Key words

Functional design, Ringtoets, semi-probabilistic assessment, WTI2017

Summary

This document concerns a functional design for semi-probabilistic assessment with Ringtoets, the user interface for future statutory safety assessments. Ringtoets is part of the WTI2017. The WTI2017 covers all instruments and guidelines for evaluating whether the primary flood defences comply with new safety standards that will be defined in terms of maximum allowable probabilities of flooding.

The report first discusses the basic principles on which semi-probabilistic assessments rest, In semi-probabilistic assessments, limit state functions are fed with design values (i.e. representative values and partial safety factors). In case of schematisation uncertainties (i.e. probabilities of mutually exclusive scenarios), the scenario probabilities and semi-probabilistic assessment results per scenario have to be combined to reach an overall verdict. The procedure for doing so is described.

The second part of the report presents requirements for semi-probabilistic assessments with Ringtoets. Detailed requirements are given for each failure mechanism for which a semi-probabilistic assessment has to be made available in Ringtoets.

The last part of the report deals with a global test plan. It introduces the types of tests that have to be carried out to ensure that all semi-probabilistic assessment procedures have been implemented correctly.

References

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Trefwoorden

Functioneel ontwerp, Ringtoets, semi-probabilistische beoordeling, WTI2017

Nederlandse samenvatting

Dit document betreft een functioneel ontwerp voor semi-probabilistische beoordelingen met Ringtoets, de user-interface van toekomstige wettelijke toetsingen. Ringtoets is onderdeel van het wettelijk toetsinstrumentarium 2017, het WTI2017. Het WTI2017 bevat instrumenten en voorschriften om te kunnen beoordelen of de primaire waterkeringen voldoen aan de nieuwe normen, die zullen worden gedefinieerd in termen van maximaal toelaatbare overstromingskansen.

In het eerste deel van het rapport worden de basisprincipes geïntroduceerd waarop semi-probabilistische toetsvoorschriften berusten. In semi-probabilistische beoordelingen worden grenstoestandfuncties gevoed met rekenwaarden (representatieve waarden en partiële veiligheidsfactoren). In geval van schematiseringsonzekerheden moeten de semi-probabilistische beoordelingen per scenario gecombineerd tot een eindoordeel, rekening houdend met de scenariokansen. De procedure om dit te doen, wordt in dit deel van het rapport toegelicht.

Het tweede deel van het rapport bevat de functionele eisen voor semi-probabilistische beoordelingen met Ringtoets. Voor elk faalmechanisme waarvoor een semi-probabilistische toetsing mogelijk moet worden gemaakt, worden eisen gepresenteerd.

Het laatste deel van het rapport betreft een globaal testplan. Hierin worden de typen tests beschreven die uitgevoerd moeten worden om te beoordelen of de semi-probabilistische procedures correct zijn geïmplementeerd.

Contents

[1 Introduction 1](#_Toc418243294)

[2 Basic concepts 3](#_Toc418243295)

[2.1 Failure probabilities and reliability indices 3](#_Toc418243296)

[2.2 The relations between probabilistic and semi-probabilistic assessments 3](#_Toc418243297)

[2.3 Reliability requirements 5](#_Toc418243298)

[2.4 Safety factors 6](#_Toc418243299)

[2.5 Scenarios 6](#_Toc418243300)

[3 Requirements 9](#_Toc418243301)

[3.1 General requirements 9](#_Toc418243302)

[3.1.1 Reliability requirements 9](#_Toc418243303)

[3.1.2 Safety factors 10](#_Toc418243304)

[3.1.3 Dealing with schematisation uncertainties 10](#_Toc418243305)

[3.2 Failure mechanism specific requirements 11](#_Toc418243306)

[3.2.1 Uplift, piping and heave 11](#_Toc418243307)

[3.2.2 Slope stability 14](#_Toc418243308)

[3.2.3 Revetment failure: asphalt revetments 16](#_Toc418243309)

[3.2.4 Revetment failure: block revetments 18](#_Toc418243310)

[3.2.5 Revetment failure: grass revetments 19](#_Toc418243311)

[3.2.6 Dune erosion 19](#_Toc418243312)

[4 Global test plan 21](#_Toc418243314)

[5 References 23](#_Toc418243315)

# Introduction

This report concerns a functional design for semi-probabilistic assessments with Ringtoets, as part of the WTI2017. It is a combination of the products C.5 and C.7 from the WTI Cluster C project plan (Diermanse, 2014).

The development of procedures for semi-probabilistic assessments touches on various disciplines: reliability engineering (cluster C), software development (cluster B), data management (cluster D) and failure mechanism modelling (horizontal clusters). This functional design was therefore developed by cluster C in close co-operation with other clusters.

WTI2017 cluster B (Software) has been consulted before and during the development of this document (R. Kamp, R. Brinkman and E. Vastenburg). Mr. R. Brinkman is the software architect that will oversee the implementation in Ringtoets; he is also the Deltares reviewer of this report. Mr. Kamp has reviewed the global test plan; he has developed the test strategy and test documents for Ringtoets. Cluster D (Data Management) has been consulted with respect to the schematisation guidelines dealing with schematisation uncertainties as well as the parameters list to avoid inconstancies or misunderstanding (M. de Visser and A. Martins Teixeira). A draft version of this document has been sent to all relevant horizontal clusters for review (e.g. A. van Duinen, U. Förster). These clusters are actively involved in the development of models and user-interfaces (with cluster B), Their input has helped to avoid inconsistencies; it has also served as an additional check on the parameter list.

A previous version of this report, published in April, has been used by Ringtoets programmers. Based on the questions that arose during programming, the report has been updated.

This report is organized as follows. Chapter 2 first discusses the relations between semi-probabilistic and probabilistic assessments, as well as the role of reliability requirements, partial safety factors and scenarios in reliability analyses. Chapter 3 then presents the requirements that have to be met by Ringtoets. Finally, a global test plan is presented in chapter 4.

# Basic concepts

## Failure probabilities and reliability indices

A flood defence will fail when the load exceeds its resistance. 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, models such as Steentoets (i.e. the model used for assessing block revetments), that are used to predict critical combinations of parameter values (i.e., combinations that would lead to revetment failure), may give predictions that are besides the (unknown) truth. Such model uncertainties also have to be taken into consideration in reliability analyses.

The probability of failure (*Pf*) equals the probability that load (*S*) exceeds resistance (*R*):

 (2.1.1)

or

 with *Z*=*R*-*S* (2.1.2)

where

*Z* limit state function

Reliability indices are also widely used to quantify the reliability of a component or system. Each probability of failure corresponds to a unique reliability index:

 (2.1.3)

where

Φ(.) standard normal distribution function

*β* reliability index

## The relations between probabilistic and semi-probabilistic assessments

Semi-probabilistic and probabilistic safety assessments are closely related. Both rely on the same target reliabilities, the same limit state functions, and the same statistical properties of the stochastic variables that represent the uncertain load and strength parameters. A semi-probabilistic assessment only rests on a number of simplifications and approximations, giving it the appearance of a deterministic procedure.

In probabilistic safety assessments, analysts consider the probability that the ultimate limit state is exceeded, i.e. that load (*S*) exceeds resistance (*R*). The probability of failure, *P*(*S*>*R*), should not exceed some maximum allowable (‘target’) value (*PT*). In semi-probabilistic assessments, analysts consider the difference between the design values of load (*Sd*) and strength (*Rd*): *Sd* should not exceed *Rd*. Design values are defined in terms of representative values (characteristic values such as 5th or 95th quantiles or nominal values) and (partial) safety factors. This use of terminology is consistent with the Eurocode (the European code for assessing structural reliability). Readers should be aware that similar terms may have different definitions in other international standards.

The design values should be calibrated such that the condition *Sd*≤*Rd* implies that the probability of failure meets the reliability requirement: *P*(*S*>*R*)≤*PT*. The relationship between probabilistic and semi-probability safety assessments is illustrated in Figure 2.1.

Probability density

Load *(S)*

0

Strength (*R*)

*Sd*

*Rd*

Design values

Fully probabilistic assessment: evaluate whether *P*(*R<S*)≤*PT*

Semi-probabilistic assessment: evaluate whether *Sd≤Rd*

Figure 2.1. The probability density functions of load (S) and strength (R), and the design values of load and strength (Sd) and (Rd).

The design values are defined as follows:

 (resistance parameter) (2.2.1)

 (load parameter) (2.2.2)

where

*Rrep* representative value of the uncertain resistance

*γR* (partial) safety factor

*Srep* representative value of the uncertain load

*γS* (partial) safety factor

In practice, most failure mechanism models involve numerous stochastic variables. To be able to carry out a semi-probabilistic assessment, representative values have to be defined for each of them. For resistance variables, this is typically a 5%-quantile value or an average value. For the hydraulic load, it is typically the value with an exceedance probability equal to the safety standard for the segment (in Dutch: “normtraject”) under consideration. Partial safety factors are typically (but not always) defined for the most important stochastic variables. Sometimes, an overall safety factor is used (for a resistance term).

In short, probabilistic and semi-probabilistic assessments *both* require:

1. A failure mechanism model
2. Probability density functions for all stochastic variables (based on statistical data and/or engineering judgment)
3. A reliability requirement

The essential difference between probabilistic and semi-probabilistic assessments is:

1. In a probabilistic assessment, a failure mechanism model is fed with all possible parameter values and their probabilities (probability density functions);
2. In a semi-probabilistic assessment, a failure mechanism model is fed with unique, ‘sufficiently safe’ values (design values). How safe ‘sufficiently safe’ is, depends ultimately on the reliability requirement and a calibration criterion. To ensure sufficient consistency between probabilistic and semi-probabilistic assessments, calibration exercises are indispensable.

## Reliability requirements

For semi-probabilistic assessments, a maximum allowable cross-sectional probability of failure per failure mechanism has to be derived from the maximum allowable probability of flooding. This is done by multiplying the maximum allowable probability of flooding with a factor (in Dutch: “faalruimtefactor”) and by including the length-effect. The cross-sectional reliability requirement is always defined in one of the following ways (Jongejan, 2013):

 (2.3.1)

or

 (2.3.2)

where

*PT,cross* cross-sectional target failure probability for the failure mechanism under consideration (per year)

*Pnorm* maximum allowable probability of flooding (per year)

*f* failure probability factor (“faalruimtefactor”) (-)

*a* fraction of the length of the segment (in Dutch: “dijktraject”; a segment may consist of many sections, or “vakken”) that is considered sensitive to the failure mechanism under consideration (-)

*L* length of the segment (m)

*b* measure for the intensity of the length effect within the part of the segment that is sensitive to the failure mechanism under consideration. It may be interpreted as the number of independent, equivalent (equally reliable) sections within the sensitive part of the segment(m)

*N* number of independent, equivalent sections/objects within the segment (*N* is a measure for the intensity of the length effect) (-)

The parameter values of *f*, *a*, *L*, *b* and *N* are normally fixed/predefined values. Their values are established in calibration exercises.

*Exception: for asphalt revetments, the sensitive length (a⋅L) of the segment equals the combined length of all asphalt revetments within a segment (or: the combined length of all “asphalt sections” within the segment).*

The values of *f* can be derived from Table 2.1. Whenever a particular failure mechanism can be split into a number of sub-failure mechanisms, the maximum allowable contributions in Table 2.1 have to be multiplied with additional factors to obtain the value of *f* for the sub-failure mechanism under consideration.

Table 2.1. Maximum allowable contributions of different failure mechanisms to the probability of flooding (Jongejan, 2013).

| Type of flood defence | Failure mechanism | Dune | Levees | Levees and dunes |
| --- | --- | --- | --- | --- |
| Levee | Overtopping | 0% | 24% | 24% |
| Uplift, piping and heave | 0% | 24% | 24% |
| Slope stability | 0% | 4% | 4% |
| Revetment failure and subsequent erosion | 0% | 10% | 10% |
| Structure | Non-closure | 0% | 4% | 4% |
| Piping | 0% | 2% | 2% |
| Structural failure | 0% | 2% | 2% |
| Dune | Dune erosion | 70% | 0% | 10% |
| Other | | 30% | 30% | 20% |
| Total | | 100% | 100% | 100% |

## Safety factors

In theory, all partial safety factors depend on the cross-sectional reliability requirement. For reasons of practicality, however, all but one safety factor is established for a fixed target reliability. This means that there is only one safety factor that tunes the stringency of the semi-probabilistic assessment rule to the precise cross-sectional reliability requirement. In general, this “β-dependent safety factor” can be written as a function of the maximum allowable probability of flooding (*Pnorm*) and the cross-sectional reliability requirement (*PT,cross*). The reason that both probabilities play a role is that the representative value of the load is typically a load with an exceedance probability equal to *Pnorm*. This means that a lower value of *PT,cross* because of a lower *Pnorm* has different consequences for the β-dependent safety factor than a lower value of *PT,cross* because of a longer segment and/or stronger length effect.

*Exception: for block revetments, the value of the safety factor will also depend on the residual strength of the filter and base layers. This is still a work in progress.*

## Scenarios

The semi-probabilistic assessment rules for slope stability and uplift, piping and heave include a procedure for handling schematisation uncertainties. This procedure revolves around scenarios.

“Schematisation uncertainties are all uncertainties related to the resistance of a flood defence which can only be captured or are more convenient to the captured by (discrete) scenarios with assigned probabilities (i.e. probability mass functions) than by (continuous) probability density functions” (Schweckendiek, 2014). Schematisation uncertainties are not limited to stratification (soil layers).

The calibrated relation between the β-dependent safety factor (*γβ*) and a cross-sectional reliability requirement may be used inversely to obtain a (safe) estimate of the conditional probability of failure per scenario *pi* :

 (2.5.1)

where

*f*--1 inverse of the calibrated relationship between *γβ* and *PT,cross* (for a given *Pnorm*)

*γβ*\* value of the β-dependent safety factor for which *Rd*=*Sd* (implying the semi-probabilistic assessment rule is met precisely)

Having estimated the conditional probability of failure for each scenario, an estimate of the probability of failure (*Pf,cons*) can be obtained:

 (2.5.2)

the following condition has to be met:

 (2.5.3)

where

*P*(*Si*) Probability of scenario *i*. The following should hold: ∑*P*(*Si*)*=*1.

Please note that, due to the conservatism in the relationship between the cross sectional reliability requirement and the β-dependent safety factor, the procedure above yields a conservative estimate of the failure probability.

# Requirements

In this chapter, the requirements are presented that have to be met by Ringtoets. Section 3.1 first presents generic requirements that apply to all or a number of failure mechanisms. Section 3.2 then presents requirements that are failure mechanism specific. A distinction is made between two user modes. Advanced users should be allowed to change default values, normal users should not be allowed to do so.

## General requirements

### Reliability requirements

1. There should be field to enter the maximum allowable probability of flooding (“maximaal toelaatbare faalkans”). A default value should be provided (e.g. from shapefile). Users should be able to modify this value.
2. There should be a table listing the maximum allowable contributions of the different failure mechanisms to the probability of flooding (in Dutch: “faalkansbegroting) and the associated reliability requirements per failure mechanism. Users should be able to select whether these requirements are displayed as annual failure probabilities or reliability indices. The entries in this table should be defined as follows, default values are given in Table 2.1, however the user should define these manually:

| Type waterkering | Faalmechanisme | Faalruimtefactor | Betrouwbaarheidseis op trajectniveau (per jaar) |
| --- | --- | --- | --- |
| Dijk & kunstwerk | Golfoverslag of overloop |  |  |
| Dijk | Opbarsten, piping en heave |  |  |
| Macroinstabiliteit |  |  |
| Falen bekleding en erosie onderlagen |  |  |
| Kunstwerk | Niet sluiten |  |  |
| Onder- of achterloopsheid |  |  |
| Constructief falen |  |  |
| Duin | Duinafslag |  |  |
| Overig | |  |  |
| Totaal | |  |  |

1. All “faalruimtefactoren” should be user-defined. Values smaller than 0 or greater than 1 should not be allowed.
2. The value in the bottom row of the third column should equal the sum of the “faalruimtefactoren”. Values greater or smaller than 1 should only be allowed for advanced users. Such values should be clearly marked and lead to a warning.
3. The value in the bottom row of the fourth (last) column should equal the sum of the “faalkanseisen op trajectniveau”. Values that differ from the maximum allowable probability of flooding should be clearly marked (only possible for advanced users, see requirement 4).

Terminology and units (Table 3.1):

Table 3.1. Dutch terms and units.

|  |  |  |
| --- | --- | --- |
| Variable | Dutch term | Unit (in Dutch) |
| Partial safety factor | Partiële veiligheidsfactor | Per jaar |
| Reliability index | Betrouwbaarheidsindex | Op jaarbasis |
| Cross-sectional target failure probability | Faalkanseis op doorsnedeniveau  (shorthand: Faalkanseis doorsnede) | Per jaar |
| Scenario probability | Scenariokans | - |

### Safety factors

1. The cross-sectional target reliability per failure mechanism should be calculated by Ringtoets on the basis of the reliability requirement for the entire segment for the failure mechanism under consideration, the length of the segment, and the values of *a* and *b*, or *N* (which may be different for the different failure mechanisms). Each of these parameter values should be visible. Default values for the parameters *a*, *b* and *N* will be provided by Cluster C (see section 2.4). Only advanced users should be able to modify these default values. Changes to the default values should be clearly marked. Users should be able to select whether the cross-sectional requirements are displayed as annual failure probabilities or reliability indices.
2. For each failure mechanism model for detailed assessments in Ringtoets, an overview of all safety factors (fixed and β-dependent) should be available. These may be presented for each (sub-)failure mechanism separately. There is an exception: the β-dependent safety factor should not be presented for semi-probabilistic assessments that involve different scenarios (i.e. slope stability and uplift, piping and heave).

### Dealing with schematisation uncertainties

The following requirements are only relevant for the failure mechanisms slope stability (“macrostabiliteit”) and uplift, piping and heave (“opbarsten, piping en heave”).

1. For each section (“vak”), users should be able to define scenarios freely. Ideally, it would be possible to define all input differently per scenario. At a minimum, the following input should be variable (Lam, 2015):
   * Entry point (“intredepunt”) (for piping)
   * Exit point (“uittredepunt”) (for piping)
   * Phreatic level (“freatisch niveau”), water level on the landside (“polderpeil”) and pore pressures (“waterspanningen) (for piping and slope stability)
   * The subsoil scenario (for piping and slope stability)

Users should be able to duplicate subsoil scenarios to effectively vary e.g. the exit point for a particular subsoil scenario.

1. For each section (“vak”), users should be able to assign probabilities (P(Si)) to scenarios freely. These probabilities have to add up to 1. Users should not be allowed to carry out calculations when the scenario probabilities do not add up to 1. It should be made clear to users that this requirement has to be met before calculations can be made.

For further details about the handling of schematization uncertainties, see sections 3.2.1 and 3.2.2.

## Failure mechanism specific requirements

### Uplift, piping and heave

The failure mechanism consists of three sub-failure mechanisms: uplift, piping and heave. All sub-mechanisms have to occur before the levee fails. For each sub-failure mechanism, the assessment is carried out per scenario. In the end, the combined results of the assessments per sub-failure mechanism per scenario are combined to an overall result.

1. Ringtoets should calculate and display the cross-sectional reliability requirement for uplift, heave and piping using the following formula (one reliability requirement for all three sub-failure mechanisms combined and hence only 1 set of *a* and *b* per segment (“dijktraject”)::

 and  (3.2.1)

where

*a,b* constants (still to be defined; eventually these should be default values in Ringtoets)

*f* maximum allowable contribution of piping failure to the probability of flooding (-)

*Pnorm* maximum allowable probability of failure (safety standard)

*L* length of the dike segment (“dijktraject”) (m)

All default values should be included in Ringtoets. Users should be able to view all parameter values. Only advanced users should be able to modify the default values. Deviations from the default values should be clearly marked.

*Default values for a and b will be provided by Cluster C in September 2015.* The values of *a* and *b* may vary between segments (“dijktrajecten”). However, there cannot be different values of *a* and *b* for the different sub-failure mechanisms within a given segment.

1. For each scenario, users should enter the distribution parameters for the stochastic variables. From these distributions, Ringtoets should calculate the representative values. These are defined by quantile values (i.e. values with a particular probability of exceedance), except for the critical heave gradient which has a fixed representative value, see

Table 3.2. Representative values for semi-probabilistic assessments of uplift, piping and heave.

| Parameter | Description  (English) | Description (Dutch) | Distribution type | Quantile | Repr. value | Unit |
| --- | --- | --- | --- | --- | --- | --- |
| *General parameters* | | | | | | |
| Dcover | Thickness of cover layer | Dikte deklaag | L | 5% | - | m |
| hexit | Phreatic level at exit point | Freatisch niveau op uittreepunt | N | 5% | - | m +NAP |
| h | high water level | Buitenwaterstand | from Hydra-Ring | Norm | - | m +NAP |
| rexit | Damping factor at exit point | Dempingfactor bij uittredepunt | L | 95% | - | - |
| *Parameters for uplift* | | | | | | |
| γsat,cover | Saturated volumetric weight of the cover layer (blanket) | Verzadigd volumegewicht toplaag | Shifted lognormal | 5% | - | kN/m3 |
| *Parameters for heave* | | | | | | |
| ic,h | critical heave gradient | Kritiek verval voor heave | L | - | 0.3 | - |
| *Parameters for piping* | | | | | | |
| L | seepage length from exit to entry | Kwelweglengte | L | 5% | - | m |
| d70 | 70%-quantile of grain size distribution of piping-sensitive layer | 70%-kwantiel voor korrelgrootte- verdeling piping-gevoelige laag | L | 5% | - | m |
| k | Darcy permeability | Darcy doorlatendheid | L | 95% | - | m/s |
| D | Thickness of aquifer | Dikte watervoerende laag | L | 95% | - | m |

All representative values should be displayed. The following parameters have fixed values:

Table 3.3. Fixed parameter values for semi-probabilistic assessments of uplift, piping and heave.

|  |  |  |  |
| --- | --- | --- | --- |
| Parameter | Description | Value | Unit |
| mp | Model factor piping | 1 | - |
| mu | Model factor uplift | 1 | - |
| γwater | Volumetric weight water | 10 | kN/m3 |
| η | White’s constant | 0.25 | - |
| γsub,particles | Submerged particle weight | 16.5 | kN/m3 |
| νwater | Kinematic viscosity of water | 1.33\*10-6 | m2/s |
| g | Gravitational acceleration | 9.81 | m/s2 |
| d70,m | 70%-quantile reference value in Sellmeijer equation | 2.08\*10-4 | m |
| θsellmeijer,revised | Friction angle | 37 | ° |
| rc | Reduction factor for piping | 0.3 | - |

The fixed values should be displayed, but only advanced users should be able to modify them. This should be clear from the way in which the values are displayed.

Uplift

1. For each scenario, the value of the β-dependent safety factor for which *Rd*=*Sd* should be calculated with representative values according to:

 (3.2.2)

where

Δφ*c,u* Critical head difference between water level on the water side and phreatic level at exit point [m]

Δφ Head difference between water level on the water side and phreatic level at exit point [m]

Heave

1. For each scenario, the value of the β-dependent safety factor for which *Rd*=*Sd* should be calculated with representative values according to:

 (3.2.3)

where

*ic,h* Critical heave gradient [-]

*i* Actual heave gradient [-]

Piping

1. For each scenario, the value of the β-dependent safety factor for which *Rd*=*Sd* should be calculated with representative values according to:

 (3.2.4)

Where

*Hc* Critical hydraulic head according to Sellmeijer equation [m]

*H* Hydraulic head (*H = h – hexit – rc.d*) [m]

Reaching an overall verdict

To reach an overall verdict, the results of assessments for uplift, piping and heave for the different scenarios have to be combined (see also section 3.1.3):

1. For each section (“vak”) the calculated β-dependent safety factor for which *Rd* = *Sd* should be displayed for all scenarios and sub-failure mechanisms (each of these factors should be called “veiligheidsfactor”); together with the (safe) estimate of the associated failure probability *Pf,i,j* (where *i* denotes the scenario and *j* the sub-failure mechanism). Such a probability should be called “geschatte faalkans”. These probabilities should be calculated on the basis of the three equations governing the β-dependent safety factors for uplift, piping and heave.

*The three equations governing the β-dependent safety factors for uplift, piping and heave will be provided by cluster C in September 2015.*

1. For each scenario *i* the smallest failure probability should be selected from the sub-mechanisms as an estimate of the probability of failure, i.e. *Pf,i*=min(*Pf,i*). The resulting failure probabilities per scenario should be combined to a conservative (safe) estimate of the cross-sectional probability of failure (*Pf,cons*) for the section (“vak”) using equation (2.5.2). This probability should be displayed, together with the ratio of this probability to the cross-sectional reliability requirement (*PT,cross*): *PT,cross*/*Pf,cons*. When *PT,cross*/*Pf,cons* < 1, the section (“vak”) fails to pass the semi-probabilistic assessment. This should be clearly marked.

*NB: Requirement 15 means that the kernel should always evaluate all three sub-failure mechanisms.*

### Slope stability

1. Ringtoets should calculate the cross-sectional reliability requirement for slope stability using the following formula:

 and  (3.2.1)

where

*a,b* Constants (still to be defined; eventually these should be default values in Ringtoets)

*f* Maximum allowable contribution of piping failure to the probability of flooding (-)

*Pnorm* Maximum allowable probability of failure (safety standard)

All default values should be included in Ringtoets. Users should be able to view all parameter values. Only advanced users should be able to modify the default values. Deviations from the default values should be clearly marked.

*Default values for a and b will be provided by Cluster C in September 2015.*

* + *a* is the fraction of the length that is sensitive to slope stability
  + *b* is a measure for the intensity of the length effect within the length *a⋅L*

1. For each soil used in the subsoil scenarios, users should enter the distribution parameters for the stochastic variables (mean, standard deviation and distribution type). The distributions should, where necessary, concern distributions of spatially averaged random variables. From these distributions, Ringtoets should calculate the representative values. These are defined by quantile values (i.e. values with a particular probability of exceedance), see Table 3.4.

Table 3.4. Representative values for semi-probabilistic assessments of slope stability.

| Parameter | Description  (English) | Description  (Dutch) | Unit | Distribution type | Quantile |
| --- | --- | --- | --- | --- | --- |
| γunsat | unit weight of soil above phreatic level | soortelijk gewicht grond boven freatisch vlak | kN/m3 | N | 50 % |
| γsat | unit weight of soil below phreatic level | soortelijk gewicht grond onder freatisch vlak | kN/m3 | N | 50 % |
| c’ | cohesion | cohesie | kN/m2 | L | 5 % |
| tan φ’ | friction angle | hoek van inwendige wrijving | ° | L | 5 % |
| S | undrained shear strength ratio (nc) | ratio ongedraineerde schuifsterkte | - | L | 5 % |
| m | strength increase exponent |  | - | L | 5 % |
| σ’vy | vertical yield stress | verticale grensspanning | kN/m2 | L | 5 % |
| Li | leakage length |  | m | ?[[1]](#footnote-1) | ?1 |
| IL | intrusion length |  | m | ?1 | ?1 |
| h | high water level |  | m +NAP | Hydra-Ring | Norm |

NB: the 5%-values for the material properties should apply to the spatial averages of these properties (see also DGeoStability).

1. Users should be able to specify the material factors that apply to the different soil layers. Each subsoil scenario may contain different soil definitions, which allow the user to specify different material factors per subsoil scenario. An overview of the material factors per soil type should be available to assist users with the selection of material factors. Ringtoets should calculate the design values (“rekenwaarde”) of the material properties by dividing the representative values (appropriate quantile values, see Table 3.4) by the selected material factors.

*The fixed safety factors (model factors, material factors) will be provided in September 2015 by Cluster C.*

1. Ringtoets should select the appropriate model factor, depending on the sliding model (Spencer or LiftVan). Ringtoets will always use the Spencer model, and only in case this does not lead to a result, LiftVan is used.

Reaching an overall verdict

To reach an overall verdict, the results of assessments per scenario have to be combined (see also section 3.1.3):

1. For each section (“vak”) and each scenario, the calculated β-dependent safety factor for which *Rd* = *Sd* should be displayed (this factor should be called “stabiliteitsfactor”), together with the associated (safe) estimate of the associated failure probability *Pf,I* (this probability should be called “geschatte faalkans”) The latter should be calculated on the basis of the equation governing the β-dependent safety factor.

*The equation governing the* β*-dependent safety factor for slope stability will be provided in October 2015 by cluster C.*

1. For each section (“vak”), the failure probabilities *Pf,i* per scenario should be combined to a conservative (safe) estimate of the probability of failure (*Pf,cons*) using equation (2.5.2). This probability should be displayed, together with the ratio of this probability to the cross-sectional reliability requirement (*PT,cross*): *PT,cross*/*Pf,cons*. When *PT,cross*/*Pf,cons* < 1, the section (“vak”) fails to pass the semi-probabilistic assessment. This should be clearly marked.

### Revetment failure: asphalt revetments

This section deals with the implementation of asphalt revetments in the semi-probabilistic assessment. Further details on how to implement Golfklap in Ringtoets are given in ‘t Hart (2015).

1. It has to be defined whether the segment is located along the “Westerschelde/Noordzeekust”, “Waddenzee” or “IJsselmeer” in order to calculate using the correct boundary conditions.
2. Ringtoets should calculate the cross-sectional reliability requirement as follows:

 and  (3.2.5)

where:

*PT,cross* cross-sectional target failure probability for the failure mechanism under consideration (per year)

*Pnorm* maximum allowable probability of flooding (per year)

*f* failure probability factor (“faalruimtefactor”) (-)

*λ1* maximum allowable contribution of asphalt revetments to the probability of flooding due to revetment failures (all types) (default *λ*1=0.33)

*λ2* maximum allowable contribution of wave impact to failure of asphalt revetments (default *λ*1=0.7)

*L* length of the segment (”dijktraject”)　(m)

*a* fraction of the length of the segment over which ans asphalt revetment is present (-). Default value: *a*=1. Users should be able to change this value.

*b* measure for the intensity of the length effect within the part of the segment that is sensitive to the failure mechanism under consideration (m)

with *b* = 1000 m. Advanced users should be able to modify the value of *a* in order to be able to give the total fraction of the length of asphalt revetments as input. Deviations from the default value should be clearly marked.

1. Ringtoets should calculate β-dependent safety factors for young and old asphalt for the water system under consideration with the following formulae (Table 3.5).

Table 3.5. The equations governing the β-dependent safety factors for young and old asphalt.

| Water system | Age class | *βT*‑dependent safety factor |
| --- | --- | --- |
| Western Scheldt/Coast | young |  |
| old |  |
| Wadden sea | young |  |
| old |  |
| IJssel lake | young |  |
| old |  |

*No safety factors are available for the Eastern Scheldt. This is because the calibration of safety factors for this water system is relatively complex and because there hardly are asphalt revetments along the Eastern Scheldt.*

The calculated safety factors for young and old asphalt should be displayed (see also requirement 27).

1. For each section (“vak”), the user should give the representative values for all stochastic parameters, except for the water level, where the representative value of the hydraulic load has a probability of exceedance equal to the maximum allowable probability of flooding (*Pnorm*). The representative load should be obtained from the Q-variant in Hydra-Ring. The model factor (*γm*) equals 1.77.

Table 3.6. Representative values for semi-probabilistic assessments of asphalt revetments.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Parameter | Description  (English) | Description  (Dutch) | Unit | Input type |
| c | Soil modulus | Beddingscoëfficiënt | MPa/m | representative value |
| d1 | Thickness of asphalt layer | Dikte asfaltlaag | M | representative value |
| E1 | Youngs modulus of asphalt | Elasticiteitsmodulus  asphalt | MPa | representative value |
| alfa | Fatigue parameter α | Vermoeiings-parameter α |  | representative value |
| beta | Fatigue parameter β | Vermoeiings-parameter β |  | representative value |
| σb | Cracking strength | Breuksterkte | MPa | representative value |
| h | Water level | Waterstand | m NAP | from Hydra-Ring |

A fixed input parameter is:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| nu | Poisson ratio | Poisson ratio | - | D | 0.35 | - |

This fixed value should be displayed, but only advanced users should be able to modify it.

1. For each section (“vak”), Ringtoets should calculate the β-dependent safety factor as follows, based on the user-defined coefficient of variation of the cracking strength CoV(σb) (“breuksterkte”):

 (3.2.6)

The value for CoV(σb) should be given as input by the user. Because this input parameter is not a representative value, it has not been included in Table 3.6.

An overview of the resulting safety factors for each section (“vak”) should be provided.

1. For each section (“vak”), Ringtoets should calculate the Miner sum based on representative values, see requirement 26. The calculated value should be displayed.
2. The following quantity (a stability factor) should be calculated:

 (3.2.8)

When *SFasph* ≥ 1, the section (“vak”) passes the semi-probabilistic assessment, otherwise it does not. The value of *SFasph* should be displayed. When *SFasph* < 1, this should be clearly marked.

1. If the significant wave height (*Hs*) is > 3 meters or the CoV(σb) > 0.35 the revetment doesn't pass the assessment. There should be a box for both conditions in case they are not satisfied. If this box is marked by the user the assessment result should be set to ‘not passed’.

### Revetment failure: block revetments

1. The representative loading conditions should be obtained from the Q-variant in Hydra-Ring, for an exceedance probability equal to the maximum allowable probability of flooding. All other Steentoets variables are representative values that users should be able to specify directly (i.e. users will not have to define distributions).
2. The representative value of the block thickness should be divided by a β-dependent safety factor. The β-dependent safety factor depends on the amount of residual strength.

*A list of safety factors or an equation governing the β-dependent safety factor will be provided by Cluster C.*

1. There will be three conditional probabilities of failure, depending on the residual strength classification (high, medium, low). The three β-dependent safety factors for the three residual strength classes should be should be displayed (see also requirement 7).
2. The conditional probability of failure (*Pcond* in equation (3.2.6)) for a particular section (“vak”) will depend on:

* The significant wave height
* The thickness of the clay layer (relative to the slope)
* The width of the levee at the “toetspeil” (water level with a probability of exceedance equal to the maximum allowable probability of flooding; this value could be taken from the “simple assessment” for the block revetment)

*The precise formulae linking these variables to conditional probabilities of failure have not been established yet.*

1. For the stability of block revetments layers under wave attack, Steentoets calculates a quantity called *fgt*. This quantity should be presented as output. When *fgt* <1, the section/revetment fails to pass the semi-probabilistic assessment, this should be clearly marked.

### Revetment failure: grass revetments

For grass revetments there are various failure mechanisms. Their specifics are listed below.

GABI (Gras Afschuiven Binnentalud)

Irrelevant: no semi-probabilistic assessment

GEBI (Gras Erosie Binnentalud)

Irrelevant: no semi-probabilistic assessment; this failure mechanism is assessed probabilistically

GEBU (Gras Erosie Buitentalud)

*The kernel for this mechanism has not been finished yet. A calibration study for safety factors is planned for this year.*

### Dune erosion

Semi-probabilistic assessments for dune erosion will be carried out with Morphan, not Ringtoets.

1. There should be a functionality to easily import a list with all assessment results from Morphan.

# 

# Global test plan

Testing the functional design for Ringtoets comprises different types of tests of which the characteristics are discussed below. Normally, such tests are specified when a technical design is available (which is written on the basis of a functional design). This is why only a global test plan is presented herein (written in co-operation with Cluster Software).

Two types of tests have to be carried out to ensure the proper implementation of the semi-probabilistic assessment procedures in Ringtoets:

1. unit tests
2. system integration tests

Unit tests are tests of small, isolated parts of the entire software code. Unit tests aim to verify whether e.g. inputs are stored correctly. Such tests have to be specified by the programmers, based on the technical design.

System integration tests aim to verify whether inputs are transformed into outputs correctly. System integration tests can be defined at different levels. When inputs x1 and x2 yield y1, inputs x3 and x4 yield y2, and y1 and y2 yield z, four different system integration tests may be distinguished:

1. Do x1 and x2 yield y1?
2. Do x3 and x4 yield y2?
3. Do y1 and y2 yield z?
4. Do x1, x2, x3 and x4 yield z?

Ultimately, a system integration test may concern the question whether a complete set of inputs yields the correct stability factor. Such a test would also involve the failure mechanism model and load model. Such models are still under development.

It is proposed to carry out unit tests (to be defined on the basis of a technical design) and a number of system tests. These system tests should, at a minimum, demonstrate that the formulae presented in chapter 3 have been implemented correctly. For instance, do a particular “faalruimtefactor” (*f*) and safety standard (*Pnorm*) yield the proper reliability requirement (*PT, segment*)? Benchmarks will be provided by cluster C when required by Cluster Software and when the calibration exercises have been finalized.

Unit tests involving the load model (incl. Hydra Ring) and resistance models can only be developed when these models have been finalized.

# References

CUR190 (2000). Kansen in de civiele techniek. ISBN 90 376 0102 2.

Diermanse, F. (2014) Programma WTI 2017 Projectplan cluster onzekerheden en probabilistiek 2015, versie 1. Deltares. 1209431-001-ZWS-0001.

’t Hart, R. (2015) Specificatie t.b.v. implementatie GOLFKLAP in Ringtoets, concept. Deltares. 1220086-009-HYE.

Jongejan, R.B. (2013). Kalibratie van semi-probabilistische toetsvoorschriften: Algemeen gedeelte. Deltares. 1207803-003-GEO-0003.

Lam, K.S. (2015). Knelpunt en voorstel voor het omgaan met scenario's in WTI2017. Memo. Deltares. 18 februari 2015.

Schweckendiek, T. (2014). Treatment of Schematisation Uncertainties in WTI-2017. Memo. 1209431-007-ZWS-0003. Deltares.

1. It has not yet been decided whether Li and IL will be treated as random variables in safety assessments. Therefore the quantiles are not known yet. These will be known when the calibration is finished in September 2015. [↑](#footnote-ref-1)