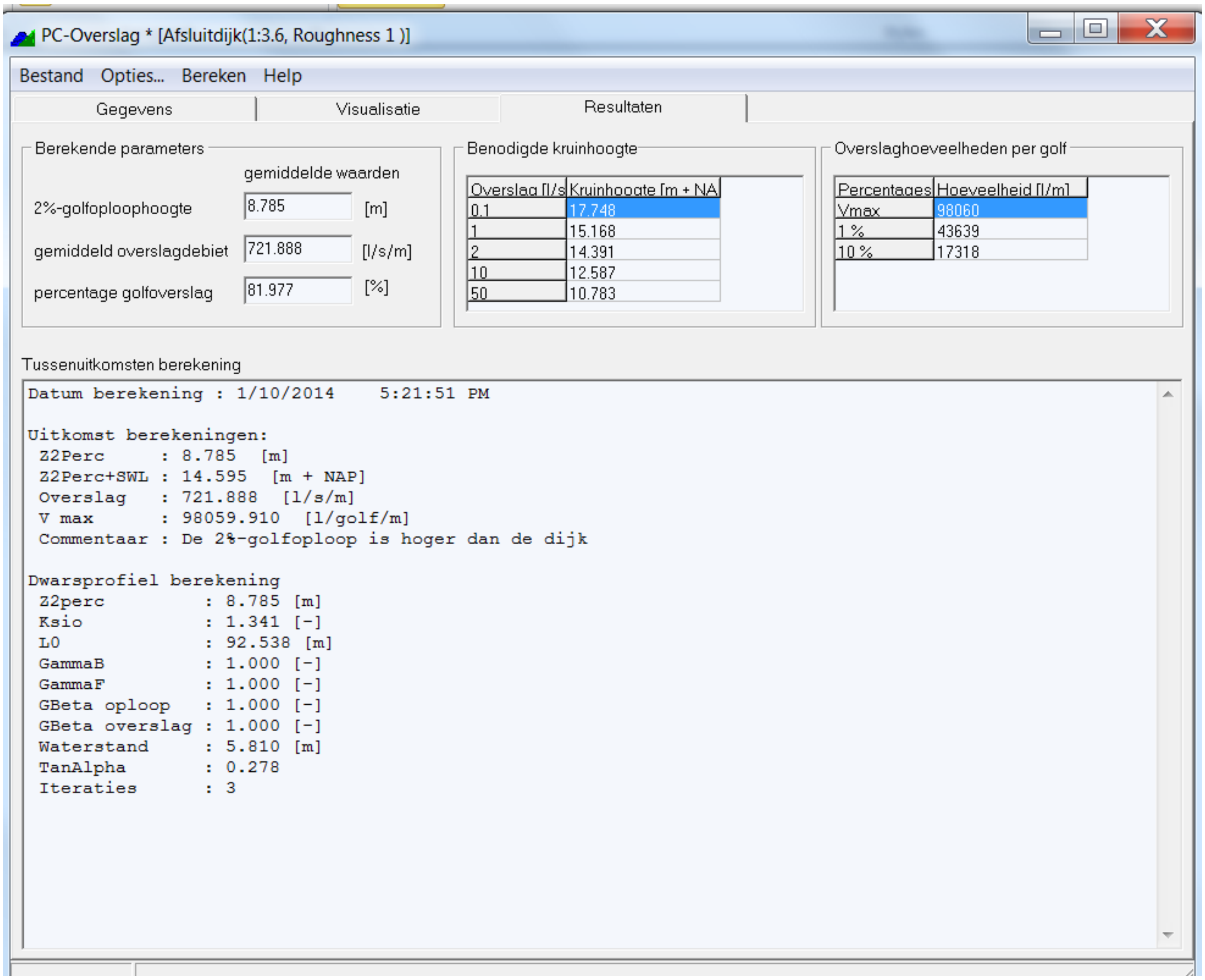


Figure E-12. Overtopping estimation RWS solution for the year 2100

E.7.2 OVERTOPPING ESTIMATION FOR RIP-RAP OVERLAYER ALTERNATIVE FOR THE YEAR 2100

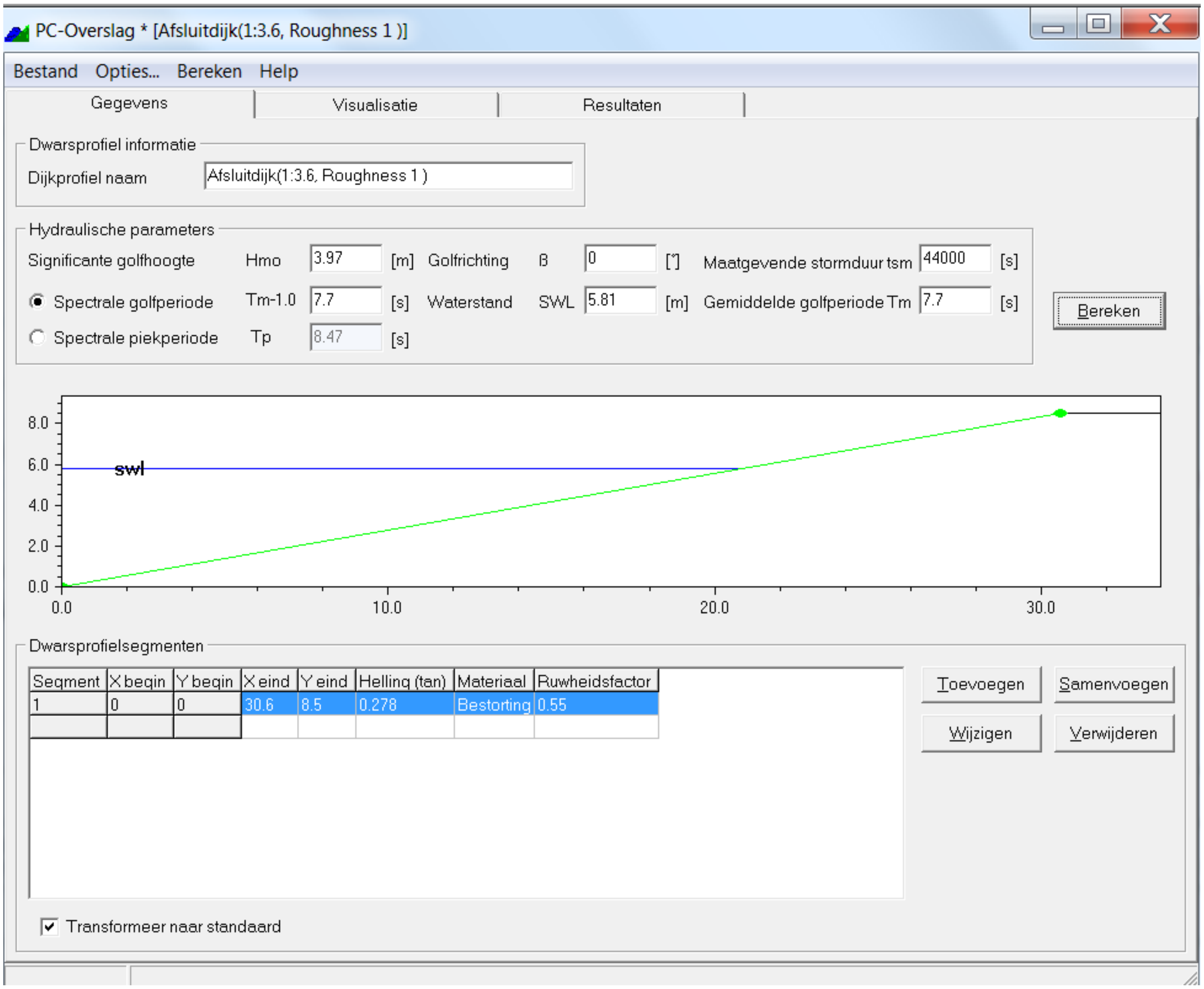


Figure E-13. Input for overtopping estimation Rip-Rap Overlayer solution for the year 2100

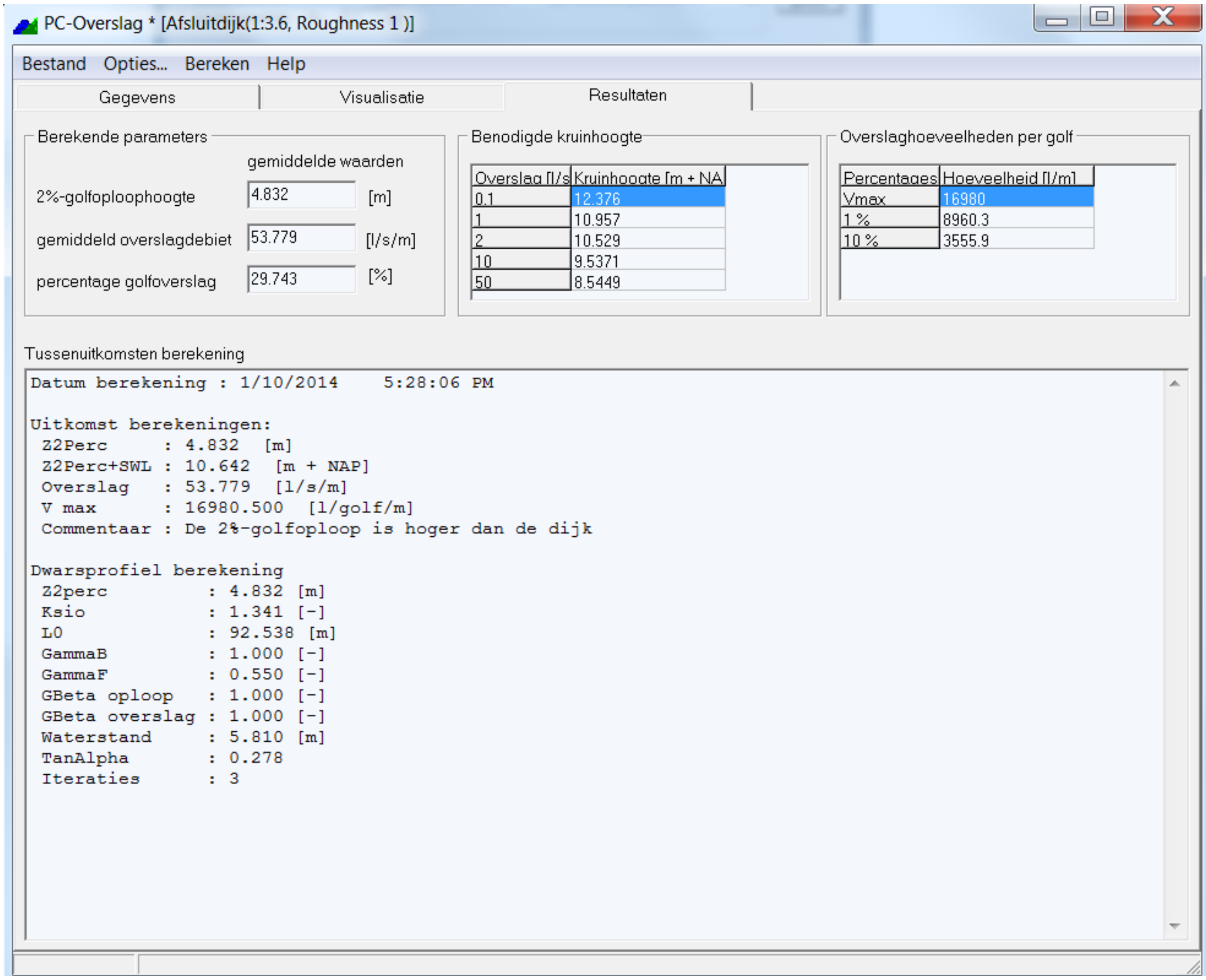


Figure E-14. Overtopping estimation Rip-Rap Overlayer solution for the year 2100

Appendix F

PROJECT ORGANIZATION

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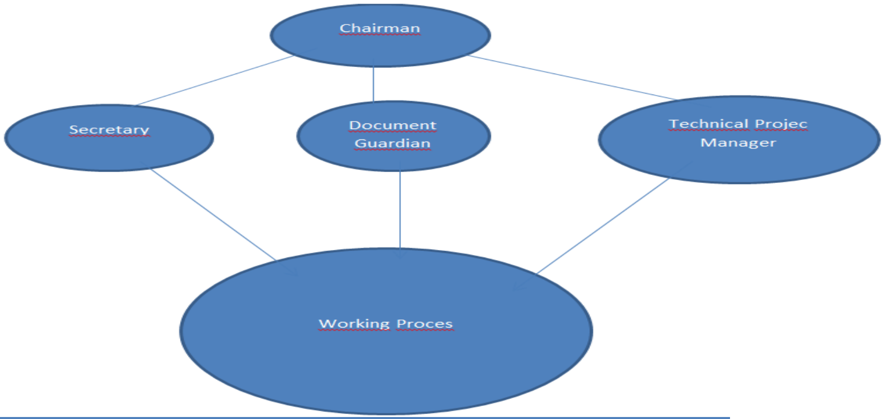
APPENDIX F – PROJECT ORGANIZATION

The objective of setting a board meeting is to identify resources needed and assigns individual responsibilities. In this project, the group set a way of working as shifting the four positions every two weeks, which can be seen in Table F- 1.

Table F- 1. Group Responsibilities and Schedule

	Topics to be Discussed
1	Group organization
2	Plan Review Preliminary Report Data collection: Boundary conditions Problem Analysis
3	Other issues
4	Close meeting to include review of key points, discussion of assignments, communications plan, and confirmation of the next meeting



Starting Date	9/17/2013	10/20/2013	11/3/2013	11/17/2013	12/3/2013	12/17/2013
Chairman	Pablo	Yuting	Carlos	Maria Jose	Pablo	Yuting
Secretary	Yuting	Carlos	Maria Jose	Pablo	Yuting	Carlos
Guardian of Documents	Carlos	Maria Jose	Pablo	Yuting	Carlos	Maria Jose
Technical Project Manager	Maria Jose	Pablo	Yuting	Carlos	Maria Jose	Pablo

Table F- 2. Group Responsibilities and Duties

	Responsibility	Duties
Chairman	Presides and conducts the meetings, is the representative of the group and Spokesperson. Casting Vote in case any deadlock on the board.	Develops and set the agendas for the meetings of the board, Counselors and Client
		Ensure the completion of the scheduled program, including the agendas for the meetings as the general schedule.
		To act as a liaison in the group
		To call special meetings of the Board where appropriate
Secretary	Serve as the authority on past actions, and Keep records on such things as time progresses	Record and maintain the minutes of each board meeting
		Notices of meeting times and places and requests contributions of items for the agenda
		Immediately (max 2 hours) after Board meetings the Secretary prepares a summary of their actions that is distributed to all board members.
		In consultation with the President, prepares agendas for the Board meetings.
Guardian of Documents	Is responsible for keep and maintain upgraded all project documents (technical reports, reports in general, drawings etc.)	Compliance of all the information, documents regarding the project. Ensures project documents are complete, current, and stored appropriately.
		Edition and format all the documentation according to the specified norms
		Keep the information clean, clear and reachable on time for every group member.
		Prepares agendas for the Board meetings (regarding documents issues)
Technical Project Manager	Responsible for accomplishing the stated project objectives	Prioritize the latest set of technical issues
		Assist the team in identifying the problem at the root of several technical issues
		Write a status report
		Prepares agendas for the Board meetings (regarding technical issues)

F.1 PROJECT LOG

Table F- 3. Project LOG in September and October

	DATE	EVENTS / TASKS	GROUP TASKS	REQUIRED DATE	WHO
SEPTEMBER / OCTOBER	29/8/2013	MEETING WITH H.J.VERHAGEN	GENERAL INFORMATION OF THE GROUP TASKS		GROUP
	7/9/2013	VISIT AFSLUITDIJK	RECOGNIZE PROJECT SITE WITH ITS PARTICULARITIES		GROUP
	11/9/2013	MEETING WITH H.J.VERHAGEN	GENERAL INFORMATION OF PROJECT		GROUP
	12/9/2013	MEETING WITH ERIC REGELING	INFORMATION AND TASKS OF PROJECT		GROUP
	18/9/2013	GROUP MEETING: CHECK INFI AND START DB REPORT	SPLIT WORK REGARDING SEARCHING FOR INFOR	22/9/2013	GROUP
	20/9/2013	GROUP MEETING: DESIGN BASIS REPORT	STARTING WRITING DB REPORT	22/9/2013	GROUP
	23/9/2013	GROUP MEETING: END AND DELIVER DB REPORT	DELIVER DB REPORT	23/9/2013	GROUP
	1/10/2013	GROUP MEETING: DEFINITION OF ALTERNATIVES+SPLIT CALCULATION WORK	RIPRAP BREAKWATER ALTERNATIVES AND CALCULATION	10/10/2013	YUTING
			BERM BREAKWATER ALTERNATIVES AND CALCULATION	10/10/2013	CARLOS
			X-BLOC BREAKWATER ALTERNATIVES AND CALCULATION	10/10/2013	MJ
			ANTIFER CUBES ALTERNATIVES AND CALCULATION	10/10/2013	PABLO
	10/10/2013	GROUP MEETING: CHECK 1ST CALCULATION AND DEFINITION; CROSS SECTION+ SPLIT CALCULATION	RIPRAP BREAKWATER ALTERNATIVES AND CALCULATION	16/10/2013	YUTING
			BERM BREAKWATER ALTERNATIVES AND CALCULATION	16/10/2013	CARLOS
			X-BLOC BREAKWATER ALTERNATIVES AND CALCULATION	16/10/2013	MJ
			ANTIFER CUBES ALTERNATIVES AND CALCULATION	16/10/2013	PABLO
	16/10/2013	GROUP MEETING	SPLIT DRAWINGS AND COST CALCULATION		GROUP
	24/10/2013	GROUP MEETING: FINISH CALCULATION, PRINT DRAWINGS, RESULTS	FRICTION ANGLE UNDERWATER	26/10/2013	CARLOS
			FILTER ON CLAY/DETAILING	26/10/2013	MJ/PABL0
			PRAPARE ALL DRAWINGS IN PDF PROFILE	26/10/2013	YUTING
	28/10/2013	MEETING WITH H.J.VERHAGEN	CHECK THE PRELIMINARY DESIGNS		GROUP
	31/10/2013	SPLIT TASKS	FIX SHEET WEIGHING	31/10/2013	YUTING
			UPLOAD SHEET MCA	31/10/2013	MJ

Table F- 4. Project LOG in November

	DATE	EVENTS / TASKS	GROUP TASKS	REQUIRED DATE	WHO
NOVEMBER	1/11/2013	GROUP MEETING: MAIL MCA VERHAGEN	MAIL I.REPORT TO ERIC AND HENK JAN	18/11/2013	PABLO
			START PLAXIS CALCULATIONS	19/11/2013	PABLO
			START CROWN WALL OPTIMISATION AND STUDY OF REMOVAL	19/11/2013	MJ
	8/11/2013	MEETING ERIC REGELING	COMPLETION OF MATERIALS QUANTITIES (COSTS)	19/11/2013	CARLOS
	16/11/2013	GROUP MEETING: DELIVER INT. REPORT	PDF CALCULATION APPENDIX - 12 ALTERNATIVES INTERMEDIATE DESIGN	27/11/2013	CARLOS
	18/11/2013	MAIL ERIC AND HENK JAN:SEND I.R. ASK FOR WEIGHING SCORES	TABLE OF CONTENTS FINAL REPORT	19/11/2013	GROUP
			OPEN FILTER DESIGN TO AVOID GEOTEXTILE WITH VERHAGEN	22/11/2013	CARLOS
	19/11/2013	GROUP MEETING:CHECK PROGRESS + TABLE OF CONTENTS FINAL REPORT	UPLOAD TO DROPBOX (INFORMATION) USED BIBLIOGRAPHY	22/11/2013	GROUP
			COMPLETE PLAXIS CALCULATIONS - WRITE CHAPTER	27/11/2013	PABLO
	22/11/2013	MEETING VERHAGEN:	COMPLETE CROWN WALL OPTIMISATION AND COMPARISON WITH REMOVAL	27/11/2013	MJ
			COMPLETE SEMI-PROBABILISTIC CALCULATIONS - WRITE CHAPTER	27/11/2013	MJ/PABLO
	26/11/3013	GROUP MEETING : CHECK PROGRESS + PREPARE MEETING WITH	UPDATE ENDNOTE FILE WITH ALL BIBLIOGRAPHY AVAILABLE	27/11/2013	YUTING
			RESEARCH ON EXAMPLES OF BREAKWATERS EXISTING IN ASIA/CHINA	27/11/2013	YUTING
	27/11/2013	MEETING VERHAGEN	PDF MULTI-CRITERIA APPENDIX READY TO INCLUDE IN FINAL REPORTIN TABLES)	27/11/2013	YUTING
			WRITE DOWN AGENDAS AND MINUTES WITH ERIC REGELING AND VERHAGEN	27/11/2013	YUTING
	29/11/2013	GROUP MEETING: CHECK VERHAGEN FEEDBACK+DRAFT FINAL REPORT /DIVIDE TASKS TO COMPLETE FINAL REPORT	DRAFT OF FINAL REPORT	29/11/2013	YUTING
			FINAL DRAWINGS WITH ADDED DETAILS FOR THE TWO FINAL ALTERNATIVES	29/11/2013	YUTING
			REVIEW MINUTES (USE MAIL INFORMATION	29/11/2013	YUTING
			ADD: PROJECT LOG, ORGANISATION CHART, SCHEDULE	29/11/2013	YUTING
			REVIEW MULTIDISCIPLINARY PROJECT GUIDELINES	29/11/2013	GROUP

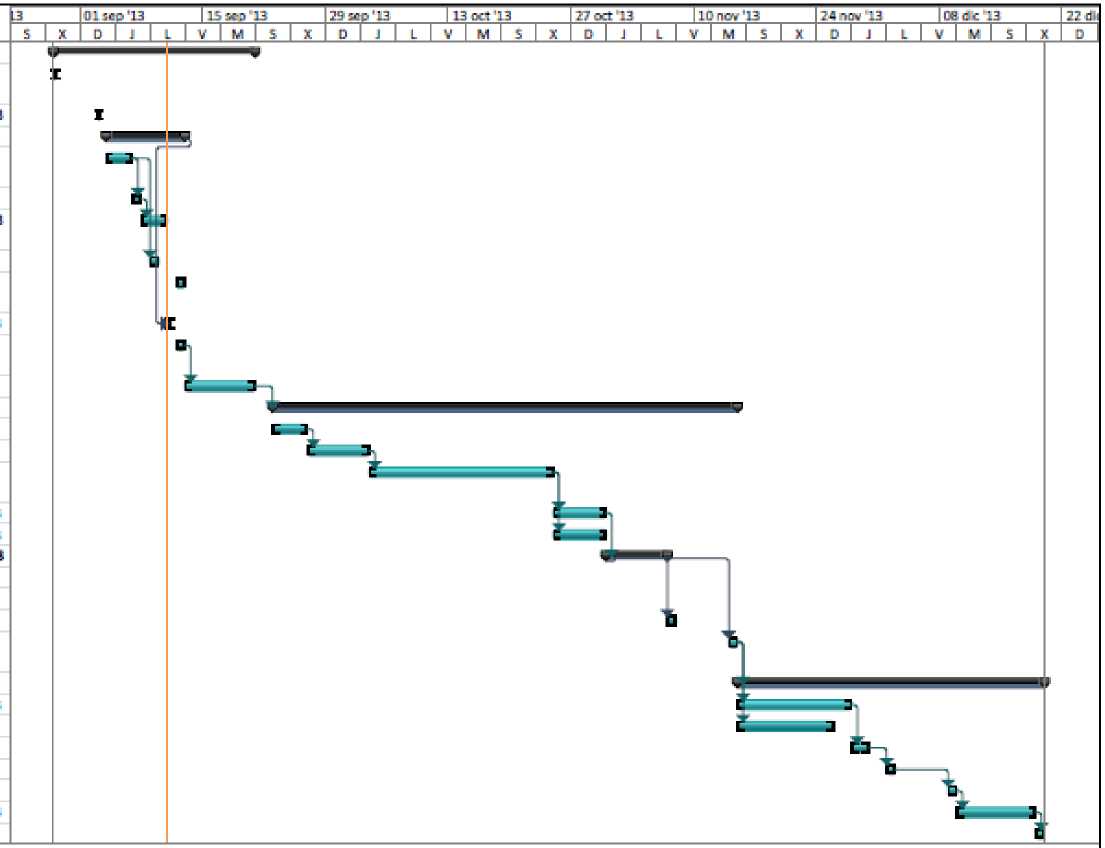
Table F- 5. Project LOG in December

	DATE	EVENTS / TASKS	GROUP TASKS	REQUIREMENT DATE	WHO
DECEMBER	5/12/2013	FINISH OVERTOPPING ALTERNATIVE SCORING	WRITE PROBABILISTIC EXPLANATION	7/12/2013	PABLO
	6/12/2013	AGREE VIA E-MAIL AND MAIL HENK JAN/ERIC GIVING DELIVERY DATES;MAIL ERIC/HENK JAN TO COMMUNICATE DELIVERY DATES	WRITE ABOUT CONSTRUCTION PROCESS	7/12/2013	MJ
			WRITE LAND AVAILABILITY, OPTIONS FOR USING IT	7/12/2013	CARLOS
	7/12/2012	GROUP MEETING TO WRITE GENERAL CONCLUSIONS FOR THE PROJECT	WRITE RWS OVERTOPPING SOLUTION (GENERAL EXPLANATION)	7/12/2013	YUTING
			GENERAL CONCLUSIONS FOR THE PROJECT	7/12/2013	GROUP
			OVERTOPPING ALTERNATIVE SCORING	5/12/2013	GROUP
			MAIL TO ERIC AND HENK JAN, EXPLAINING WHEN WE DELVER REPORT (3RD WEEK DECEMBER) AND WHEN WE DO THE PRESENTATION (ONE WEEK AFTER RECEIVING FEEDBACK)	6/12/2013	GROUP
			MULTICRITERIA ANALYSIS - FINAL REPORT	7/12/2013	YUTING
			COST ANALYSIS - QUANTITIES OVERTOPPING ALTERNATIVE AND CROWN WALL CORRECTION	7/12/2013	MJ
			COST ANALYSIS - FINAL TABLE	7/12/2013	CARLOS
			WRITE CONCLUSION REPORT ADDING ALL INDIVIDUAL PARTS	7/12/2013	GROUP
	13/12/13	LIMIT DATE FOR COMMENTS TO THE REPORT	COMMENTS TO THE REPORT	13/12/2013	GROUP
			MODIFICATIONS OF REPORT	14/12/2013	GROUP
	14/12/13	GROUP MEETING TO IMPLEMENT COMMENTS AND MODIFICATIONS. FINAL VERSION OF REPORT	FINISH THE FINAL VERSION OF REORT	20/12/2013	GROUP

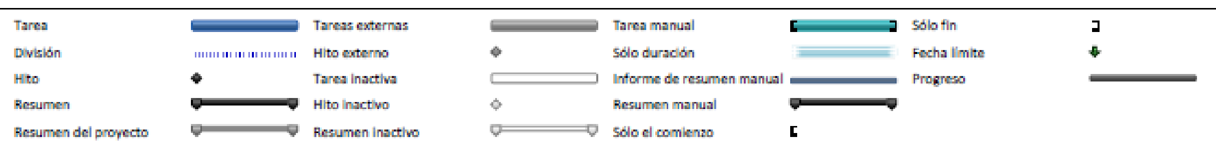
F.2 PROJECT SCHEDULE

Table F- 6. Project Schedule

Id	Nombre de tarea	Duración	Comienzo	Fin
1	**Phase 1**	**17 días**	**jue 29/08/13**	**vie 20/09/13**
2	Kick-off meeting w/Verhagen	0.05 días	jue 29/08/13	jue 29/08/13
3	Group meeting	0.1 días	mar 03/09/13	mar 03/09/13
4	**Gathering Information**	**7 días**	**mié 04/09/13**	**jue 12/09/13**
5	Reviewing existing information	3 días	mié 04/09/13	vie 06/09/13
6	Site Visit	1 día	sáb 07/09/13	sáb 07/09/13
7	Draft site visit report and schedule	3 días	dom 08/09/13	mar 10/09/13
8	Expenses list	1 día	lun 09/09/13	lun 09/09/13
9	Brochure Draft for sponsors	1 día	jue 12/09/13	jue 12/09/13
10	Meeting with Verhagen	0.1 días	mié 11/09/13	mié 11/09/13
11	Meeting with RWS Ir. Regeling	1 día	jue 12/09/13	jue 12/09/13
12	Preliminary report Phase 1	6 días	vie 13/09/13	vie 20/09/13
13	**Phase 2**	**39 días**	**lun 23/09/13**	**jue 14/11/13**
14	Alternatives	4 días	lun 23/09/13	jue 26/09/13
15	Calculations	5 días	vie 27/09/13	jue 03/10/13
16	Defining cross sections & construction method	15 días	vie 04/10/13	jue 24/10/13
17	Intermediate drawings	4 días	vie 25/10/13	mié 30/10/13
18	Cost estimation	4 días	vie 25/10/13	mié 30/10/13
19	**Detailed design**	**5 días**	**mié 30/10/13**	**mié 06/11/13**
20	Intermediate Report			
21	Final Drawings			
22	Submittal Phase 2	1 día	jue 07/11/13	jue 07/11/13
23	Meeting with Ir. Verhagen & Ir. Regeling	1 día	jue 14/11/13	jue 14/11/13
24	**Phase 3**	**25 días**	**jue 14/11/13**	**jue 19/12/13**
25	Final report	9 días	vie 15/11/13	mié 27/11/13
26	Final Drawings	7 días	vie 15/11/13	lun 25/11/13
27	Appendix	2 días	jue 28/11/13	vie 29/11/13
28	Final submittal	1 día	lun 02/12/13	lun 02/12/13
29	Meeting with Verhagen	1 día	lun 09/12/13	lun 09/12/13
30	Presentation	7 días	mar 10/12/13	mié 18/12/13
31	Presentation for RWS	1 día	jue 19/12/13	jue 19/12/13



Proyecto: MDP schedule-v1
Fecha: mié 11/09/13



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