Derivation of the semi-probabilistic safety assessment rule for inner slope stability

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Calibration STBI 2016

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1230086-009

Deltares

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Keywords
WBI 2017, safety factors, calibration, levees, slope stability, probabilistic analysis, reliability

Summary
In the Netherlands, all primary flood defences are periodically tested against statutory safety standards. The new safety assessment framework WBI 2017 (defined in terms of allowable probabilities of flooding) allows for probabilistic as well as semi-probabilistic assessments, which are based on a partial safety factor approach. To ensure consistency between probabilistic and semi-probabilistic assessments, the semi-probabilistic rules have to be (re)calibrated in order give similar results as probabilistic assessments.

This report is about the semi-probabilistic assessment of the failure mode inner slope instability (STBI), and the corresponding relationship between the safety factor and a specific requirement in terms of probability of failure. The derivation of this relationship is called calibration. In comparison with the calibration performed in 2015, some improvements are incorporated in the 2016 calibration: the use of local data, including the uncertainty of pore pressure uncertainties and the use of a new version of the WBI Macrostability kernel.

This report presents the safety format, calibration procedure and results of 2016 of the calibration of the semi-probabilistic assessment rule for STBI within the WBI 2017. The calibration procedure involves the following steps: 1) establish a reliability requirement for the cross-section, 2) establish the safety format, 3) establish the safety factors and 4) compare the calibration results with present-day rules. The slope stability computations have been based on an undrained material model for low permeability materials (peat, clay) and a drained material model for sand. Uplift-Van has been used to determine the critical slip circle. The effects of overtopping have not been considered in the calibration. Hence, dikes of which the pore water pressures are significantly affected by overtopping should be covered by a separate rule.

In order to establish the safety format and safety factors, 48 computations of cases have been carried out. These represent 27 different locations and conditions in the Netherlands, of which 17 locations with local and regional data. For each dike, the berm lengths have been varied to obtain the right order of magnitude for the reliability. The safety factor, reliability index and FORM sensitivity factors have been computed for each case. This has resulted in the choice of a safety format that entails the computation of a factor of safety (determined by Uplift-Van) using characteristic (5%) values of the strength parameters, and furthermore a model factor (1.06 for Uplift-Van), a design water level ('Waterstand Bij Norm', WBN) and one target reliability dependent, overall safety factor that a dike has to comply with. This target reliability dependent safety factor (γ_n) has been fit using 34 of the cases. The resulting calibrated fit is γ_n = 0.15 $\cdot$ $\beta_{T,cross}$ + 0.41; in which $\beta_{T,cross}$ is the target reliability of the cross-section. No significant effect has yet been found of differentiating the calibrated safety factor to the safety standard, geology and uplift/no uplift.

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Rijkswaterstaat - Water, Verkeer en Leefomgeving	1230086-009	1230086-009-GEO-0030	121

The main difference with the current safety format is the absence of material factors. This is mainly because the uncertainties in material parameters are covered sufficiently by the use of characteristic values. Compared to the 2015 calibration, the required safety factor is 0.1 lower. The calibration is based on the latest insights with respect to STBI modelling within WBI. However, there is limited experience with undrained slope stability analysis in the Netherlands. Therefore, it is recommended to perform future evaluations of the STBI assessment and comparisons between semi-probabilistic and probabilistic assessments to check the assumptions and computed relationship between safety factors and reliability index. There is large scatter in the relation between reliability and required safety factor. In case a dike is assessed ‘unsafe’ based on a semi-probabilistic assessment, a probabilistic assessment could lead to a ‘safe’ assessment. This is recommended especially for dikes whose factor of safety does not differ strongly from the required factor of safety.

Disclaimer: In this report (version 3), all the cases are made anonymous compared to the original report (version 2). Hence, there are no references provided to the original data sources.

Version	Date	Author	Initials	Review	Initials	Approval	Initials
1	Sept. 2016	Dr. W. Kanning		Dr. R.B. Jongejan		Dr. M. Sule	
		Dr. A. Teixeira		Ing. A. van Duinen			
		Ir. M. van der Krogt					
		Ir. K. Rippi					
2	Nov.2016	Dr. W. Kanning		Dr. R.B. Jongejan		Dr. M. Sule	
		Dr. A. Teixeira		Ing. A. van Duinen			
		Ir. M. van der Krogt					
		Ir. K. Rippi					
3	Apr. 2017	Dr. W. Kanning		Dr. R.B. Jongejan		Dr. M. Sule	
		Dr. A. Teixeira		Ing. A. van Duinen			
		Ir. M. van der Krogt					
		Ir. K. Rippi					

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Samenvatting
In Nederland worden alle primaire waterkeringen periodiek beoordeeld aan de hand van wettelijke veiligheidsnormen. In het kader van de nieuwe normen (gedefinieerd in termen van overstromingskansen) en het nieuwe wettelijk beoordelingsinstrumentarium WBI 2017 kan zowel volledig probabilistisch worden beoordeeld als semi-probabilistisch met partiële veiligheidsfactoren. Voor consistentie tussen beide methodes moeten semi-probabilistische beoordelingsregels gekalibreerd worden om tot vergelijkbare resultaten in semi-probabilistische analyses te komen als in probabilistische analyses.

In dit rapport wordt de kalibratie van het semi-probabilistische beoordelingsvoorschrift voor het faalmechanisme macrostabiliteit binnenwaarts (STBI) in het WBI 2017 beschreven en toegepast. In vergelijking met de 2015 kalibratie is de 2016 kalibratie verbeterd op de volgende punten: er zijn cases gebaseerd op lokale schuifsterkte parameters meegenomen, onzekerheid in waterspanningen is meegenomen en een nieuwe versie van het D-Geo Stability rekenhart is toegepast.

Dit rapport presenteert het veiligheidsformat, kalibratieprocedure en kalibratieresultaten voor het semi-probabilistisch voorschrift voor STBI binnen WBI 2017. De kalibratie behelst de volgende stappen: 1) het vaststellen van de doelbetrouwbaarheid van een doorsnede, 2) het vaststellen van het veiligheidsformat, 3) het vaststellen van de partiële veiligheidsfactoren en 4) het vergelijken van de resultaten met huidige voorschriften. De stabiliteitsberekeningen zijn gebaseerd op een ongedraineerd materiaalmodel voor slecht doorlatende materialen (veen en klei) en gedraineerd materiaalmodel voor zand. Uplift-Van is de gebruikte zoekmethode voor het kritieke schuifvlak. Effecten door overslag zijn niet beschouwd in deze kalibratie. De afgeleide veiligheidsfactoren zijn dan ook enkel geldig voor gevallen zonder overslag.

Voor de kalibratie van veiligheidsfactoren zijn 27 dijkvakken beschouwd. Voor iedere dijk is de bermlengte gevarieerd om in de juiste range van betrouwbaarheid te komen. Dit resulteert in een totaal van 48 geanalyseerde cases. Voor iedere case zijn de stabiliteitsfactor, betrouwbaarheidsindex en invloedcoëfficiënten berekend. Op basis van deze resultaten is het veiligheidsformat vastgesteld: de stabiliteitsfactor (bepaald met Uplift-Van) wordt berekend met karakteristieke (5%) waarden voor de sterkteparameters; verder is voorzien in een modelfactor (1.06 voor Uplift-Van), de waterstand bij norm (WBN) en een betrouwbaarheidsindex-afhankelijke veiligheidsfactor. De afgeleide factor (γ_n) is γ_n = 0.15 · $\beta_{T,cross}$ + 0.41, waarin $\beta_{T,cross}$ de vereiste betrouwbaarheid is. Analyses laten zien dat er geen significante differentiatie van het veiligheidsformat is als wordt gekeken naar norm, geologie, opdrijven en opbarsten. Dit komt mogelijk door het aantal cases.

Een verschil met het huidige veiligheidsformat is de afwezigheid van materiaalfactoren. De onzekerheden ten aanzien van materiaalparameters wordt namelijk al voldoende verdisconteerd door het gebruik van representatieve waarden. Vergeleken met de 2015 kalibratie is de benodigde schadefactor 0.1 lager in de 2016 kalibratie. De kalibratie is gebaseerd op de laatste STBI inzichten binnen het WBI. Aangezien er echter beperkte ervaring is in Nederland met ongedraineerde stabiliteitsanalyses, wordt het aanbevolen om

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de STBI-toetsing in de toekomst te evalueren, alsmede de semi-probabilistische sommen te controleren met probabilistische analyses om de uitgangspunten van het gekalibreerde voorschrift te valideren. Verder wordt opgemerkt dat er een grote spreiding is in de relatie tussen veiligheidsfactor en betrouwbaarheid. Dit betekent dat als een dijk wordt afgekeurd in de semi-probabilistische beoordeling, het wordt aanbevolen om een probabilistische beoordeling uit te voeren om mogelijk tot goedkeuring te komen (mits het veiligheidstekort niet te groot is).

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Contents

Appendices

Symbols (Latin)

Symbol	Definition	Unit
a	Fraction of the length that is sensitive to the failure under study	-
A	Constant of linear regression in $\gamma = g(\beta)$	-
b	Length-effect factor for slope stability failure	m
B	Constant of linear regression $\gamma = g(\beta)$	-
c'	Effective soil cohesion	kN/m^2
CoV	Coefficient of variation = σ / μ	-
C	Constant of linear regression in $\beta = g^{-1}(\gamma)$	-
D	Constant of linear regression in $\beta = g^{-1}(\gamma)$	-
f	Failure probability factor for the failure mechanisms	-
$FORM$	First order reliability method	-
FoS_{des}	Factor of safety computed for design values of input parameters	-
FoS_{char}	Factor of safety given MHW computed with design values of input parameters	-
h_{dec}	decimate height, water level difference that corresponds to a difference in exceedance frequency of a factor 10	m
IL	Intrusion length	m
k	value that corresponds to a quantile, e.g. for 5% quantile k =1.65	-
L	Total length of the dike segment	m
m	Strength increase exponent	-
m_d	Model uncertainty	-
M_R	Resisiting moment for macrostability limit equilibrium	kN.m
M_S	Driving moment for macrostability limit equilibrium	kN.m
OCR	Over consolidation ratio of the soil	-
$P(\cdot)$	Probability of an event	-
P_f	Probability of failure	yr^{-1}
PL	Phreatic line	-
P_{norm}	Maximum allowable probability of failure (safety standard)	yr^{-1}
P_T	Target failure probability: maximum allowable probability of flooding due to the series of events triggered by the instability of the inner slope that lead to flooding	yr^{-1}
$P_{T,cross}$	Cross-sectional target failure probability; the average cross-sectional probability of failure may not exceed $P_{T,cross}$	yr^{-1}
P^*_{cross}	Calculated cross-section failure probability	yr^{-1}
POP	Pre-overburden pressure in the soil	kN/m^2
R	Resistance	-*
R_k	Characteristic value of the stochastic resistance variable	-*
R_d	Design value of the stochastic resistance variable	-*
R_{rep}	Representative value of the stochastic resistance variable	-*
R^*	Design point value (from FORM) of the stochastic resistance variable	-*
S	Load *–or–* undrained shear strength ratio	-*
S_i	Subsoil Scenario i	-
S_k	Characteristic value of the load	-*
S_d	Design load	-*
s_u	Undrained shear strength	kN/m^2
$\tan(\varphi')$	Tangent of the effective friction angle of the soil	-

Symbol	Definition	Unit
T	Return period that corresponds to the safety standard of a segment	yr
u	Standard normally distributed variable (mean μ=0 and standard deviation σ=1)	-
WL	Water level at a particular moment relative to NAP	m
WBI	Wettelijk BeoordelingsInstrumentarium	
WBN	“waterstand bij norm”, i.e. design water level	m
WNC	WaterNet Creator, part of the software	
X_i	Stochastic variable	-*
$X_{d,i}$	Design value of the stochastic variable	-*
$X_{k,i}$	Characteristic value of the stochastic variable	
Z	Limit state function ($Z = R - S$)	-
Z_{II}	Linearized and normalized limit state function	-

* unit depends on the variable concerned

Symbols (Greek)

Symbol	Definition	Unit
α_i	Influence coefficient for stochastic variable X_i ($\sum\alpha_i^2$=1)	-
α_R	Influence coefficient of the resistance in the limit state function	-
α_S	Influence coefficient of the (hydraulic) load in the limit state function	-
β	Reliability index	-
β_{norm}	Reliability index that corresponds to the safety standard	-
β_T	Target reliabiltiy index: minimum allowable reliability index for flooding due to the series of events triggered by the instability of the inner slope that lead to flooding	-
β^*_{cross}	Calculated cross-sectional reliability index	
$\beta_{T,cross}$	Cross-sectional reliability requirement (reliability index)	-
γ_d	β_T – invariant model factor	-
γ_m	β_T – invariant material factor	-
γ_n	β_T – dependent safety factor	-
γ^*_n	Calculated safety factor = FoS_{des} / γ_d	
γ_R	Partial safety factor for stochastic resistance variable R	-
γ_S	Partial safety factor for stochastic load variable S	-
γ_{unsat}	Unsaturated volumetric unit weight	kN/m^3
γ_{sat}	Saturated volumetric unit weight	kN/m^3
λ_{out}, λ_{in}	Foreland and hinterland leakage lengths	m
$\Phi(\cdot)$	Standard normal distribution function	-
μ	Mean value	-*
σ	Standard deviation	-*
σ'_{vy}	Effective vertical yield stress = $\sigma'_{v,i} + POP$	kN/m^2
$\sigma'_{v,i}$	Effective vertical stress	kN/m^2
τ	Ultimate shear stress	kN/m^2
ψ	Dilatancy angle	deg

* unit depends on the variable concerned

1 Introduction

1.1 The WBI project context and background on calibrations

The Dutch primary flood defences are periodically tested against statutory safety standards. These standards were, until recently, defined in terms of design loads. Then, policymakers decided to move towards safety standards defined in terms of maximum allowable probabilities of flooding. To facilitate such a move, a new set of instruments for assessing the safety of flood defences is currently being developed: the WBI 2017.

The WBI 2017 will include probabilistic as well as semi-probabilistic assessment procedures. The latter rest on a partial safety factor approach and allow engineers to evaluate the reliability of flood defences without having to resort to probability calculus. To ensure consistency between probabilistic and semi-probabilistic assessments, the currently used safety factors have to be (re)calibrated. Important aspects within the standard WBI 2017 calibration procedure concern the derivation of reliability requirements, the definition of design values on the basis of influence coefficients, and the handling of spatial correlations.

This report concerns the calibration of slope stability of the inner slope (STBI).

1.2 Relation with the 2015 STBI calibration

An initial calibration study was carried out in 2015 (Kanning et al., 2015). This calibration study had two main limitations: there were no cases with local measurements and an older version of the WBI Macrostability kernel (software to evaluate STBI) was used. This resulted in the start of the 2016 calibration with more cases, cases with local data and a recent version of the STBI software. The 2016 calibration uses the same method as the 2015 calibration. The main differences are:

- Most new cases are real dikes and based on locally measured shear strength properties. These include more dike types (e.g. sand dikes) than the 2015 calibration.
- A new version of the Macrostability kernel and Waternet Creator has been used (see section 1.3.5)
- Pore water pressure uncertainties have been incorporated.

In the 2016 calibration, the 2015 cases have been used to derive the safety factor as well. The 2015 cases have been re-calculated based on the newest version of the software (see section 1.3.5), taking into account water pressure uncertainties. Most emphasis in this report is on the 2016 cases and the results of the 2015 cases; for details of the 2015 cases, the reader is referred to Kanning et al (2015). Parts of this report are similar to the 2015 report.

1.3 Objectives and scope

1.3.1 Objectives

The main objective is to derive the semi-probabilistic assessment format for the inner slope stability failure mechanism for dikes in the Netherlands and to calibrate the needed safety factors.

More specifically, the main objectives are:

- to determine the reliability requirement accounting for the failure probability budget assigned to slope stability and the length-effect;
- to establish the safety format in terms of the envisaged characteristic values and partial factors to be applied, and
- to derive, the functional relationship of the β– dependent safety factor to be applied in semi-probabilistic assessments of slope stability, as well as other possible safety factors.

1.3.2 Scope of the report

The calibration has been carried out based on the WBI implementation of the assessment of slope stability of the inner slope (STBI), see Van Deen and Van Duinen (2016). This entails:

- Critical State Soil Mechanics (CSSM) modelling using the SHANSEP model for impermeable (i.e. clay and peat) layers
- Drained material modelling based on friction angle for permeable layers (i.e. sand)
- D-Geo Stability computations for the Uplift-Van method.
- Pore water pressures are modelled with the Waternet Creator

The calibration of safety factors covers the failure mechanism slope instability of the inner slope (STBI), slope instability of the outer slope is outside the scope of this report. Since there is no outer slope calibration available, the STBI calibration could be used for the outer slope, as has been done similarly in the past. This is not validated however. Hence, when slope stability is mentioned in this report, it refers to the failure mechanism instability of the inner slope. Slope stability is referred to in the Netherlands as macrostability, which is why the kernel and prototype (used for reliability analysis) are called macrostability. In this report, when referring to safety factors, in fact partial safety factors are meant. When referring to a factor of safety, the computed factor of safety using D-Geo Stability is meant.

Besides the calibration, this report discusses the following activities:

- study of the results of the calibration procedure;
- determination and analysis of the test set used for the calibration;
- comparison with the semi-probabilistic assessment rules of the WTI 2011;
- analysis of the safety format for undrained shear strength based on CPT correlation and comparison with the safety factor derived for the S, m and yield stress (Appendix K)

1.3.3 Limitations

Some general limitations are:

- Overtopping: no overtopping influences are considered in the calibration (i.e. overtopping discharge < 1.0 l/s/m). Overtopping could e.g. affect the phreatic line and slope instability could reduce the resistance of the inner (grass) slope against overtopping. Hence, the safety format applies to slope stability evaluations without overtopping. When the interaction between overtopping and slope stability is expected to be important, this will have to be assessed separately.
- Traffic: no traffic load is incorporated in the calibration according to generic WBI choices (see Van Deen and Van Duinen, 2016).
- Slope stability methods: Other slope stability methods (e.g. Bishop, Spencer) than Uplift-Van have not been considered explicitly in this report. However, it is expected that

the choice of the slope stability method will not have major impact on the calibration results. There could be a different model factor (the model factor for Spencer is provided in this report). However, the calibration results could be applicable for e.g. Spencer where the safety format and all partial factors (except the model factor) are the same.

For more specific modelling choices refer to Chapter 7.

1.3.4 Additional benefits of calibration

There are various additional benefits of the calibration, next to the calibrated safety format:

- Testing of the software, a list of bugs that were found and how is deals with these is presented in Appendix D,
- Comparison various computation kernels,
- Tips for the schematization guidelines (communicated to and included in Van Deen and Van Duinen, 2016).

1.3.5 Software and data

The slope stability computations are made with the WBI Macrostability kernel in the D-Geo Stability user interface (C# version); the version of May 9th, 2016. The Waternet Creator version May 9th, 2016, is used to determine the phreatic line and water pressures in the soil layers as a function of outside water level. The probabilistic calculations are made with the Macrostability kernel and a D-Geo Stability prototype implemented in Python using PYRE, see also Appendix A.

The versions of the Macrostability kernel and Waternet Creator (WNC) that was used has been tested by applying these to the various cases. A list of errors is presented in Appendix D, most issues were incorporated in the kernel, or a workaround was presented. The version of the kernel and WNC that was used is not the final WBI Macrostability kernel due to time-limitations. The main change with 2015 that was incorporated is the horizontal equilibrium in the horizontal part of the sliding plane. This was incorporated in the May 9th, 2016 version. Any remaining differences between the May 9th version and the final WBI Macrostability kernel are expected to be minor.

For the data used for the 2015 cases, see Kanning et al. (2015). The data used for the additional 2016 is based on local projects; see summary tables in Appendix F or the individual case reports in Appendix L.

Disclaimer: In this report (version 3), all the cases are made anonymous compared to the original report (version 2). Hence, there are no references provided to the original data sources.

1.4 Approach

Generally speaking, the calibration procedure can be summarised in the following steps (based on Jongejan, 2013):

Step 1: Establish a reliability requirement for the cross-section level, which is based on the maximum allowable probability of flooding.

Step 2: Establish the safety format. This includes a study on the FORM influence coefficients (α) based on a wide variety of test data sets. Based on this, characteristic values and partial safety factors that are to be included or not in the semi-probabilistic assessment rule are chosen.

Step 3: Establish the safety factors. This step comprises:

a) the recommendation of reliability index β – invariant safety factors (based on results of step 2),
b) generating "designs" that fulfil the semi-probabilistic assessment rule for a range of values of the so-called β – dependent safety factor,
c) assessment of the probability of failure of each "designed" test set member,
d) and application of calibration criteria to select the appropriate functional relationship of the β – dependent safety factor.

Step 4: Compare calibration results with present-day rules. Having finalized the theoretical exercise above, it is highly recommended in the fourth step to compare the calibrated semi-probabilistic assessment rules to the present-day rules, to explain potential differences, and to provide an indication of the consequences.

The calibration has been carried out by the main authors of the report. For the computation of cases, they have been assisted by M.L. Taccari, M. Ponziani, S. Luijendijk, D. Nugroho who are greatly acknowledged for their support.

1.5 Outline of the report

This report is based on the same structure as the calibration reports of the other failure mechanisms. The structure of the 2015 STBI calibration report (Kanning et al, 2015) is followed as much as possible. Most generic texts of the 2015 report are copied into this report. The outline of the report follows the subsequent calibrations steps (see 1.4):

- Chapter 2 introduces the basic concepts and definitions of probabilistic and semi-probabilistic design;
- Chapter 3 provides concise descriptions of the computational models applied in the WBI 2017 for slope stability and the relevant input parameters;
- Chapter 4 discusses the procedure developed and envisaged for the final calibration;
- Chapter 5 further describes the first step of this procedure, *i.e.* the definition of reliability requirements;
- Chapter 6 discusses the second step, *i.e.* the establishment of the safety formats; Chapter 7 discusses the third and final step, *i.e.* the establishment of safety factors;
- Chapter 8 provides an overview of the results of the calibration;
- Chapter 9 presents a summary of the semi-probabilistic assessment steps and comparison with the present-day relations are given;
- Chapter 10 provides a discussion on the results
- Chapter 11 summarizes the most important findings and provides recommendations following from this study.

2 Basic concepts

This section provides a brief overview of the probabilistic context and link between the probabilistic and semi-probabilistic assessments of engineering structures in general. More detailed description of the probabilistic background can be found in standard textbooks.

2.1 Failure probabilities, reliability indices and influence coefficients

A flood defence will fail when the load (S) exceeds its resistance/strength (R). The resistance parameters of a flood defence are, in principle, deterministic. In practice, however, they are uncertain due to spatial variability, a limited number of measurements and measurement uncertainties. Also, the models used to predict critical combinations of parameter values (i.e., combinations that would lead to failure), might produce outcomes that are besides the (unknown) truth. Such model uncertainties also have to be taken into consideration in reliability analyses. This means that the resistance of a flood defence should be treated as a stochastic variable, just like the uncertain loads.

The probability of failure (P_f) equals the probability that load (S) exceeds resistance (R). Herein Z stands for the limit state function. Herein, Z is the limit state function.

$$P_f = P(R - S < 0) = P(Z < 0) \tag{2.1}$$

The First Order Reliability Method (FORM) (Rackwitz, 2001) is an efficient method to compute failure probabilities. In a FORM-analysis, the limit state function is normalized and linearized in the design point. The design point is the combination of parameter values with the highest probability density for which Z=0. The linearized and normalized limit state function (Z_{II}) resulting from a FORM-analysis has the following form:

$$Z_{II} = \beta - \sum_{i=1}^{n} \alpha_i u_i \tag{2.2}$$

Herein, β is the reliability index, α_i is the influence coefficient for stochastic variable X_i ($\sum\alpha_i^2$=1), and u_i is a standard normally distributed variable (a normal distribution with mean μ=0 and standard deviation σ=1), representing a normalized stochastic variable, involved in the limit state function.

An influence coefficient is a measure for the relative importance of the uncertainty related to a stochastic variable. The squared value of an influence coefficient corresponds to the fraction of the variance (σ^2) of the linearized and normalized limit state function that can be attributed to a stochastic variable.

Generally, a FORM-analysis yields a close approximation of the probability of failure:

$$P(Z_{II} < 0) \approx P(Z < 0) \tag{2.3}$$

Note that the failure probability estimate $P(Z_{II}$<0) is equal to $P(Z$<0) when the limit state function is linear and all stochastic variables are independent and normally distributed.

From equation (2.2) and the fact that the sum of the squares of the alpha values is equal to 1, it follows that:

$$P(Z_{II} < 0) = \Phi(-\beta) \tag{2.4}$$

Herein, $\Phi(\ )$ stands for the standard normal cumulative distribution function.

It also follows from equation (2.2) that the design point value ($X_{d,i}$) of a normally distributed stochastic variable X_i with a given mean value μ_i and standard deviation σ_i equals:

$$X_{d,i} = \mu_i + \alpha_i \cdot \beta \cdot \sigma_i \tag{2.5}$$

2.2 The relations between probabilistic and semi-probabilistic assessments

Semi-probabilistic and probabilistic safety assessments are closely related. Both rely on predefined safety standards, limit state functions, and the statistical properties of the stochastic variables that represent the uncertain load and strength parameters. The same uncertainties play a role in semi-probabilistic and probabilistic assessments. Yet a semi-probabilistic assessment rests on a number of simplifications and approximations, giving it the appearance of a deterministic procedure.

In probabilistic safety assessment on calculates the probability of exceeding the ultimate limit state, in which the load (S) and resistance (R) are compared. The evaluated probability of failure, $P(S>R)$, has to be smaller than a given maximum allowable (‘target’) value (P_T).

In semi-probabilistic assessment, one analyses the difference between the design values of load (S_{des}) and strength (R_{des}): S_{des} should not exceed R_{des}. Design values are defined in terms of representative values (e.g. characteristic values such as 5th or 95th percentiles – 5% or 95%) and (partial) safety factors. This use of terminology is consistent with the Eurocode EN 1990 (CEN, 2002). Readers should be aware that similar terms may have different definitions in other international standards.

It is recommended to calibrate the design values such that the condition $S_{des} \leq R_{des}$ is fulfilled. This implies that the probability of failure meets the reliability requirement: $P(S>R) \leq P_T$. The relationship between probabilistic and semi-probability safety assessments is illustrated in Figure 2.1.

The resistance is decreased by the ratio $1/\gamma_R$ and whereas the load is increased by γ_S[1]. The design values of normally distributed resistance and load variables are given in the following equations.

$$R_d = \mu_R - \alpha_R \cdot \beta_T \cdot \sigma_R = R_k / \gamma_R \quad \text{(resistance/strength parameter)} \tag{2.6}$$

$$S_d = \mu_S - \alpha_S \cdot \beta_T \cdot \sigma_S = S_k \cdot \gamma_S \quad \text{(load parameter)} \tag{2.7}$$

[1] *Notice that the partial factor γ_S is mentioned here for the sake of completeness in the description of the theoretical concept. In WBI 2017 this value is typically set equal to 1.0 so that the design water level equals the representative value.*

Herein, μ_R and μ_S are the expected values of R and S, α_R and α_S are the values of the FORM-influence coefficients for R and S, β_T the target reliability index, σ_R and σ_S its standard deviation of R and S, R_k and S_k are the characteristic values of R and S (e.g. 5^{th} percentile for strength parameters and 95^{th} percentile for load parameters) and γ_R and γ_S are the (partial) safety factors.

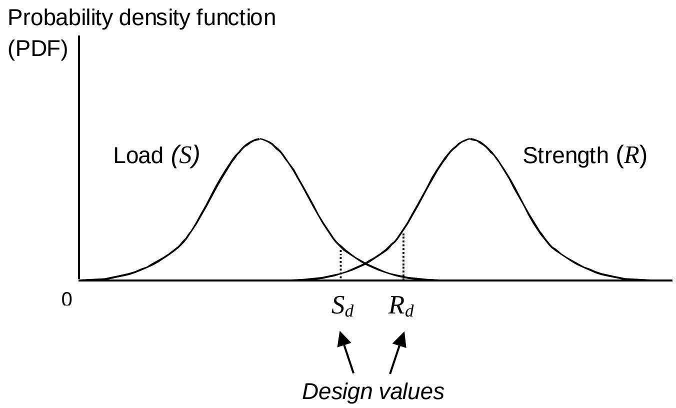

Figure 2.1. Probability density function of load (S) and strength (R), and the correspondent design values S_d and R_d.

In short, probabilistic and semi-probabilistic assessments *both* require:
- A model of the failure mechanism,
- The probability density functions (PDF) for all stochastic variables (based on statistical data and/or engineering judgment) and
- a reliability requirement ('target') reliability.

The essential differences between probabilistic and semi-probabilistic assessments are:
- In a probabilistic assessment, a failure mechanism model is fed with all possible parameter values and their probabilities (i.e. probability density functions),
- In a semi-probabilistic assessment, a failure mechanism model is fed with unique, 'sufficiently safe' values (i.e. design values). How safe 'sufficiently safe' is, depends ultimately on the reliability requirement and a calibration criterion.

As such, to ensure consistency between probabilistic and semi-probabilistic assessments, calibration exercises are indispensable. The equations for deriving the characteristic values of normally and log-normally distributed variables are given in Appendix B.

3 Slope stability

This section gives a brief overview of the limit equilibrium models and corresponding input which are used in slope stability assessments in the Netherlands. Additionally, an overview of the basics of drained shear strength of soils is given. Different limit equilibrium models are available in D-Geo Stability. The (not publicly available) D-Geo Stability user interface (C# version) with the WBI Macrostability kernel of 09 May 2016 has been used for calibrating safety factors.

For more information about slope stability assessments, please refer to Van Duinen (2014a) and Van Deen and Van Duinen (2016). The limit equilibrium models form the basis of the Macrostability kernel (Van der Meij and Trompille, 2016), that is used to compute the slope stability factor (*FoS*). For more and detailed information on limit equilibrium models, the reader is referred to (Bishop, 1955; Van, 2001; Spencer, 1967).

3.1 Notation

A distinction is made throughout the report between the computed factor of safety and the required factor of safety. The following notation is used:

- FoS: the generic **computed** factor of safety (in Dutch: “stabiliteitsfactor”), used as the ratio between resisting and driving moment. Because the resisting and the driving moment are uncertain, FoS is a stochastic variable.
- FoS_{des}: The **computed** factor of safety using design values of the input variables .
- γ_n is the **required** factor of safety (in Dutch: *schadefactor).* This is the so called overall or β – dependent safety factor. The final γ_n is fitted based on a test case set.

3.2 Limit equilibrium models

Limit equilibrium models compare the driving moment M_S of a potential slip plane or surface with the resisting moment M_R to obtain the stability factor or factor of safety (FoS) via eq.(3.1).

$$FoS = \frac{M_R}{M_S} \tag{3.1}$$

To calculate FoS, the following models are used in the calibration:

Uplift-Van

High pore pressures at the horizontal interface of weak layers with an underlying sand layer can cause reduction or even complete loss of shear resistance at this plane. This can yield an uplift failure mechanism. The Uplift-Van method assumes that the total slip plane is composed of a horizontal part bounded by two circular parts. The factor of safety (*FoS*) is determined using the equilibrium of the horizontal forces acting on the compressed area between the active and passive slip circles. The method becomes equal to Bishop’s method if the length of the horizontal part reduces to zero and the radiuses of the active and the passive circle coincide. In contrast to Bishop, Uplift-Van satisfies horizontal equilibrium between active, horizontal and passive parts; Spencer satisfies horizontal equilibrium between al segments but is not used (Van der Meij and Trompille, 2016).

3.3 Shear strength

3.3.1 Mohr-Coulomb for drained analysis

The Mohr-Coulomb model is used for modelling the drained shear strength of soils with high permeability in the Macrostability kernel. This is mainly applicable to present sand layers. Herein the cohesion c' (0 for sand), the angle of dilatancy ψ (also 0) and the effective friction angle φ' are used to calculate the ultimate shear tress τ in relation to the vertical effective stress $\sigma'_{v,i}$, given in the equation below. A more detailed description is given in (Van der Meij and Trompille, 2016).

$$\tau = c' + \sigma'_{v,\mathrm{i}} \frac{\cos\psi \cdot \sin\varphi'}{1-\sin\psi \cdot \sin\varphi'} \tag{3.2}$$

3.3.2 Critical state soil mechanics model for undrained analysis

The critical state soil mechanics model (CSSM) is used for modelling the undrained shear strength of soils with low permeability. The undrained shear strength model for the Macrostability kernel is as follows, for more information see Van Deen and Van Duinen (2016):

$$s_u = \sigma'_{v,i} \cdot S \cdot OCR^{m} \quad \text{with} \quad OCR = \sigma'_{vy} / \sigma'_{v,i} \quad \text{and} \quad \sigma'_{vy} = \sigma'_{v,i} + POP \tag{3.3}$$

Herein, s_u is the undrained shear strength [kN/m^2], $\sigma'_{v,i}$ the in-situ effective vertical stress [kN/m^2], S the undrained shear strength ratio (normally consolidated) = $(s_u/\sigma'_{v,i})_{nc}$ [-], OCR the Over-Consolidation Ratio [-], m the strength increase exponent [-], σ'_{vy} the vertical yield stress [kN/m^2], and POP the pre-overburden pressure [kN/m^2]. The POP can be either a direct input per layer or an indirect input, deduced from a list a pre-consolidation stress measurements and X- and Z-coordinates. POP and $\sigma'_{v,i}$ are a function of the outside water level.

The undrained model has been used as the default model in the calibration, with the exception of sand layers that have been modelled as drained.

3.3.3 Slope stability computations in D-Geo Stability

The slope stability calculations have been carried out with the D-Geo Stability user interface using the WBI Macrostability kernel of 09 May 2016. Herein, the low permeablity layers have been modelled by means of the undrained shear strength and the aquifer layers (or e.g. sand cores) have been modelled as drained layers. The soil parameters have been derived from expert judgement in combination with laboratory tests for both the undrained and the drained parameters. Additionally to S and m, yield stress points had to be defined in each undrained layer. It is recommended to place at least one yield stress point in each undrained layer; if the vertical stresses change through e.g. a dike or berm, one should add additional yield stress points to consider these conditions. Each yield stress point has been derived for the calibration based on effective stress for daily water level conditions. Alternatively, one case use local measurements if available. If a value of the pre-overburden pressure (POP) is available, one can use the relation $\sigma'_{vy} = \sigma'_{v,i} + POP$ to estimate the value of the yield stress. In the cases presented in this report, we used expert judgment to adjust the yield stress values to realistic values, if necessary.

Inside the D-Geo Stability software, the Waternet creator is used for the generation of pore pressures. Note that the Waternet creator may give unrealistic values if not all required values are filled in and if wrong layers are defined as aquifer.

If there is a blanket layer of less than 4 meters and an uplift potential bigger than 1.2, the shear strength of the low permeable, undrained layers in this region has to be reduced to 0 due to uplift. Note that in the present version of D-Geo Stability (10/2015) one has to manually select strength reduction in case this happens.

Note also that one has to check carefully the boundary conditions of the search algorithm that is employed to find the realistic slip plane with the lowest factor of safety. In case of the Uplift-Van method, one should pay attention to the coarseness of the search grids and corresponding tangent lines. If necessary, one has to modify them to find the slip surface or other calculation options such as *minimal slice depth*, *zone area*, *number of slices*, etc. In case of the Spencer algorithm, one should check carefully the boundary conditions of the genetic algorithm. It is highly recommended to vary the default *automatic boundary conditions* to find the slip surface with the lowest safety factor. Note that shallow slip surfaces might not lead to a slope stability failure. These shallow surfaces have been excluded using an entry zone for the slip plane through the crest.

3.4 Considered uncertainties

There are various uncertainties that affect the reliability of a dike. These involve load parameters (e.g. outside water level, pore water pressures) and strength parameters (shear strength properties, subsoil composition).
A difference can be made between the sources of uncertainty:

1. Natural variability is uncertainty that results from random natural processes. An example is the annual maximum water level that varies from year to year. Natural variability in the time domain is not reducible. A typical example of such natural variability is the outside water level (as are most load properties). This type of natural variability is not reducible by doing extra measurements.
2. Knowledge uncertainty results from limited knowledge of a true property. An example is shear strength (as are most strength properties), where uncertainty mainly stems from spatial variability, limited samples and characterization uncertainty. Knowledge uncertainty is reducible by e.g. doing more measurements.

In the calibration, most load and strength properties are covered in the safety format. Which parameters this concerns is discussed in the following sections. A special case is uncertainty regarding the subsoil composition and other possible deviations from the modelled dike. These are supposed to be covered in subsoil scenarios (see Chapter 9 and Chapter 10). These are part of the safety format, but will not be discussed in detail in this calibration.

3.5 List of input variables

When using the Macrostability kernel to model the mechanism, one needs the input variables given in Table 3.1. Also, this table provides information on which parameters are considered random variables and their default values (when applicable).

An additional parameter to be considered is the model uncertainty. Model uncertainties are uncertainties that arise due to the fact that models are imperfect representations of reality. Model uncertainties can be addressed using a variable (m_d) that represents the ratio of the predicted over the real response for the model used. The model uncertainty m_d is applied by dividing the factor of safety *FoS* by m_d, see eq.(3.4). This means that the mean of a model uncertainty higher than 1 means on average the model is too optimistic and the computed factor of safety needs to be reduced. In the case of the slope stability failure mode, the model uncertainties for the different failure plane models described above are given in Table 3.2. These are based on Van Duinen (2015) and show a mean very close to 1. The pore water pressure uncertainties are modelled by making the leakage length and the intrusion length random variables according to Kanning and Van der Krogt (2016).

Table 3.1 Parameters for Slope stability analyses used in the Macrostability kernel

Symbol	Unit	Description	Drained	Undrained	Distribution	Default	Used ranges in the calibration
γ_{unsat}	[kN/m^3]	unit weight of soil above phreatic level	x	x	Deterministic	*	Appendix F or L
γ_{sat}	[kN/m^3]	unit weight of soil below phreatic level	x	x	Deterministic	*	Appendix F or L
c'	[kN/m^2]	effective cohesion	x		Lognormal	*	Appendix F or L
$tan(\varphi')$	[-]	effective friction angle	x		Lognormal	*	CoV = 0.05-0.15
S	[-]	undrained shear strength ratio (nc)		x	Lognormal	*	Appendix F or L
m	-	strength increase exponent		x	Lognormal	*	CoV =0.03
σ'_{vy}	[kN/m^2]	vertical yield stress		x	Lognormal	*	σ=6 kN/m^2
λ_{in} ,λ_{out}	[m]	leakage length	x	x	Lognormal	-	CoV =0.20 (Rozing, 2015)
IL	[m]	intrusion length	x	x	Lognormal	-	CoV =0.30 (Rozing, 2015)
$PL1$	[m+NAP]	Phreatic line schematisation	x	x	Deterministic	***	-
WL	[m+NAP]	water level	x	x	Gumbel	**	Appendix F or L

* Each parameter has to be specified for each layer. One can find suggestions on the variability and default values of the soil random variables in the "Schematiseringshandleiding" (Van Duinen, 2014a; Van Deen and Van Duinen, 2016 - Appendix G).

** The hydraulic properties have to be specified per cross-section depending on the location. The water level is assumed to follow a Gumbel distribution, which can be derived from the mean water level and the decimate height (see e.g. Schweckendiek, 2014) – summary Table F.2.

*** PL1, the phreatic line is modelled as deterministic according to the WaternetCreator defaults since a) this is conservative, b) there is limited effect on the stability factor (*FoS*) and c) stable implementation proved challenging.

Table 3.2 Model uncertainty for different limit equilibrium models

model	distribution type	mean value	standard deviation	model factor (95% quantile)
Spencer	lognormal	1.008	0.035	1.07
Uplift-Van	lognormal	1.005	0.033	1.06

3.6 A quick take on the safety format

In a probabilistic analysis, the model uncertainty m_d is used together with the factor of safety FoS (see eq.(3.1)) in the following limit state function (Z):

$$Z = FoS/\,m_d - 1 \tag{3.4}$$

In a semi-probabilistic analysis, the partial factor γ_d (model factor) is used to cover the model uncertainty , together with the factor of safety FoS_{des} (calculated with design values of the input parameters) and other safety factors, in the following equation:

$$\frac{M_{R,d}}{M_{S,d}} = FoS_{des} \tag{3.5}$$

The following condition should be met:

$$\frac{1}{\gamma_d \cdot \gamma_n} \cdot FoS_{des} > 1 \tag{3.6}$$

Herein, Z is the limit state function, m_d is the model uncertainty, γ_d is the model safety factor, γ_n is the *schadefactor* (TAW, 1989) which is the so called overall or β– dependent safety factor in this report, see also Chapter 6.

3.7 Spatial averaging

Spatial averaging plays an important role because vertical fluctuations in shear strength properties have relatively small scales of fluctuation compared to the size of the failure plane. This results in partial averaging (only the vertical part) of uncertainty over the failure plane. This is important since it reduces the variance in shear strength properties. How much averaging occurs depends on the contribution of vertical fluctuations to the total variance in the data. This depends on whether the data is from a local of regional dataset. This calibration uses cases based on regional datasets. Partial averaging of shear strength properties, as well as the effect of the limited amount of samples, has been considered. This is further explained in Appendix C.

3.8 Previously recommended safety factors

As a reference, previously recommended safety factors are presented in Table 3.3. It should be noted that safety factors are only relevant for the material model for which it is derived; and in in relation to the whole safety format. Hence, a direct comparison of safety factors for different material models is not possible.

Table 3.3 Review of the safety factors for slope stability (studies, assessment and design).

		Source			
		Van der Meer et al. (2008) / TRWG addendum	Jongejan et al. (2012)	Jongejan et al. (2014)	OI2014 v3 (2015), based on Jongejan et al. (2014)
Purpose of document/study		Design, assessment	Test WTI calibration procedure	Preliminary comparison of CSSM and MC	Preliminary design
Safety factor	Description				
Material	γ_m				
γ_{unsat}	unit weight of soil above phreatic level	1.0	1.0	1.0	1.0
γ_{sat}	unit weight of soil below phreatic level	1.0	1.0	1.0	1.0
	Drained				
c'	effective cohesion	Clay: 1.25 Peat: 1.50 Sand: -	1.0 (all soil types)	-	-
tan(φ')	tangent of effective friction angle	Clay: 1.20 Peat: 1.25 Sand: 1.20	1.0 (all soil types)	-	-
	Undrained	-	-		
S	undrained shear strength ratio (NC)	-	-	1.03 – 1.17*	1.05 – 1.18 avg. 1.08
POP	pre overburden pressure	-	-	1.00 – 1.09*	1.00 – 1.13 avg. 1.08
Model	γ_d				
	Drained	B**: 1.0	1.03	-	ULV & SP** No uplift: 0.95 Uplift: 1.05
	Undrained	-	-	ULV: 1.03	ULV**: 1.06 SP**: 1.07
β – dependent	*Schadefactor* $\gamma_n = \gamma_\beta$				
	Drained	1 + 0.13 ($\beta_{eis,dsn}$−4.0)	1 + 0.35 ($\beta_{eis,dsn}$−5.0)	-	-
	Undrained	-	-	1 + 0.18 ($\beta_{eis,dsn}$−4.8)	1 + 0.21 ($\beta_{eis,dsn}$−4.3)

* These values correspond to a relatively strict target reliability in combination with less pessimistic influence coefficients; other material factors, for other combinations, have also been presented in Jongejan et al. (2014).
** B = Bishop. The model factor varies, for *drukstaafmodel* between 0.9 and 1.0 and for *opdrukveiligheden* between 1.2 and 1.0.
** ULV = Uplift-Van
** SP = Spencer-Van der Meij

3.9 Specific implementation D-Geo Stability

Yield stress points
In the WBI2017, different methods are available for undrained slope stability computations (e.g. see Van Deen and Van Duinen, 2016). In the calibration, stability computations have been made using yield stress points (Van der Meij and Trompille, 2013). The yield stresses can be determined based on laboratory experiments or calculated based on the effective stress in the yield stress point for the daily water level and the POP value (see Van Deen and Van Duinen, 2016 for more information). A combination of these procedures and expert judgment has been used for the calibration. An alternative method would be to determine the local yield stresses based on CPT's, see Appendix K. The uncertainty of the yield stress points has been estimated on the basis of available laboratory test data and expert judgement, see 7.3.3.

In a previous study (Jongejan et al., 2014), because of software limitations, the POP was the input parameter that had to be chosen, based on which the yield stresses were determined. The modelling framework used in the present study is a clear improvement since the POP should ideally not be treated as a fixed value.

Waternet Creator
The Waternet Creator as of 09-05-2016 has been used for the calibration. This Waternet Creator defines the phreatic line inside a dike and piezometric level (PL) lines in the soil layers beneath the dike as a function of the outside water level, assuming overtopping is absent. The resulting phreatic line is probably slightly conservative, which is more important for actual design than for the calibration of safety factors. This is because it influences both the outcomes of probabilistic and semi-probabilistic evaluations.

Berm optimization
The berms that have been designed to increase the reliability of dike sections have not been optimized. The height of the berm is usually around one-third of the dike height. Optimizations of the berm dimensions and weight may lead to smaller berms. This is mainly of interest for the actual design of berms, but less relevant for the calibration of partial factors.

4 Calibration procedure

In this chapter, the following procedure is applied for calibrating the semi-probabilistic safety assessment rules for inner slope stability. The procedure is based on Jongejan (2013) and Jongejan et al. (2014).

Step 1: Establish the reliability requirement. This requirement is defined as a maximum allowable probability of failure for the failure mechanism under consideration for an entire segment (*dijktraject*). The length-effect is also discussed in this step. This effect is taken into account in step 3(c), when deciding which safety factors may be considered sufficiently safe.

Step 2: Establish the safety format. This step comprises the following activities:

a) establish a test set that ideally covers a wide range of cases. The test set members concern existing or fictitious cross-sections of dikes;
b) calculate influence coefficients for each test set member, for a specific target failure probability or a range of values;
c) based on the outcomes of the previous activity and practical considerations, define representative values, i.e. characteristic values and safety factors that are to be included in the semi-probabilistic assessment rule.

Step 3: Establish safety factors. This step comprises the following activities:

a) establish, on the basis of representative influence coefficients and a target reliability index, the values of all but one safety factor. Herein, these safety factors will be called β_T – invariant safety factors (β_T stands for the required, or target, reliability index);
b) for each test set member, determine the required stability berm so that $R_d = S_d$, for a range of values of the remaining β_T – dependent safety factor. When this condition is fulfilled, each (modified) test set member would just pass a semi-probabilistic assessment. Then calculate the probability of failure of each (modified) test set member. The objective of this step is to establish a relationship between the value of the β_T – dependent safety factor and the probability of failure (or reliability index), for each test set member;
c) apply a calibration criterion to select the appropriate value of the β_T – dependent safety factor. The calibration criterion provides a reference for deciding which design values are sufficiently safe. According to the criterion, the failure probability of a segment should be smaller than the target failure probability that applies to the segment (step 1).

Step 4: Compare calibration results with present-day rules. A 4th step is to compare the calibrated semi-probabilistic assessment rule with the present-day $\gamma - \beta$ relations. For this comparison, the OI2014_v3 (Rijkswaterstaat, 2015) has been used.

The following chapters give more detail on the steps stated above.

5 Step 1: establishing the reliability requirement

This chapter discusses the establishment of the reliability requirement that is needed for calibration purposes. It starts with a maximum allowable probability of flooding (section 5.1), from which the reliability requirement for slope stability is derived (section 5.2). The relationship between the reliability requirement for entire dike segments and cross-sectional failure probabilities is discussed section 5.3.

5.1 Target probabilities of flooding

The flood safety standards are defined in terms of target probabilities of flooding (DPV, 2015). These standards apply to dike segments (*dijktraject*). A dike segment is a dike system or part thereof. Segments can be over 20 km long and are usually located in one water system. Segments may consist of numerous dike sections and/or hydraulic structures. For the calibration, a reliability requirement is needed that can be translated to a requirement for a cross-section.

5.2 Reliability requirement for slope stability in general

For calibrating a semi-probabilistic assessment rule for a particular failure mechanism, a reliability requirement for that failure mechanism is needed. Such a reliability requirement can be derived from a fault tree analysis. Each failure mechanism may lead to flooding, the fault tree's top event. The combined probabilities of the various failure mechanisms may not exceed the maximum allowable probability of flooding. To ensure this requirement is met, the maximum allowable failure probabilities for the failure mechanisms, their 'failure probability factors', should be defined in such a manner that their combined value does not exceed the maximum allowable probability of flooding. The maximum allowable contributions of the different failure mechanisms to the maximum allowable probability of flooding are shown in Table 5.1.

Table 5.1 Maximum allowable failure probabilities per failure mechanism, defined as a fraction of the maximum allowable probability of flooding - Jongejan (2013).

Type of flood defence	Failure mechanism	Failure probability factor (*f*)	
		Sandy coast	**Other (dikes)**
Dikes and structures	Overflow and wave overtopping	0	0.24
Dikes	Uplift and piping	0	0.24
	Macro instability of the inner slope	**0**	**0.04**
	Revetment failure and erosion	0	0.10
Structures	Non-closure	0	0.04
	Piping	0	0.02
	Structural failure	0	0.02
Dunes	-	0.70	0 or 0.10
Other	-	0.30	0.30 or 0.20
Total		1.00	1.00

The fractions in Table 5.1 are based on the expected importance of the different failure mechanisms if all dike systems were to meet their (assumed) safety standards. These estimates are based on calculations with PC-Ring and VNK2-data as well as a number of expert sessions with representatives of research institutes (TNO, Deltares, Delft University of Technology), engineering consultancies, water boards, and *Rijkswaterstaat*. For further details about the maximum allowable failure probabilities per failure mechanism, the reader is referred to Jongejan (2013). It should be noted that the fractions of Table 5.1 are the basis of the calibration. However, the WBI also allows for a redistribution of fractions, as well as a full probabilistic analysis for more detailed assessments. This is outside the scope of this report.

The default failure probability factor f for the slope stability mechanism[2] is 0.04. This factor leads to maximum allowable failure probabilities (P_T) as shown in Table 5.2. The reliability requirements are also expressed in terms of reliability indices (β_T). It should be noted that the reliability requirements (P_T or β_T) in Table 5.2 apply to dike segments. These should not be confused with cross-sectional reliability requirements. Due to the length-effect, cross-sectional reliability requirements will have to be more stringent than reliability requirements for entire segments. In Table 5.2, requirements are shown for the anticipated, new safety standards.

Table 5.2 Reliability requirement for a range of safety standards – slope stability mechanism.

f	**P_{norm}**	**Reliability requirement (entire dike segment)**	
[-]	**[yr^{-1}]**	$P_T = f.P_{norm}$ [yr^{-1}]	$\beta_T = -\Phi^{-1}(P_T)$ [yr^{-1}]
0.04	1/300	1.3E-04	3.65
	1/1,000	4.0E-05	3.94
	1/3,000	1.3E-05	4.20
	1/10,000	4.0E-06	4.47
	1/30,000	1.3E-06	4.69
	1/100,000	4.0E-07	4.94

5.3 Reliability requirement for slope stability at cross-section level

The difference between the reliability requirement for an entire segment and the reliability requirement for individual cross-sections will increase with decreasing spatial correlations and decrease with greater variability in cross-sectional reliabilities. The latter is because the failure probabilities of the weakest cross-sections will dominate the failure probability of the entire segment when the weakest cross-sections have relatively high probabilities of failure (Calle and Kanning, 2013).

In the case of the slope stability failure mechanism, the length-effect is characterised by the parameters a and b, and the relation between the reliability requirement for a dike cross-section and the reliability requirement for a dike segment is given as follows:

$$P_T = P_{T,cross}\left(1+\frac{a\cdot L}{b}\right) \tag{5.1}$$

and

$$P_T = f\cdot P_{norm} = \frac{f}{T} \tag{5.2}$$

[2] *The macrostability mechanism refers to the inner slope stability failure mechanism. From now on this terminology will be used in this report.*

where:

- P_T the target failure probability of a dike segment for a certain failure mechanism [yr^{-1}],
- $P_{T,cross}$ the target failure probability of a dike cross-section for that mechanism [yr^{-1}],
- T the return period that corresponds to the safety standard of a segment [yr],
- L the total length of the segment [m],
- a the fraction of the length that is sensitive to the slope stability failure [-],
- b a measure for the intensity of the length effect within the length $a.L$ [m],
- P_{norm} the maximum allowable failure probability (safety standard) [yr^{-1}],
- f the budget for the failure mechanism under consideration [-].

The length-effect parameters a and b, can be interpreted as follows. The constant a may be interpreted as the percentage of dikes that contribute significant to the total failure probability for slope stability and b may be interpreted as the equivalent auto-correlation length of the performance (or limit state) function. LOR2 (TAW, 1989) states a = 0.033 and b = 50m, which is based on an analysis of a single dike ring. At present, there are no new insights on which to base alternative values, which is why the parameter values of a and b have been maintained. Table 5.3 shows the range of $\beta_{T,cross}$ (reliability index corresponding to $P_{T,cross}$)for several segment lengths and values of T (=1/P_{norm}), a and b. It shows that the range of $\beta_{T,cross}$ is roughly between 4 and 6; this is the range the calibration focuses on. It also shows $\beta_{T,cross}$ is not very sensitive to variations in a and b. This means they do not play a major role in the calibration exercise. Hence, the factors a and b have not been studied further.

Table 5.3 Range of $\beta_{T,cross}$.

parameter	Variation 1	Variation 2	Variation 3	Variation 4
a [-]	0.033	0.033	0.2	0.2
b [-]	50	50	200	50
L [m]	5000	30000	5000	30000
f [-]	0.04	0.04	0.04	0.04
T [yr]	300	30000	30000	30000
$P_{T,cross}$ [yr^{-1}]	3.1E-05	1.9E-08	6.7E-08	3.3E-09
$\beta_{T,cross}$ [-]	4.0	5.5	5.3	5.8

6 Step 2: establishing the safety format

The safety format concerns the definition of representative values (characteristic values) and the partial safety factors that are to be included in the semi-probabilistic assessment rule. The safety format depends on the relative importance of the uncertainties in the random variables (see also section 2.2). To obtain insight into the relative importance of the uncertainties, probabilistic analyses of representative cases are indispensable. Section 6.1 first discusses general considerations for the safety format. Section 6.2 discusses the test set for which probabilistic analyse have been carried out. The calculated influence coefficients are discussed in section 6.3. These lie at the heart of the safety format that is detailed in section 6.4.

6.1 General considerations for the safety format

The goal of partial safety factors is to enable a semi-probabilistic design or assessment based on safety factors that complies with a target reliability (β_T). Ideally, each variable has its own partial safety factor (e.g. γ_R) that ensures the variable is in, or very close to, the design point ($R*$). The design point is the most likely combination of parameters at failure.

However, there are a number of reasons to deviate from this format:

- **Simplicity**: It might not be practically workable for each variable to have its own partial safety factor.
- **Consistency safety format:** The safety format of STBI should comply with the general WBI 2017 safety format, which includes typically one β-dependent overall safety factor. Also, the WBI design water level (“waterstand bij norm”; WBN) might be far away from the design point for strength dominated mechanisms such as stability.
- **Variation in influence factors:** The influence factors α may change from case to case, and a choice should be made for a representative α per variable.

In the WBI 2017, these deviations from the theoretical optimum are dealt with by calibrating a β-dependent safety factor to the results for a wide variety of cases. This ensures that the semi-probabilistic assessment rule is broadly applicable.

6.2 Establishing a test set

6.2.1 Considerations to establish a test set

To obtain insight into the relative importance of the random variables, probabilistic analyses have been carried for a representative set of cases (test set). The test set cases reflect the variety of sub-soil conditions and loading conditions found throughout the Netherlands. The test set is composed of actual dikes from the VNK2-project and Delta Programma Veiligheid (calibration 2015, see Kanning et al, 2015) and actual dikes where local undrained shear strength data is available (new in the 2016 calibration). It must be noted that the VNK2 project focused on cases that were considered relatively unsafe; hence, there is a bias in this part of the test set towards unsafe dikes. The new cases have a mix of local, regional and default data for the various parameters, depending on the information available (see Table 6.1).

General specifications that were used to select the representative test set are:
- The test cases are primary flood defences;
- Different water systems are covered by the test cases;

- Different geo-hydrological (with or without uplift) and (drained and undrained) soil conditions are covered;
- Different soil profiles and dike geometries are represented;
- Mix of local, regional and default data
- Different WaterNet Creator dike compositions are represented: clay on clay, clay on sand, sand on clay and sand on sand.
- Mix of materials that are modelled as undrained (for lowly permeable materials such as clay and peat) and materials that are modelled as drained (permeable material such as sand)
- Furthermore, the considered safety standards cover the entire range of the safety standards as defined in DPV (2015).

6.2.2 Location of test set cases

The location of the test set members (cases) is shown in Figure 6.1. For further details about the test set, see the summary tables in Appendix F or the individual case's reports in Appendix L.

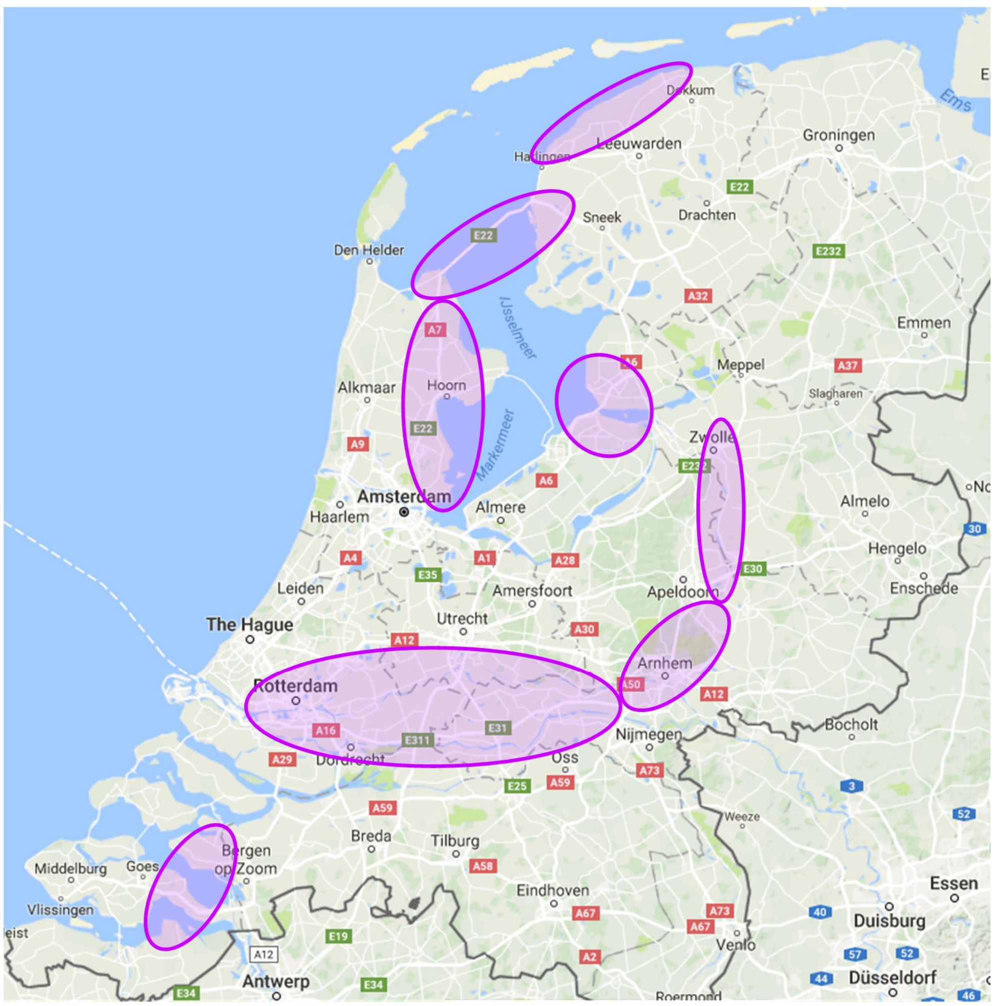

Figure 6.1 Test set members for the STBI calibration exercise in 2016 (dark blue refer to the cases of 2015, light blue refers to the added cases with local/regional data).

6.2.3 Case descriptions

The case descriptions are shown in Table 6.1. The table shows there is a good coverage with respect to geology, uplift or not, safety standard and the source of the data. More information about the cases is presented in Chapter 7. See also the summary tables in Appendix F or the individual case's reports in Appendix L. It should be noted that various dike types are present in the test-set. However, these were only assigned 'Clay on Clay' or 'Sand on Clay' in the WaterNet Creator to represent the pore water pressures realistically.

Table 6.1 Summary of the characteristics of the selected cases (cases 1-17 are from 2016, case 18-27 are from the 2015 calibration).

Case #:	location	geology	uplift	1/T [yr^{-1}]	Data source
1	Nederrijn	Riverine	no	1/30,000	Defaults
2	Lek river	transition	yes	1/10,000	Regional
3	Lek river	transition	no	1/30,000	Local
4	Lek river	Riverine	no	1/30,000	Regional
5	Lek river	Riverine	no	1/30,000	Regional
6	Waal river	Riverine	no	1/30,000	Regional
7	Waal river	Riverine	no	1/30,000	Regional
8	Waal river	Riverine	no	1/30,000	Regional
9	Waal river	Riverine	no	1/30,000	Regional
10	Waddenzee	Marine	yes	1/3,000	Regional
11	Ijsselmeer	Lake	yes/no	1/3,000	Defaults
12	Ijsselmeer	Lake	yes	1/3,000	Defaults
13	Maas river	Riverine	no, though shear strength reduction	1/3,000	Defaults
14	Lek river	transition	no	1/10,000	Local
15	Markermeer	Lake	no	1/3,000	Regional
16	Dam	Marine	no	1/10,000	Defaults
17	Waddenzee	transition	no	1/10,000	Regional
18	Maas river	Riverine	no, though shear strength reduction	1/10,000	Defaults
19	Waal river	Riverine	no, though shear strength reduction	1/10,000	Defaults
20	Waal river	Riverine	yes/no	1/10,000	Defaults
21	Waal river	Riverine	no	1/30,000	Defaults
22	Ijssel river	Riverine	yes/no	1/3,000	Defaults
23	Lek river	transition	yes	1/30,000	Defaults
24	Ijssel river	Riverine	no, though shear strength reduction	1/3,000	Defaults
25	Ijsselmeer	Marine	no	1/3,000	Defaults
26	Oude Maas river	Marine	no	1/3,000	Defaults
27	Westerschelde	Marine	yes/no	1/30,000	Defaults

As mentioned in the previous chapters, the cases have been adapted with berms in order to reach the required reliability levels. Since the calibration is aimed at assessments, the POP values have been kept the same as in a situation without berms and the effective stresses have been increased due to weight of the berm.

6.3 Defining representative influence coefficients

The relative importance of the uncertainties, related to random variables, can be expressed in terms of FORM influence coefficients (see also section 2.1), which are determined in a FORM analysis, see Appendix A. An inspection of influence coefficients (α) provides useful clues about appropriate representative values (quantiles) and/or the variables for which partial safety factors should be introduced. Influence coefficients can be obtained from FORM calculations. Figure 6.1 shows the squared influence coefficients for (groups of) random variables, for the considered cases.

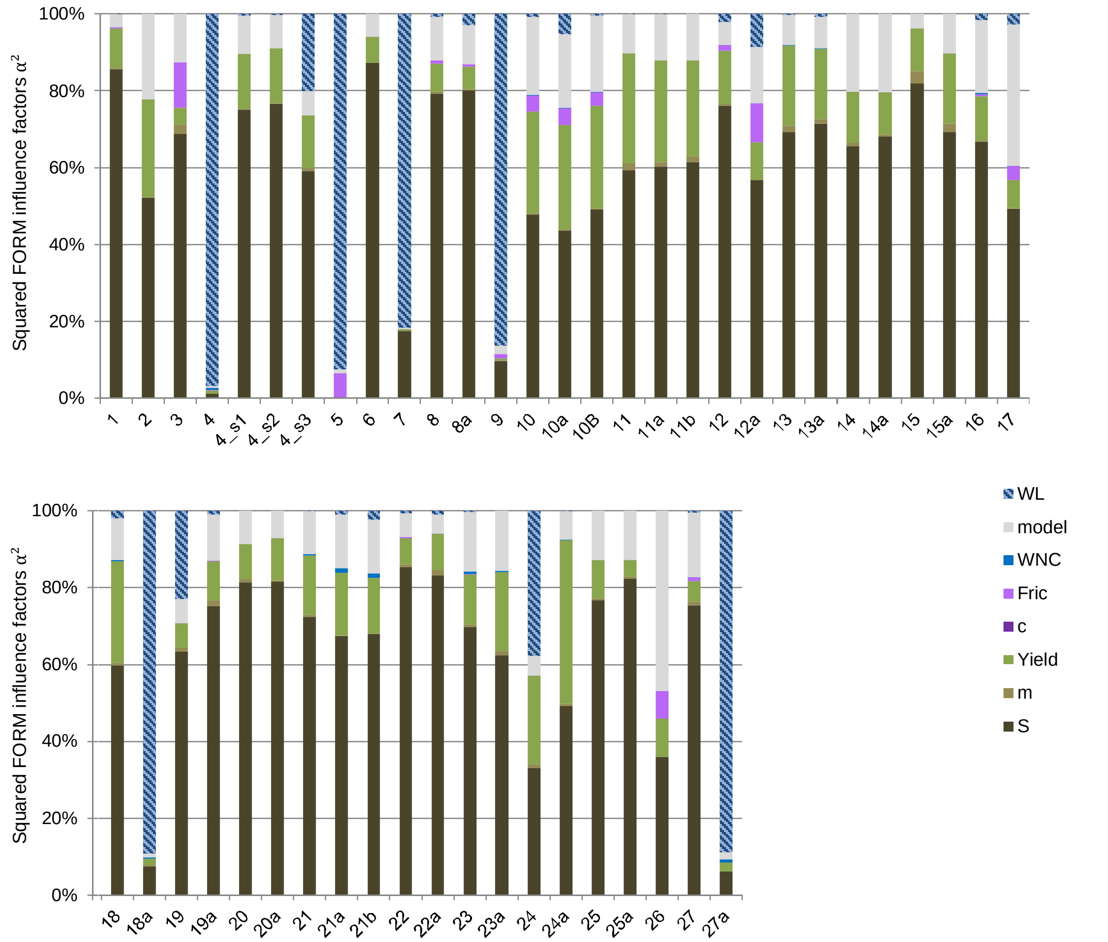

Figure 6.2 Squared FORM influence factors α^2 ("alfa^2") of the computed cases

In Figure 6.2, *WL* is the outside water level, model is the model uncertainty, *WNC* is the pore water pressure uncertainty modelled in the Waternet Creator (WNC), *Fric* is the friction angle (for drained materials), c is the cohesion for drained materials (does not apply), *yield* is the yield stress, m is the strength increase exponent and S is the undrained shear strength ratio.

Figure 6.2 shows that the uncertainty related to the hydraulic loading conditions (outside water level WL) is significantly less important than found in VNK2 and Jongejan et al. (2013) for drained stability analyses. In case of undrained behaviour, a smaller sensitivity is to be expected, this is also discussed in Kanning et al (2015). The yield stress and the undrained shear strength ratio (S) appear to have the highest influence, together with the model uncertainty.

There are several cases with a very high influence of the water level (α^2 > 0.5):
- Case 4: the layer “dijksmateriaal”is modelled as drained (drained parameters for the dike body), and hence experiences more pore water pressure influence than the other undrained cases,
- The slip circle in Case 5 changes from shallow to deep due to the increasing water pressures,
- The slip circle in Case 7 become longer due to higher water pressures (see Appendix L – L.8),
- Case 9 is a ‘sand dike on clay’ with corresponding drained behaviour,
- Case 18:_berm experiences uplift,
- Case 27a has both drained dike material (sand on clay dike) and experiences uplift.

There are other cases with uplift but these also have large failure planes, resulting in a relatively high contribution of S (most of the shear strength along the slip circle is mobilized outside the uplift zone) and thus a low influence of the water level. Case 24a has a relatively high alfa of the yield stress since the uncertainty in yield stress is relatively high compared to *S*. The Case 26 has likely a high alfa for the model uncertainty because of the many layers the slip circle crosses.

The limited effect of the water level could be due to the (undrained) material model, the variance of input parameters or due to overly conservative (water pressure) schematizations (which is less the case in the 2016 calibration than it was in the 2015 calibration). The implications of the low influence of the water level are further discussed in Chapter 10.

6.4 Safety format: representative values and safety factors

6.4.1 General considerations

Representative values and safety factors should ideally be chosen on the basis of (target) reliability indices and influence coefficients, see section 6.3, to obtain an efficient format. On the other hand the safety format should be as simple as possible. Hence, a balance between simplicity and effectiveness is pursued. The following reasoning is followed to derive the safety format.

For pragmatic reasons, representative values should be defined as uniformly as possible. The consistent use of 5%-quantiles for strength parameters is preferable over the use of e.g. the 10%-quantile for variable X_1, the 25%-quantile for X_2, the 55%-quantile for a variable X_3 and so on. The use of the 5%-quantile as representative value is due to practical reasons (WBI 2017 uniformity).

Second, within the WBI 2017, the strategy, for reasons of uniformity, is to select the load (i.e. water level on the water side) with an exceedance probability equal to the allowable probability of flooding (Jongejan, 2013). This ensures consistency across failure mechanisms in the WBI 2017 and facilitates comparisons between today's rules and $\gamma - \beta$ relations.

Third, representative values are normally defined as quantiles. Yet when it comes to the model uncertainty parameter, it seems practical to choose a representative value equal to 1. The design value of the model uncertainty parameter is then directly equal to its partial safety factor.

Finally, in theory, design values of all variables should depend on reliability requirements. That would be impractical, however. A pragmatic solution is to define β_T– invariant factors for all important variables (that could be 1.0 or different than 1.0) and a separate β_T– dependent safety factor to account for the stringency of the safety standard and the remaining uncertainties. This β_T – dependent safety factor is to be applied to the ratio $M_{R,d}$ / $M_{S,d}$ – eq.(3.5).

6.4.2 Current representative values

The result of a deterministic analysis is a factor of safety FoS_{des} based on design values. In a semi-probabilistic safety assessment, the input parameters are representative values (see Appendix B) or design values (if factored with a partial safety factor). Table 6.2 presents the current characteristic values (TRWG for drained, OI2014 for undrained). Note that in current practice with drained analysis only the cohesion and (tangent of the) friction angle are factored with partial safety factors (see e.g. TAW, 1989).

Table 6.2. Summary of the representative values for the slope stability computations (based on TRWG and OI2014).

Symbol	Unit	Description	Drained	Undrained	Representative values
γ_{unsat}	[kN/m^3]	unit weight of soil above phreatic level	x	x	50 %
γ_{sat}	[kN/m^3]	unit weight of soil below phreatic level	x	x	50 %
c'	[kN/m^2]	effective cohesion	x		5 %
$tan(\varphi')$	[-]	tangent of effective friction angle	x	x	5 %
S	[-]	undrained shear strength ratio (NC)		x	5 %
m	-	strength increase exponent		x	5 %
σ'_{vy}	[kN/m^2]	vertical yield stress		x	5 %
POP	[kN/m^2]	pre overburden pressure		x	-*
λ_{in} ,λ_{out}	[m]	leakage length	x	x	50 %
IL	[m]	intrusion length	x	x	50 %
$PL1$	[m+NAP]	phreatic line	x	x	WNC default**
WL	[m+NAP]	water level	x	x	Design water level, WBN

* no representative values used: POP is not a variable in the calibration, it is used to determine the vertical yield stress.

** WaterNet Creator default values, see e.g. Kanning and van der Krogt (2016).

6.4.3 Partial safety factors

Partial safety factors are meant to bridge the gap between representative values and design point values. This should result in a safety format where the obtained reliability is as close as possible to the target reliability. The following equation shows how to derive partial safety factors for resistance variables:

$$\gamma_R = \frac{R_{rep}}{R^*} = \frac{\mu + k \cdot \sigma}{\mu + \alpha \cdot \beta_T \cdot \sigma} = \frac{1 + k \cdot CoV}{1 + \alpha \cdot \beta_T \cdot CoV} \tag{6.1}$$

Where:

γ_R is the safety factor for the variable R

R_{rep} is the representative/characteristic value

R^* is the design point value
μ is the mean value of R
σ is the standard deviation of R
k is the value that corresponds to a quantile, e.g. for 5% quantile k =1.65
α is the influence coefficient of the variable R, 0 < α < 1
CoV is the coefficient of variation defined as σ / μ
β_T is the target reliability index

In the following figure, the theoretically optimal partial safety factor as a function as the coefficient of variation (*CoV*) and influence coefficient (*α*) is shown for different reliability indices. The graphs are based on 5% quantile values as representative values. The figure shows that for *α*'s higher than 0.4 (α^2 larger than ~0.1) and a target reliability of 4.3, partial safety factors become greater than 1. For lower *α*'s, the use of only a representative value is sufficient, or even too much, to cover the uncertainty.

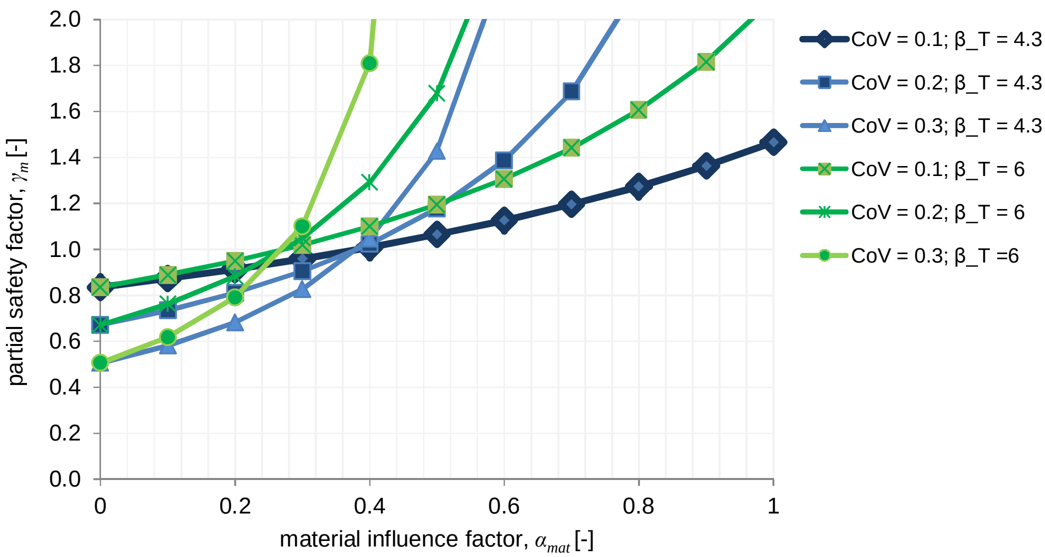

Figure 6.3 Relation material factor (γ_m) and sensitivity coefficients (α_{mat})

6.4.4 Material factor

From all the considered variables, Figure 6.2 shows that only S would be a candidate for a partial safety factor (material factor) greater than one. The other variables do not contribute enough to the failure probability to warrant such a partial factor. Since partial factors smaller than 1 are counter-intuitive, such values are best avoided.

In case of a lognormal distribution (as is the case for $\boldsymbol{S}$), the partial safety factor (γ_m) is given by:

$$\gamma_m = \exp\left[\left(-1.65 + \beta \cdot \alpha_{mat}\right) \cdot \sqrt{\ln\left[1 + CoV_{mat}{}^2\right]}\right]$$
$$\Leftrightarrow \gamma_m = \exp\left[\left(-1.65 + 4.3 \cdot \sqrt{0.65}\right) \cdot \sqrt{\ln\left[1 + 0.15^2\right]}\right] \tag{6.2}$$

A typical value of β is 4.3, a typical value of α^2_{mat} for S is 0.65 (see Figure 6.2) and a typical value of CoV_{mat} is 0.15 (see Appendix F or L). This results in a **possible material factor for *S* of 1.3** based on applying equation 6.2.

It should be noted that cumulated squared alphas of S are shown in Figure 6.2. In reality there is more than 1 layer contributing. This could result in lower alphas of S per layer and hence lower material factors.

6.4.5 Proposal representative values and partial factors

In addition to the representative values from Table 6.2, it is proposed not to use partial safety factors for the drained and undrained variables (material factors) on all parameters except S, for the following reasons:

1. The influence coefficients and computational results (Figure 6.2) do not indicate an explicit need for safety factors; the uncertainty is mostly covered by the 5% quantiles.
2. It keeps the safety format simple.

Based on the influence coefficients of Figure 6.2, a material factor may be considered for S. For simplicity, only a β-independent factor (material factor) is considered. This is further explored after considering the calibration results in 10.3.

6.4.6 Model uncertainty

The model uncertainty (see Table 3.2) is covered by a model factor (γ_d). Based on a squared influence coefficient of the model uncertainty of about 0.15 (Figure 6.2), a basic reliability index of about 4.3, and a representative value equal to 1.0 (see above), the model factor should correspond with a value with a cumulative probability equal to $\Phi(4.3\cdot\sqrt{0.15}) = 0.95$, i.e. a 5% upper bound value. The resulting model factor is presented in Table 6.3 below.

Table 6.3 Model uncertainties and model factor

model	distribution type	mean value	standard deviation	Model factor, γ_d
Uplift-Van	lognormal	1.005	0.033	1.06

6.5 The resulting safety format

This section provides a summary of the safety format.

The criterion for slope stability is (see Chapter 3):

$$\frac{1}{\gamma_d \cdot \gamma_n} \cdot F_{s,des} > 1 \tag{6.3}$$

The safety format for the slope stability mechanism is defined as follows:

1. The representative values of all random strength variables[3] are 5%-quantiles and 50% quantiles, see Table 6.2, apart from the model uncertainty parameter. This is in accordance with current assessment rules;
2. The representative value of the model uncertainty parameter is equal to one; The model safety factor (γ_d), is 1.06 for Uplift-Van, see Table 3.2;

[3] *Increasing the values of these variables **decreases** the failure probability.*

3. The representative value of the outside water level (design water level or WBN) is defined as the water level with an exceedance probability equal to the safety standard;
4. The material factor on S is 1 or 1.3 (see 10.3);
5. $F_{s,des}$ is computed with design values of the input parameters (representative values divided by partial safety factors)
6. A β_T – dependent safety factor γ_n is introduced to cover all other uncertainties. It is applied to $F_{s,des}$ together with γ_d see eq.(6.1).

The γ_n factor is the only variable that needs calibration and a choice needs to be made whether a material factor should be applied and how large it should be.

7 Step 3: establishing the safety factors

This chapter discusses the derivation of partial safety factors for semi-probabilistic assessments of dikes with respect to the slope stability failure mechanism. Safety factors should be sufficiently safe but not unduly stringent. A calibration criterion is used to decide 'how safe is safe enough'. This criterion is introduced in section 7.1. Section 7.2 discusses how the safety factor has been calibrated. The main modelling choices for the calibration are presented in 7.3.

7.1 The calibration criterion

According to the WBI 2017 calibration criterion, the failure probability of a dike segment should be smaller than the target failure probability that applies to this segment (*dijktraject*). This criterion is fulfilled, with a sufficient accuracy, when the average of cross-sectional failure probabilities in the segment is smaller than the target failure probability for a dike cross-section in this segment.

When relating the cross-sectional reliabilities of individual test set members to reliability requirements/targets that apply to entire segments, the length-effect has to be accounted for. This was discussed in section 5.3.

7.2 Calibrating the beta-dependent safety factor

7.2.1 Calibration procedure

Overviews of the calibration procedure and how the software is used are presented Appendix A. The greater the value of the overall safety factor for the slope stability mechanism, the greater the required berm and the greater the reliability index. The required berm and corresponding reliability indices have been calculated for a range of berm lengths. The berm lengths have been adapted in such a way that the reliability indices are in the order 3.5 – 5.5 (see Section 5.3). In other words, the following algorithm has been applied to each case:

1. Select inputs:
   - a dike cross-section with geometry and input parameters for soil properties and geo-hydrological characterization,
   - the water level with an exceedance probability equal to the safety standard for the case under consideration (i.e. depending on the location of the cross-section and the envisaged new safety standard),
   - the β_T – invariant safety factors following from step 2 and 3 (if applicable) and
   - the recommended representative values (step 2) of all variables present in the limit state function(s) and model-uncertainty factor γ_d (Table 3.2),
2. Increase the safety of the cross-section by adding a stability berm.
3. Determine the factor of safety (FoS_{des}) for the cross-section generated, based on characteristic values and given WBN, and perform a reliability analysis on the geometry at the cross-section level.
4. Repeat points 1 to 3 for different values of the safety factor.

For the overview of the calculated reliability indices (β_{cross}) as a function of FoS_{des} please refer to chapter 8.

With the plot of $\gamma_n - \beta_{cross}$, a study into the clustering of the results has been carried out (clustering per water system, safety standard, blanket thickness class) to see if it would be beneficial to differentiate between different types of conditions. No significant clustering was found.

7.2.2 Safety factor as function of the reliability

The next step is to propose the $\gamma_n - \beta_{T,cross}$ relation in a functional form (typically a linear function). The functional form has the following format:

$$\gamma_n = g(\beta_{T,cross}) = A \cdot \beta_{T,cross} + B \tag{7.1}$$

with

$$\beta_{T,cross} = -\Phi^{-1}\left(\frac{f/T}{1+\frac{a \cdot L}{b}}\right) \tag{7.2}$$

where:

- A,B are constants [-],
- $\beta_{T,cross}$ cross-sectional reliability requirement (reliability index) [-],
- f is the budget for the failure mechanism under consideration [-].
- T is the return period that corresponds to the safety standard of a segment [yr],
- L is the total length of the segment [m],
- a is the fraction of the length that is sensitive to the failure under study [-],
- b is a measure for the intensity of the length effect within the length [m],

Equation 7.1 should represent the average values of the computed cross-sectional failure probabilities for the factors of safety. This probability is roughly equal to the 20%-quantile value of the calculated reliability indices based on modelled normal distributions. Both metrics may be used in calibration exercises to relate cross-sectional reliability requirements to the results of probabilistic analyses (see Jongejan, 2013). Considerable differences between these two metrics can result from e.g. the presence of outliers or a strong scatter.

For a given cross-sectional reliability requirement (as set and explained in chapter 5– step 1), the values of the β_T – dependent safety factors can be obtained from the proposed γ_n – $\beta_{T,cross}$ relation.

The steps to perform a semi-probabilistic slope stability assessment of a dike cross-section are described in section 9.2.1.

7.3 Modelling choices calibration STBI

7.3.1 General

This section discusses the various modelling choices that have been made for the calibration. For case-specific modelling choices, the reader is referred to the case reports (Appendix L). The 2015 cases are mainly based on default parameters estimates, while the 2016 cases are based on a mix of local, regional and default data. Both case sets are based on the same general modelling choices.

7.3.2 Hydraulic loads

The hydraulic loads are based on known (new) design water levels ('Waterstand bij norm – WBN', equivalent to the formerly known 'maatgevend hoogwater – MHW') and their exceedance frequencies, in combination with the local decimate height. These parameters were used to fit Gumbel distributions. The new safety standards have been used for the test cases and therefore the WBN also correspond to the new standards. For some cases, a comparison was made between Gumbel distributions based on the old data (old MHW + old norm + decimate height) and new data (new WBN + new norm + decimate height).Similar results were obtained in those cases.

For some cases, e.g. Case 18, the new WBN is higher than the crest – see Table F.2 – which was dealt with by lowering the WBN to be able to compute the stability factor, *FoS*.

The pore water pressures have been modelled as a function of the outside water level in the Waternet Creator (see also Kanning and van der Krogt, 2016). This was done by determining leakage length, intrusion length and offsets to model the phreatic line. Uncertainties in the pore water pressures (intrusion, leakage lengths) are incorporated in the calibration according to Kanning and van der Krogt (2016). This includes for instance shear strength reduction that occurs due to rupture of the blanket.

7.3.3 Shear strength properties

Shear strength properties include the undrained shear strength ratio *S*, strength increase exponent m and yield stress. The distributions of these properties have been determined taking into account the effects of spatial averaging and the limited number of samples. Hence, the used distributions are representative for the layers for which they are modelled. An overview of the properties is presented in Appendix F, more details can be found in the individual case reports (Appendix L). The uncertainty in S and m is material specific and case specific (if local data is available), otherwise defaults have been used.

For the standard deviation of the yield stress, a fixed value of 6 kPa has been used, as this is roughly found in POP measurements. This corresponds to a coefficient of variation of 0.2 to 0.4 for POP values that are representative for a significant part of the critical slip circle (see Appendix F and G). This includes the effect of spatial averaging (see Appendix C). Since there is limited uncertainty in effective stress (and it averages mostly), the uncertainty in POP translates directly into the uncertainty in the yield stress. Uncertainty in yield stress is mostly covered in a semi-probabilistic analysis by using its 5% lower bound as representative value (see Chapter 6). In case the locally found yield stress exhibits significantly higher uncertainty, it is recommended to perform a probabilistic analysis instead of a semi-probabilistic analysis.

The shear strength parameter can be determined based on measurements. The type of experiment that is typically used to determine each parameter is shown in Table 7.1.

Table 7.1 Typical tests carried out to determine shear strength properties

Parameter	Lab
m	K0-CRS (Consolidation, Constant rate of strain), both peat and clay
S	DSS (Direct simple shear) for peat; Triaxial CAU for rest (i.e. clay)
*POP/yield stress**	K0-CRS (Consolidation, Constant rate of strain)

* POP/yield stress may also be determined based on a correlation with a CPT using a so-called Nkt value

7.3.4 Difference between yield stress under and next to the dike

Due to the different stress levels and histories of the same soil layers below the dike and next to the dike, these soil layers have been cut into 2 parts. Each part got assigned a different yield stress point in order to better reflect the local stress state. The two parts of the soil layer have been treated as independent in the reliability analysis due to software complexities. Modelling the 2 parts as fully correlated would likely yield a lower reliability than modelling these as independent (two independent layers results in an overestimation of the reliability as the likelihood of both being weak is relatively low). However, analyses show that a proper representation of the yield stresses is more important than the resulting inaccuracy due to the non-conservative independence between the layer parts. Furthermore, the effect is expected to be relatively limited as usually one of the two parts of the soil is dominant in the stability computation.

7.3.5 Relevant slip circles

The slip circle not necessarily results in flooding when they are e.g. very shallow. In this calibration, only slip circles that are relevant for flood risk (i.e. potentially lead to flooding) have been considered. This is in line the definition of the norms in terms of probabilities of flooding. In this calibration, slip circles have been considered relevant when they enter halfway into the inner slope or further towards the water side, similar to Van Deen and Van Duinen (2016). This is shown in Table 7.1.

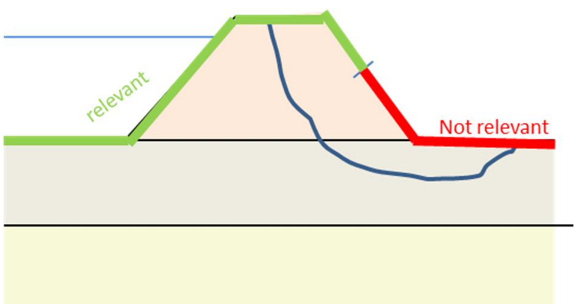

Figure 7.1 Relevant slip circles: slip circles that enter in the green zone are deemed relevant for the flood risk.

7.3.6 Model uncertainty

Model uncertainty has been incorporated according to section 6.4.6. However, at the time of writing this report, model uncertainty was still under discussion. Relatively minor changes in the distribution of the model uncertainty may be dealt with by a corresponding change in model factor. However, larger changes in the model uncertainty distribution may affect the influence coefficients and thus the other safety factors as well.

8 Calibration results

This chapter presents the results of the calibration of the semi-probabilistic inner slope stability mechanism (STBI), i.e. it presents the $\gamma_n - \beta_{T,cross}$ relation (in short the $\gamma - \beta$ relation) to be applied in the STBI safety assessment. The results follow from step 3 of the calibration procedure, as described in the previous chapter. First the calibration is presented for the case with material factors equal to 1. Subsequently a materials factor higher than 1 is considered.

In this report, γ_n is the *required* factor of safety that follows from the calibration. Later in this chapter, FoS_{des} is the factor or safety of a dike that is *computed* with design values.

8.1 Test case results

8.1.1 Approach

The cases that have been discussed in Chapter 6 have been assessed probabilistically and semi-probabilistically. The first gives the reliability index (β), which is computed using the probabilistic model (see Appendix A) and the inputs as discussed in Chapter 5, 6 and 7. The second gives the factor of safety of the dike (FoS_{des}) using design values of the input parameter according to the safety format. FoS_{des} is divided by the model factor γ_d (1.06) to obtain for each case the required safety factor $\gamma_n(= FoS_{des}/\gamma_d)$ that is needed to obtain a certain reliability. This results for each case in a β and γ_n. Combining these two outputs allows the calibration of the required safety factor γ_n for all cases. Berms have been added to obtain factors of safety in the required reliability index range. Berm designs have not been optimized. Default values have been used for the density of soil material, the height is usually around 1/3 to 1/2 of the dike height.

8.1.2 Results of the computations

The results of the computations of the cases are shown in Figure 8.1. The figure shows the required safety factor γ_n as a function of the computed reliability index, β for the cross-section under consideration. Figure 8.1 shows the test cases including an added berm as well (all with the same symbol). The corresponding influence coefficients were shown in Figure 6.2. As a reference, the 2015 calibration fit is shown as well in Figure 8.1. In total, 48 cases have been considered, based on 27 separate locations.

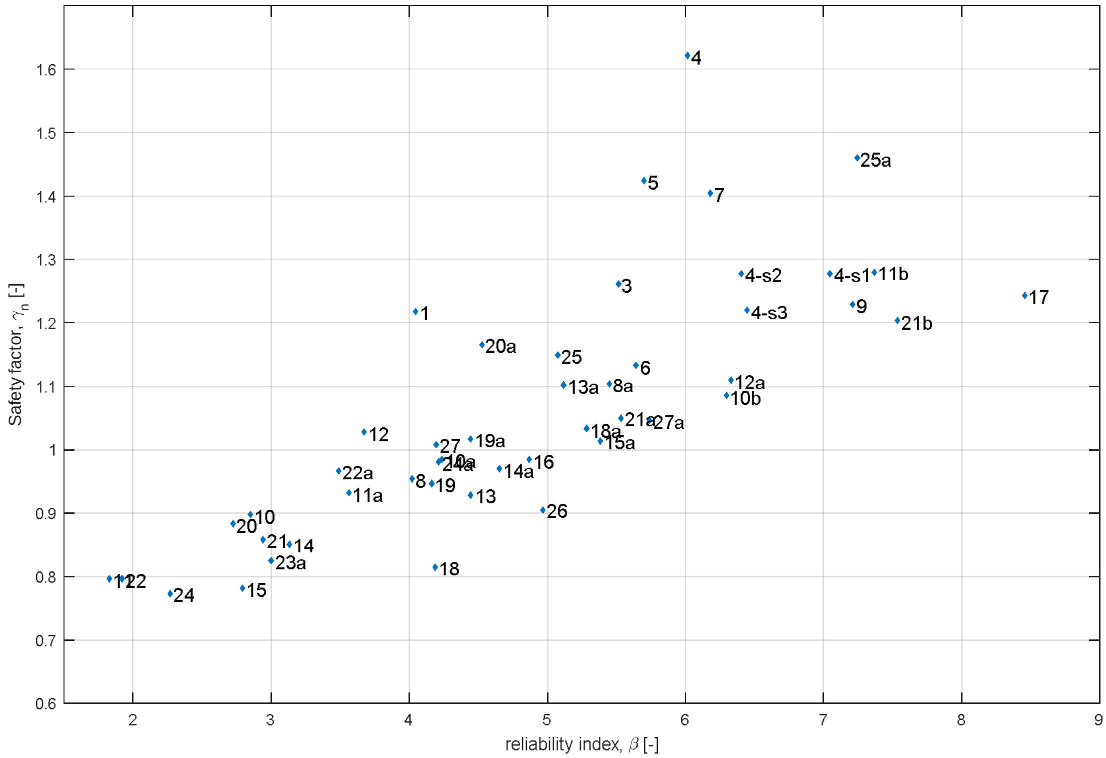

Figure 8.1 Test case results showing the computed FoS_{des} / γ_d = γ_n and computed reliability indices for the 2016 test set.

The output for all test cases can be consulted in the individual test case reports (Appendix L). The $\gamma - \beta$ computations presented in Figure 8.1 are based on the inputs discussed in Chapter 6. This implies that cases with different safety standards (and hence design water levels with different exceedance probabilities) are shown in the figure.

The main conclusions from Figure 8.1 are that, even though there is quite some scatter (changes in γ_n of up to 0.4 for the same reliability level), there is a clear trend: a higher γ_n corresponds to a higher reliability index β. In general it also seems that cases with berms tend to be low in the cloud. This is likely the result of more layers being crossed because of the berm resulting in more averaging over layers.

A more detailed discussion of the results is provided in the following sections.

8.1.3 Results of the individual cases

The following two tables present the results in detail for all cases, also shown in Figure 8.1.

Table 8.1 Detailed results of the semi-probabilistic and probabilistic results of the test cases – calibration exercise 2016.

a) Cases 2016

	Case Number	1	2	3	4	4_s1	4_s2	4_s3	5	6	7	8	8a	9	10	10a	10B	11	11a	11b	12	12a	13	13a	14	14a	15	15a	16	17
WL data	WBN	16.25	3.89	4.30	6.26	6.26	6.26	6.26	8.10	8.36	7.18	8.07	8.07	7.18	4.85	4.85	4.85	1.10	1.10	1.11	2.14	2.14	8.50	8.50	3.86	3.86	0.61	0.61	5.09	5.93
	hdec	0.70	0.44	0.44	0.79	0.79	0.79	0.79	0.75	0.74	0.70	0.73	0.73	0.70	0.46	0.46	0.46	0.27	0.27	0.27	0.49	0.49	0.70	0.70	0.41	0.41	0.19	0.19	0.49	0.56
	T	30000	10000	30000	30000	30000	30000	30000	30000	30000	30000	30000	30000	30000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	10000	10000	3000	3000	10000	10000
	WBN > crest ?										yes	yes	yes	yes																
Beta Final		4.05	0.84	5.51	6.01	7.05	6.40	6.45	5.70	5.64	6.18	4.02	5.45	7.21	2.85	4.23	6.30	1.83	3.56	7.36	3.67	6.33	4.45	5.12	3.13	4.65	2.79	5.39	4.87	8.45
FoS_des	(WBN)	1.29	0.78	1.34	1.72	1.35	1.35	1.29	1.51	1.20	1.49	1.01	1.17	1.30	0.95	1.04	1.15	0.84	0.99	1.36	1.09	1.18	0.99	1.17	0.90	1.03	0.83	1.08	1.04	1.32
	modelfactor	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06
gamma_n	(WBN)	1.22	0.74	1.26	1.62	1.28	1.28	1.22	1.42	1.13	1.40	0.95	1.10	1.23	0.90	0.98	1.08	0.80	0.93	1.28	1.03	1.11	0.93	1.10	0.85	0.97	0.78	1.01	0.98	1.24
Design points	model unc.	1.03	1.02	1.07	1.02	1.08	1.07	1.06	1.02	1.05	1.02	1.05	1.06	1.04	1.05	1.07	1.10	1.03	1.05	1.09	1.03	1.09	1.05	1.05	1.05	1.08	1.02	1.06	1.08	1.19
	WL	13.29	2.20	2.39	9.65	3.09	3.03	4.88	10.50	5.17	9.59	5.07	5.33	11.73	3.38	3.59	3.42	0.21	0.22	0.22	0.66	1.17	6.25	6.33	2.28	2.28	-0.02	-0.02	3.39	4.18
	crest height	17.13	5.10	6.01	6.50	6.50	6.50	6.50	8.21	8.81	6.73	7.82	7.82	7.10	8.30	8.30	8.30	4.19	4.19	4.19	4.46	4.46	8.81	8.81	5.40	5.40	3.16	3.16	9.96	8.06
	WL > crest ?				yes				yes		yes			yes																
Alphas_cum	S-Ratio	-0.925	-0.721	-0.830	-0.115	-0.867	-0.875	-0.769	0.000	-0.934	-0.419	-0.890	-0.895	-0.312	-0.691	-0.661	-0.702	-0.770	-0.776	-0.784	-0.872	-0.753	-0.832	-0.845	-0.810	-0.826	-0.905	-0.832	-0.817	-0.702
	m	-0.061	-0.051	-0.152	-0.003	-0.048	-0.050	-0.083	0.000	-0.033	-0.021	-0.072	-0.059	-0.030	-0.057	-0.047	-0.033	-0.134	-0.115	-0.126	-0.074	-0.033	-0.125	-0.113	-0.086	-0.064	-0.178	-0.151	-0.041	-0.038
	Yield	-0.322	-0.504	-0.213	-0.091	-0.377	-0.377	-0.371	0.000	-0.260	-0.063	-0.270	-0.240	-0.076	-0.515	-0.521	-0.518	-0.534	-0.513	-0.498	-0.371	-0.313	-0.456	-0.427	-0.365	-0.332	-0.334	-0.426	-0.341	-0.273
	c	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Fric	-0.058	-0.003	-0.342	-0.023	0.000	0.000	0.000	-0.257	-0.010	-0.001	-0.098	-0.085	-0.110	-0.202	-0.210	-0.187	0.000	0.000	0.000	-0.123	-0.316	0.000	0.000	-0.005	-0.006	-0.005	-0.004	-0.077	-0.188
	WNC	0.000	0.005	0.000	0.070	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.031	0.030	0.034	0.017	0.012	0.003	0.028	0.035	0.040	0.045	0.000	0.000	0.000	0.000	0.053	0.007
	model	0.179	0.472	0.355	0.075	0.316	0.293	0.251	0.097	0.244	0.064	0.335	0.317	0.145	0.452	0.437	0.445	0.320	0.348	0.349	0.242	0.382	0.282	0.286	0.450	0.451	0.194	0.322	0.434	0.607
	WL	0.043	0.015	-0.007	0.984	0.071	0.058	0.447	0.962	0.000	0.903	0.092	0.173	0.929	0.085	0.230	0.063	0.023	0.020	0.005	0.148	0.293	0.047	0.085	0.000	-0.001	0.000	0.000	0.130	0.166
Alphas_cum^2	S-Ratio	0.855	0.520	0.688	0.013	0.751	0.766	0.592	0.000	0.871	0.176	0.792	0.801	0.097	0.478	0.437	0.492	0.593	0.602	0.614	0.761	0.568	0.693	0.714	0.657	0.682	0.819	0.692	0.667	0.493
	m	0.004	0.003	0.023	0.000	0.002	0.002	0.007	0.000	0.001	0.000	0.005	0.004	0.001	0.003	0.002	0.001	0.018	0.013	0.016	0.005	0.001	0.016	0.013	0.007	0.004	0.032	0.023	0.002	0.001
	Yield	0.103	0.254	0.046	0.008	0.142	0.142	0.138	0.000	0.068	0.004	0.073	0.058	0.006	0.266	0.272	0.268	0.285	0.263	0.248	0.137	0.098	0.208	0.183	0.133	0.110	0.111	0.182	0.117	0.074
	c	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Fric	0.003	0.000	0.117	0.001	0.000	0.000	0.000	0.066	0.000	0.000	0.010	0.007	0.012	0.041	0.044	0.035	0.000	0.000	0.000	0.015	0.100	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.035
	WNC	0.000	0.000	0.000	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.000	0.000	0.000	0.001	0.001	0.002	0.002	0.000	0.000	0.000	0.000	0.003	0.000
	model	0.032	0.223	0.126	0.006	0.100	0.086	0.063	0.009	0.060	0.004	0.112	0.101	0.021	0.204	0.191	0.198	0.103	0.121	0.122	0.058	0.146	0.079	0.082	0.203	0.204	0.038	0.103	0.189	0.368
	WL	0.002	0.000	0.000	0.967	0.005	0.003	0.200	0.925	0.000	0.816	0.008	0.030	0.863	0.007	0.053	0.004	0.001	0.000	0.000	0.022	0.086	0.002	0.007	0.000	0.000	0.000	0.000	0.017	0.027

Table 8.1 Detailed results of the semi-probabilistic and probabilistic results of the test cases – calibration exercise 2016.

b) Cases 2015

	Case Number	18	18a	19	19a	20	20a	21	21a	21b	22	22a	23	23a	24	24a	25	25a	26	27	27a
WL data	WBN	13.41	13.40	12.79	12.79	12.57	12.57	6.50	6.50	6.50	6.93	6.93	3.64	3.64	10.84	10.84	0.98	0.98	2.99	6.72	6.72
	hdec	0.73	0.73	0.73	0.73	0.73	0.73	0.57	0.57	0.57	0.69	0.69	0.20	0.20	0.66	0.66	0.25	0.25	0.27	0.67	0.67
	T	10000	10000	10000	10000	10000	10000	30000	30000	30000	3000	3000	30000	30000	3000	3000	3000	3000	3000	30000	30000
	WBN > crest ?	yes	yes			yes	yes														
Beta Final		4.19	5.28	4.16	4.44	2.72	4.53	2.94	5.54	7.54	1.92	3.49	-2.22	3.00	2.27	4.21	5.08	7.24	4.97	4.19	5.74
FoS_des	(WBN)	0.86	1.09	1.00	1.08	0.94	1.24	0.91	1.11	1.28	0.84	1.02	0.55	0.88	0.82	1.04	1.22	1.55	0.96	1.07	1.11
	modelfactor	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06
gamma_n	(WBN)	0.82	1.03	0.95	1.02	0.88	1.17	0.86	1.05	1.20	0.80	0.97	0.52	0.83	0.77	0.98	1.15	1.46	0.91	1.01	1.05
Design points	model unc.	1.05	1.02	1.04	1.05	1.03	1.05	1.04	1.08	1.10	1.02	1.03	0.98	1.04	1.02	1.04	1.07	1.09	1.12	1.06	1.03
	WL	10.85	15.25	11.08	11.52	9.79	9.80	4.09	4.24	4.47	4.70	4.77	2.76	2.78	9.05	9.07	0.14	0.14	2.09	3.90	8.76
	crest height	13.30	13.30	13.40	13.40	12.48	12.48	7.53	7.53	7.53	7.03	7.03	5.62	5.62	11.40	11.40	3.84	3.84	4.49	9.11	9.11
	WL > crest ?		yes																		
Alphas_cum	S-Ratio	-0.773	-0.274	-0.796	-0.868	-0.902	-0.903	-0.851	-0.821	-0.824	-0.924	-0.912	-0.835	-0.790	-0.576	-0.702	-0.876	-0.908	-0.599	-0.868	-0.246
	m	-0.082	-0.062	-0.097	-0.116	-0.097	-0.058	-0.062	-0.050	-0.053	-0.086	-0.118	-0.091	-0.106	-0.086	-0.075	-0.071	-0.062	-0.017	-0.102	-0.018
	Yield	-0.515	-0.127	-0.252	-0.320	-0.301	-0.330	-0.395	-0.402	-0.379	-0.261	-0.307	-0.358	-0.453	-0.482	-0.652	-0.316	-0.210	-0.317	-0.229	-0.155
	c	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Fric	0.000	0.000	0.000	-0.025	0.000	0.000	0.000	0.000	0.000	-0.043	-0.027	-0.049	0.000	0.000	0.000	-0.034	-0.017	-0.267	-0.102	-0.019
	WNC	0.059	0.052	0.001	0.000	0.000	0.000	0.060	0.112	0.115	0.000	0.002	0.078	0.061	0.027	0.044	0.000	0.000	0.002	0.017	0.086
	model	0.330	0.103	0.253	0.346	0.294	0.268	0.334	0.373	0.373	0.250	0.220	0.393	0.394	0.225	0.270	0.356	0.356	0.685	0.410	0.137
	WL	0.137	0.944	0.479	0.103	0.008	0.006	0.031	0.101	0.152	0.080	0.104	0.060	0.011	0.615	-0.033	0.000	-0.003	0.003	0.066	0.942
Alphas_cum^2	S-Ratio	0.597	0.075	0.634	0.753	0.813	0.816	0.724	0.674	0.679	0.854	0.832	0.697	0.624	0.331	0.493	0.767	0.825	0.359	0.754	0.061
	m	0.007	0.004	0.009	0.014	0.009	0.003	0.004	0.003	0.003	0.007	0.014	0.008	0.011	0.007	0.006	0.005	0.004	0.000	0.011	0.000
	Yield	0.265	0.016	0.064	0.103	0.091	0.109	0.156	0.162	0.143	0.068	0.094	0.128	0.205	0.232	0.425	0.100	0.044	0.100	0.052	0.024
	c	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Fric	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.002	0.001	0.002	0.000	0.000	0.000	0.001	0.000	0.071	0.010	0.000
	WNC	0.003	0.003	0.000	0.000	0.000	0.000	0.004	0.013	0.013	0.000	0.000	0.006	0.004	0.001	0.002	0.000	0.000	0.000	0.000	0.007
	model	0.109	0.011	0.064	0.120	0.087	0.072	0.111	0.139	0.139	0.062	0.048	0.155	0.156	0.050	0.073	0.127	0.127	0.470	0.168	0.019
	WL	0.019	0.892	0.229	0.011	0.000	0.000	0.001	0.010	0.023	0.006	0.011	0.004	0.000	0.378	0.001	0.000	0.000	0.000	0.004	0.888

In this table, *WL* refers to water level, *beta_final* to the computed reliability index, *gamma_n* to the computed safety factor divided by the material factor γ_n, *alpha's cum* refer to the cumulated (all layers combined) values of the FORM sensitivity coefficients α. For the other parameters, refer to Chapter 3.

A brief description of each case is provided in Table 8.2. For more information about the individual cases, the reader is referred to the individual test case report (Appendix L). A general observation is that the design point value of the water level is, for most cases, close to the median value (and thus much lower than the WBN), which is consistent with the low α values shown in Figure 6.2. All cases (inputs, schematizations and outcomes) have been checked by the WBI Cluster STBI.

Table 8.2 Description and analysis of the test cases – calibration exercise 2016. Cases not considered for the calibration fit are marked in grey.

Case	Description and analysis
Case 1)	No uplift. Relatively high reliability, so no berm added. The uncertainty is dominated by the S and, to a much lesser extent, the yield stress point(s). It is noted that the shallow slip plane changes slightly with the WL and the reliability index decreases more strongly for WL > NAP+15 m.
Case 2)	No uplift. Very low reliability, however, no berm added. The uncertainty is dominated mostly by the S, but also the yield stress point(s) and the model uncertainty. The slip plane goes quite deep, and its shape is not sensitive to the WL.
Case 3)	No uplift. Relatively high reliability, so, no berm added. The slip plane mainly crosses the body of the dike and its shape is not sensitive to the WL, so, uncertainty is dominated by the S of the materials in the dike body.
Case 4)	No uplift. Relatively high reliability, so, no berm added. The slip plane is quite deep and does not change with WL. Uncertainty is dominated by WL; however, the design point of the WL is far above the crest of the dike (results less credible).
Scenarios Case 4) 4_s1) 4_s2) 4_s3)	No uplift, except for one (4_s3) of the scenarios, where uplift/rupture of the blanket may occur (thin blanket). Relatively high reliability, so no berm added. Long and shallow slip planes are found. The slip plane mainly crosses the dike material, so, uncertainty is dominated by the S of the materials in the dike body.
Case 5)	No uplift. Relatively high reliability, so no berm added. The slip plane is quite deep and does not change with WL. Uncertainty is dominated by WL; however, the design point of the WL is far above the crest of the dike (results less credible). The slip plane varies with the WL, being quite deep for low WL and shallow for high WL.
Case 6)	No uplift. Relatively high reliability, so no berm added. The uncertainty is clearly dominated by the S. Deep slip plane, which barely changes with WL (just becomes slightly longer).
Case 7)	No uplift. Relatively high reliability, so no berm added. The slip plane is medium deep and long, and does not change with WL. Uncertainty is dominated by WL; however, the design point of the WL is much above the crest of the dike (results less credible). For this location WBN is higher than the crest level.
Case 8) 8a)	No uplift. Berm added. Both geometries behave similarly. The slip plane is very similar, medium deep slip plane; shape hardly changes with WL. The uncertainty is dominated mostly by the S, and to a much lesser extent, the model uncertainty. The increase of berm provides an increased FoS and reliability index, in line with the calibrated line. For this location WBN is higher than the crest level.
Case 9)	No uplift. Relatively high reliability, so, no berm added. Slip plane mainly goes through the sandy core of the dike, shape not sensitive to WL. However, the design point of the WL is far above the crest of the dike (results less credible). For this location WBN is higher than the crest level.

Case	Description and analysis
Case 10) 10a) 10b)	Uplift only for very high WL. Sand dike on clay, multiple berms studied. FoS increases with the berm. The slip plane is shallower for case 10) than for 10a) and 10b). Neither is sensitive to the WL. The uncertainty is dominated by the S, however also the yield stress point(s) and the model uncertainty play an important role.
Case 11) 11a) 11b)	Uplift for case 11. No uplift for berm cases 11a, 11b. Slip plane gets slightly longer (along the interface of blanket and aquifer) with higher WL, for any geometry. The uncertainty is dominated by the S, however also the yield stress point(s) and the model uncertainty play a role.
Case 12) 12a)	Uplift is present. Sand dike on clay, berm added. Shallow slip plane for both cases, and shape not sensitive to the WL. The uncertainty is, in both, dominated mostly by the S.
Case 13) 13a)	Uplift/rupture present. Slip plane along the interface with the aquifer, exit at the ditch. Shape not sensitive to the WL. The uncertainty is dominated by the S from the clay layers and also the yield stress point(s).
Case 14) 14a)	No uplift. Berm added. The uncertainty is dominated by the S and, to a much lesser extent, the model uncertainties. A medium deep slip plane is found for case 14, while case 14a presents a deep slip plane. Either's shape changes with the WL.
Case 15) 15a)	No uplift. Berm added. Uncertainty dominated by S, with slight influence also of the model uncertainty and the yield stress point(s). The slip plane varies with the WL, being quite deep for high WL and shallow for low WL.
Case 16)	No uplift. Sand dike on clay. Relatively high reliability, so no berm added. The uncertainty is dominated mostly by the S, there is also a slight influence of the yield stress point(s). The deep slip plane shape does not change with the WL.
Case 17)	No uplift. Sand dike on clay. Relatively high reliability, so no berm added. Uncertainty dominated by both the Su-ratio and the model uncertainty. Deep slip plane slightly changes with WL, becoming longer (towards the crest) with higher WL.
Case 18) 18a)	Uplift/rupture for high WL. Berm added. Slip plane shape does not change with WL, it goes until the bottom of the thin blanket. Uncertainty influence is different for case 18 and 18a. For case 18a, the design point of the WL is far above the crest of the dike (probabilistic results less credible, still this case was included in the calibration fit because it was in the middle of the fit cloud and omitting it would not alter the fit). For case 18 the most important uncertainties are the S and the yield stress point(s). For this location WBN is higher than the crest level.
Case 19) 19a)	Uplift/rupture. Added berm. Uncertainty dominated by the S. There is also a slight influence of the WL for case 19. Slip plane goes to the bottom of the thin blanket, and its shape is not sensitive to the WL. Case 19a had some issues with the deterministic computation, however, care was taken in the probabilistic computation and this case was included in the calibration fit.
Case 20) 20a)	Uplift/rupture. Added berm. For this location WBN is higher than the crest level. Uncertainty is almost totally dominated by the S. Slip planes are slightly different for 20 and 20a. Both change slightly with the WL change.
Case 21) 21a) 21b)	No uplift. Added berms. The slip planes (with and without berm) are large and deep. Uncertainty dominated by the S.
Case 22) 22a)	Uplift/rupture. Case with very high reliability, therefore the dike was made steeper (22a). Results show that the dominant uncertainty is the S, and the slip plane's shape barely changes with the WL. Slip plane along the interface between the blanket and the aquifer.
Case 23) 23a)	Occurrence of uplift. Added berm. Due to low volumetric weights at the inner side, effective stresses are low and consequently the normative slip circle exits in the ditch for 23a. Slip plane shape not sensitive to the WL. Uncertainty dominated by the Su-ratio for 23 and 23a. However, also the yield stress point(s) appear to have some influence in 23a.

Case	Description and analysis
Case 24) 24a)	No uplift. Added berm. In case of mean WL, critical slip circle through blanket and shape does not vary with WL. Su-ratio is dominant uncertainty, but also the yield stress point(s) appear to have some influence. For case 24, also the WL shows to be an influent variable.
Case 25) 25a)	No uplift. Added berm. For both cases, results show that the dominant uncertainty is the S, and the slip plane's shape barely changes with the WL.
Case 26)	No uplift. Relatively high reliability, so, no berm added. Results show that the dominant uncertainty is the S, and also the model uncertainty to a lesser extent The slip plane's shape barely changes with the WL.
Case 27) 27a)	No uplift for 27. Occurrence of uplift for 27a. Sand dike on clay. Slip circle in the dike is mainly through drained material. High influence of the WL uncertainty for 27a, while for 27 the S shows the greatest influence.

8.1.4 Comparison with previous case results

The computed safety factors differ from the results that were found in the projects from which the cases originate. This may be due to the use of material factors, different assumptions for pore water pressures (calibration is based on the WNC) or due to a different version of D-Geo Stability.

8.2 Calibration of the overall safety factor

This section considers the calibration of the overall safety factor including a material factor on S of 1.0. The results including a material of 1.3 on S are presented and discussed in section 8.4.

8.2.1 Considered cases

The combination of the overall safety factor γ_n (computed FoS_{des} divided by model factor γ_d) and reliability index β is shown for all cases in Figure 8.2. Some cases are not incorporated for the final calibration fit, these are shown in grey in Figure 8.2, the reasons are as follows:

- Cases with a β higher than 7.0 have been removed since these are outside the area relevant for the calibration (see 5.3).
- Cases with a β lower than 2.0 have been removed for the same reason. Cases with a β between 2.0 and 3.5 are outside the primary scope for the assessment. However, since the WBI allows for a working with scenarios, scenarios with a low probability of occurrence and a low β should be accommodated as well. This is why the lower bound of the relevant β was set to 2.0.
- The two cases in the Lek (Cases 4 and 5) and the 1 case the Waal (Case 7) with a γ_n around 1.4 – 1.6 and a β around 6.0 have been removed since the design point of the water level is far above the crest of the dike. This means that β is determined in the part of the fragility curve that is based on extrapolation, which makes the results less credible.
- Two other cases have been omitted, Case 22 and Case 24a, because of convergence problems in the probabilistic computations.

Out of the 48 cases, 34 cases have been used for the calibration fit (blue dots in Figure 8.2), of the 48 available computations, 14 cases have been omitted for the reasons mentioned above.

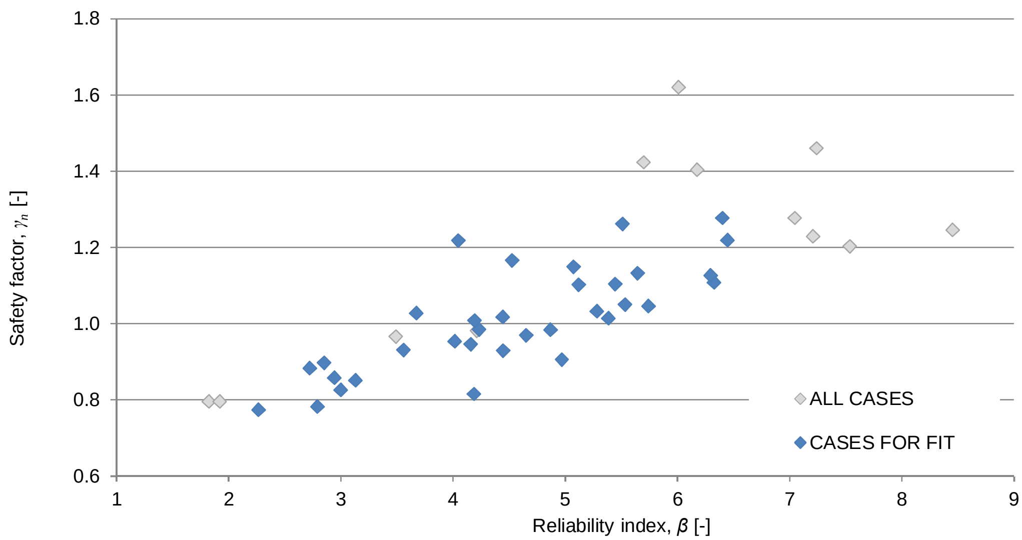

Figure 8.2 Considered cases for the calibration 2016.

8.2.2 Fitting approach

In accordance with the general WBI calibration procedure (Jongejan, 2013), the $\gamma - \beta$ relation is fitted to the 20% quantiles of the betas, see Chapter 7. This roughly corresponds to a fit on the mean failure probability. In this approach, the deviation of the actual beta from the fitted beta is minimized. This is the horizontal distance from fitted line (opposite to the more regular minimization of the vertical distance from the fitted line). In theory, the fit should be curved (see Chapter 6), but the results show it is mostly straight within the relevant beta range.

First the relation between gamma and beta is established as:

$$\beta_{T,cross} = C \cdot \gamma_n + D \tag{8.1}$$

Next, a least square error fit is made. The slope of this line (C) is fixed. The value of D is corrected by subtracting 0.84 times the error of the fit to fulfil the 20% beta fit criterion. The obtained beta-gamma relation is transformed into the required $\gamma - \beta$ relation:

$$\gamma_n = A \cdot \beta_{T,cross} + B \tag{8.2}$$

8.2.3 Calibration fit

As discussed in the previous section, the 20% beta fit has been applied to the cases as shown in Figure 8.2. The result is the proposed relation between γ_n and β, which is shown in Figure 8.3. This relationship is referred to as the Calibration fit in both the figure and the remainder of the report.

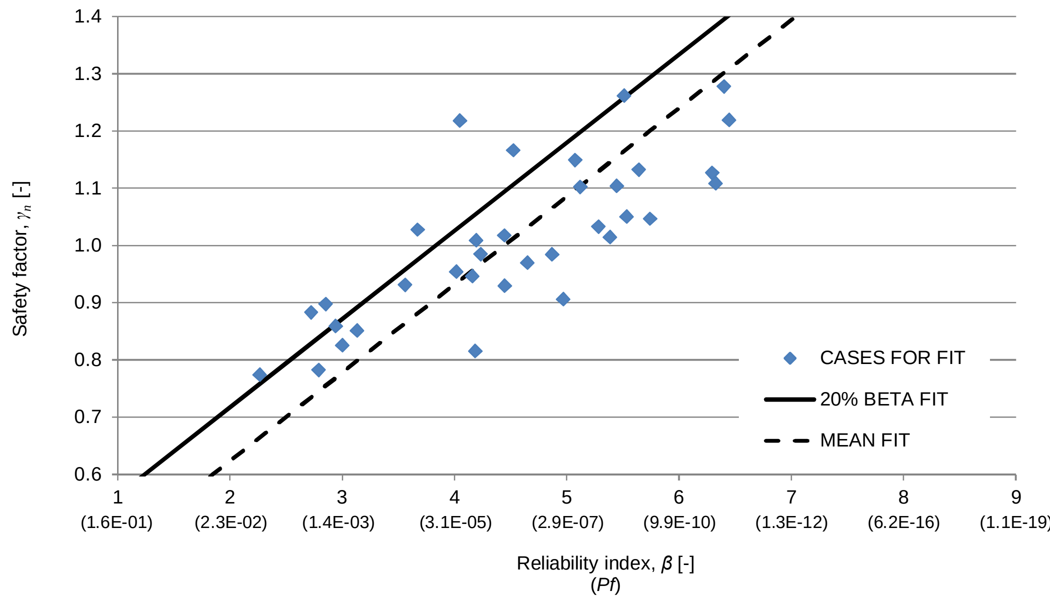

Figure 8.3 The final calibration fit resultant of the calibration exercise 2016.

The equation corresponding to the calibration fit is, for a material factor γ_m = 1.0:

$$\gamma_n = 0.15 \cdot \beta_{T,cross} + 0.41 \quad for\ \gamma_m = 1 \tag{8.3}$$

The equation has no lower bound (it is not limited by a lower bound of e.g. 1.0). In practice, the absence of a lower bound is unlikely to be of practical importance because a safety factor of 1.0 corresponds to a very high probability of failure.

8.3 Differentiation of the safety factors

Differentiation of safety factors could make the semi-probabilistic assessment rule more efficient. For instance, if the relation between beta and gamma is different between cases with and without uplift, a safety format could be derived for cases with and without uplift, leading to a more efficient assessment.

In order to understand if the gamma-beta relationship would benefit from a differentiation for a specific type of clustering, multiple analyses were carried out. In Appendix J, one can see these in more detail. The following clusters/differentiations, have been considered:

(1) Safety standard
(2) Origin of the soil data
(3) Riverine or marine deposits
(4) Water system
(5) Dike type (WNC)
(6) Uplift
    a. at WBN
    b. at the WL design point
(7) Blanket layer thickness
(8) Water level influence
(9) Slip plane at the design point

No significant clustering effect was observed for any of these analyses. An example of a clustering analysis is shown in Figure 8.4, where the cases are split between Marine and Riverine; no clustering is observed. Some clusters also have the difficulty that it would be almost impossible for the user to know prior to the assessment how to classify a particular case, namely (6) uplift, the (8) water level influence and the (9) deep or shallow slip plane.

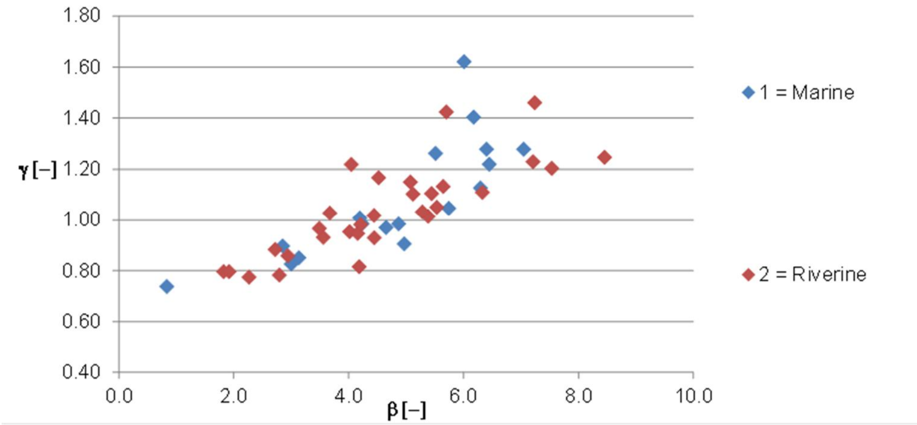

Figure 8.4 Example clustering to water system

The most intuitive differentiation would be with respect to (1) safety standards. However, the results show a very small effect (different required safety factor for different safety standard, order difference of 0.02 on *FoS*[4]) for the cases where there is a limited influence of the water level (which is the majority). Only the cases with a high influence of the water level (limited amount in the total analysis - see Figure 6.2) show a more significant decrease. However, these will hardly influence the calibration fit. This can be explained by the fact that the failure probabilities are relatively insensitive to the uncertainty related to the water level, see also section 6.3.

8.4 Material factors

In this section, the effect on the calibrated overall safety factor of applying material factors is discussed.

8.4.1 Effect material factor on the cases

A material factor on S may make the safety format more efficient (see 6.4.4). By applying a material factor, the computed safety factor (SF) becomes smaller, see Figure 8.5. In this figure, the safety factor (γ_n) is recomputed for material factors 1.3 and 1.4. Since there are no other changes, the reliability index remains the same.

[4] *The difference for cases without high water level influence is 0.01 to 0.04 when the safety standard changes from 1/1000 to 1/10000. The calibration fit is somewhere in between, reducing the difference even further.*

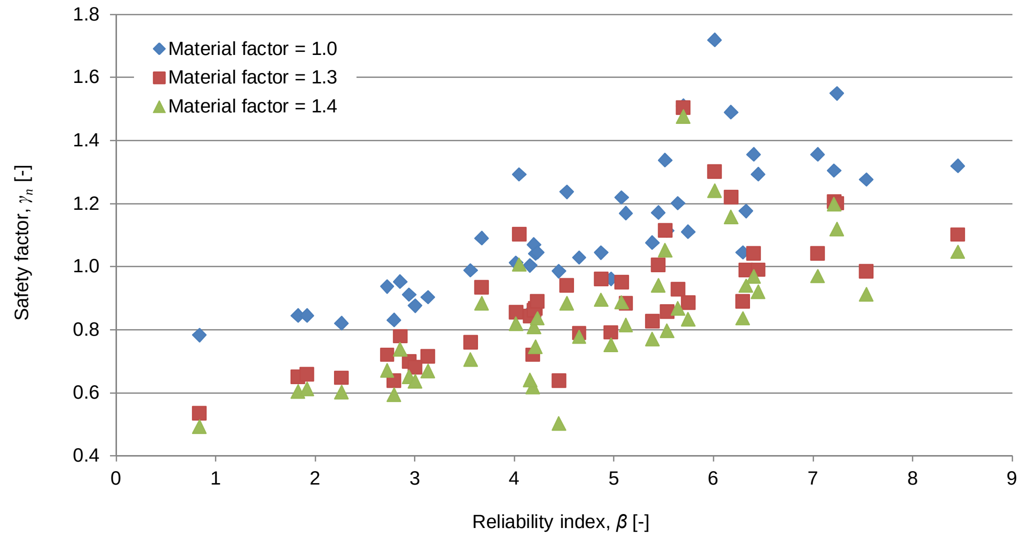

Figure 8.5 Effect of material factors on calculated safety factor

8.4.2 Effect material factor on the calibrated safety factor

On average, the application of a material factor on S of 1.3 results in a 0.18 lower required safety factor. Hence, the calibrated overall safety factor γ_n becomes:

$$\gamma_n = 0.15 \cdot \beta_{T,cross} + 0.23 \qquad for\ \gamma_m = 1.3 \tag{8.4}$$

This is also shown in Figure 8.6. We can conclude that a higher material factor goes hand in hand with a lower overall safety factor. A recommendation for a choice of material factors is presented in section 10.3.

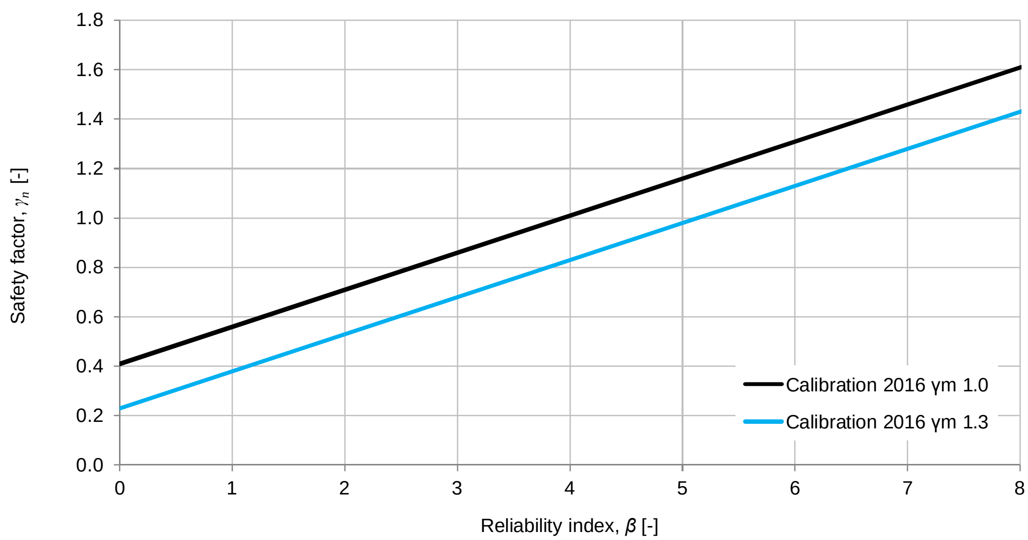

Figure 8.6 Comparison overall safety factor with a material factor of 1.0 and 1.3

The effect the difference between the two fits on the accuracy of the safety format and the effect on required berms is presented in sections 10.3.2 and 10.3.3.

8.5 Conclusions of the calibration

The main conclusions of the calibration study are:

- A new overall safety factor is obtained that also includes cases with local data (opposite to the 2015 calibration that was mainly done based on defaults).
- There is no reason to differentiate between different safety standards due to the limited influence of the water level on the safety factors.
- There is no reason, based on the considered cases, for differentiating between uplift/no uplift, marine/river conditions or other types of conditions; this may change when more cases become available.
- Incorporating a material factor on S results in a lower overall safety factor.

9 Step 4: assessment steps and comparison with previous procedures

This chapter presents in the first section (section 9.1) how to carry out a semi-probabilistic assessment for the slope stability failure mechanism, including how to deal with sub-soil scenarios. In section 9.2.1, a comparison of the calibrated relations with the present-day ones, is made. Section 9.3 provides a preliminary consequence analysis. Two example computations with the new calibrated safety factors are presented in section 9.4.

9.1 Inner slope stability semi-probabilistic assessment steps

This section outlines the steps of a semi-probabilistic assessment of a dike cross-section regarding the slope stability mechanism, following Jongejan & Klerk (2015), see Figure 9.1. The assessment is carried out per sub-soil scenario, in the end, the combined results of the assessments per sub-soil scenario are combined to an overall result. It is assumed that the dike cross-section is situated in a dike segment (*dijktraject*) with the safety standard of $1/T$ years and n is the number of sub-soil scenarios.

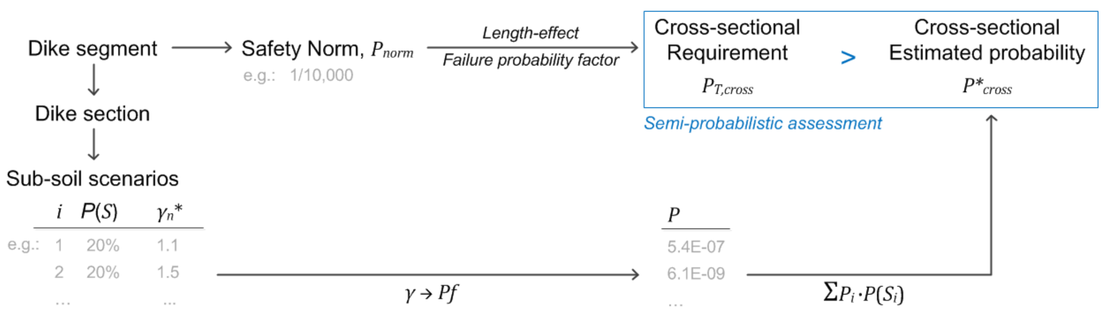

Figure 9.1 Schematised semi-probabilistic assessment for the slope stability mechanism in the WBI 2017 (as in Jongejan & Klerk (2015)).

The goal is to compare the target reliability with the calculated reliability index or probability of failure:

$$\beta^*_{cross} \geq \beta_{T,cross} \Leftrightarrow P^*_{cross} \leq P_{T,cross} \tag{9.1}$$

where $\beta_{T,cross}$ ($P_{T,cross} = \Phi(-\beta_{T,cross})$) is the target reliability index at the cross-section level and β^*_{cross} ($P^*_{cross} = \Phi(-\beta^*_{cross})$) the derived/estimated reliability index for the dike cross-section. In this section all variables with an asterisk (*) are computed values and variables with a subscript "$_T$" refer to target values. One should follow the steps below in the assessment.

1. Determine characteristic values of variables involved in the semi-probabilistic rule, as specified in section 6.5, for each sub-soil scenario. Characteristic values of random variables are marked with index $char$. Derive the outside water level with an exceedance probability equal to the safety standard of the dike segment.

2. With the characteristic values, model factor and design water level, determine the β–dependent safety factors for each sub-soil scenario ($\gamma_{n,i}$* and $i = 1,\ldots, n$, where n = the number of subsoil scenarios considered):

$$\gamma_n{*} = \frac{1}{\gamma_d} \cdot \frac{M_{R,d}}{M_{S,d}} = \frac{1}{\gamma_d} \cdot FoS_{des} \tag{9.2}$$

Where, γ_n^* is the assessed/occurring $\beta-$ dependent safety factor for the cross-section, γ_d is the model safety factor, and FoS_{des} the factor of safety (calculated with design values of the input parameters).

3. The calibrated $\gamma - \beta$ relation(s) may be used inversely to obtain a (safe) estimate of the conditional reliability index per sub-soil scenario. Accordingly, use the recommended rules to transform the occurring safety factors into reliability indices ($\beta_{n,i}*$ and i = 1,…, n).

$$\beta_n{*} = g^{-1}(\gamma_n{*}) \tag{9.3}$$

where g(.) is the $\gamma - \beta$ relation, see Chapter 8

4. To reach an overall verdict, the results of assessments for slope stability for the different sub-soil scenarios have to be combined. Having the failure probabilities for each sub-soil scenario, calculate the total occurring failure probability $P*_{cross}$ and reliability index $\beta*_{cross}$ by:

$$P*_{cross} = \sum_{i=1}^{n} P_i \cdot \mathrm{P}(S_i) \quad \text{and} \quad \beta*_{cross} = -\Phi^{-1}\left(P*_{cross}\right) \tag{9.4}$$

where $\mathrm{P}(S_i)$ is the probability of sub-soil scenario i and $\sum_{i=1}^{n} \mathrm{P}(S_i) = 1$. $P*_{cross}$ is a conservative (safe) estimate of the cross-sectional probability of failure.

5. Determine the target failure probability (or reliability index) of the dike cross-section by using:

$$P_{T,cross} = \frac{f\ /T}{\left(1 + \frac{a \cdot L}{b}\right)} \quad \text{and} \quad \beta_{T,cross} = -\Phi^{-1}\left(P_{T,cross}\right) \tag{9.5}$$

Where T is the inverse of the standard of protection [year], L is the total length of the segment [m], a is a fraction of the length that is sensitive to slope stability [-], b is a measure for the intensity of the length-effect within the part of the segment that is sensitive to slope stability (the length of independent, equivalent dike sections) [m] and f is the slope stability failure probability factor (default value equal to 0.04).

6. The considered dike cross-section complies with the safety standard regarding the slope stability failure mechanism if it fulfils eq.(9.1).

Steps 1 to 4 refer to the estimation of the failure probability, whereas Step 5 refers to the derivation of the target failure probability. In the last step (Step 6), both failure probabilities (or reliability indices) are compared.

9.2 Comparison with current methods and safety factors

9.2.1 Comparison with current safety factors

The currently applied safety format applies to undrained analyses and can therefore only be compared to the **OI2014_v3**, see Section 3.5. The differences in the safety format as compared to the current assessments are discussed in Chapter 7 and in Section 3.5. The main differences with the OI2014_v3 are:

1. The value of the material factor which is 1.0 in this calibration and around 1.08 in the OI2014v3.
2. β-dependent overall safety factor which ranges between 1.0 and 1.3 in this calibration. This is a bit higher than OI2014_v3.

The model factor for Uplift-Van is 1.06 according to both the calibration and the OI2014v3. It should be noted that the OI2014_v3 was not based on a full calibration study.

The net result of these differences between OI2014_v3 and the 2016 calibration is a semi-probabilistic rule that is broadly similar, see Figure 9.2. The OI2014_v3 gamma-beta relation is divided by 1.08 in this figure to account for the used material factor in OI2014_v3. For low beta's (around 4), the results are roughly the same. For higher beta's (around 6), OI2014_v3 requires a higher safety factor. It is not possible though to draw firm conclusions on what this would mean for required berms since there are differences in the implementation of undrained shear strength computations between the two methods.

Compared to the **2015 calibration**, the required safety factor based on the 2016 calibration is on average 0.1 lower.

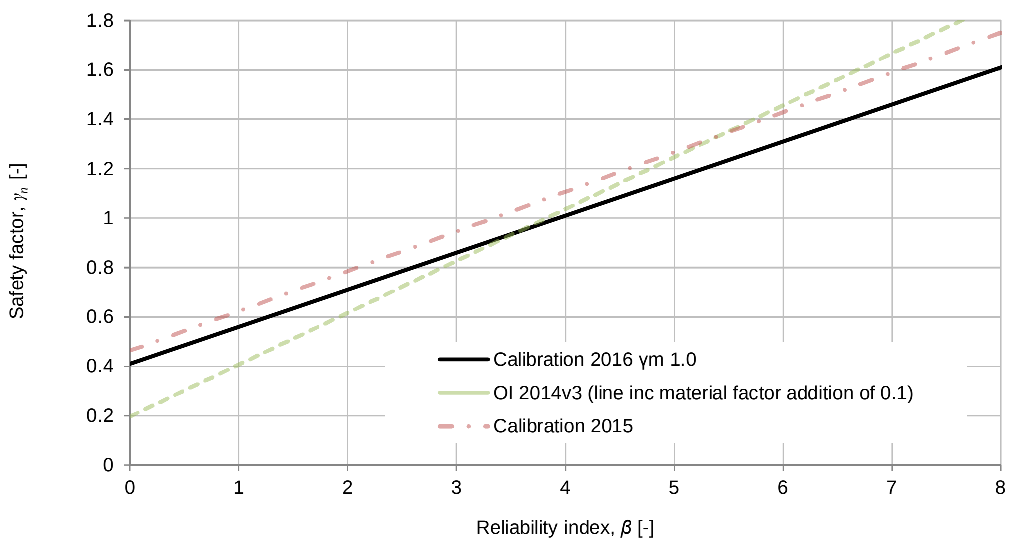

Figure 9.2 Comparison 2016 calibration with the 2015 calibration and OI2014_v3

9.2.2 Comparison with 2015 calibration

In this section, the calibration results of 2016 are compared with the 2015 calibration results. As a cloud, there is not much difference. However, there are quite some differences between the individual cases due to changes in software, not incorporating traffic loads in 2016 and to a lesser extend the incorporation of water pressure uncertainties.

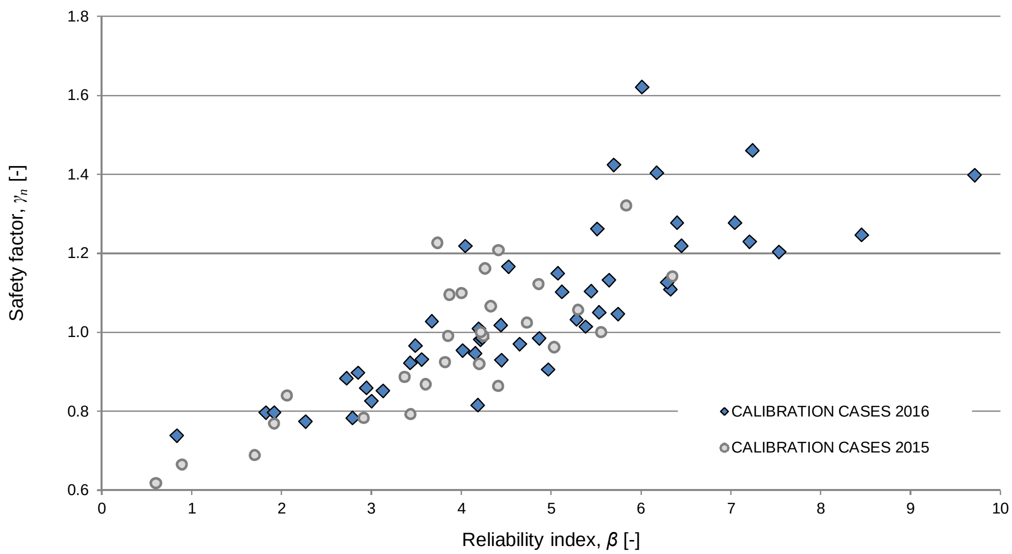

Figure 9.3 Comparison of 2015 and 2016 calibration results.

9.3 Examples

9.3.1 Example: calculate required factor of safety

This example shows how to calculate the required factor of safety for a case with 1 subsoil scenario. This is not the full WBI assessment since this assessment typically requires the combination of multiple subsoil scenarios (see section 9.1 and next sub-section 9.3.2) by converting computed safety factors to failure probabilities and back. The computed and target failure probabilities are thus compared for an assessment.

In order to calculate the required safety factor, the first step is the determination of the maximum allowable probability of failure. According to the Safety Standards (DPV, 2015) the safety standard for this particular dike section is 1/3000 per year, so:

$$P_{norm} = 1/3000 \tag{9.6}$$

This safety standard applies to a complete segment, which can fail as a result of different failure mechanisms. To assess a specific cross-section, based on the aforementioned safety standard, the length-effect and the failure budget need to be taken into account (see eq.(9.5)). For dikes, the standard failure budget (*f*) for inner slope stability is equal to 0.04. The length of the considered segment is 24.4 km (based on *Bijlage Werkgetallen nHWBP versie 1.2 oktober 2014*). For slope stability, the default values are used: a = 0.033 and b = 50m. Therefore:

$$P_{T,cross} = \frac{P_{norm} \cdot f}{\left(1 + \dfrac{a \cdot L}{b}\right)} = \frac{1/3000 \cdot 0.04}{17.2} = 7.8 \cdot 10^{-7} \tag{9.7}$$

The corresponding required reliability for this maximum cross-sectional probability of failure is:

$$\beta_{T,cross} = \Phi\left(1 - P_{T,cross}\right) = 4.80 \tag{9.8}$$

For inner slope stability, this required reliability is translated into a β-dependent factor of safety using the calibrated relation – eq. (9.9). This is visualized in Figure 9.4.

$$\gamma_{n,required} = 0.15 \cdot \beta_{T,cross} + 0.41 = 1.13 \tag{9.9}$$

Hence, the computed FoS_{des} divided by the model factor 1.06 should be larger than 1.13.

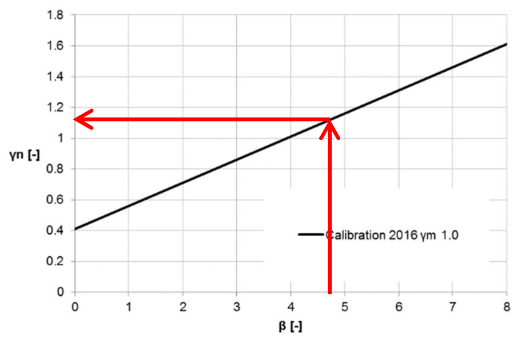

Figure 9.4 Derivation of the required factor of safety, given a target reliability.

9.3.2 Example of a semi-probabilistic assessment with SOS subsoil scenarios

This section discusses the application of the SOS (“Stochastisch Ondergrond Scenario’s”) subsoil scenarios. It should be emphasized that SOS is a global subsoil schematisation which is merely meant make geotechnical engineers aware of possible uncertainties in the stratification (in order to not overlook them).

The Case 4 is used to demonstrate the working with SOS scenarios; for the computations, refer to Appendix L.

The considered scenarios are (see Figure 9.5):

- Scenario 1 is a mixture of peat and clay, very comparable to the original schematisation.
- Scenario 3 is the same as scenario 1, however the first sandy layer is not present and the peat layer is thicker.
- Scenario 5 is the same as scenario 1, however an in between sand layer is present.

Based on the SOS, the probabilities of occurrence of the scenarios are 0.5, 0.35 and 0.15 respectively.

Figure 9.5 Considered SOS scenarios for Case 4: 4_s1, 4_s2 and 4_s3

The computed reliability indexes per scenario are (see Appendix L): 7.05, 6.40 and 6.45. The total failure probability for this cross section can be determined by:

$$P_f = \sum_i P(S_i) \cdot P_f(S_i) \tag{9.10}$$

Where $P(S_i)$ is the probability of the scenario and $P_f(S_i)$ is the probability of failure given the scenario. For the scenarios of Case 4, these results in a combined failure probability of 3.6 10^{-11} (β= 6.52).

Alternatively, if there are no probabilistic computations done, the combination of the scenario's (for which only the FoS is known) is done through the calibration fit. The computed safety factors are first transformed to β's using the calibration fit.

Table 9.1 SOS scenarios for Case 4

Scenario	***P(S$_i$)***	**FoS$_{des}$**	**β according to calibration fit 2016**	***P$_f$(S$_i$)***
1	0.5	1.40	6.6	1.0E-11
3	0.35	1.38	6.47	1.8E-11
5	0.15	1.28	5.8	5.0E-10

After this, eq.(9.13) is applied to compute the total failure probability, which is 5.3E-10 per year (β=6.1).

Hence, the combined failure probability based on a direct probabilistic computation is lower than a combined failure probability based on the calibrated γ-β relation. This is likely due to the large scatter in the calibration results on which one calibrated relation is determined. For individual cases this will result in deviation from a direct probabilistic computation.

10 Discussion on the results and implications

10.1 Which uncertainties are covered in the calibration?

10.1.1 General

The calibrated partial safety factors are supposed to be applicable to the majority of Dutch dikes. The safety factors cover a range of uncertainties in shear strength properties and water pressures as described in this report. Hence, the calibration covers regular uncertainties in shear strength properties and water pressures. Other uncertainties, such as uncertainty about the subsoil layering and phreatic line variations, can be accounted for by defining separate scenarios (see e.g. 9.3.2).

In case there is doubt whether a semi-probabilistic assessment yields a realistic result, a full probabilistic computation is a good fall-back option.

10.1.2 Model uncertainty

The model uncertainty in the calibration is based on Van Duinen (2015) and is relatively limited, which is reflected by the limited influence coefficients. In case the model uncertainty is changed to a small extend, this can be dealt with by modifying the model factor correspondingly. Only if the FORM sensitivity coefficient becomes larger than 0.4, the whole safety format may need re-evaluation.

10.1.3 Defaults

The schematisation guidelines (Schematiseringshandleiding; Van Deen and Van Duinen, 2016) provide default values for S, m and POP, see Appendix G. When these are compared to actual values (see Appendix F), it can be seen that on average the defaults are a bit lower (i.e. more conservative) than the local data shows. However, this is certainly not always the case. Hence, it should be stressed that defaults may only be used in the absence of local data. Defaults should not be used instead of local data.

10.1.4 Traffic loads

Including traffic loads in the assessment will affect the computed safety factor, though it will likely not affect the calibrated safety factors significantly, see Appendix E.

10.1.5 Assessment vs design

The calibration has been carried out with an assessment situation in mind, based on yield stresses that are determined in the lab. This has resulted in e.g. a choice to keep the POP the same in case berms are applied. In case of a design setting, the POP may reduce to 0 below the newly constructed berm. How much this affects the calibration is unclear, but is likely limited. Also a direct determination of yield stress based on CPT might be a reason that safety format as discussed in this report is not directly applicable. This is further discussed in Appendix K, where a preliminary analysis concluded that there is no reason yet to change the safety format for CPT based yield stress determination.

10.2 Comparison with overall factor of safety

Historically, an overall factor of safety was used to determine slope stability. This was defined as the mean resistance divided by the mean load along the slip plane. The overall factor of safety is also (partly) determined for the test cases in order to obtain general insight in the calibration results.

The factors of safety have also been computed using mean values for the shear strength properties keeping everything else equal. The results are shown in Appendix H. On average, the difference in FoS based on mean values and the FoS based on characteristic values is 0.43, similar to what was found in Zwanenburg (2014). This emphasizes the importance of the uncertainty in the shear strength properties. The overall factor of safety can be estimated using the approach of Zwanenburg (2014). Additional to the safety due to the difference between characteristic and mean values (factor of 1.43) the following factors should be taken into account: the model factor (1.06), overall safety factor (1.0 to 1.3) and schematization factor of ~1.1 (this factor is replaced within WBI by working with scenarios). This results in an overall safety factor of around 1.7-2.2, depending on the safety level.

10.3 Material factors

10.3.1 General

Material factors are partial safety factors on shear strength properties. The application of material factors larger than 1 may results in a more optimal safety format in case of a dominant uncertain property. The probabilistic calculations showed the highest influence coefficients for S (see Figure 6.2). Other parameters have on average squared influence coefficient smaller than 0.1, which is around the theoretical threshold for material factors greater than 1. Model uncertainty and yield stress are also above this threshold, but only for specific cases. Hence, a material factor of 1.3 (see 6.4.4) *only* on S is considered in this section. The following considerations are discussed:

- Differences between actual and target reliabilities
- Required berm dimensions
- Differentiation to materials
- Implementation considerations

Furthermore it should be noted that the *cumulated* influence coefficient for S may warrant a material factor larger than one. Cumulated refers to the addition of the influence coefficients of S of all layers. When there are multiple layers present, as is mostly the case, the influence coefficients of the *individual* layers may not be sufficient to warrant a material factor larger than 1.

10.3.2 Effect on differences between actual and target reliabilities

Section 8.4.1 showed the effect of a material factor on the needed overall safety factor. The same analysis has been carried out to determine the difference between target reliability and actual reliability for each case. This shows that on average the deviation from the target reliability is 0.1 smaller in case material factors are applied. Hence, the safety format becomes more accurate, but the effect is limited with respect to the total scatter (for a safety factor of 1, beta can change between 3.5 and 5.5).

10.3.3 Effect on required berm dimensions

The effects of the safety format with a material factor 1.0 and 1.3 (and corresponding required overall safety factor) on required berm dimensions are presented in Appendix I. The analysis shows that for an average case, the required berms are slightly smaller with the use of a material factor of 1.3 (1 m less berm). For cases with larger slip circles or high outside water influence, a material factor of 1.0 results in the smallest required berm. Hence, there is a small effect on the required berm dimensions based on the material factor choice, but this depends on the local conditions and can go both ways.

10.3.4 Differentiation to materials

In Appendix F and L, it is shown that based on the available cases; there is no significant difference in uncertainty and FORM sensitivity coefficients between the various materials. Hence, it is not possible yet to make the material factors material specific.

10.3.5 Implementation considerations

There are various implementation considerations that may affect the choice for the absolute value of the material factor (1.0 or 1.3):

- Absolute value overall safety factor: with a material factor of 1.3, the required overall (β-dependent) safety factor will become smaller than 1 for various dikes. This is not what practitioners are used to.
- Consistency with current methods: Currently, material factors larger than 1 are used in e.g. OI2014. The Eurocode uses different material factors, but none that are specifically meant for the slope stability of dikes.
- Flexibility for future changes: changing material factors requires new slope stability calculations, while changing the overall (β-dependent) safety factor (on FoS) does not require new calculations.

10.3.6 Recommendation

It is recommended to use a material factor of 1.0 because:

1. **It has negligible consequences for the accuracy of the semi-probabilistic rule**.
2. There is not yet enough reason to make a **differentiation** to the various **materials**; neither in terms of uncertainty or in terms of influence coefficients
3. Material factors of 1.0 keep the safety format **simple** and **consistent** within WBI.
4. There will be less dikes with a **required safety factor smaller than 1.**

These are considered more important than disadvantages such as small possible local optimizations (which can be dealt with by probabilistic analysis).

It should be noted that with a material factor of 1.0, the material uncertainties are mainly covered by the application of representative values.

The material factors of 1.0 apply to the materials of undrained layers as well as drained layers within a slope stability analysis that is governed by undrained materials. If a slope stability analysis is governed by drained materials, the results of the calibration do not necessarily apply. One option is to fall back on the old safety format for drained analysis. This is not calibrated for the WBI requirements. Another alternative is to use the presented 2016 calibration and validate if it can safely be applied for limited amounts of drained slope stability analyses as well. The latter option is recommended.

10.4 Slip planes crossing multiple layers: pseudo characteristic values

The use of pseudo characteristic values (TAW, 2001) refers to the use of less conservative representative values when a slip plane goes through multiple independent layers. As it is not likely that all the layers are relatively weak (lower part of the probability distribution) at the same time, less conservative values may be applied.

In this calibration study, the safety factors have been based on real, representative cases. The critical slip planes typically cross various layers. Hence, the reasoning behind the pseudo-characteristic values is already incorporated in the calibrated safety factors. The result is that pseudo characteristic values should not be used when applying the safety format from this calibration.

10.5 Scatter in calibration relations

There is large scatter in the calibration results. This means that for a computed safety factor of 1.0, the obtained reliability index is between 3.7 and 5.7, see Figure 10.1. Hence, if a dike is assessed unsafe based on a semi-probabilistic assessment; it could be worthwhile to perform a probabilistic computation.

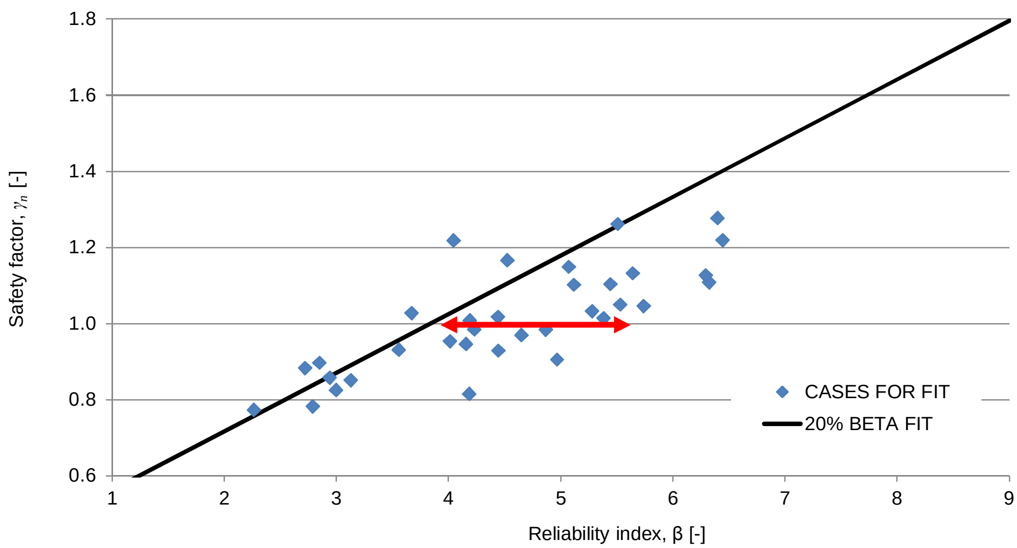

Figure 10.1 Scatter in the calibration results

10.6 Reliability updating

The 2016 calibration confirmed the limited influence of the outside water level on the FoS and reliability index. This is shown by the FORM sensitivity coefficients (see Figure 6.2) and can also be seen in fragility curves in Appendix L. As was discussed in the 2015 calibration (Kanning et al, 2015), this was mainly due to the undrained material model, as well as due to the high initial level of the phreatic line and the relatively high shear strength uncertainty. Furthermore, the analysis presented in Appendix H confirms the dominant shear strength parameter uncertainty.

When the reliability index is relatively low, and most uncertainty is caused by knowledge uncertainty (e.g. shear strength parameter uncertainty), reliability updating using performance observations would have a significant impact on reliabilities. This could be the case when the influence of the outside water level is limited. Hence, reliability updating could have significant application potential based on the calibration results. This is further discussed in Schweckendiek and Kanning (2016).

11 Conclusions and recommendations

11.1 Conclusions

A new set of partial safety factors has been calibrated that is valid for inner slope stability computations using the Uplift-Van limit equilibrium method. The following conclusions are drawn based on the 2016 calibration:

- The required safety factor following the 2016 calibration is approximately **0.1 less** than the safety factor from the 2015 calibration.

- The calibrated safety format applies to undrained slope stability analysis that does **not** incorporate **overtopping (overtopping discharge < 1.0 l/s/m), outer slope stability** and **traffic loads.** In the absence of better alternatives, the results of the STBI calibration could be used for assessments of outer slope stability as well, as has been done in the past. This has not been validated however.

- The calibration is applicable to dikes where the low-permeable materials (e.g. clay) are modelled as **undrained** using the CSSM model and where the highly permeable materials (e.g. sand) are modelled as **drained** using Mohr-Coulomb.

- The calibration has helped to **improve the quality** of D-Geo Stability (kernel and interface) and the WaternetCreator.

- **Pseudo characteristic values** (see 10.4) cannot be used in combination with the 2016 calibration results as the effect that allowed the use of pseudo characteristic values is already incorporated in the calibration.

11.2 Recommendations

The following recommendations are made based on the 2016 calibration:

- In case there are doubts about the results of a semi-probabilistic assessment, a **probabilistic assessment** is recommended.

- The calibration is based on the latest insights with respect to the modelling of inner slope stability within WBI. Therefore, the calibration results are not expected to change in the near future. However, there is still limited experience with undrained slope stability analysis in the Netherlands. This goes for the new Macrostability kernel and interface (software D-Geo Stability) and various modelling choices. Therefore, it is recommended to perform **future evaluations of the STBI assessment** and **comparisons** between semi-probabilistic and probabilistic assessments to check the assumptions underlying the relationship between safety factors and reliability indices.

- The main difference with the current safety formats (e.g. OI2014_v3; Rijkswaterstaat, 2015) is the use of **material factors of 1**. This is made possible because the uncertainties in many material parameters are covered sufficiently by representative values, and because the introduction of a higher material factor for S would not significantly improve the accuracy of semi-probabilistic assessments.

- One key difference between the WBI 2017 and the OI2014_v3 (Rijkswaterstaat, 2015) is the absence of the **schematization factor**, which is supposed to be replaced by working with subsoil scenarios (and other modelled scenarios that reflect uncertainty in e.g. the phreatic line). It is recommended to investigate whether both approaches cover the same amount of uncertainty.

- The calibrated safety format applies to slope stability analyses that are governed by materials that are modelled as undrained. If a slope stability analysis is governed by **drained** materials, the results of the calibration do not necessarily apply. It is recommended to use the presented 2016 calibration for analyses that are governed by drained behaviour as well for the short term; and validate if the format can safely be applied as well for limited amounts of slope stability analyses that are governed by drained behaviour.

- There is **large scatter** in the relation between reliability and required safety factor. In case a dike is judged to be ‘insufficiently safe’ based on a semi-probabilistic assessment, a probabilistic assessment could lead to a ‘sufficiently safe’ verdict. Hence, probabilistic assessments are recommended for dikes that are assessed unsafe (and whose factor of safety does not differ strongly from the required factor of safety).

- I**nsight into required berm lengths** for Dutch dikes using the new calibrated rule is limited and based on very few cases. Gaining more insight into the required berm lengths according to the calibrated rule is recommended.

- The calibration study has been carried out with safety assessments in mind. In case of a design, several assumptions may not be appropriate. This could be the case for e.g. POP values under berms or the direct determination of yield stress based on CPT correlations (see Appendix K where a preliminary analysis concluded that there is no reason yet to change the safety format for CPT based yield stress determination). It is recommended to evaluate whether the results of this calibration study can be **applied to design** as well.

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A Probabilistic computations of slope stability

This appendix gives a summary of the workflow of the STBI probabilistic prototype. This workflow is further elaborated in Huber (2015). The prototype is based on FORM calculations and is developed as a probabilistic test environment, using programming language Python which links the Macrostability kernel with the probabilistic libraries PYRE (https://github.com/hackl/pyre).

A.1 Workflow

Standard reliability approaches like FORM are efficient and fast means for the calculation of the reliability of complex systems. However, FORM can be sensitive to discontinuities or singularities of the limit state equation. In case of slope stability problems, these discontinuities can be caused by nonlinear material behaviour, pore pressure distributions, which change with the water table and other nonlinearities like the reduction of the uplift potential in the present version of the D-Geo Stability software (9 May, 2016). This shows the need for a robust and efficient probabilistic calculation method, which can be used to calculate the reliability of a slope stability problem.

As such, the prototype does not consider the water level (*WL)* directly as a random variable; instead, a conditional probability of failure $p_{f,i}|WL_i$ is calculated, which is used to construct a metamodel or fragility curve, as shown in the following figures:

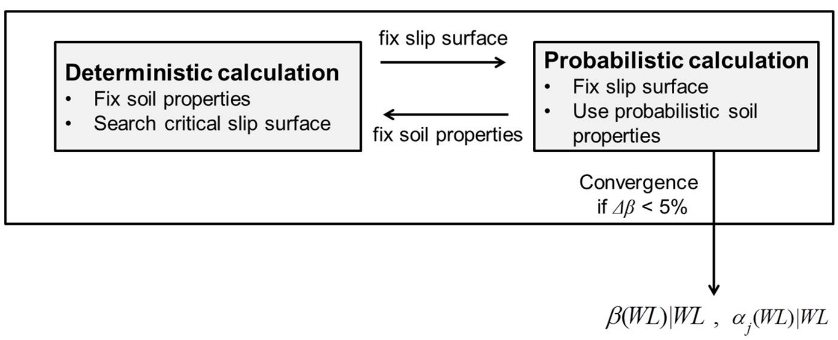

Figure A.1 Calculation scheme of the conditional reliability index β(WL) | WL and of the conditional sensitivity factor α(WL)|WL for different water levels.

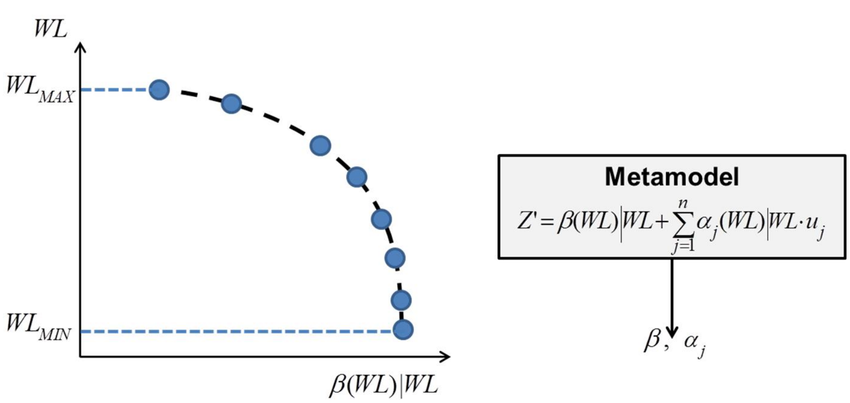

Figure A.2 Using the conditional reliability index β(WL) | WL and the a(WL) | WL to construct the metamodel.

The workflow for the calculation of the reliability index and of the influencing factors, with the prototype for slope stability, comprises of the following steps:

3 At first we introduce the **random variables** by defining their distribution functions, their corresponding mean values and standard deviations;

4 The representative values of the soil strength properties are used within the Macrostability kernel for the calculation of the critical slip surface for a given water level WL_i. Herein, the Uplift-Van model with undrained approach is used. This **slip surface is fixed** for the reliability analysis. This fixed slip surface is checked in step 5 ;

5 **Reliability analyses** are performed using FORM and the Macrostability kernel; within this the limit state equation Z as in eq.(A.1) is used:

$$Z = FoS / m_d - 1 \tag{A.1}$$

6 Herein FoS is the factor of safety coming from the stability computation [-] and m_d the model uncertainty [-];

7 After each reliability analysis, a **check** is made if the **slip surface** is resulting in the minimum stability factor and therefore the minimum reliability index (for a given design point[5]). For this reason, one has to use the values of the design point for a given WL_i within an additional stability calculation and extract the critical slip surface from it. This slip surface is fixed and used for a reliability evaluation;

This loop (two previous steps) is repeated until the change of the reliability index is less than a given threshold of 5 %.

8 The steps 1 to 4 are repeated for different water levels between the lowest water level WL_{min} and the maximum water level WL_{max}. WL_{min} is the lowest point of the surface at the river side and WL_{max} is the height of the dike crest.

At this point, the following is known for different water levels:
– conditional probability of failure $p_{f,i}|WL_i$,
– the corresponding reliability index $\beta|WL_i$ and
– the vector of influence coefficients $\alpha_i|WL_i$

These results are used for the construction of a **metamodel** Z', which is used to create a limit state function as in eq.(A.2).

$$Z' = \beta \,|\, WL(WL) - \sum_{i=1}^{n} \alpha_i \,|\, WL(WL) \cdot u_i \tag{A.2}$$

This metamodel Z' is used for the evaluation of the probability of failure. Within this, the conditional reliability index $\beta|WL_i$ and the influence coefficients $\alpha_i|WL_i$ are linearly interpolated between the calculated reliability indices $\beta|WL_i$ and influence coefficients $\alpha_i|WL_i$. Note that the water level WL_i is assumed to be between WL_{max} and WL_{min}.

[5] *The design point is represents the combination of parameters, at which the slope is most likely to fail.*

9 Finally, one has to **check** if the design-point of the waterlevel is between WL_{max} and WL_{min}; if the design point is smaller WL_{min} the results of WL_{min} are taken as result; if it is bigger than WL_{max} an error message is given. Ideally, another computation with the design point of the water level should ensure that the inaccuracy of the interpolation cannot become an important factor. Due to time constrains this has not been implemented yet.

A.2 Output

The probabilistic prototype has the following output:

- Results conditional on (a selection of) specific water levels
  - probability of failure $p_f(WL)$
  - reliability index $\beta(WL)$
  - vector of influence coefficients $\boldsymbol{\alpha}(WL)$
  - design point *(*WL*)*

- Results independent of the water level (including integration over water level domain)
  - probability of failure p_f
  - reliability index β
  - vector of influence coefficients $\boldsymbol{\alpha}$
  - design point

- Plots of the metamodel (reliability vs. water level)

A.3 Limitations

The STBI calculation using the fixed slip circles based on 5%-quantiles of the resistance parameters is an approximation of the actual slip surface in the FORM design point. The approximation is improved by checking the slip surface after the reliability analysis, by using the design point values for the input properties, and by iterating towards the relevant (design point) slip surface, along which the slope fails.

The approximation using a fragility curves or metamodel is validated with Monte Carlo analyses for various simple reliability problems and slope stability, refer to Huber et al (2016). Moreover, the approximate results are compared with results of FORM analyses, in which the soil properties and the water level are treated as a random variable and by using the fixed slip circle approach at the same time. The results show good agreement for the investigated cases, see A.4. Due to the computation time of the STBI analyses, Monte Carlo analyses for slope stability were not performed for the analysed cases in this study. However, this was done in the Reliability Updating project (Schweckendiek et al, 2016). This showed good agreement between FORM and Crude Monte Carlo.

Furthermore, the user has to carefully select the boundary conditions for the STBI calculations consisting of the following points:

- Manual selection of the slip surface using the Uplift-Van approach. No stable results could be obtained using automatic boundary conditions with the present version of D-Geo Stability (9 May, 2016).
- It is recommended to search for the slip surface using Uplift-Van iteratively by changing the search settings for the slip surface to get the one with the lowest factor of safety.

A.4 Validation of the prototype

The probabilistic computations of the prototype (PM) have been validated with computations with the Probabilistic Toolkit (PT) for a simplified case given in Table A.1.

The main differences between the PM and the PT are:

1) The PM uses a fixed slip circle approach to in the iterative calculation of the reliability. This approach is not used in the PT, which is using a not fixed slip circle in the FORM calculations.
2) The PM employs a metamodel using a fragility curve (Resistance) and water level distribution (Load) to calculate the reliability of the cross-section.
3) One cannot prevent wrong or unrealistic slip surfaces in the PT.

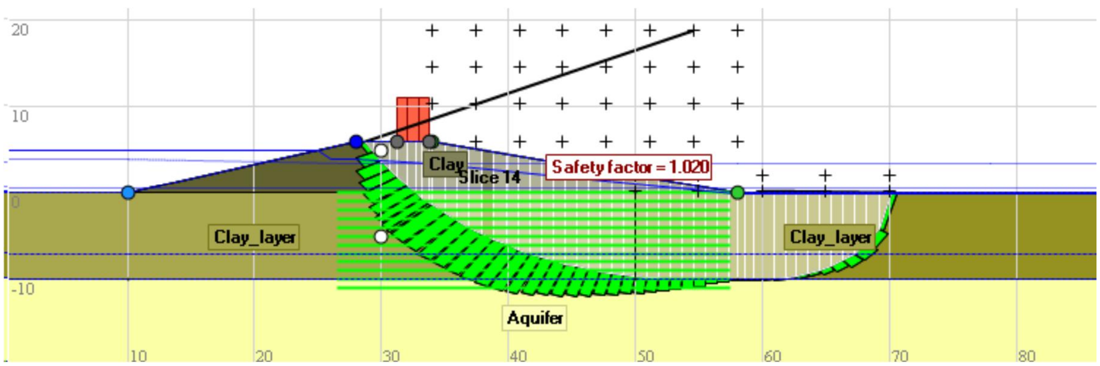

Figure A.3 Simplified case for validation Toolkit

The results of the PT and the PM are given in Table A.1. The resulting reliability index is nearly the same and also the squared alpha values are nearly the same. It can be concluded from this simplified example that both approaches offer more or less the same results. However, it has to be pointed out that this cannot be generalized to all possible cases. Generally speaking, it can be difficult to find the reliability index using FORM in case of a discontinuous limit state function. Factors like the distribution of the pore pressure, which changes for different water levels or the reduction of the uplift potential in D-Geo Stability can hinder FORM in finding a slip surface. This can be overcome by the proposed methodology.

Table A.1 Comparison Probabilistic Toolkit and Prototype

	Probabilistic Toolkit	**Prototype**
α^2		
CuPc	0.61	0.66
m	0.00	0.00
Yield stress	0.27	0.21
cohesion	0	0
friction	0	0
Model_fac	0.10	0.10
WL	0.02	0.02
Beta	**1.89**	**1.86**

B Characteristic values, safety factors and design points

The following equations allow the determination of characteristic values, safety factors and design points for normally and log-normally distributed random variables. Herein, X is a normally distributed random variable and Y is a log-normally distributed random variable. Furthermore, μ is the mean value while σ is the standard deviation, the coefficient of variance (CoV) of is defined as σ / μ.

B.1 Variables with Normal distribution

B.1.1 Characteristic and design value

If a random variable is normally distributed with mean μ and standard deviation σ, then the characteristic value (X_k) of this variable, based for example on the 5%-quantile, is equal to:

$$X_k = \mu - 1.65 \cdot \sigma \tag{B.1}$$

and, based on the 95%-quantile, it is equal to:

$$X_k = \mu + 1.65 \cdot \sigma \tag{B.2}$$

For the design value (X_d), which is based on the reliability index β_{cross} and the representative α-value, is derived as follows:

$$X_d = \mu - \beta_{cross} \cdot \alpha \cdot \sigma \tag{B.3}$$

This applies for a sufficient amount of samples. In case of a limited amount of samples, please refer to Appendix C.

B.1.2 Safety factor

In case of a normally distributed strength variable R with mean μ and standard deviation σ, the safety factor, based on the 5%-quantile, the reliability index β_{cross} and the representative α-value, is derived as follows:

$$\gamma_R = \frac{R_k}{R_d} = \frac{\mu - 1.65 \cdot \sigma}{\mu - \beta_{cross} \cdot \alpha \cdot \sigma} \tag{B.4}$$

Analogously, for a normally distributed load variable S, the safety factor based on the 95%-quantile is derived as follows:

$$\gamma_S = \frac{S_k}{S_d} = \frac{\mu - \beta_{cross} \cdot \alpha \cdot \sigma}{\mu + 1.65 \cdot \sigma} \tag{B.5}$$

B.2 Variables with Log-normal distribution

B.2.1 Characteristic value

If Y is log-normally distributed random variable, then $X = \ln(Y)$ is normally distributed. For Y, with mean μ and standard deviation σ, then the characteristic value (Y_k), based on the 5%-quantile, is derived as follows:

$$Y_k = \exp\left[m - 1.65 \cdot s\right] \tag{B.6}$$

and, based on the 95%-quantile, it is equal to:

$$Y_k = \exp\left[m + 1.65 \cdot s\right] \tag{B.7}$$

Where:

$$\begin{cases} s^2 = \ln\left[1 + \left(\dfrac{\sigma}{\mu}\right)^2\right] \\ m = \ln\left[\mu\right] - \dfrac{1}{2} \cdot s^2 \end{cases} \tag{B.8}$$

For the design value (Y_d), which is based on the reliability index β_{cross} and the representative α-value, is derived as follows:

$$Y_d = \exp\left[m - \beta_{cross} \cdot \alpha \cdot s\right] \tag{B.9}$$

B.2.2 Safety factor

In case of a log-normally distributed strength variable R with the coefficient of variation CoV, the safety factor, a representative value that corresponds to a 5%-quantile, the reliability index β_{cross} and the representative α-value, is derived as follows:

$$\gamma_R = \frac{R_k}{R_d} = \exp\left[(-1.65 + \beta_{cross} \cdot \alpha)\sqrt{\ln\left[1 + CoV^2\right]}\right] \tag{B.10}$$

Analogously, for a normally distributed load variable S, the safety factor based on the 95%-quantile is derived as follows:

$$\gamma_S = \frac{S_k}{S_d} = \exp\left[(-1.65 - \beta_{cross} \cdot \alpha)\sqrt{\ln\left[1 + CoV^2\right]}\right] \tag{B.11}$$

C Spatial Averaging

This appendix describes how averaging of uncertainties is implemented in the calibration of slope stability. Averaging can to be taken into account because the soil properties fluctuate rapidly in the vertical dimension relative to the dimension of the failure plane, resulting in averaging of the vertical part of the variance.

C.1 Description averaging

There are various formulas with respect to spatial averaging in slope stability analyses, e.g. the one from TRWG (2001):

$$\sigma\left(c_{u,G}\right)^2 = \Gamma(G)^2 \cdot \sigma(c_u)^2 \tag{C.1}$$

Where $\sigma(c_{u,G})^2$ is the variance of the average shear strength along a slip circle, $\sigma(c_u)^2$ is the point variance of the slip circle and $\Gamma(G)^2$is the variance reduction factor; see TRWG (2001) and below.

As we typically deal with regional datasets, a stochastic model was developed. This model basically says that a part of the regional variance (${\sigma_{reg}}^2$) is due to local fluctuations of the shear strength (${\sigma_{loc}}^2$) and another part is due to regional fluctuations in of the local mean of the shear strength (${\sigma_{loc,aver}}^2$).

There are three effects that determine the local, average standard deviation ($\sigma_{loc,aver}$), that should be input for a computation based on the measured data (σ_{reg}):

1. Incorporate the relation between regional and local variability: the a factor
2. Incorporate local averaging along failure plane: the γ_d factor
3. Incorporate the effect of limited measurements: n

This can be summarized by eq.(C.2), an equation used in VNK2 and in the 'schematiseringshandleiding' (Van Deen and Van Duinen, 2016).

$$\sigma_{loc,aver} = \sigma_{reg}\sqrt{(1-a) + a \cdot \gamma_d + \frac{1}{n}} \tag{C.2}$$

where:

- σ_{reg} is the standard deviation of the regional variation
- a is the portion of the total variability stemming from local variability (and (1-a) the fluctuations of local means) [default: a = 0.75, Leidraad Rivieren]. In case of a local dataset, a =1.
- $\gamma_d$is the variance reduction factor: γ_d= min($D_v\sqrt{\pi}/d$, 1)
- D_v is vertical correlation length, d is layer thickness
- *n* is the number of samples

When it is assumed that all local variance averages, γ_d goes to 0 and eq.C.2 reduces to:

$$\sigma_{loc,aver} = \sigma_{reg}\sqrt{(1-a) + \frac{1}{n}} \tag{C.3}$$

This equation is found in e.g. Van Deen and Van Duinen (2016) and TRWG (2001).

C.2 Including averaging in the WBI

S, m and yield stress are the parameters currently being considered for spatial averaging. The inputs of the cases provided by Cluster Macrostability already incorporate eq.(C.3). Hence, there was already an implicit assumption of full local averaging (γ_d = 0). Cluster STBI's input is based on a regional dataset, as is common. Due to the averaging already being incorporated, the Su data can be treated as means and variances of the local average shear strength, and no more processing is necessary.

D Solved bugs and workarounds

This appendix presents a list of the detected bugs and less intuitive options in D-Geo Stability software, found during the calibration exercise 2016. Multiple files/cross-sections were set up and analysed with the software D-Geo Stability and Uplift-Van method, and these were an important and necessary exercise not only for the calibration itself but also for the testing the newest version of D-Geo Stability.

Version: D-Geo Stability versions from March until **9-May-2016**

Note that some of the elements of the following list might be related to the interface of D-Geo Stability (C#) and not to the Macrostability kernel itself.

D.1.1 Waternet creator (WNC)

Situation:	In case the input value for the "Average high outside water level (GHW)" is lower than the PL2 input value, the PL2 is changed to GHW.
Expected behaviour:	A warning message should be displayed
Problem/Error:	No warning message
Solved in version 9-May-2016?	No. Issue solved in the following release
Work around/ solution:	Solved in the software by adding a warning message "PL2 is changed because GHW is lower than PL2" added

Situation:	Creating a dike cross-section with the WNC option "Sand dike on Clay"
Expected behaviour:	No error message should be shown in case of a sand dike body with more than one sand layer. The error message has to apply only for the first deep aquifer.
Problem/Error:	Program gives the following error message: "Aquifer isn't defined over complete width (Dijksmateriaal)"
Solved in version 9-May-2016?	No. Issue solved in the following release
Work around/ solution:	Solved in the software by showing the error message only for the first deep aquifer. Meanwhile, the workaround with the version 9 may was to extend the other sand layer to the edges of the cross-section (thin layer)

Situation:	Input "Outside water level (MHW)" is below GHW input value, which is lower than the outer/river toe of the cross-section (characteristic point "Dike toe at river")
Expected behaviour:	Inform the user by showing an error message
Problem/Error:	Unexpected error, software crashes
Solved in version 9-May-2016?	No
Work around/ solution:	**Workaround by the user:** the user has to make sure the input "Outside water level (MHW)" is equal to *max*(GHW, Z_"Dike toe at river")

Situation:	Changing the geometry of a cross-section
Expected behaviour:	WNC can accommodate in real time or generate new lines along with the changes in geometry
Problem/Error:	WNC (i.e. generated pore water pressures) can give strange results, there is a limitation of the WNC to adapt to changes in geometry
Solved in version 9-May-2016?	No, accepted limitation of the software
Work around/ solution:	**Workaround by the user:** The user has to always turn off the WNC before making a change in geometry (e.g. merging layers, dividing layers, creating a berm, etc.) If a strange WN line appears in the cross-section, one should: • turn off the WNC, delete every WN line present in the cross-section and then turn on the WNC to generate new, correct WN lines • another way can be to delete all the WN lines and points via the xml structure, and then generate new, correct WN lines

Situation:	Cross-section where by change a waternet line intersects over a distance of 0.01 m in the vertical direction, with a horizontal geometry line (i.e. soil layer boundary)
Expected behaviour:	Correct generation of the vertical stresses and therefore the shear strength computation
Problem/Error:	Because of the pre-processing/calculation grid side of stresses, no shear strength is calculated for some of the slip plane slices due to a wrong WNC (pore water pressure) in the layer
Solved in version 9-May-2016?	Yes
Work around/ solution:	Solved in the software

Situation:	2 aquifers are present in the cross-section and there is uplift in the hinterland (cross-section ‘clay dike on clay’ with an intermediate aquifer)
Expected behaviour:	Correct head reduction/adjustment for PL3 and PL4
Problem/Error:	The WNC (option adjust PL3 and PL4) cannot calculate a correct head reduction/adjustment for the intermediate aquifer (PL4)
Solved in version 9-May-2016?	No. Issue solved in the following release
Work around/ solution:	**Workaround by the user:** user has to model the cross-section with only 1 aquifer

Situation:	In a specific case with very low outside water level
Expected behaviour:	Correct PL1 line generated by the WNC
Problem/Error:	the PL1 line is not drawn correctly
Solved in version 9-May-2016?	No. Issue solved in the following release
Work around/ solution:	**Workaround by the user:** user has to be aware of the generated PL1 line, and where the characteristic points are placed, so that the best schematisation of the

	phreatic line can be made

Situation:	In a cross-section, for all layers that are intersected by the PL1, hydrostatic pore water pressures should be applied (according to the functional design)
Expected behaviour:	Hydrostatic pressure for all layers that are intersected by PL1
Problem/Error:	The pore water pressure distribution within the dike is not hydrostatic
Solved in version 9-May-2016?	Yes
Work around/ solution:	Solved by the software Note: Be aware that there are cases where the hydrostatic zone can be schematised in an undesirable way, since the complete thickness of a layer will be considered hydrostatic even if the PL1 slightly crosses the layer boundary

D.1.2 Other

Situation:	File saved with the Reliability Model option Enabled
Expected behaviour:	Normal save and open behaviour
Problem/Error:	Cannot open saved file
Solved in version 9-May-2016?	Yes
Work around/ solution:	Solved by the software

Situation:	Calculated safety factor is very sensitive for grid settings
Expected behaviour:	Safety factor not sensitive to small grid changes
Problem/Error:	The relaxation factor has an (unexpected) influence on the safety factor
Solved in version 9-May-2016?	Yes
Work around/ solution:	Solved by the software, was originated by the wrong implementation of the momentum equilibrium for Uplift-Van, so, for very specific grid settings a wrong low FoS was obtained

Situation:	Yield stress points location and different layers with the same name
Expected behaviour:	Correct back calculation of the POP, correct values in the correct location in the cross-section
Problem/Error:	If two yield stress points are added inside layers which are one under and one next to the dike, and if they are assigned exactly the same name, the value of the POP is back-calculated and then averaged. This is sometimes not desirable and can lead to wrong results.
Solved in version 9-May-2016?	No, since it is not a software issue
Work around/ solution:	**Workaround by the user:** When including the yield stress points in a cross-section, one should always keep in mind the following points:

	• A geometry division between under and next the dike has to be present, at a level where the PL1 does not change much with the change in the outside water level (this is important when e.g. a berm is present) • If the same soil layer is present across the cross-section (left to right), this division has to be present (under and next the dike) and the soil name should be different (e.g. clay_under and clay_next) • Averaging between soils with the same name is made, so make sure this is desirable and is performed correctly • The location of a yield stress point in the dike body is very sensitive to the changes in PL1 e.g. left side and right side of the dike body, yield stress point should always be in the middle of the dike body • A yield stress point cannot be placed in a location that becomes wet and dry over the course of the analysis (e.g. middle of the dike body) • A yield stress point should be placed in a location where uplift may occur, if uplift occurs the back-calculation of POP goes wrong, since the vertical effective stress is zero

Situation:	Any cross-section
Expected behaviour:	Easy to recognize or identify the passive and active grid
Problem/Error:	Safety factor computation goes wrong
Solved in version 9-May-2016?	No, since it is not a software issue
Work around/ solution:	**Workaround by the user:** Delete grid and activate/generate it again

E Influence of traffic loads

In all calibration calculations, no external traffic load has been taken into account. In order to understand the influence of this choice, a consequence analysis has been carried out for the outcomes of "deterministic" and probabilistic calculations for two cross-sections with and without traffic load. The first involves a small slip plane and the second involves a large (deep) slip plane – Kanning et al. (2015).

Both cases with traffic load and without traffic load are depicted in Figure E.1. It is clearly seen that ignoring the traffic load leads to an increase in both the Factor of Safety (representative values) and the reliability index. The shift in beta relates to a shift in gamma that is in the same angle as the calibration fit. Hence, the traffic load is not expected to influence the results of the calibration based on these two cases. The influence coefficients are also nearly the same.

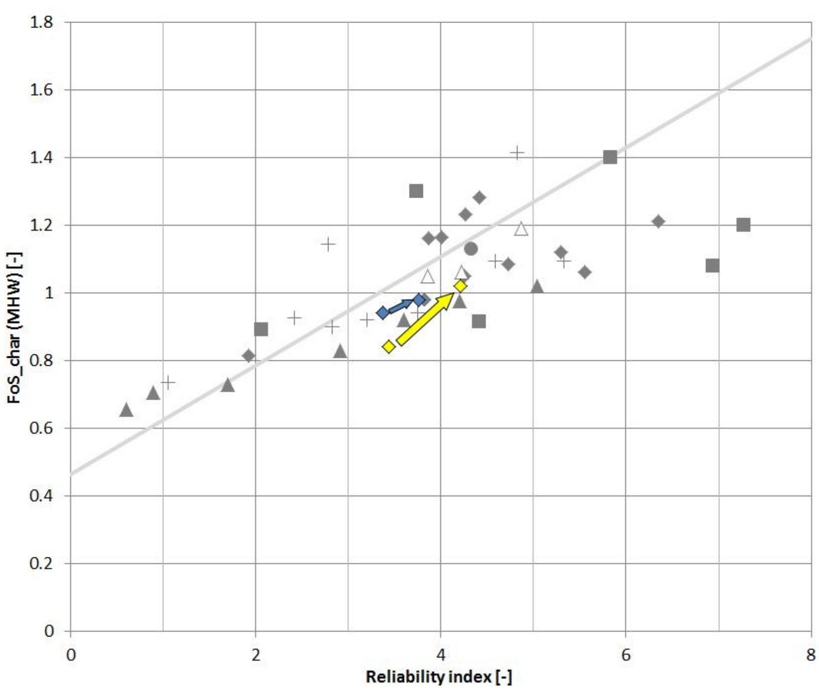

Figure E.1 Calibration fit (grey) with the calibration points of two cross-sections, with and without traffic load based on Kanning et al (2015).

F Overview of the test set

The calibration exercise carried out in 2016 takes into account the test set of the calibration of 2015 (Kanning et al., 2015) in addition to new cases that were collected in other parts of the Netherlands with availability of local and regional data. Together, the test set includes 27 different locations, of which 17 use local or regional information.

First of all, it is important to mention the differences between the cases of 2015 presented in Kanning et al. (2015) and presented here. The profiles, or cross-sections, of 2015 were computed in 2015 with a different Macrostability kernel and with soil parameters based on expert judgement. In 2016, the following changes are made in order to go more in line with the WBI 2017:

- The **-wbi kernel**, latest version of 9 May 2016, is used.
- The **soil parameters**, namely the m-strength parameter and the undrained shear strength ratio (S), are taken as specified in the WBI 2017 schematisation guidelines for inner slope stability (Van Deen and Van Duinen, 2016 – see Appendix G).
- Parameters for the automatic pore pressures generator, i.e. **waternet creator** (WNC), were taken as uncertain, in contrast to the deterministic and conservative assumptions used in 2015.
- No **traffic load** was taken into account in the calibration exercise of 2016, since in the WBI 2017 the traffic load is ignored in safety assessments.

The following section F.1 concerns the details, i.e. location and characteristics, of the test set that was used as a basis for the calibration exercise presented in this report. In section F.2 extensive summary tables are presented, including, per case, all the inputs and uncertainties for soil parameters, waternet creator parameters and yield stress points.

F.1 Test set main characteristics

The following table (F.1) summarizes the most important characteristics of the test set; a map of these cross-sections/locations is presented right after – Figure F.1.

Table F.2 presents the summary of the water level characteristics. For some of the cases, both old and new safety standards (‘norm’) are presented just for illustration. For those cases, approximately the same Gumbel distribution is achieved using the old ‘norm’ or the new ‘norm’ values.

Table F.1 Summary table with description (geology and behaviour characteristics) of the cross-sections and source of the data used for the computations

ID	Description	Source
Cases 2016		
1	Located in the Nederrijn region, a non-tidal Rhine river area, schematised as ‘clay dike on clay’ with a thin cover layer (< 4 m).	Schem. guidelines defaults
2	Located along the Lek, in the tidal area of the Rhine river, schematised as ‘clay dike on clay’ with a very thick cover layer (> 6 m).	Regional data
3	Located along the Lek, in the tidal area of the Rhine river, schematised as ‘clay dike on clay’ with a very thick cover layer (> 6 m).	Local data
4	Located along the Lek, in the tidal area of the Rhine river, schematised as ‘clay dike on clay’ with a very thick cover layer (> 6 m).	Regional data
5	Located along the Nederrijn region, a non-tidal river area, schematised as ‘clay dike on clay’ with a very thick cover layer (> 6 m).	Regional data
6	Located along the Waal, in the non-tidal Rhine region, schematised as ‘clay dike on clay’ with a very thick cover layer (> 6 m).	Regional data
7	Located along the Waal, in the non-tidal Rhine region, schematised as ‘clay dike on clay’ with a very thick cover layer (> 6 m).	Regional data
8	Located along the Waal, in the non-tidal Rhine region, schematised as ‘clay dike on clay’ with a very thick cover layer (> 6 m).	Regional data
9	Located along the Waal, in the non-tidal Rhine region, schematised as ‘clay dike on clay’ with a very thick cover layer (> 6 m).	Regional data
10	Located in the Waddenzee area, influenced by the tides, schematised as ‘sand dike on clay’ with a very thick cover layer (> 6 m).	Regional data
11	Located in the north part of the lake Ijssel, schematised as ‘clay dike on clay’ with a thin cover layer (< 4 m).	Schem. guidelines defaults
12	Located in the south part of the lake Ijssel, schematised as ‘sand dike on clay’ with a thin cover layer (< 4 m).	Schem. guidelines defaults
13	Located in the Maas river, a non-tidal area, schematised as ‘clay dike on clay’ with a thin cover layer (< 4 m).	Schem. guidelines defaults
14	Located along the Lek, in the tidal area of the Rhine river, schematised as ‘clay dike on clay’ with a very thick cover layer (> 6 m).	Local data
15	Located in the Markermeer area, schematised as ‘clay dike on clay’ with a very thick cover layer (> 6 m).	Regional data
16	Dam, schematised as ‘sand dike on clay’ with a very thick cover layer (> 6 m).	Schem. guidelines defaults
17	Located in the along Waddenzee, schematised as ‘sand dike on clay’ with a very thick cover layer (> 6 m).	Regional data

ID	Description	Source
Cases 2015		
18	Located in the non-tidal Maas river area, schematised as 'clay dike on clay' with a thin cover layer (< 4 m).	VNK database, schematisation guidelines defaults
19	Located in the non-tidal area of the Waal, schematised as 'clay dike on clay' with a thin cover layer (< 4 m).	
20	Located in the non-tidal area of the Waal, schematised as 'clay dike on clay' with a thin cover layer (< 4 m).	
21	Located along the Waal, in the non-tidal Rhine region, schematised as 'clay dike on clay' with a very thick cover layer (> 6 m).	
22	Along the Ijssel river, lower part schematised as 'clay dike on clay' with a thin cover layer (< 4 m).	
23	Located along the Lek, in the tidal area of the Rhine river, schematised as 'clay dike on clay' with a very thick cover layer (> 6 m).	
24	Along the Ijssel river in the non-tidal area, schematised as 'clay dike on clay' with a thin cover layer (< 4 m).	
25	Schematised as 'clay dike on clay' with a medium thick cover layer (4-6 m).	
26	Schematised as 'clay dike on clay' with a very thick cover layer (> 6 m).	
27	Schematised as 'sand dike on clay' with a medium thick cover layer (4-6 m).	

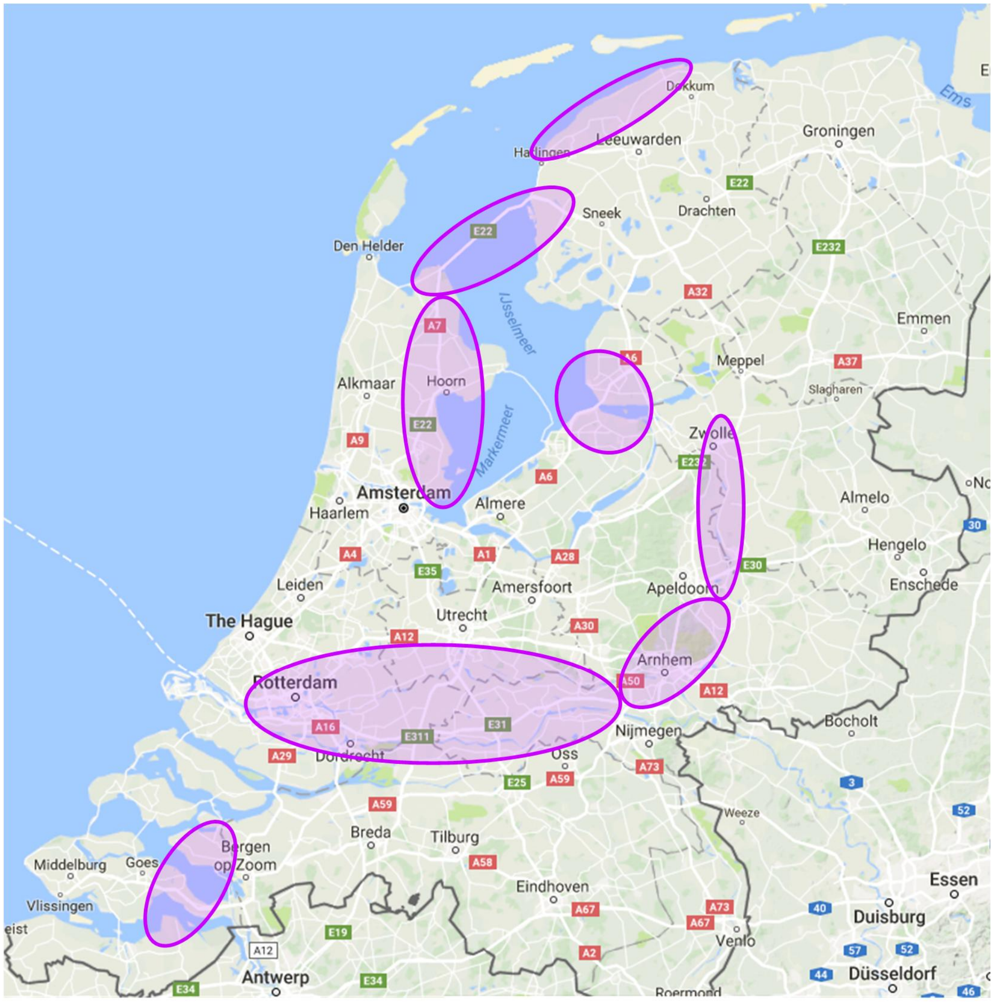

Figure F.1 Test set members of calibration exercise 2016.

Table F.2 Summary table of the water level characteristics, used to derive the Gumbel distribution

ID	Safety standard, "norm" [yr^{-1}]	WBN [m + NAP]	"decimeringshoogte" [m]	Crest level [m + NAP]
Cases 2016				
1	30,000	16.25	0.70	17.13
2	10,000	3.89	0.44	5.10
3	30,000	4.30	0.44	6.01
4	30,000	6.26	0.79	6.50
5	30,000	8.10	0.75	8.21
6	1,250*	7.34*	0.74	8.81
	30,000	8.36	0.74	8.81
7	1,250*	6.21*	0.70	6.73
	30,000	7.18 (!)	0.70	6.73 (!)
8	1,250*	7.06*	0.73	7.82
	30,000	8.07 (!)	0.73	7.82 (!)
9	1,250*	6.21*	0.70	7.10
	30,000	7.18 (!)	0.70	7.10 (!)
10	3,000	4.85	0.46	8.30
11	3,000	1.11	0.27	4.19
12	3,000	2.14	0.49	4.46
13	3,000	8.50	0.70	8.81
14	2,000*	3.57*	0.41	5.40
	10,000	3.86	0.41	5.40
15	10,000*	0.71	0.19	3.16
	3,000	0.61	0.19	3.16
16	4,000*	4.90*	0.49	9.96
	10,000	5.09	0.49	9.96
17	10,000	5.93	0.56	8.06
Cases 2015				
18	10,000	13.41 (!)	0.73	13.30 (!)
19	10,000	12.79 (!)	0.73	13.40 (!)
20	10,000	12.57	0.73	12.48
21	30,000	6.50	0.57	7.53
22	3,000	6.93	0.69	7.03
23	2,000*	3.40*	0.20	5.62
	30,000	3.64	0.20	5.62
24	3,000	10.84	0.66	11.40
25	3,000	0.98	0.25	3.84
26	3,000	2.99	0.27	4.49
27	30,000	6.72	0.67	9.11

* older safety standards.

(!) WBN higher than the crest

F.2 Soil parameters summary tables

The following tables present the soil parameters and waternet creator (WNC) inputs (section F.2.1 for new cases added in 2016, and section F.2.2 for new parameters used in the test set of 2015) and also the yield stress points tables (section F.2.3 for new cases 2016, and section F.2.4 for the test set of 2015).

In the soil parameters tables have the following information:
- Some of the soil names, e.g. H_Rk_k, H_Ro_z&k, P_Rk_k&s, are named as defined in the WBI-SOS. These names refer to geological units, detail to be found in the schematisation guidelines for macrostability – Appendix C (Van Deen and Van Duinen, 2016). E.g.: H_Rk_k is Hogere komafzettingen.
- C, is the cohesion of sandy layers [kPa
- Phi_mean, is the mean value of the friction angle of sandy layers [deg]
- Phi_dev, is the standard deviation of the friction angle of sandy layers [deg]
- Phi_cov(on the tangent), is the coefficient of variation of the tangent of the friction angle of sandy layers [-]
- S_mean, refers to the mean of S, the undrained shear strength ratio for undrained layers [-]
- S_dev, refers to the standard deviation of the S [-]
- S_cov, is the coefficient of variation of the S [-]
- m_mean, is the strength increase exponent's mean value [-]
- m_dev, is the standard deviation of the strength increase exponent [-]
- m_cov, is the correspondent coefficient of variation of the strength increase exponent [-]
- POP, is the mean pre-overburden pressure used to compute the yield stress points. Not in all cases these values are used, sometimes local data/measurements of the yield stress points are available (2016) or expert judgement was used for the yield stresses (2015). These cases are marked with N.A.

Following, the WNC inputs represent:
- WL, the water level [m+NAP]
- GHW, the average high water level [m+NAP]
- Polder, is the polder water level [m+NAP]
- min_out, is the minimum value of the phreatic line on the outside side of the dike [m+NAP]
- min_in, is the minimum value of the phreatic line on the inside side of the dike [m+NAP]
- LL_out, is the mean value of the leakage length towards the outside of the dike [m]
- LL_in, is the mean value of the leakage length towards the outside of the dike [m]
- PL2, is the head level at the aquifer layer [m+NAP]
- IntL, is the mean value of the intrusion length [m]

The pore water pressure uncertainties are modelled by making the leakage length (LL_out, LL_in) and intrusion length (IntL) random variables according to Kanning and Van der Krogt (2016), see also Table 3.1.

In the yield stress points tables have the following information:
- sigmaY, is the mean yield stress point value [kPa]
- std, is the applied standard deviation [kPa]
- COV, is the corresponding coeffient of variation [-]

F.2.1 Soil properties 2016 cases

Case 13

WBI

Key	Name	Model	C	Phi_mean	Phi_dev	Phi_cov(on tg)	S_mean	S_dev	S_cov	m_mean	m_dev	m_cov	POP	POP_cov
7	klei - dijklichaam	CuCalculated	-	-	-	-	0.31	0.08	0.26	0.90	0.03	0.03	30	0.20
36	klei - onder dijk	CuCalculated	-	-	-	-	0.29	0.06	0.21	0.90	0.03	0.03	17	0.35
65	klei - naast dijk	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	34	0.18
94	WL_zandondergrond	CPhi	0.00	35.00	2.00	0.05	-	-	-	-	-	-	-	

Key	WL	GHW	polder	min_out	min_in	LL_out	LL_in	PL2	IntL
354	8.00	4.90	3.50	6.20	6.20	320.00	1200.00	4.60	0.00

Case 16

WBI

Key	Name	Model	C	Phi_mean	Phi_dev	Phi_cov(on tg)	S_mean	S_dev	S_cov	m_mean	m_dev	m_cov	POP	POP_cov
7	Dijksmateriaal	CPhi	0.00	32.00	1.60	0.04	-	-	-	-	-	-	-	-
36	Klei_zand_2	CuCalculated	-	-	-	-	0.15	0.02	0.13	0.92	0.03	0.03	31	0.19
65	Klei_zand	CuCalculated	-	-	-	-	0.23	0.02	0.09	0.92	0.03	0.03	31	0.19
92	Klei_humeus_zand_2	CuCalculated	-	-	-	-	0.29	0.09	0.31	0.93	0.04	0.04	24	0.25
121	Klei_humeus_zand	CuCalculated	-	-	-	-	0.29	0.09	0.31	0.93	0.04	0.04	17	0.35
148	Zand	CPhi	0.00	32.00	1.60	0.04	-	-	-	-	-	-	-	-
385	Kleideklaag	CuCalculated	-	-	-	-	0.15	0.00	0.00	0.92	0.00	0.00	31	0.19

Key	WL	GHW	polder	min_out	min_in	LL_out	LL_in	PL2	IntL
458	5.00	-0.02	-0.20	0.88	0.88	268.00	849.00	0.00	2.00

Case 14

WBI

Key	Name	Model	C	Phi_mean	Phi_dev	Phi_cov(on tg)	S_mean	S_dev	S_cov	m_mean	m_dev	m_cov	POP	POP_cov
164	Plesitoceen	CPhi	0.00	32.60	1.60	0.04	-	-	-	-	-	-	-	-
193	Basisveen naast	CuCalculated	-	-	-	-	0.36	0.07	0.19	0.90	0.03	0.03	26.8	0.22
221	Geul kleiig zand	CPhi	0.00	35.20	2.40	0.06	-	-	-	-	-	-	-	-
249	Rand geul zandige klei	CuCalculated	-	-	-	-	0.25	0.06	0.24	0.90	0.03	0.03	18.7	0.32
277	Hollandveen naast	CuCalculated	-	-	-	-	0.36	0.04	0.11	0.90	0.03	0.03	18.7	0.32
305	Gorkum licht(venige klei)	CuCalculated	-	-	-	-	0.33	0.05	0.15	0.90	0.03	0.03	13.9	0.43
333	Gorkum zwaar naast	CuCalculated	-	-	-	-	0.25	0.04	0.16	0.90	0.03	0.03	18.2	0.33
361	Gorkum naast	CuCalculated	-	-	-	-	0.24	0.06	0.25	0.90	0.03	0.03	18.2	0.33
389	Basisveen onder	CuCalculated	-	-	-	-	0.36	0.07	0.19	0.90	0.03	0.03	26.8	0.22
417	Rand geul zandige klei na	CuCalculated	-	-	-	-	0.25	0.04	0.16	0.90	0.03	0.03	18.7	0.32
445	Geul kleiig zand onder	CPhi	0.00	32.60	1.60	0.04	-	-	-	-	-	-	-	-
473	Gorkum licht onder	CuCalculated	-	-	-	-	0.24	0.05	0.21	0.90	0.03	0.03	13.9	0.43
501	Hollandveen onder	CuCalculated	-	-	-	-	0.36	0.04	0.11	0.90	0.03	0.03	18.7	0.32

529	Gorkum zwaar onder	CuCalculated	-	-	-	-	0.25	0.04	0.16	0.90	0.03	0.03	18.2	0.33
557	Gorkum zandige kleilaag	CuCalculated	-	-	-	-	0.25	0.04	0.16	0.90	0.03	0.03	18.2	0.33
585	Dijksmateriaal Kleiig naast	CuCalculated	-	-	-	-	0.30	0.03	0.10	0.90	0.03	0.03	50	0.12
613	Dijksmateriaal Kleiig	CuCalculated	-	-	-	-	0.30	0.03	0.10	0.90	0.03	0.03	50	0.12
640	Dijksmateriaal zandig	CPhi	2.00	32.60	1.60	0.04	-	-	-	-	-	-	-	-
668	Stortsteen	CPhi	0.00	35.20	2.40	0.06	-	-	-	-	-	-	-	-
696	Klei van Tiel naast	CuCalculated	-	-	-	-	0.25	0.06	0.24	0.90	0.03	0.03	26	0.23

Key	WL	GHW	polder	min_out	min_in	LL_out	LL_in	PL2	IntL
1300	1.08	1.08	-0.50	1.50	1.50	460.00	1453.00	-0.50	1.00

Case 10

WBI

Key	Name	Model	C	Phi_mean	Phi_dev	Phi_cov(on tg)	S_mean	S_dev	S_cov	m_mean	m_dev	m_cov	POP	POP_cov
7	zand	CPhi	0.00	38.00	5.25	0.12	-	-	-	-	-	-	-	-
36	b.veen_2	CuCalculated	-	-	-	-	0.31	0.03	0.08	0.89	0.03	0.03	N.A.	N.A.
65	b.veen	CuCalculated	-	-	-	-	0.31	0.03	0.08	0.89	0.03	0.03	N.A.	N.A.
92	klei.cal 2	CuCalculated	-	-	-	-	0.21	0.02	0.09	0.93	0.04	0.04	N.A.	N.A.
121	klei.cal	CuCalculated	-	-	-	-	0.21	0.02	0.09	0.93	0.04	0.04	N.A.	N.A.
148	klei+v_2	CuCalculated	-	-	-	-	0.25	0.02	0.08	0.93	0.04	0.04	N.A.	N.A.
177	klei+v	CuCalculated	-	-	-	-	0.25	0.02	0.08	0.93	0.04	0.04	N.A.	N.A.
204	klei.dui	CuCalculated	-	-	-	-	0.30	0.03	0.08	0.93	0.02	0.02	N.A.	N.A.
233	klei.afd	CuCalculated	-	-	-	-	0.40	0.04	0.09	0.93	0.02	0.02	N.A.	N.A.
677	verk.	CPhi	0.00	0.00	0.00	nan	-	-	-	-	-	-	-	-

Key	WL	GHW	polder	min_out	min_in	LL_out	LL_in	PL2	IntL
766	0.95	0.95	-0.80	0.68	0.68	118.00	374.00	0.00	1.50

Case 6

WBI

Key	Name	Model	C	Phi_mean	Phi_dev	Phi_cov(on tg)	S_mean	S_dev	S_cov	m_mean	m_dev	m_cov	POP	POP_cov
7	Veen (O)	CuCalculated	-	-	-	-	0.44	0.05	0.11	0.67	0.03	0.04	21	0.29
36	Veen (N)	CuCalculated	-	-	-	-	0.44	0.05	0.11	0.67	0.03	0.04	21	0.29
65	Venige Klei (O)	CuCalculated	-	-	-	-	0.26	0.04	0.17	0.90	0.04	0.04	17	0.35
94	Venige Klei (N)	CuCalculated	-	-	-	-	0.26	0.04	0.17	0.90	0.02	0.02	24	0.25
123	Klei 14-16 (O)	CuCalculated	-	-	-	-	0.35	0.11	0.30	0.89	0.02	0.02	38	0.16
152	Klei 14-16 (N)	CuCalculated	-	-	-	-	0.35	0.11	0.30	0.89	0.02	0.02	34	0.18
181	Zand	CPhi	0.00	32.00	1.60	0.04	-	-	-	-	-	-	-	-
210	Oud Dijksmat.	CuCalculated	-	-	-	-	0.41	0.11	0.26	0.85	0.03	0.04	30	0.20
239	Nieuw Dijksmat.	CPhi	2.97	32.80	0.13	0.00	-	-	-	-	-	-	-	

Key	WL	GHW	polder	min_out	min_in	LL_out	LL_in	PL2	IntL
743	8.50	1.50	1.60	4.81	4.81	1365.49	1306.10	1.20	2.00

Case 7

WBI Key	Name	Model	C	Phi_mean	Phi_dev	Phi_cov(on tg)	S_mean	S_dev	S_cov	m_mean	m_dev	m_cov	POP	POP_cov
122	Veen (O)	CuCalculated	-	-	-	-	0.44	0.05	0.11	0.67	0.03	0.04	10	0.60
150	Veen (N)	CuCalculated	-	-	-	-	0.44	0.05	0.11	0.67	0.03	0.04	10	0.60
178	Kleiig Veen (O)	CuCalculated	-	-	-	-	0.41	0.07	0.16	0.85	0.02	0.02	17	0.35
206	Kleiig Veen (N)	CuCalculated	-	-	-	-	0.41	0.07	0.16	0.85	0.02	0.02	24	0.25
234	Venige Klei (O)	CuCalculated	-	-	-	-	0.26	0.04	0.17	0.90	0.04	0.04	17	0.35
262	Venige Klei (N)	CuCalculated	-	-	-	-	0.26	0.04	0.17	0.90	0.04	0.04	24	0.25
290	Zand	CPhi	0.00	32.00	1.60	0.04	-	-	-	-	-	-	-	-
318	Klei 14-16 (O)	CuCalculated	-	-	-	-	0.35	0.11	0.30	0.89	0.02	0.02	38	0.16
346	Klei 14-16 (N)	CuCalculated	-	-	-	-	0.35	0.11	0.30	0.89	0.02	0.02	34	0.18
374	Oud Dijksmat.	CuCalculated	-	-	-	-	0.41	0.11	0.26	0.85	0.03	0.04	30	0.20
402	Nieuw Dijksmat.	CPhi	2.97	32.80	0.13	0.00	-	-	-	-	-	-	-	-
430	Klei >16 (O)	CPhi	2.90	30.60	0.33	0.01	-	-	-	-	-	-	-	-
458	Klei >16 (N)	CPhi	2.90	30.60	0.33	0.01	-	-	-	-	-	-	-	-

Key	WL	GHW	polder	min_out	min_in	LL_out	LL_in	PL2	IntL
1164	1.50	1.23	-0.20	2.88	2.88	1378.67	1396.46	0.50	2.00

Case 8

WBI Key	Name	Model	C	Phi_mean	Phi_dev	Phi_cov(on tg)	S_mean	S_dev	S_cov	m_mean	m_dev	m_cov	POP	POP_cov
7	Veen (O)	CuCalculated	-	-	-	-	0.44	0.05	0.11	0.67	0.03	0.04	21	0.29
36	Veen (N)	CuCalculated	-	-	-	-	0.44	0.05	0.11	0.67	0.03	0.04	21	0.29
65	Kleiig Veen (O)	CuCalculated	-	-	-	-	0.41	0.07	0.16	0.85	0.02	0.02	17	0.35
94	Kleiig Veen (N)	CuCalculated	-	-	-	-	0.41	0.07	0.16	0.85	0.02	0.02	24	0.25
123	Venige Klei (O)	CuCalculated	-	-	-	-	0.26	0.05	0.17	0.90	0.04	0.04	17	0.35
152	Venige Klei (N)	CuCalculated	-	-	-	-	0.26	0.05	0.17	0.90	0.04	0.04	24	0.25
181	Klei 14-16 (O)	CuCalculated	-	-	-	-	0.35	0.11	0.30	0.89	0.02	0.02	38	0.16
210	Klei 14-16 (N)	CuCalculated	-	-	-	-	0.35	0.11	0.30	0.89	0.02	0.02	34	0.18
239	Klei +16 (O)	CPhi	2.90	30.60	0.33	0.01	-	-	-	-	-	-	-	-
268	Klei +16 (N)	CPhi	2.90	30.60	0.33	0.01	-	-	-	-	-	-	-	-
297	19-03 Z	CPhi	0.00	30.00	1.60	0.05	-	-	-	-	-	-	-	-
326	Oud Dijksmat.	CuCalculated	-	-	-	-	0.41	0.11	0.26	0.85	0.03	0.04	30	0.20
355	Nieuw Dijksmat.	CPhi	2.97	32.80	0.13	0.00	-	-	-	-	-	-	-	-
384	Antropogeen	CPhi	3.94	27.30	1.16	0.04	-	-	-	-	-	-	-	-
413	19-71 ZP	CPhi	0.00	30.00	1.60	0.05	-	-	-	-	-	-	-	-

Key	WL	GHW	polder	min_out	min_in	LL_out	LL_in	PL2	IntL
915	7.80	3.50	-0.50	1.09	1.09	1118.87	839.81	1.50	2.00

Case 9

WBI Key	Name	Model	C	Phi_mean	Phi_dev	Phi_cov(on tg)	S_mean	S_dev	S_cov	m_mean	m_dev	m_cov	POP	POP_cov
7	Zand	CPhi	0.00	30.00	1.60	0.05	-	-	-	-	-	-	-	-
36	Oud Dijksmat.	CuCalculated	-	-	-	-	0.41	0.11	0.26	0.85	0.03	0.04	30	0.20
65	Nieuw Dijksmat.	CPhi	2.97	32.80	0.13	0.00	-	-	-	-	-	-	-	-

94	KR-03 19-69 KS	CuCalculated	-	-	-	-	0.35	0.11	0.30	0.89	0.02	0.02	38	0.16
123	KR-04 19-24 KZ	CPhi	2.90	30.60	0.33	0.01	-	-	-	-	-	-	-	-
152	KR-05 19-69 KS	CuCalculated	-	-	-	-	0.35	0.11	0.30	0.89	0.02	0.02	38	0.16
181	KR-06 19-58 VK	CuCalculated	-	-	-	-	0.41	0.07	0.16	0.85	0.02	0.02	17	0.35
210	KR-07 19-24 KZ	CPhi	2.90	30.60	0.33	0.01	-	-	-	-	-	-	-	-
239	KR-08 19-61 VM	CuCalculated	-	-	-	-	0.44	0.05	0.11	0.67	0.03	0.04	21	0.29
268	AL-02 19-38 KH	CuCalculated	-	-	-	-	0.26	0.05	0.17	0.90	0.04	0.04	24	0.25
297	AL-03 19-69 KS	CuCalculated	-	-	-	-	0.35	0.11	0.30	0.89	0.02	0.02	34	0.18
326	AL-05 19-38 KH	CuCalculated	-	-	-	-	0.26	0.05	0.17	0.90	0.04	0.04	24	0.25
355	AL-06 19-58 VK	CuCalculated	-	-	-	-	0.41	0.07	0.16	0.85	0.02	0.02	24	0.25
384	AL-07 19-58 VK	CuCalculated	-	-	-	-	0.41	0.07	0.16	0.85	0.02	0.02	24	0.25

Key	WL	GHW	polder	min_out	min_in	LL_out	LL_in	PL2	IntL
911	6.84	1.80	-0.50	1.09	1.09	262.37	782.72	1.00	2.00

Case 11
WBI

Key	Name	Model	C	Phi_mean	Phi_dev	Phi_cov(on tg)	S_mean	S_dev	S_cov	m_mean	m_dev	m_cov	POP	POP_cov
32	Pleistoceen zand	CPhi	0.00	30.00	1.50	0.05	-	-	-	-	-	-	-	-
60	klei van Duinkerken naa	CuCalculated	-	-	-	-	0.15	0.02	0.13	0.92	0.03	0.03	31	0.19
88	Hollandveen naast	CuCalculated	-	-	-	-	0.36	0.03	0.08	0.89	0.03	0.03	19	0.32
116	klei van Duinkerken ond	CuCalculated	-	-	-	-	0.23	0.02	0.09	0.92	0.03	0.03	31	0.19
144	Holland veen onder	CuCalculated	-	-	-	-	0.36	0.36	1.00	0.89	0.03	0.03	19	0.32
172	antropogene klei	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.92	0.03	0.03	30	0.20

Key	WL	GHW	polder	min_out	min_in	LL_out	LL_in	PL2	IntL
607	1.10	-0.40	-0.58	1.30	1.30	42.00	64.00	-0.85	0.00

Case 5
WBI

Key	Name	Model	C	Phi_mean	Phi_dev	Phi_cov(on tg)	S_mean	S_dev	S_cov	m_mean	m_dev	m_cov	POP	POP_cov
7	klei_onder_veen_be	CuCalculated	-	-	-	-	0.28	0.02	0.07	0.90	0.02	0.02	17	0.35
36	veen_be	CuCalculated	-	-	-	-	0.42	0.04	0.10	0.91	0.02	0.02	19	0.32
65	veen_kleiig_be	CuCalculated	-	-	-	-	0.35	0.03	0.09	0.90	0.02	0.02	17	0.35
94	klei_boven_veen_be	CuCalculated	-	-	-	-	0.35	0.03	0.09	0.90	0.02	0.02	17	0.35
123	zand (pleistoceen)	CPhi	0.00	32.62	1.63	0.04	-	-	-	-	-	-	-	-
152	klei_onder_veen_al	CuCalculated	-	-	-	-	0.28	0.02	0.07	0.90	0.02	0.02	24	0.25
181	veen_al	CuCalculated	-	-	-	-	0.42	0.04	0.10	0.91	0.02	0.02	19	0.32
210	zand_tussenlaag	CPhi	0.00	29.79	1.50	0.05	-	-	-	-	-	-	-	-
239	veen_kleiig_al	CuCalculated	-	-	-	-	0.35	0.03	0.09	0.90	0.02	0.02	24	0.25
268	klei_boven_veen_al	CuCalculated	-	-	-	-	0.35	0.03	0.09	0.90	0.02	0.02	24	0.25
297	dijkmateriaal_kleiig	CPhi	0.00	35.77	3.60	0.09	-	-	-	-	-	-	-	-
326	klei_toplaag	CPhi	0.00	35.77	3.60	0.09	-	-	-	-	-	-	-	-

Key	WL	GHW	polder	min_out	min_in	LL_out	LL_in	PL2	IntL

1448	8.10	3.20	1.55	2.00	2.00	520.30	1430.50	1.30	0.00

Case 4
WBI

Key	Name	Model	C	Phi_mean	Phi_dev	Phi_cov(on tg)	S_mean	S_dev	S_cov	m_mean	m_dev	m_cov	POP	POP_cov
7	klei_onder_veen_be	CuCalculated	-	-	-	-	0.28	0.02	0.07	0.90	0.02	0.02	17	0.35
36	veen_kleiig_be_3	CuCalculated	-	-	-	-	0.35	0.03	0.09	0.90	0.02	0.02	17	0.35
65	klei_boven_veen_be_4	CuCalculated	-	-	-	-	0.35	0.03	0.09	0.90	0.02	0.02	17	0.35
94	veen_kleiig_be_2	CuCalculated	-	-	-	-	0.35	0.03	0.09	0.90	0.02	0.02	17	0.35
123	klei_boven_veen_be_3	CuCalculated	-	-	-	-	0.35	0.03	0.09	0.90	0.02	0.02	17	0.35
152	klei_boven_veen_be_2	CuCalculated	-	-	-	-	0.35	0.03	0.09	0.90	0.02	0.02	17	0.35
181	veen_kleiig_be_1	CuCalculated	-	-	-	-	0.35	0.03	0.09	0.90	0.02	0.02	17	0.35
210	klei_boven_veen_be_1	CuCalculated	-	-	-	-	0.35	0.03	0.09	0.90	0.02	0.02	17	0.35
239	veen_kleiig_be	CuCalculated	-	-	-	-	0.35	0.03	0.09	0.90	0.02	0.02	17	0.35
268	klei_boven_veen_be	CuCalculated	-	-	-	-	0.35	0.03	0.09	0.90	0.02	0.02	17	0.35
297	zand (pleistoceen)	CPhi	0.00	32.62	1.63	0.04	-	-	-	-	-	-	-	-
326	klei_onder_veen_al	CuCalculated	-	-	-	-	0.28	0.02	0.07	0.90	0.02	0.02	24	0.25
355	veen_kleiig_al_3	CuCalculated	-	-	-	-	0.35	0.03	0.09	0.90	0.02	0.02	24	0.25
384	klei_boven_veen_al_5	CuCalculated	-	-	-	-	0.35	0.03	0.09	0.90	0.02	0.02	24	0.25
413	veen_kleiig_al_2	CuCalculated	-	-	-	-	0.35	0.03	0.09	0.90	0.02	0.02	24	0.25
442	klei_boven_veen_al_4	CuCalculated	-	-	-	-	0.35	0.03	0.09	0.90	0.02	0.02	24	0.25
471	zand_tussenlaag	CPhi	0.00	29.79	1.49	0.05	-	-	-	-	-	-	-	-
500	klei_boven_veen_al_3	CuCalculated	-	-	-	-	0.35	0.03	0.09	0.90	0.02	0.02	24	0.25
529	klei_boven_veen_al_2	CuCalculated	-	-	-	-	0.35	0.03	0.09	0.90	0.02	0.02	24	0.25
558	veen_kleiig_al_1	CuCalculated	-	-	-	-	0.35	0.03	0.09	0.90	0.02	0.02	24	0.25
587	klei_boven_veen_al_1	CuCalculated	-	-	-	-	0.35	0.03	0.09	0.90	0.02	0.02	24	0.25
616	veen_kleiig_al	CuCalculated	-	-	-	-	0.35	0.03	0.09	0.90	0.02	0.02	24	0.25
645	klei_boven_veen_al	CuCalculated	-	-	-	-	0.35	0.03	0.09	0.90	0.02	0.02	24	0.25
674	dijkmateriaal_zand	CPhi	0.00	29.79	1.49	0.05	-	-	-	-	-	-	-	-
703	dijkmateriaal_kleiig	CPhi	0.00	35.77	3.58	0.09	-	-	-	-	-	-	-	-
732	klei_toplaag	CPhi	0.00	35.77	3.58	0.09	-	-	-	-	-	-	-	-
761	dijkmateriaal_kleiig_2	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.92	0.03	0.03	24	0.25

Key	WL	GHW	polder	min_out	min_in	LL_out	LL_in	PL2	IntL
1928	6.26	1.38	-0.17	1.10	1.10	465.00	1432.00	0.00	3.00

Case 2
WBI

Key	Name	Model	C	Phi_mean	Phi_dev	Phi_cov(on tg)	S_mean	S_dev	S_cov	m_mean	m_dev	m_cov	POP	POP_cov
152	dijkenklei nieuw	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.92	0.03	0.03	50	0.12
180	dijkenklei oud	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.92	0.03	0.03	50	0.12
208	antropogeenzand	CPhi	0.00	38.00	3.80	0.09	-	-	-	-	-	-	-	-
237	klei van Tiel (o)	CuCalculated	-	-	-	-	0.25	0.02	0.08	0.93	0.02	0.02	46	0.13
265	klei van Tiel (n)	CuCalculated	-	-	-	-	0.25	0.02	0.08	0.93	0.02	0.02	11	0.55
293	Hollandveen (o)	CuCalculated	-	-	-	-	0.36	0.03	0.08	0.89	0.03	0.03	40	0.15
321	Hollandveen (n)	CuCalculated	-	-	-	-	0.36	0.03	0.08	0.89	0.03	0.03	16	0.38

349	klei van Gorkum (o)	CuCalculated	-	-	-	-	0.29	0.06	0.21	0.93	0.04	0.04	46	0.13
377	klei van Gorkum (n)	CuCalculated	-	-	-	-	0.29	0.06	0.21	0.93	0.04	0.04	11	0.55
405	basisveen (o)	CuCalculated	-	-	-	-	0.36	0.03	0.08	0.89	0.03	0.03	40	0.15
433	basisveen (n)	CuCalculated	-	-	-	-	0.36	0.03	0.08	0.89	0.03	0.03	16	0.38
461	zand	CPhi	0.00	38.00	3.80	0.09	-	-	-	-	-	-	-	-

Key	WL	GHW	polder	min_out	min_in	LL_out	LL_in	PL2	IntL
982	3.89	1.08	-1.50	1.50	1.50	130.00	364.88	-0.50	1.00

Case 4_s1

WBI

Key	Name	Model	C	Phi_mean	Phi_dev	Phi_cov(on tg)	S_mean	S_dev	S_cov	m_mean	m_dev	m_cov	POP	POP_cov
7	H_Rk_k (1)	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	-	-
36	H_Rk_k	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	-	-
63	H_Vhv_v (1)	CuCalculated	-	-	-	-	0.38	0.02	0.05	0.90	0.03	0.03	21	0.29
92	H_Vhv_v	CuCalculated	-	-	-	-	0.38	0.02	0.05	0.90	0.03	0.03	21	0.29
119	H_Ro_z&k (1)	CPhi	0.00	35.00	2.00	0.05	-	-	-	-	-	-	-	-
148	H_Ro_z&k	CPhi	0.00	35.00	2.00	0.05	-	-	-	-	-	-	-	-
175	P_Rk_k&s (1)	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	22	0.27
204	P_Rk_k&s	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	22	0.27
231	P_Rg_zm	CPhi	0.00	35.00	2.00	0.05	-	-	-	-	-	-	-	-
260	klei - dijklichaam	CuCalculated	-	-	-	-	0.31	0.08	0.26	0.90	0.03	0.03	-	-
289	klei - dijklichaam (1)	CuCalculated	-	-	-	-	0.31	0.08	0.26	0.90	0.03	0.03	-	-

Key	WL	GHW	polder	min_out	min_in	LL_out	LL_in	PL2	IntL
1451	6.00	1.38	-0.17	1.10	1.10	465.00	1432.00	0.00	3.00

Case 4_s2

WBI

Key	Name	Model	C	Phi_mean	Phi_dev	Phi_cov(on tg)	S_mean	S_dev	S_cov	m_mean	m_dev	m_cov	POP	POP_cov
7	H_Rk_k (1)	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	-	-
36	H_Rk_k	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	-	-
63	H_Vhv_v (1)	CuCalculated	-	-	-	-	0.38	0.02	0.05	0.90	0.03	0.03	21	0.29
92	H_Vhv_v	CuCalculated	-	-	-	-	0.38	0.02	0.05	0.90	0.03	0.03	21	0.29
119	H_Ro_z&k (1)	CPhi	0.00	35.00	2.00	0.05	-	-	-	-	-	-	-	-
148	H_Ro_z&k	CPhi	0.00	35.00	2.00	0.05	-	-	-	-	-	-	-	-
175	P_Rk_k&s (1)	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	22	0.27
204	P_Rk_k&s	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	22	0.27
231	P_Rg_zm	CPhi	0.00	35.00	2.00	0.05	-	-	-	-	-	-	-	-
260	klei - dijklichaam	CuCalculated	-	-	-	-	0.31	0.08	0.26	0.90	0.03	0.03	-	-
289	klei - dijklichaam (1)	CuCalculated	-	-	-	-	0.31	0.08	0.26	0.90	0.03	0.03	-	-

Key	WL	GHW	polder	min_out	min_in	LL_out	LL_in	PL2	IntL
1409	3.00	1.38	-0.17	1.10	1.10	465.00	1432.00	0.00	3.00

Case 4_s3

WBI

Key	Name	Model	C	Phi_mean	Phi_dev	Phi_cov(on tg)	S_mean	S_dev	S_cov	m_mean	m_dev	m_cov	POP	POP_cov
7	H_Rk_k (1)	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	-	-
36	H_Rk_k	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	-	-
63	H_Vhv_v (1)	CuCalculated	-	-	-	-	0.38	0.02	0.05	0.90	0.03	0.03	21	0.29
92	H_Vhv_v	CuCalculated	-	-	-	-	0.38	0.02	0.05	0.90	0.03	0.03	21	0.29
119	H_Ro_z&k (1)	CPhi	0.00	35.00	2.00	0.05	-	-	-	-	-	-	-	-
148	H_Ro_z&k	CPhi	0.00	35.00	2.00	0.05	-	-	-	-	-	-	-	-
175	H_Rg_zf	CPhi	0.00	35.00	2.00	0.05	-	-	-	-	-	-	-	-
204	klei - dijklichaam	CuCalculated	-	-	-	-	0.31	0.08	0.26	0.90	0.03	0.03	-	-
233	klei - dijklichaam (1)	CuCalculated	-	-	-	-	0.31	0.08	0.26	0.90	0.03	0.03	-	-

Key	WL	GHW	polder	min_out	min_in	LL_out	LL_in	PL2	IntL
1313	6.00	1.38	-0.17	1.10	1.10	175.00	550.00	0.00	0.00

Case 1

WBI

Key	Name	Model	C	Phi_mean	Phi_dev	Phi_cov(on tg)	S_mean	S_dev	S_cov	m_mean	m_dev	m_cov	POP	POP_cov
7	zand ondergrond	CPhi	0.00	39.14	1.96	0.04	-	-	-	-	-	-	-	-
36	klei antropogeen onder	CuCalculated	-	-	-	-	0.31	0.08	0.26	0.90	0.03	0.03	30	0.20
65	klei antropogeen	CuCalculated	-	-	-	-	0.31	0.08	0.26	0.90	0.03	0.03	30	0.20
92	klei Holoceen onder	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	38	0.16
121	klei Holoceen	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	34	0.18
150	klei dijk	CPhi	0.00	41.67	4.17	0.08	-	-	-	-	-	-	-	-
179	dijk, zand, oud	CPhi	0.00	36.53	1.83	0.04	-	-	-	-	-	-	-	-
208	dijk, zand, nieuw	CPhi	0.00	36.53	1.83	0.04	-	-	-	-	-	-	-	-
237	bekleding	CuCalculated	-	-	-	-	0.31	0.08	0.26	0.90	0.03	0.03	30	0.20

Key	WL	GHW	polder	min_out	min_in	LL_out	LL_in	PL2	IntL
587	16.25	12.70	12.60	12.60	12.60	258.07	724.33	11.00	0.00

Case 3

WBI

Key	Name	Model	C	Phi_mean	Phi_dev	Phi_cov(on tg)	S_mean	S_dev	S_cov	m_mean	m_dev	m_cov	POP	POP_cov
272	4 - veen (O)	CuCalculated	-	-	-	-	0.37	0.04	0.11	0.89	0.03	0.03	N.A.	N.A.
300	4 - veen (N)	CuCalculated	-	-	-	-	0.35	0.03	0.09	0.89	0.03	0.03	N.A.	N.A.
328	9 - veen (O)	CuCalculated	-	-	-	-	0.37	0.04	0.11	0.89	0.03	0.03	N.A.	N.A.
356	12 - klei (N)	CuCalculated	-	-	-	-	0.25	0.08	0.32	0.93	0.02	0.02	N.A.	N.A.
384	15 - klei (komklei) (O)	CuCalculated	-	-	-	-	0.31	0.04	0.13	0.93	0.02	0.02	N.A.	N.A.
412	16 - klei (O)	CuCalculated	-	-	-	-	0.31	0.04	0.13	0.93	0.02	0.02	N.A.	N.A.
440	16 - klei (N)	CuCalculated	-	-	-	-	0.23	0.02	0.09	0.93	0.02	0.02	N.A.	N.A.
468	31 - klei	CuCalculated	-	-	-	-	0.30	0.06	0.20	0.92	0.03	0.03	N.A.	N.A.
496	32 - zand	CPhi	0.00	38.00	6.00	0.13	-	-	-	-	-	-	N.A.	N.A.
524	OA	CPhi	0.00	32.00	4.00	0.11	-	-	-	-	-	-	N.A.	N.A.
552	OB	CuCalculated	-	-	-	-	0.33	0.03	0.09	0.92	0.03	0.03	N.A.	N.A.

Key	WL	GHW	polder	min_out	min_in	LL_out	LL_in	PL2	IntL
1012	4.03	1.08	-1.50	1.16	1.16	30.00	1000.46	-0.50	3.00

Case 15
WBI

Key	Name	Model	C	Phi_mean	Phi_dev	Phi_cov(on tg)	S_mean	S_dev	S_cov	m_mean	m_dev	m_cov	POP	POP_cov
71	KLEI, antr	CuCalculated	-	-	-	-	0.38	0.22	0.58	0.88	0.09	0.10	33	0.18
99	KLEI, siltig Kr	CuCalculated	-	-	-	-	0.26	0.04	0.15	0.86	0.07	0.08	22	0.27
127	Veen, kleiig Kr	CuCalculated	-	-	-	-	0.41	0.04	0.10	0.92	0.04	0.04	17	0.35
155	Veen, Kr	CuCalculated	-	-	-	-	0.53	0.10	0.19	0.89	0.08	0.09	17	0.35
183	KLEI, siltig Kr2	CuCalculated	-	-	-	-	0.26	0.04	0.15	0.86	0.07	0.08	22	0.27
211	Zand, Calais	CPhi	0.00	35.00	1.80	0.04	-	-	-	-	-	-	-	-
239	KLEI, siltig Kr3	CuCalculated	-	-	-	-	0.26	0.04	0.15	0.86	0.07	0.08	22	0.27
267	Veen, Kr 2	CuCalculated	-	-	-	-	0.53	0.10	0.19	0.89	0.08	0.09	17	0.35
295	KLEI, siltig BiT 2	CuCalculated	-	-	-	-	0.26	0.22	0.85	0.86	0.09	0.10	33	0.18
323	KLEI, antr BiT	CuCalculated	-	-	-	-	0.38	0.22	0.58	0.88	0.09	0.10	33	0.18
350	Veen, BiT 1	CuCalculated	-	-	-	-	0.53	0.10	0.19	0.89	0.08	0.09	17	0.35
378	Veen, BiT 2	CuCalculated	-	-	-	-	0.53	0.10	0.19	0.89	0.08	0.09	17	0.35
406	Veen, BiT 3	CuCalculated	-	-	-	-	0.53	0.10	0.19	0.89	0.08	0.09	17	0.35
434	KLEI, siltig BiT	CuCalculated	-	-	-	-	0.26	0.04	0.15	0.86	0.07	0.08	22	0.27
462	KLEI, zandig KrBit	CuCalculated	-	-	-	-	0.26	0.04	0.15	0.86	0.07	0.08	22	0.27
490	Klei hum Toplaag A	CuCalculated	-	-	-	-	0.28	0.09	0.32	0.90	0.05	0.06	29	0.21
518	Veen, A	CuCalculated	-	-	-	-	0.53	0.10	0.19	0.89	0.08	0.09	17	0.35
546	KLEI, humeus A	CuCalculated	-	-	-	-	0.28	0.09	0.32	0.90	0.05	0.06	29	0.21
574	Veen, A2	CuCalculated	-	-	-	-	0.53	0.10	0.19	0.89	0.08	0.09	17	0.35
602	KLEI, siltig A	CuCalculated	-	-	-	-	0.26	0.04	0.15	0.86	0.07	0.08	22	0.27
630	KLEI, zandig A	CuCalculated	-	-	-	-	0.26	0.04	0.15	0.86	0.07	0.08	22	0.27
658	KLEI, zandig A2	CuCalculated	-	-	-	-	0.26	0.04	0.15	0.86	0.07	0.08	22	0.27
686	KLEI, siltig A2	CuCalculated	-	-	-	-	0.26	0.04	0.15	0.86	0.07	0.08	22	0.27
714	Veen A3	CuCalculated	-	-	-	-	0.53	0.10	0.19	0.89	0.08	0.09	17	0.35
742	WL_Zand, Pleistoceen	CPhi	0.00	35.00	1.80	0.04	-	-	-	-	-	-	-	-
770	Zand, antropogeen	CPhi	0.00	35.00	1.80	0.04	-	-	-	-	-	-	-	-
798	KLEI, humeus Kr	CuCalculated	-	-	-	-	0.28	0.09	0.32	0.90	0.05	0.06	29	0.21
826	voorland	CPhi	0.00	35.00	1.80	0.04	-	-	-	-	-	-	-	-
854	KLEI, humeus BiT	CuCalculated	-	-	-	-	0.28	0.09	0.32	0.90	0.05	0.06	29	0.21

Key	WL	GHW	polder	min_out	min_in	LL_out	LL_in	PL2	IntL
1605	1.10	-0.40	-1.38	1.18	1.18	3000.00	2000.00	-1.84	2.30

Case 12
WBI

Key	Name	Model	C	Phi_mean	Phi_dev	Phi_cov(on tg)	S_mean	S_dev	S_cov	m_mean	m_dev	m_cov	POP	POP_cov
7	dijksmateriaal_klei	CuCalculated	-	-	-	-	0.31	0.08	0.26	0.90	0.03	0.03	35	0.17
36	klei, humeus, N	CuCalculated	-	-	-	-	0.29	0.06	0.21	0.90	0.03	0.03	25	0.24
65	klei, humeus, O	CuCalculated	-	-	-	-	0.29	0.06	0.21	0.90	0.03	0.03	35	0.17
92	Zand cunet	CPhi	0.00	35.00	2.00	0.05	-	-	-	-	-	-	-	-
121	Diep zand	CPhi	0.00	35.00	2.00	0.05	-	-	-	-	-	-	-	-
150	Keileem	CPhi	0.00	35.00	2.00	0.05	-	-	-	-	-	-	-	-
179	klei	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	25	0.24

Key	WL	GHW	polder	min_out	min_in	LL_out	LL_in	PL2	IntL
534	-0.40	-0.40	-4.95	-1.10	-1.10	112.00	433.00	-5.00	0.00

Case 17

WBI

Key	Name	Model	C	Phi_mean	Phi_dev	Phi_cov(on tg)	S_mean	S_dev	S_cov	m_mean	m_dev	m_cov	POP	POP_cov
7	Dense Sand (DZ)	CPhi	0	32	1.6	0.04	-	-	-	-	-	-	-	-
36	Peat (V)_N	CuCalculated	-	-	-	-	0.34	0.025	0.07	0.9	0.027	0.03	21	0.29
65	Peat (V)	CuCalculated	-	-	-	-	0.34	0.025	0.07	0.9	0.027	0.03	21	0.29
92	Soft Clay (OZK)_N	CuCalculated	-	-	-	-	0.34	0.025	0.07	0.9	0.027	0.03	24	0.25
121	Soft Clay (OZK)	CuCalculated	-	-	-	-	0.34	0.025	0.07	0.9	0.027	0.03	17	0.35
148	Loose Sand (Z)	CPhi	0	32	1.6	0.04	-	-	-	-	-	-	-	-
177	Medium Clay (BK)	CuCalculated	-	-	-	-	0.3	0.016	0.05	0.9	0.027	0.03	31	0.19
206	Oude Kleidijk MedClay	CuCalculated	-	-	-	-	0.31	0.08	0.26	0.9	0.027	0.03	30	0.20

Key	WL	GHW	polder	min_out	min_in	LL_out	LL_in	PL2	IntL
639	1.26	1.26	0.2	1.5	1.5	434.7	1464	-0.5	1

F.2.2 Soil properties 2015 cases

Case 18

WBI

Key	Name	Model	C	Phi_mean	Phi_dev	Phi_cov(on tg)	S_mean	S_dev	S_cov	m_mean	m_dev	m_cov	POP
7	WL_zandondergrond (2)	CPhi	0.00	38.02	2.47	0.06	-	-	-	-	-	-	-
36	Klei siltig 3/4 - h1	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	N.A.
65	Klei siltig 3	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	N.A.
94	Klei siltig 2 en -3, h1enh2	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	N.A.
123	Klei siltig -dijklichaam	CuCalculated	-	-	-	-	0.31	0.08	0.26	0.90	0.03	0.03	N.A.

Key	WL	GHW	polder	min_out	min_in	LL_out	LL_in	PL2	IntL
391	10.00	7.70	10.30	11.19	11.19	272.00	962.00	8.00	0.00

Case 19

WBI

Key	Name	Model	C	Phi_mean	Phi_dev	Phi_cov(on tg)	S_mean	S_dev	S_cov	m_mean	m_dev	m_cov	POP
7	WL_zandondergrond	CPhi	0.00	34.58	2.37	0.06	-	-	-	-	-	-	-
36	achter dijk – Klei siltig 2	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	N.A.
65	voor dijk - Klei siltig 2	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	N.A.
94	onder dijk - Klei siltig 2	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	N.A.
123	dijklichaam	CuCalculated	-	-	-	-	0.31	0.08	0.26	0.90	0.03	0.03	N.A.
152	dijksmateriaal_klei	CPhi	1.00	35.00	1.75	0.04	-	-	-	-	-	-	-

Key	WL	GHW	polder	min_out	min_in	LL_out	LL_in	PL2	IntL
485	8.00	6.00	6.00	9.00	9.00	112.92	1184.32	5.70	0.00

Case 20

WBI

Key	Name	Model	C	Phi_mean	Phi_dev	Phi_cov(on tg)	S_mean	S_dev	S_cov	m_mean	m_dev	m_cov	POP
7	WL_zandondergrond	CPhi	0.00	34.58	2.37	0.06	-	-	-	-	-	-	-
36	klei - achterland – Klei zandig1	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	N.A.
65	klei - achterland – Klei siltig 2h2	CuCalculated	-	-	-	-	0.29	0.06	0.21	0.90	0.03	0.03	N.A.
94	klei - bermmateriaal	CuCalculated	-	-	-	-	0.31	0.08	0.26	0.90	0.03	0.03	N.A.
123	klei - voorland - Klei siltig 3	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	N.A.
152	klei - onder dijk - Klei siltig 2h2	CuCalculated	-	-	-	-	0.29	0.06	0.21	0.90	0.03	0.03	N.A.
181	klei - onder dijk - Klei siltig 3	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	N.A.
210	klei - dijkmateriaal	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	N.A.
239	dijksmateriaal_klei	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	N.A.

Key	WL	GHW	polder	min_out	min_in	LL_out	LL_in	PL2	IntL
639	12.00	4.50	5.00	8.37	8.37	231.82	901.01	5.00	0.00

Case 21

WBI

Key	Name	Model	C	Phi_mean	Phi_dev	Phi_cov(on tg)	S_mean	S_dev	S_cov	m_mean	m_dev	m_cov	POP
7	P_Rg_zg: grof rivierzand	CPhi	0.10	30.00	5.00	0.15	-	-	-	-	-	-	-

36	H_Ro_k&z: klei en zandlagen onder	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	N.A.
65	H_Ro_k&z: klei en zandlagen naast	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	N.A.
92	H_Rk_k&v: komafz klei en veen	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	N.A.
121	H_Vbv_v: Veen	CuCalculated	-	-	-	-	0.38	0.02	0.05	0.90	0.03	0.03	N.A.
148	P_Rk_k&s: klei, siltig onder	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	N.A.
175	P_Rk_k : Klei, siltig &s naast	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	N.A.
202	klei - dijklichaam	CuCalculated	-	-	-	-	0.31	0.08	0.26	0.90	0.03	0.03	N.A.

Key	WL	GHW	polder	min_out	min_in	LL_out	LL_in	PL2	IntL
2142	6.00	1.23	1.19	3.02	3.02	465.14	1432.36	1.23	0.00

Case 24

WBI

Key	Name	Model	C	Phi_mean	Phi_dev	Phi_cov(on tg)	S_mean	S_dev	S_cov	m_mean	m_dev	m_cov	POP
7	WL_4 zand (1)	CPhi	0.00	35.24	2.40	0.06	-	-	-	-	-	-	-
36	WL_zand los	CPhi	0.00	35.24	2.40	0.06	-	-	-	-	-	-	-
65	2b klei zandig (1)	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	N.A.
94	1 klei dijk (1)	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	N.A.
123	2b bekleding	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	N.A.
152	zand los	CPhi	0.00	35.24	2.40	0.06	-	-	-	-	-	-	-

Key	WL	GHW	polder	min_out	min_in	LL_out	LL_in	PL2	IntL
473	10.00	5.37	8.20	9.50	9.50	1084.00	3440.00	7.00	0.00

Case 23

WBI

Key	Name	Model	C	Phi_mean	Phi_dev	Phi_cov(on tg)	S_mean	S_dev	S_cov	m_mean	m_dev	m_cov	POP
158	zand	CPhi	0.00	35.00	5.25	0.13	-	-	-	-	-	-	-
186	kreftenheye	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	N.A.
214	basisveen	CuCalculated	-	-	-	-	0.29	0.03	0.10	0.90	0.03	0.03	N.A.
242	gorkum zwaar	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	N.A.
270	hollandveen diep	CuCalculated	-	-	-	-	0.38	0.02	0.05	0.90	0.03	0.03	N.A.
298	gorkum licht 13,6	CuCalculated	-	-	-	-	0.29	0.06	0.21	0.90	0.03	0.03	N.A.
326	gorkum licht 14,2	CuCalculated	-	-	-	-	0.29	0.06	0.21	0.90	0.03	0.03	N.A.
354	hollandveen onder	CuCalculated	-	-	-	-	0.29	0.03	0.10	0.90	0.03	0.03	N.A.
382	hollandveen naast	CuCalculated	-	-	-	-	0.38	0.02	0.05	0.90	0.03	0.03	N.A.
410	hollandveen 11,4	CuCalculated	-	-	-	-	0.29	0.03	0.10	0.90	0.03	0.03	N.A.
438	tiel onder	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	N.A.
466	tiel naast	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	N.A.
494	dijksmateriaal oud	CuCalculated	-	-	-	-	0.31	0.08	0.26	0.90	0.03	0.03	N.A.
522	dijksmateriaal nieuw	CuCalculated	-	-	-	-	0.31	0.08	0.26	0.90	0.03	0.03	N.A.

Key	WL	GHW	polder	min_out	min_in	LL_out	LL_in	PL2	IntL
1473	3.65	0.50	-2.10	1.90	1.90	760.00	1140.00	0.50	3.00

Case 22

WBI Key	Name	Model	C	Phi_mean	Phi_dev	Phi_cov(on tg)	S_mean	S_dev	S_cov	m_mean	m_dev	m_cov	POP
7	WL_4 zand	CPhi	0.00	35.24	2.40	0.06	-	-	-	-	-	-	-
36	2a klei gerijpt onder	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	N.A.
65	2a klei gerijpt naast	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	N.A.
92	2d klei onger./hum. (1)	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	N.A.
121	WL_4a zand los	CPhi	0.00	35.24	2.40	0.06	-	-	-	-	-	-	-
150	1 klei dijk a	CuCalculated	-	-	-	-	0.31	0.08	0.26	0.90	0.03	0.03	N.A.
179	1 klei dijk b	CuCalculated	-	-	-	-	0.31	0.08	0.26	0.90	0.03	0.03	N.A.
206	2b klei zandig	CuCalculated	-	-	-	-	0.31	0.08	0.26	0.90	0.03	0.03	N.A.
235	dijksmateriaal_klei	CPhi	1.00	35.00	1.75	0.04	-	-	-	-	-	-	-

Key	WL	GHW	polder	min_out	min_in	LL_out	LL_in	PL2	IntL
655	6.00	2.05	2.00	4.50	4.50	298.60	1509.52	2.00	0.00

Case 25

WBI Key	Name	Model	C	Phi_mean	Phi_dev	Phi_cov(on tg)	S_mean	S_dev	S_cov	m_mean	m_dev	m_cov	POP
7	WL_ZAND_pl	CPhi	0.00	42.20	2.53	0.05	-	-	-	-	-	-	-
36	VEEN_bas	CuCalculated	-	-	-	-	0.31	0.01	0.03	0.90	0.03	0.03	N.A.
65	KLEI_cal	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	N.A.
94	KLEI_dyk	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	N.A.
123	ZAND_dyk	CPhi	0.00	36.79	2.44	0.06	-	-	-	-	-	-	-
152	KLEI_bkl	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	N.A.
523	KEILM_pl	CuCalculated	-	-	-	-	0.45	0.03	0.07	0.90	0.03	0.03	N.A.

Key	WL	GHW	polder	min_out	min_in	LL_out	LL_in	PL2	IntL
622	0.98	-0.40	-2.04	0.77	0.77	1000.00	1000.00	-3.00	0.70

Case 26

WBI Key	Name	Model	C	Phi_mean	Phi_dev	Phi_cov(on tg)	S_mean	S_dev	S_cov	m_mean	m_dev	m_cov	POP
7	WL_pleistoceen zand (1)	CPhi	0.00	36.77	2.44	0.06	-	-	-	-	-	-	-
36	al -p - kreftenheye O	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	N.A.
65	al -p - kreftenheye N	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	N.A.
92	Hollandveen (2) O	CuCalculated	-	-	-	-	0.31	0.01	0.03	0.90	0.03	0.03	N.A.
121	Hollandveen (2) N	CuCalculated	-	-	-	-	0.31	0.01	0.03	0.90	0.03	0.03	N.A.
148	Gorkum Licht (1) O	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	N.A.
177	Gorkum Licht (1) N	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	N.A.
204	Zand van Duinkerke O	CPhi	2.41	25.27	1.95	0.07	-	-	-	-	-	-	-
233	Zand van Duinkerke N	CPhi	2.41	25.27	1.95	0.07	-	-	-	-	-	-	-
260	OB (1)	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	N.A.
289	Klei van Duinkerke O	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	N.A.
318	Klei van Duinkerke N	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	N.A.
345	OA (1)	CPhi	0.00	36.77	2.44	0.06	-	-	-	-	-	-	-
374	dijksmateriaal_klei	CPhi	0.00	35.00	5.25	0.13	-	-	-	-	-	-	-

Key	WL	GHW	polder	min_out	min_in	LL_out	LL_in	PL2	IntL
1044	2.99	NaN	-1.85	1.25	1.25	857.59	2571.25	-0.50	1.00

Case 27

WBI

Key	Name	Model	C	Phi_mean	Phi_dev	Phi_cov(on tg)	S_mean	S_dev	S_cov	m_mean	m_dev	m_cov	POP
7	WL_Pleistoceen of oudere	CPhi	0.00	34.26	2.36	0.06	-	-	-	-	-	-	-
36	Calais klei	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	N.A.
65	Hollandveen	CuCalculated	-	-	-	-	0.31	0.01	0.03	0.90	0.03	0.03	N.A.
94	Duinkerke klei	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	N.A.
123	kleilaag v. dijk	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	N.A.
152	Klei, z. Duinkerk	CuCalculated	-	-	-	-	0.25	0.03	0.12	0.90	0.03	0.03	N.A.
181	Dijkkern uit zand	CPhi	0.00	38.02	2.47	0.06	-	-	-	-	-	-	-
210	Jong zeezand	CPhi	0.00	29.89	2.19	0.07	-	-	-	-	-	-	-
677	dijksmateriaal_klei	CuCalculated	-	-	-	-	0.22	0.02	0.09	0.90	0.00	0.00	N.A.

Key	WL	GHW	polder	min_out	min_in	LL_out	LL_in	PL2	IntL
807	6.30	2.75	0.25	3.00	3.00	104.00	301.00	0.50	1.10

F.2.3 Yield stress values 2016 cases

This section presents the yield stress values per layer per case. The key numbers are shown with the name of the yield stress point (see Appendix L), as well as the mean value of the yield stress in each point ('sigmaY') in kN/m2.

Case 13

Key	Name	sigmaY
211	PreConsolidationStress	67.8
213	PreConsolidationStress (1)	86.6
215	PreConsolidationStress (2)	78.6

Case 16

Key	Name	sigmaY
259	PreConsolidationStress	230.6
261	PreConsolidationStress (1)	181.0
263	PreConsolidationStress (2)	79.7
265	PreConsolidationStress (3)	37.1

Case 14

Key	Name	sigmaY
1034	-	87.8
1036	-	51.4
1038	-	37.4
1040	-	29.9
1042	-	24.2
1044	-	95.7
1046	-	75.3
1048	-	65.4
1050	-	76.0
1052	-	25.7
1054	-	180.8
1056	-	29.2
1058	-	156.9
1060	-	159.7
1062	-	167.7
1064	-	197.1
1066	-	53.2

Case 10

Key	Name	sigmaY
514	PreConsolidationStress	79.0
516	PreConsolidationStress (1)	40.0
518	PreConsolidationStress (2)	85.0
520	PreConsolidationStress (3)	109.0
522	PreConsolidationStress (4)	104.0

Case 6

Key	Name	sigmaY
466	PreConsolidationStress (8)	111.0
468	PreConsolidationStress (10)	63.6
470	PreConsolidationStress (12)	175.2
472	PreConsolidationStress (13)	160.1
474	PreConsolidationStress (14)	153.3
476	PreConsolidationStress (15)	106.9
478	PreConsolidationStress (16)	48.6

Case 7

Key	Name	sigmaY
796	PreConsolidationStress	113.0
798	PreConsolidationStress (5)	84.1
800	PreConsolidationStress (8)	73.9
802	PreConsolidationStress (11)	82.3
804	PreConsolidationStress (14)	155.4
806	PreConsolidationStress (15)	143.4
808	PreConsolidationStress (16)	159.8
810	PreConsolidationStress (18)	99.9

Case 8

Key	Name	sigmaY
716	PreConsolidationStress	184.1
718	PreConsolidationStress (1)	84.4
720	PreConsolidationStress (2)	88.1
722	PreConsolidationStress (3)	146.8
724	PreConsolidationStress (4)	155.7
726	PreConsolidationStress (5)	121.4
728	PreConsolidationStress (6)	102.6

Case 9

Key	Name	sigmaY
667	PreConsolidationStress	170.4
669	PreConsolidationStress (1)	81.8
671	PreConsolidationStress (2)	80.4
673	PreConsolidationStress (3)	78.2
675	PreConsolidationStress (4)	68.6
677	PreConsolidationStress (5)	145.0
679	PreConsolidationStress (6)	166.6
681	PreConsolidationStress (7)	47.4
683	PreConsolidationStress (8)	130.0
685	PreConsolidationStress (9)	35.7
687	PreConsolidationStress (10)	88.7

Case 11

Key	Name	sigmaY
386	PreConsolidationStress	20.3
388	PreConsolidationStress (1)	57.4
390	PreConsolidationStress (2)	41.7
392	PreConsolidationStress (3)	42.3
394	PreConsolidationStress (4)	30.0

Case 5

Key	Name	sigmaY
961	PreConsolidationStress	78.0
963	PreConsolidationStress (1)	70.1
965	PreConsolidationStress (2)	71.7
967	PreConsolidationStress (3)	46.9
969	PreConsolidationStress (4)	122.3
971	PreConsolidationStress (5)	141.7
973	PreConsolidationStress (6)	150.4
975	PreConsolidationStress (7)	150.1

Case 4

Key	Name	sigmaY
1444	PreConsolidationStress	39.4
1446	PreConsolidationStress (1)	84.4

Case 2

Key	Name	sigmaY
766	PreConsolidationStress (1)	81.0
768	PreConsolidationStress (2)	82.0
770	PreConsolidationStress (3)	89.0
772	PreConsolidationStress (4)	102.0
774	PreConsolidationStress (5)	57.0
776	PreConsolidationStress (6)	83.0
778	PreConsolidationStress (7)	116.0
780	PreConsolidationStress (8)	146.0
782	PreConsolidationStress (9)	12.0
784	PreConsolidationStress (10)	21.0
786	PreConsolidationStress (11)	37.0
788	PreConsolidationStress (12)	11.0
790	PreConsolidationStress (13)	14.0

Case 4_s1

Key	Name	sigmaY
872	PreConsolidationStress	134.3
874	PreConsolidationStress (3)	47.1
876	PreConsolidationStress (1)	132.3
878	PreConsolidationStress (2)	25.8

Case 4_s2

Key	Name	sigmaY
852	PreConsolidationStress	134.3
854	PreConsolidationStress (1)	132.3
856	PreConsolidationStress (2)	25.8
858	PreConsolidationStress (3)	47.1

Case 4_s3

Key	Name	sigmaY
754	PreConsolidationStress	134.3
756	PreConsolidationStress (1)	132.3
758	PreConsolidationStress (2)	25.8
760	PreConsolidationStress (3)	47.1

Case 1

Key	Name	sigmaY
396	-	67.4
398	-	38.6
400	-	96.8
402	-	36.2
404	-	160.1

Case 3 Streefkerk_UpliftVan.dsx

Key	Name	sigmaY
758	-	60.0
760	-	50.7
762	-	42.5
764	-	173.2
766	-	187.4
768	-	188.8
770	-	178.4
772	-	167.9
774	-	148.0
776	-	145.9
778	-	140.9

Case 15

Key	Name	sigmaY
1240	-	48.5
1242	-	52.4
1244	-	43.1
1246	-	30.4
1248	-	22.7
1250	-	33.9
1252	-	19.7
1254	-	29.5
1256	-	130.5
1258	-	93.2
1260	-	91.2
1262	-	64.4
1264	-	71.1
1266	-	123.8
1268	-	110.6
1270	-	96.1
1272	-	81.3
1274	PreConsolidationStress	67.1
1276	-	33.0
1278	-	86.3

Case 12

Key	Name	sigmaY
366	PreConsolidationStress	214.1
368	PreConsolidationStress (1)	32.2
370	PreConsolidationStress (2)	51.4

Case 17

Key	Name	sigmaY
453	PreConsolidationStress	238.83
455	PreConsolidationStress (1)	204.39
457	PreConsolidationStress (2)	166.05
459	PreConsolidationStress (3)	149.21

461	-	77.91639
463	PreConsolidationStress (4)	174.51
465	-	31
467	-	37.81062
469	-	116.5161
471	-	90.63538
473	-	58.25706
475	-	57.54195

F.2.4 Yield stress values 2015 cases

This section presents the yield stress values per layer per case. The key numbers are shown with the name of the yield stress point (see Appendix L), as well as the mean value of the yield stress in each point (‘sigmaY’) in kN/m2.

Case 18

Key	Name	sigmaY
234	PreConsolidationStress	31.0
236	PreConsolidationStress (1)	70.0
238	PreConsolidationStress (2)	83.0
240	PreConsolidationStress (3)	94.0

Case 19

Key	Name	sigmaY
275	PreConsolidationStress	55.9
277	PreConsolidationStress (1)	144.7
279	PreConsolidationStress (3)	134.8

Case 20

Key	Name	sigmaY
382	PreConsolidationStress (3)	23.0
384	PreConsolidationStress (5)	30.0
386	PreConsolidationStress	62.0
388	PreConsolidationStress (1)	48.0
390	PreConsolidationStress (2)	76.0
392	PreConsolidationStress (6)	155.0
394	PreConsolidationStress (4)	56.0

Case 21

Key	Name	sigmaY
1200	PreConsolidationStress	30.0
1202	PreConsolidationStress (1)	30.0
1204	PreConsolidationStress (2)	109.0
1206	PreConsolidationStress (4)	122.0

Case 24

Key	Name	sigmaY
311	PreConsolidationStress	35.0
313	PreConsolidationStress (1)	45.0
315	PreConsolidationStress (2)	90.0
317	PreConsolidationStress (3)	65.0

Case 23

Key	Name	sigmaY
807	PreConsolidationStress	246.0
809	PreConsolidationStress (1)	375.0
811	PreConsolidationStress (2)	265.0
813	PreConsolidationStress (3)	121.0
815	PreConsolidationStress (4)	153.0
817	PreConsolidationStress (5)	159.0
819	PreConsolidationStress (6)	145.0
821	PreConsolidationStress (7)	163.0
823	PreConsolidationStress (8)	167.0
825	PreConsolidationStress (9)	180.0
827	PreConsolidationStress (10)	157.0
829	PreConsolidationStress (11)	66.0
831	PreConsolidationStress (12)	20.0
833	PreConsolidationStress (13)	21.0
835	PreConsolidationStress (14)	33.0
837	PreConsolidationStress (19)	33.0
839	PreConsolidationStress (15)	44.0
841	PreConsolidationStress (16)	31.0
843	PreConsolidationStress (17)	54.0
845	PreConsolidationStress (18)	57.0

Case 22

Key	Name	sigmaY
384	PreConsolidationStress	30.0

386	PreConsolidationStress (2)	120.0
388	PreConsolidationStress (3)	120.0

Case 25

Key	Name	sigmaY
317	PreConsolidationStress (1)	20.0
319	PreConsolidationStress (2)	36.0
321	PreConsolidationStress (3)	48.0
323	PreConsolidationStress (4)	15.0
325	PreConsolidationStress (8)	150.0
327	PreConsolidationStress (9)	163.0
329	PreConsolidationStress (10)	171.0

Case 26

Key	Name	sigmaY
745	PreConsolidationStress	77.9
747	PreConsolidationStress (1)	85.5
749	PreConsolidationStress (2)	72.3
751	PreConsolidationStress (3)	56.1
753	PreConsolidationStress (4)	55.0
755	PreConsolidationStress (5)	52.2
757	PreConsolidationStress (6)	51.3
759	PreConsolidationStress (7)	98.8
761	PreConsolidationStress (8)	48.8
763	PreConsolidationStress (9)	27.3
765	PreConsolidationStress (10)	27.0
767	PreConsolidationStress (11)	106.5
769	PreConsolidationStress (12)	70.5
771	PreConsolidationStress (13)	31.5
773	PreConsolidationStress (18)	26.5

Case 27

Key	Name	sigmaY
490	PreConsolidationStress (1)	43.0
492	PreConsolidationStress (2)	35.0
494	PreConsolidationStress (3)	30.0
496	PreConsolidationStress (4)	23.0
498	PreConsolidationStress (5)	101.0
500	PreConsolidationStress (6)	92.0
502	PreConsolidationStress (7)	68.0
504	PreConsolidationStress (8)	79.0
506	PreConsolidationStress (9)	213.0
508	PreConsolidationStress (10)	204.0
510	PreConsolidationStress (11)	196.0
512	PreConsolidationStress	225.0

G Overview of default soil properties

When regional or local data were absent, values for the undrained shear strength ratio (S) and strength exponent parameter (m), have been taken from an earlier version the WBI-2017 schematisation guideline for inner slope stability (Van Deen and Van Duinen, 2016). This appendix presents the recommendations present in that guideline. The values used for the pre-overburden pressure (POP) have been taken from Jongejan et al. (2014) as used in Van Deen and Van Duinen (2016).

Table G.1 Typical values for the normal consolidated undrained shear strength ratio S for Dutch soils. The values for 'loss' and 'keileem' will be added later.

Soil type (Dutch)	**Typical values for S [-] 1)**	**Mean value S [-]**	**Standard deviation S [-] 2)**	**Coefficient of variation S [-] 2)**
Veen mineraalarm	0,28 – 0,54	0,38	0,02	0,06
Verslagen veen	0,29 – 0,43	0,38	0,03	0,10
Veen kleiig	0,24 – 0,38	0,29	0,03	0,12
Veen compact	0,30 – 0,33	0,31	0,01	0,04
Gyttja	0,27 – 0,34	0,30	0,03	0,10
Klei venig / klei organisch	0,16 – 0,38 3)	0,29	0,06	0,20
Klei	0,22 – 0,28	0,25	0,03	0,10
Klei zandig	0,22 – 0,26	0,25	0,03	0,10
Löss				
Keileem				
Dijksmateriaal	0,23 – 0,47	0,31	0,08	0,25

1) The low value can be applied as characteristic low value

2) The averaging of uncertainties along a slip plane is taken into account in the values for the standard deviation and coefficient of variation.

3) S = 0,20 can be used as characteristic low value, however incidentally lower values are found.

Table G.2 Typical values for the strength exponent for Dutch soils.

Soil type (Dutch)	**Strength increase exponent m [-]**	**Coefficient of variation m [-]**
All	0.5 – 1.0 Recommended mean: 0.9	0.03

Table G.3 Typical values for the pre-overburden pressure for Dutch soils.

Soil type (Dutch)	**Mean value POP below dike [kPa]**	**Coefficient of variation POP below**	**Mean value POP landside of the dike [kPa]**	**Coefficient of variation POP landside**
veen mineraalarm	19	0.42	19.0	0.42
veen	21	0.17	21.0	0.17
veen kleiig	17	0.35	24.0	0.21
klei organisch (komklei)	17	0.35	24.0	0.21
klei met plantenresten (ondiep)	31	0.29	31.0	0.32
klei met plantenresten (diep)	16	0.28	16.0	0.34
klei zwaar (rivier ondiep)	38	0.29	34.0	0.29

klei zwaar (rivier diep)	17	0.35	24.0	0.21
klei zwaar (marien ondiep)	31	0.29	31.0	0.32
klei zwaar (marien diep)	16	0.28	16.0	0.34
klei zandig (rivier ondiep)	38	0.29	34	0.29
klei zandig (rivier diep)	17	0.35	24.0	0.21
klei zandig (marien ondiep)	31	0.29	31.0	0.32
klei zandig (marien diep)	16	0.28	16.0	0.34
dijksmateriaal klei	30	0.33	n/a	n/a
dijksmateriaal klei	[1]			
dijksmateriaal zand	[1]			
zand	[1]			
loss				
keileem				

[1] Do not apply undrained strength for this soil type

H Factor of Safety for slope stability analyses with mean values

The following table presents the evaluated Factor of Safety (FoS) per cross-section (with and without berms) using the WBN and mean or design values for the soil parameters, WNC and yield stress points (i.e. FoS_{mean}, FoS_{char}). The design values are the same as the characteristic values since the individual/partial safety factors are all set equal to 1.0 ($FoS_{char} = FoS_{des}$).

The difference between the two FoS is presented in the last column. The values highlighted in grey refer to cases where the FoS was extrapolated, since the value of the WBN was slightly higher than the crest level.

Table H.1 Difference between the safety factor for an analysis with mean values and the safety factor for an analysis with representative values.

ID	WBN [m + NAP]	FoS_mean	FoS_char	Difference
Cases 2016				
1	16.25	1.83	1.29	0.54
2	3.89	1.03	0.78	0.25
3	4.30	1.69	1.34	0.35
4	6.26	2.15	1.72	0.43
4_s1	6.26	2.17	1.35	0.82
4_s2	6.26	1.95	1.35	0.60
4_s3	6.26	1.90	1.29	0.61
5	8.10	1.77	1.51	0.26
6	8.36	1.85	1.20	0.65
7	7.18	2.10	1.49	0.61
8	8.07	1.44	1.01	0.43
8a	8.07	1.60	1.17	0.43
9	7.18	1.83	1.30	0.53
10	4.85	1.22	0.95	0.27
10a	4.85	1.33	1.04	0.29
10b	4.85	1.39	1.15	0.24
11	1.11	1.2	0.84	0.36
11a	1.11	1.41	0.99	0.42
11b	1.11	1.92	1.36	0.56
12	2.14	1.54	1.09	0.45
12a	2.14	1.7	1.18	0.53
13	8.50	1.39	0.99	0.41
13a	8.50	1.71	1.17	0.54
14	3.86	-	-	-
14a	3.86	-	-	-
15	0.61	-	-	-
15a	0.61	1.34	1.08	0.27
15b	0.61	-	-	-
16	5.09	1.4	1.043	0.36
17	5.93	1.57	1.32	0.25

Cases 2015				
18	13.41	1.31	0.86	0.45
18a	13.41	-	-	-
19	12.79	1.52	1.00	0.52
19a	12.79	1.57	1.08	0.49
20	12.57	1.37	0.94	0.43
20a	12.57	1.84	1.24	0.60
21	6.5	1.32	0.91	0.41
21a	6.5	1.6	1.11	0.49
21b	6.5	1.87	1.28	0.60
22	6.93	1.32	0.84	0.48
22a	6.93	1.69	1.02	0.67
23	3.64	0.82	0.55	0.27
23a	3.64	1.26	0.88	0.39
24	10.84	1.26	0.82	0.44
24a	10.84	1.55	1.04	0.51
25	0.98	1.58	1.22	0.36
25a	0.98	1.96	1.55	0.41
26	2.99	1.33	0.96	0.37
27	6.72	1.27	1.07	0.20
27a	6.72	1.44	1.11	0.33

The following graph presents the difference between the safety factor for slope stability analyses with mean values and the safety factor for slope stability analyse with characteristic values, per case. The horizontal line depicts the mean value of the differences, equal to 0.43.

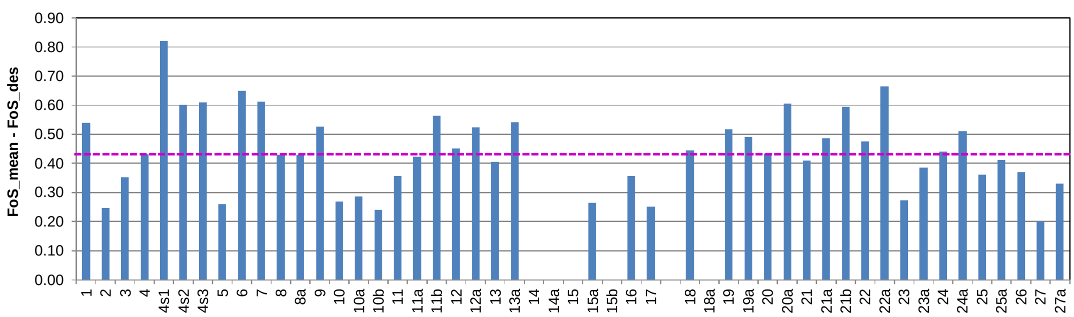

Figure H.1 Difference between Factor of Safety for mean values and Factor of Safety based on design values, and correspondent mean value.

I Influence safety format on required berm lengths

This appendix shows, in greater detail, the sensitivity analysis that underlies the choice for material factors equal to 1.0. It is analysed which berms (length) have to be designed to reach the stability factor (*FoS*) which complies with a certain target reliability, using different sets of material factors (and thus different beta-gamma relations).

Slope stability analyses have been carried out for three cases: an "**average case**", a "**water level sensitive case**" and a "**large slip circle case**". At the time of this study, only preliminary results for the calibration were available, therefore the 2015-data were used.

I.1 Calibration fit for different material factors

The use of a different set of material factors (e.g. γ_m of 1.0, 1.2 or 1.4) will result in a different calibration fit for the beta dependent safety factor (γ_n). Therefore, the beta-gamma relation differs per set of material factors.

The 2015-fit is only valid for the material factor on equal to 1.0. So, for a subset of the data, the sensitivity of the required γ_n against a material factor of 1.2 and 1.4 was analysed. This results on average in a 0.15 and 0.27 lower value of γ_n respectively, for all values of β_T. Therefore, for the purpose of this study, it was chosen to use the following relations.

Table I.1 Estimated beta-gamma relationship for different material factors

Material factor on S	Beta-gamma relation
$\gamma_m = 1.0$	$\gamma_n = 0.161 \cdot \beta_T + 0.463$
$\gamma_m = 1.2$	$\gamma_n = 0.161 \cdot \beta_T + 0.313$
$\gamma_m = 1.4$	$\gamma_n = 0.161 \cdot \beta_T + 0.193$

For two cases, the required berm length to reach a target reliability of $\beta_T = 4.5$ is determined. For different material factors, the required stability factor is different.

I.2 Average case: Case 8

For this cross-section, it was chosen to design a berm with a height of approximately one third of the dike height, i.e. at NAP+4.00. The berm has been designed with a horizontal crest and an inner slope of 1:3. The soil type of the berm material is the dike material: "Nieuw Dijksmat". Also the characteristic points have been moved if necessary. Yield stress points and other soil properties have not been changed. The berm lengths (measured as the horizontal distance from the inner slope until the landside top of the berm) have been determined iteratively with steps of 0.5 m.

Table I.2 Average case: required safety factors (based on Table I.1) and correspondent assessed safety factors

Material factor on S	Required factor	FoS, Base case	Berm length	FoS, with berm
$\gamma_m = 1.0$	$\gamma_n(\beta_T = 4.5) = 1.19$	1.01	4.5 m	1.198
$\gamma_m = 1.2$	$\gamma_n(\beta_T = 4.5) = 1.04$	0.90	4 m	1.05

$\gamma_m = 1.4$	$\gamma_n(\beta_T = 4.5) = 0.92$	0.82	3.5 m	0.93

I.3 Water level sensitive case: Case 18

Here, it was chosen to design a berm with a height of approximately one third of the dike height, i.e. at NAP+11.50. The berm has been designed with a horizontal crest and an inner slope of 1:3. The soil type of the berm material is the dike material: "Ks#-dijklichaam". Also the characteristic points have been moved if necessary. Yield stress points and other soil properties have not been changed. The berm lengths (measured as the horizontal distance from the inner slope until the landside top of the berm) have been determined iteratively with steps of 0.5 m.

Table I.3 water level sensitive case: required safety factors (based on Table I.1) and correspondent assessed safety factors

Material factor on S	Required factor	FoS, Base case	Berm length	FoS, with berm
$\gamma_m = 1.0$	$\gamma_n(\beta_T = 4.5) = 1.19$	0.86	6 m	1.19
$\gamma_m = 1.2$	$\gamma_n(\beta_T = 4.5) = 1.04$	0.72	7.5 m	1.04
$\gamma_m = 1.4$	$\gamma_n(\beta_T = 4.5) = 0.92$	0.62	8 m	0.92

I.4 Large and deep slip circle: Case 14

Case 14 has a large and deep slip circle. The modelled berm height is NAP+2.0 and the berm material is "Dijksmateriaal kleiig". The effect of the berm on the FoS has been determined in steps of 10m. The results are presented in the table below.

Table I.4 Large and deep slip circle case: required safety factors (based on Table I.1) and correspondent assessed safety factors

Material factor on S	Required factor	FoS, Base case	Berm length	FoS, with berm
$\gamma_m = 1.0$	$\gamma_n(\beta_T = 4.5) = 1.19$	0.91	30 m	1.20
$\gamma_m = 1.2$	$\gamma_n(\beta_T = 4.5) = 1.04$	0.76	35 m	1.05
$\gamma_m = 1.4$	$\gamma_n(\beta_T = 4.5) = 0.92$	0.67	40 m	0.95

I.5 Observations

The following observations are made based on the three cases:

- The two cases with a small slip circle need a relatively small berm, in order to reach the target reliability of beta 4.5. The required length of berm that is required to reach the required FoS is reasonable (5-10 m).
- The case with a large slip circle needs a relatively large berm, in order to reach the target reliability of beta 4.5.
- For Case 8, the required berm length is smaller with a higher material factor
- For Case 18, the required berm length is larger with a higher material factor
- For Case 14, the required berm length is larger with a higher material factor
- Differences in the required berm lengths with a different material factor are small (order of 10-25%)

J Clustering analysis

This appendix shows, in more detail, the analysis that supports the decision not to define different gamma-beta relationships for different types of cases/conditions. The following clusters were analysed:

(1) Safety standard
(2) Origin of the soil data
(3) Riverine or marine deposits
(4) Water system
(5) Dike type (WNC)
(6) Uplift
  a. at WBN
  b. at the WL design point
(7) Blanket layer thickness
(8) Water level influence
(9) Slip plane at the design point

The table at the end of this appendix contains the classification of each test case.

J.1 Safety standards

Theoretically, $\gamma_n$values can be derived for multiple safety standards. The effect this has is investigated in this section. The different safety levels affect the value of the design water level, WBN. The higher the safety standard, the higher the WBN. The higher the WBN, the lower the safety factor γ_n, while the reliability index remains the same – see e.g. Figure J.1.

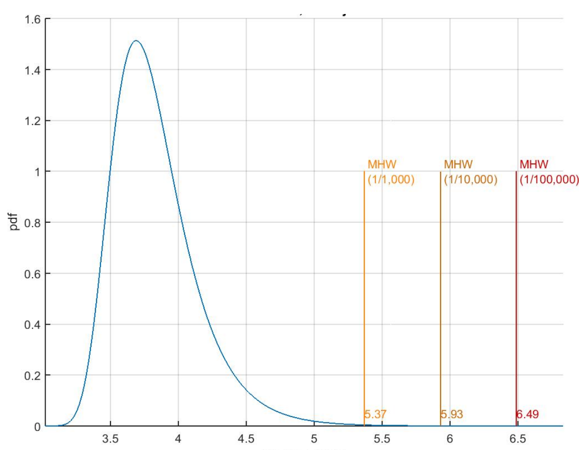

Figure J.1 Example of a water level distribution and the corresponding WBNs for the return periods of 1/1,000, 1/10,000 and 1/100,000.

To gain insight into the influence of different safety standards in the calibrated gamma-beta relationship, we computed the FoS_{des} for a selection of the cases for WBN corresponding to the safety standards 1/1,000, 1/10,000 and 1/100,000. The result is shown in Figure J.2. The figure shows a small decrease in γ_n with increased safety standards, though the effect is small for the cases where there is a limited influence of the water level (majority of the cases). This was to be expected. Only the cases with a high influence of the water level (limited amount in the total analysis - see Figure 6.2) show a more significant decrease. However, these will hardly influence the calibration fit.

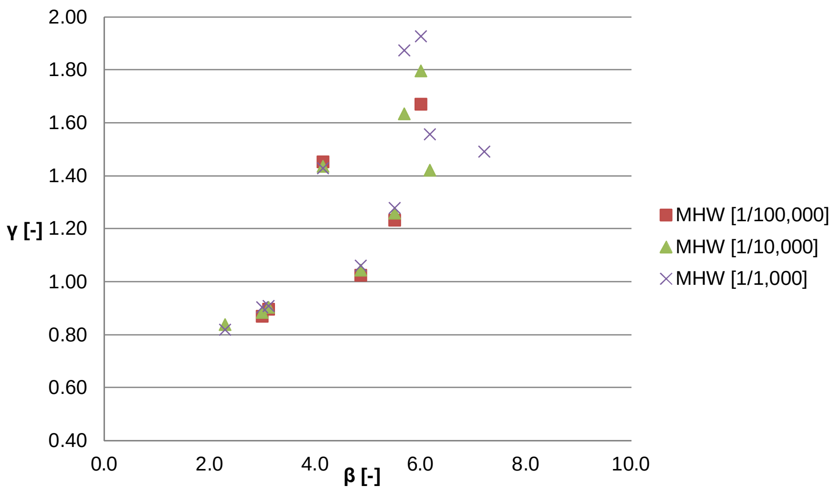

Figure J.2. Influence of the safety level on the safety factor γ_n.

Based on these results, it can be concluded that the influence of the safety standard, on the calibrated overall safety factor, is small. It should be noted that the cases show a good distribution over the various safety standards (see section 6.2); these are all used in the calibration fit. Hence, the various safety standards are well represented in the calibration fit. Keep in might that, even though the different safety standards hardly have an effect on the required safety factor, the different safety standards still affect the target reliability, as discussed in Chapter 5.

J.2 Origin of the soil data

The uncertainties related to soil parameters can be very different when default values are used (e.g. van Deen and van Duinen, 2016) or when local data is taken into account. The test cases of 2016 calibration include a variety of cases, which originate from local, regional and default data (see section 6.2).

In this section we analyse if the calibration exercise leads to different gamma-beta relationships for local, default and regional data. In Figure J.3 one can see these 3 different sets. No clear clustering can be observed in this graph. Furthermore, a closer look into the means and standard deviations of S (the most influential parameter in the analysis), shows that the best estimates given by van Deen and van Duinen (2016) and the data derived from local and regional investigation, are quite comparable – see Appendix G and H. This means that the defaults are realistic and slightly on the safe side, but that they should only be used in the absence of local/regional data.

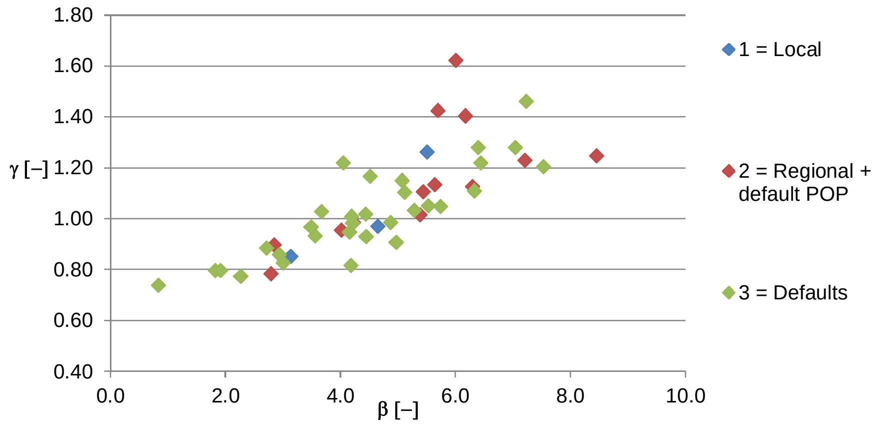

Figure J.3. Influence of the origin of the data on the safety factor γ_n – reliability index relationship.

Based on these results, it can be concluded that there is hardly any influence of the data source (local, regional or default) on the calibrated overall safety factor. The test cases show a good distribution over the various data source/origin (see section 6.2); and these are all used in the calibration fit. Hence, this characteristic is well represented in the calibration fit.

J.3 Riverine and marine deposits

In Figure J.4, the results for γ_n and reliability are sorted according to the geology. Broadly speaking, cases left of the line shown in the map (Figure J.4, right) have a marine geology, whereas cases west of the line have a riverine geology. The marine cases show both lower reliability as safety factor, but also a smaller spread. This could be related to thick layers of weak soil which are present in this area. In the area with riverine geology, the clay layers are often less thick and more compressed (higher volumetric weights). Both sets show more or less the same trend, especially within the range (2 to 6), with the Riverine set have a few more upward outliers. However, the differences are insufficient to draw firm conclusions. For this reason there is no ground for calibrating different $\gamma - \beta$ relations for riverine and marine deposits.

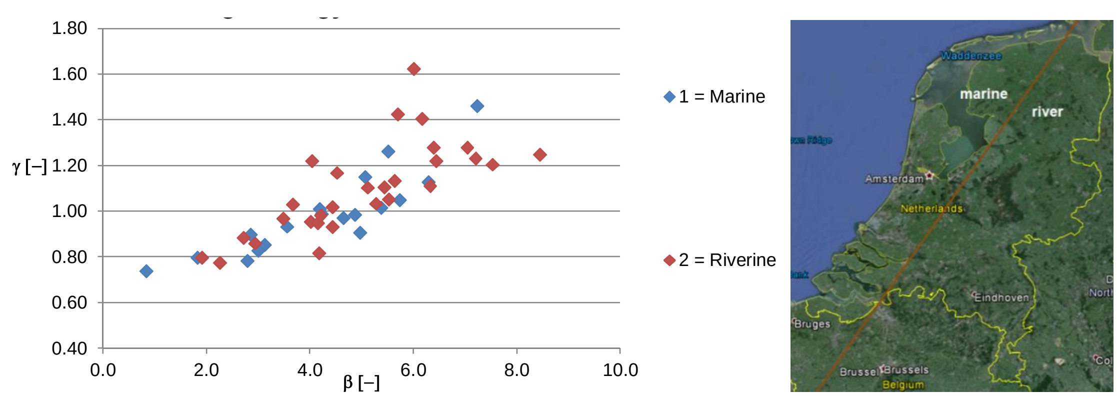

Figure J.4. Influence of the marine or riverine sub-soil on the safety factor γ_n – reliability index relationship (left figure). Separation in marine (west) and river (east) (right figure)

J.4 Water system

In Figure J.5, the results are sorted according to the water system. Marine water system refers to locations that have a WL which is influenced by tides (lower duration of high WL), meanwhile the riverine water system refers to locations that where the water level is more influenced by discharge of rivers (higher duration of the WL). Both sets show more or less the same trend. For this reason there is no ground for calibrating different $\gamma - \beta$ for different water systems.

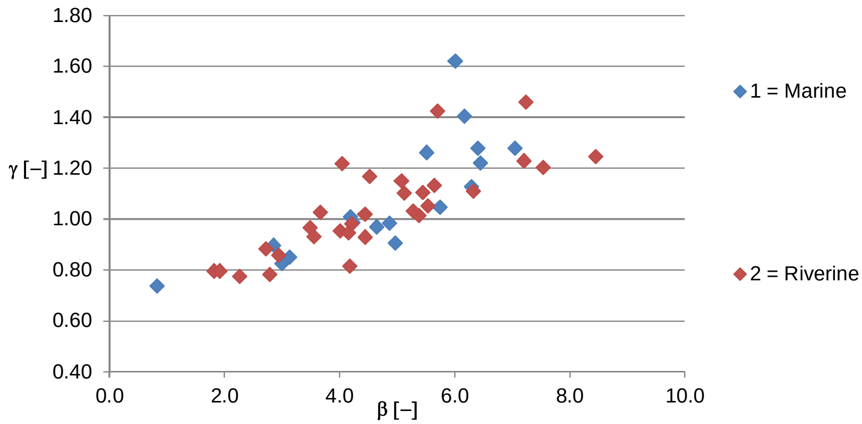

Figure J.5. Influence of the marine or riverine water system on the safety factor γ_n – reliability index relationship.

J.5 Dike type (WaterNet Creator)

Another possible reason for differentiation concerns the dike type, classified by the way in which the pore water pressures are modelled by the WaterNet Creator (WNC). The two classes shown in Figure J.6 are the most common throughout the Netherlands. It should be noted that also other dike types have been considered in the calibration; however, these were assigned 'Clay on Clay' or 'Sand on Clay' in the WNC to represent the pore water pressures realistically. The test cases are shown in Figure J.6. Based on these results, the gamma-beta relationship appears to be less steep for a 'Sand dike on clay' than for a 'Clay dike on clay'.

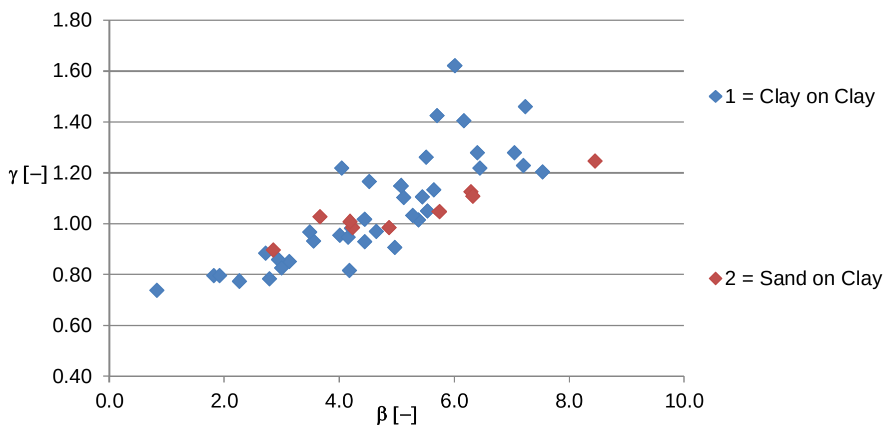

Figure J.6. Influence of the marine or riverine water system on the safety factor γ_n – reliability index relationship.

The difference between the two dike types is relevant. However, the number of cases is limited. More importantly, the WNC dike type not necessarily correlates with an exact dike configuration, merely with a certain modelling of pore water pressures. As it not easy beforehand to determine which WNC type is best used to model the pore water pressures, it is recommended not to make a distinction between different dike types.

J.6 Uplift

In this section the results are divided into cases with and without uplift conditions. The cases with blanket rupture are generally cases with a relatively thin blanket layer; the cases with reduced shear strength by PL3 reduction (uplift, reduction of shear due to high pressures in the sand layer, which is called PL3) are cases with a thicker layer of weak soils with low weight. The cases have been classified according to:

1 Blanket rupture ('opbarsten', blanket < 4m)
2 Uplift, i.e. reduced shear strength due to excess water pressures in sand aquifer ('opdrijven')
3 No uplift

The main difference between the first two is that with blanket rupture (1), there is no shear strength present in the passive zone due to rupture of the blanket; while with reduced shear strength (2), the blanket does not rupture. Hence, there is still shear strength present in the passive zone of the blanket, but not at the interface between blanket and aquifer. For more information about uplift and blanket rupture, the reader is referred to the 2015 calibration (Kanning et al, 2015) or Kanning and van der Krogt (2016).

Whether a case shows blanket rupture (1), uplift (2) or no uplift (3) has been determined for both the water level in the design point (derived from the probabilistic analysis) and the WBN level. This difference was made because the design point of the water level is often significantly lower than the water level for which uplift occurs. Hence, there may be a difference, see following Figures J.7 and J.8.

The difference between blanket rupture (1), uplift (2) or no uplift (3) is not significant and the amount of cases is limited. Hence, it was decided not to calibrate different gamma-beta relationships for these three clusters. Furthermore, it would be quite un-practical and difficult, from a user's point of view, to classify a case as e.g. an "uplift case" prior to the assessment.

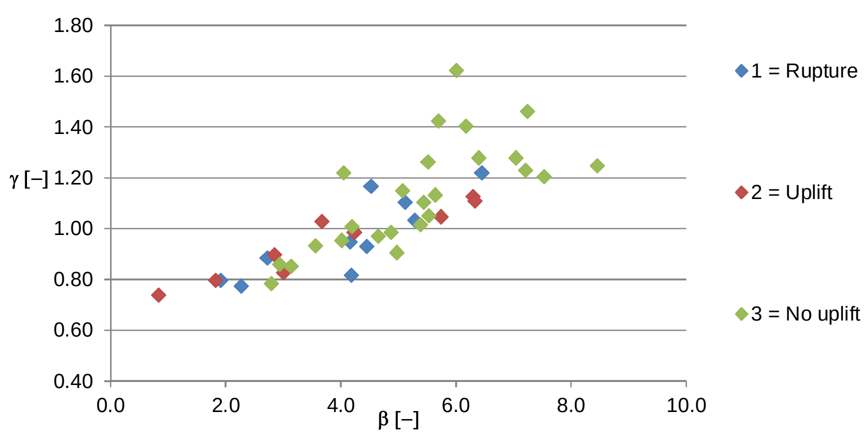

Figure J.7 γ_n *versus reliability separated in uplift or non-uplift for the WBN.*

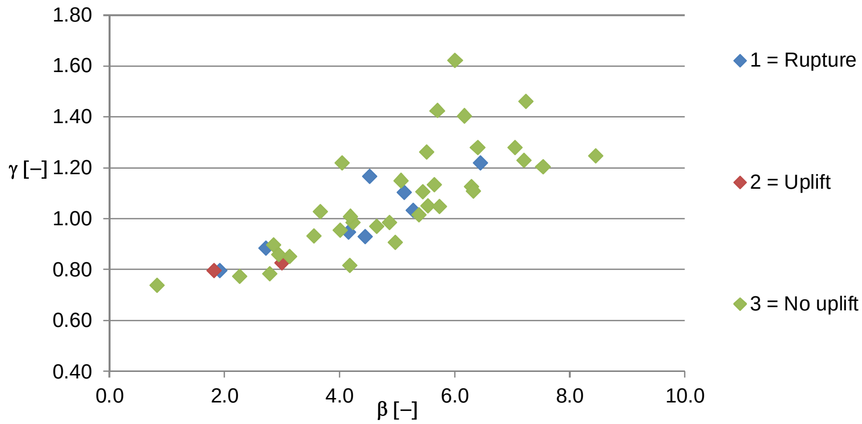

Figure J.8 γ_n *versus reliability separated in uplift or non-uplift for the water level in the design point.*

J.7 Blanket layer thickness

Theoretically, there could be a an influence of the blanket layer thickness on the relationship between gamma and betas the blanket layer can influence the occurrence of uplift/rupture and the slip plane size. The following graph, Figure J.9, shows the computational results for thin, medium and thick blanket layers. It is clear that higher reliability indices and safety factors are achieved with thicker blankets; however, the beta-gamma relationship is not different for the 3 classes/clusters. Hence, it was decided not to calibrate different gamma-beta relationships for different blanket layer thicknesses.

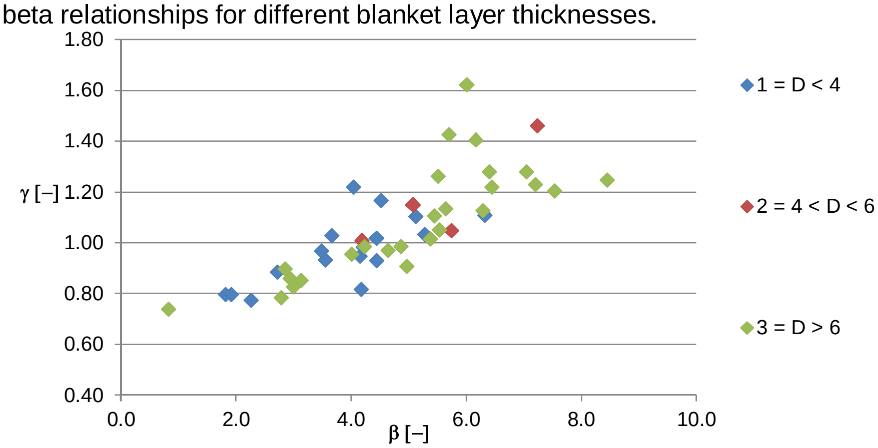

Figure J.9 γ_n *versus reliability separated for different blanket thicknesses.*

J.8 Water level influence

The influence of the uncertainty related to the water level could also lead to a different gamma-beta relationship. The results seen Figure J.10, do not show a clear trend though. Furthermore, it would be almost impossible for users to know the water level influence prior to the assessment. As such, it was decided not to calibrate different gamma-beta relationships.

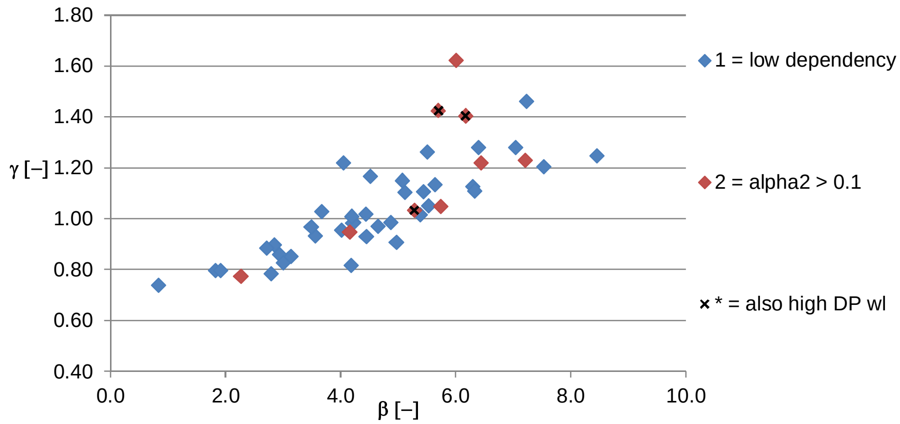

Figure J.10 γ_n versus reliability separated related to the water level influence.

J.9 Slip plane at the design point

Finally, the size of the slip plane mobilized during failure could be a parameter for differentiation. However, it would be almost impossible for users to know this prior to an assessment. As such, it was decided not to calibrate different gamma-beta relationships for different sizes of the slip plane at the design point. Nevertheless, Figure J.11 shows the results of this clustering for the test cases.

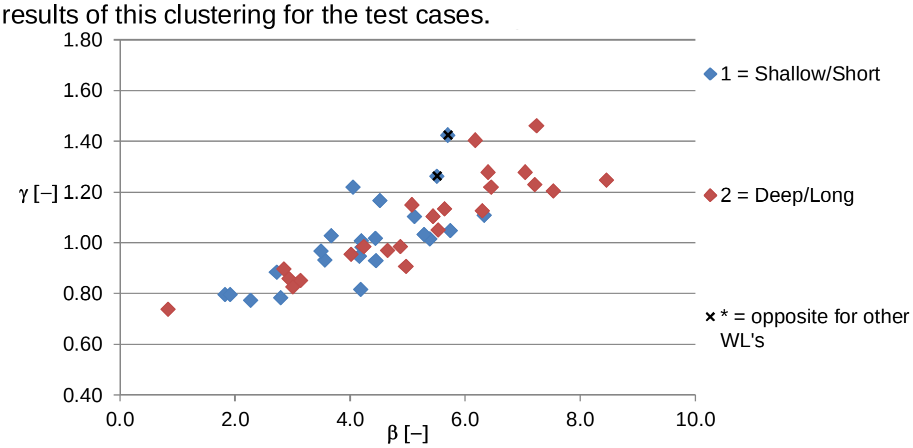

Figure J.11 γ_n versus reliability separated for the size/type of slip plane at the design point.

J.10 Summary table of the clusters

			Characterisation					Results			
			Geology subsoil	Water system	WNC dike type	Blanket layer	Origin S	Uplift at WBN	Uplift at the design point (DP)	Water level dependency	Slip plane in design point (DP)
			1 = Marine	1 = Marine	1 = Clay on Clay	1 = D < 4	1 = Local	1 = Rupture	1 = Rupture	1 = low dependency	1 = Shallow/Short
			2 = Riverine	2 = Riverine	2 = Sand on Clay	2 = 4 < D < 6	2 = Regional[1)]	2 = Uplift	2 = Uplift	2 = alpha2 > 0.1	2 = Deep/Long
#	β	γ				3 = D > 6	3 = Defaults	3 = No uplift	3 = No uplift	* = also high DP wl	* = opposite for other WL's
1	4.05	1.22	2	2	1	1	3	3	3	1	1
2	0.84	0.74	1	1	1	3	3	2	3	1	2
3	5.51	1.26	1	1	1	3	1	3	3	1	1*
4	6.01	1.62	2	1	1	3	2	3	3	2	
4_s1	7.05	1.28	2	1	1	3	3	3	3	1	2
4_s2	6.40	1.28	2	1	1	3	3	3	3	1	2
4_s3	6.45	1.22	2	1	1	3	3	1	1	2	2
5	5.70	1.42	2	2	1	3	2	3	3	2*	1*
6	5.64	1.13	2	2	1	3	2	3	3	1	2
7	6.18	1.40	2	1	1	3	2	3	3	2*	2
8	4.02	0.95	2	2	1	3	2	3	3	1	2
8a	5.45	1.10	2	2	1	3	2	3	3	1	2
9	7.21	1.23	2	2	1	3	2	3	3	2	2
10	2.85	0.90	1	1	2	3	2	2	3	1	2
10a	4.23	0.98	1	1	2	3	2	2	3	1	2
10b	6.30	1.13	1	1	2	3	2	2	3	1	2
11	1.83	0.80	1	2	1	1	3	2	2	1	1
11a	3.56	0.93	1	2	1	1	3	3	3	1	1
11b	#N/A	#N/A	1	2	1	1	3	3	3	1	1
12	3.67	1.03	2	2	2	1	3	2	3	1	1
12a	6.33	1.11	2	2	2	1	3	2	3	1	1

13	4.45	0.93	2	2	1	1	3	1	1	1	1
13a	5.12	1.10	2	2	1	1	3	1	1	1	1
14	3.13	0.85	1	1	1	3	1	3	3	1	2
14a	4.65	0.97	1	1	1	3	1	3	3	1	2
15	2.79	0.78	1	2	1	3	2	3	3	1	1
15a	5.39	1.01	1	2	1	3	2	3	3	1	1
16	4.87	0.98	1	1	2	3	3	3	3	1	2
17	8.45	1.25	2	2	2	3	2	3	3	1	2
18	4.19	0.82	2	2	1	1	3	1	3	1	1
18a	5.28	1.03	2	2	1	1	3	1	1	2*	1
19	4.16	0.95	2	2	1	1	3	1	1	2	1
19a	4.44	1.02	2	2	1	1	3	excluded		1	1
20	2.72	0.88	2	2	1	1	3	1	1	1	1
20a	4.53	1.17	2	2	1	1	3	1	1	1	1
21	2.94	0.86	2	2	1	3	3	3	3	1	2
21a	5.54	1.05	2	2	1	3	3	3	3	1	2
21b	7.54	1.20	2	2	1	3	3	3	3	1	2
22	1.92	0.80	2	2	1	1	3	1	1	1	1
22a	3.49	0.97	2	2	1	1	3	excluded		1	1
23	-2.22	0.52	1	1	1	3	3	2	2	1	2
23a	3.00	0.83	1	1	1	3	3	2	2	1	2
24	2.27	0.77	2	2	1	1	3	1	3	2	1
24a	4.21	0.98	2	2	1	1	3	excluded		1	1
25	5.08	1.15	1	2	1	2	3	3	3	1	2
25a	7.24	1.46	1	2	1	2	3	3	3	1	2
26	4.97	0.91	1	1	1	3	3	3	3	1	2
27	4.19	1.01	1	1	2	2	3	3	3	1	1
27a	5.74	1.05	1	1	2	2	3	2	3	2	1

K Analysis safety format Su based on CPT correlation

See separate document (total number of pages: 17)

L Individual test case reports

See separate document (total number of pages: 216)