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Failure Mechanism Module Grass Wave Runup Zone Requirements and Functional Design

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Hans de Waal
Andre van Hoven

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Summary
This document contains the requirements and functional design for a software kernel that computes the erosion of a grass revetment in the wave runup zone. This kernel will be referred to as the 'grass-runup' kernel. This kernel eventually forms a part of the WTI 2017 failure mechanism library.

References
KPP 2015 WK07 Waterveiligheidsinstrumentarium - VTV Tools.

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1	July 2015	J.P. de Waal		J.W. van der Meer		M.R.A. van Gent	
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1 Introduction

1.1 Purpose and scope of this document

This document contains the requirements and functional design for a kernel that computes the erosion of a grass revetment in the wave runup zone. This kernel will be referred to as the 'grass-runup' kernel. This kernel eventually forms a part of the WTI 2017 failure mechanism library.

The document will not give any background on the context of the WTI project and on the derivation or motivation of the supported physical models. For this purpose the reader is referred to the VTV2017 and to its supporting technical reports and their background reports underneath.

1.2 Other system documents

The full documentation on the grass runup kernel comprises the following documents.

Title	Content
Scientific background (Van Hoven, 2015a) and (Van der Meer et al, 2015)	Scientific background of methods and rules
Requirements and functional design	This document
Technical Design	Definition of the different software components and their interaction
Programmers documentation	Description of the arguments and usage of different software components, generated from in-line comment with Doxygen
Test plan	Description of the different regression and acceptation tests, including target values.
Test report	Description of the test results.

1.3 Assumptions and constraints

CNS 1 As a general constraint, the sofware design needs to comply with the general design description for WTI software, contained in separate documents: (Knoeff and De Waal, 2014), (Brinkman, 2012) and for failure mechanism modules (Visschedijk and De Waal, 2013).

CNS 2 As a general constraint, the kernel needs to comply with the relevant general requirements and further rules for the programming, documentation and testing of WTI software. This set of requirements and rules is contained in separate documents: (Kuyper, 2012), and for failure mechanism modules (Icke, 2014) and (De Waal and The, 2015)

CNS 3 As a general WTI software constraint, the failure mechanism library will contain only components for a deterministic analysis to calculate a factor of safety or a limit state function (LSF, for probabilistic analysis), with a choice between different models for different (sub)mechanisms, that can be called separately. In case of different submechanisms, the limit state functions will be supplied only per submechanism. The combination of these submechanisms inside a certain probabilistic procedure is expected to be performed in the external software (notably the probabilistic core of Ringtoets, called Hydra-Ring).

CNS 4 As a general WTI software constraint, all model constants need to be adaptable outside the kernel, in order to allow for varying values during probabilistic analysis.

CNS 5 As a general WTI software constraint, the failure mechanism library needs to support at least all models that are prescribed for detailed assessment according to the VTV2017.

CNS 6 As a general WTI software constraint, the software interface (API) must allow usage from C# (Ringtoets), as well as from FORTRAN (Hydra-Ring), and MATLAB (test environment). The API should include a pointer to a feedback function for messages and warnings, with standardized interface.

2 Requirements

2.1 General and nonfunctional requirements

The externally defined general and non-functional requirements for all WTI software apply, see CNS 2.

2.2 Functional requirements for the grass-runup kernel

REQ 1 Every computation by the kernel deals with:

- one point (level) on the outer slope of the dike;
- one storm event (time series of hydraulic load parameters)

REQ 2 It must be possible to provide the kernel with the time series of hydraulic load parameters within a storm event in two ways:

1 via direct input of a time series of water level and wave conditions (no action by the kernel required);
2 via input of a time series of water level and a tabulated relationship between water level and wave conditions (the kernel generates the time series of wave conditions).

REQ 3 It must be possible to account for the number of waves in a stationary (part of the) storm event (also known as 'sea state') in two ways:

1 via the cumulative overload for the actual number of waves ('no-scaling');
2 via linear scaling of the cumulative overload for a fixed number of waves ('scaling').

3 Formulae

3.1 Introduction

Consider a (fixed point at) level z_{eval} (input) on the grass revetment on the outer slope of the dike and consider one full storm event, described by a series of hydraulic load parameters (water level and wave conditions) at the toe of the dike.

The basis of failure mechanism (and therefore the heart of the computation) is defined for a time interval of stationary hydraulic load parameters at the toe (sea state). For this time interval the kernel computes a 'cumulative overload' value at the considered level at the slope, based on the number of individual wave runup events and the statistics of the wave runup phenomenon within the time interval.

The kernel schematizes a storm event as a series of stationary time intervals. The kernel calculates the cumulative overload value for a storm event by accumulating the results of the stationary time intervals (at the considered level on the outer slope).

In the area below still water z_{swl} the erosive load due to the wave *impact* is assumed to be dominant over the erosive load due to the wave *runup* velocity. Therefore, the analysis of grass-runup is restricted to:

$$z_{eval} > \max_{storm\ event}\left(z_{swl}\right) \tag{3.1}$$

Where:

z_{eval} Level of interest on the outer slope (mNAP)
z_{swl} Still water level (mNAP)

In the following sections the formulae for the failure mechanism are elaborated.

3.2 Failure mechanism

If at the level of interest z_{eval} the effective load of a single wave runup event exceeds a critical load then the runup event adds to the cumulative overload D_{load} at z_{eval}. If the cumulative overload exceeds a certain critical value D_{crit}, then the grass will start to erode (show damage) and - after continued load exceeding a higher critical value - will fail. The formula describing this process is:

in terms of the failure function Z:

$$Z = D_{crit} - D_{load} \tag{3.2}$$

and in terms of the Factor of Safety (FoS):

$$FoS = \frac{D_{crit}}{D_{load}} \tag{3.3}$$

The failure mechanism description does not take residual strength of the dike core into account.

The critical value D_{crit} may be interpreted as the strength, and the cumulative overload D_{load} as the (hydraulic) load. More details about strength and load are given in section 3.3 and 3.4, respectively.

In applications like Ringtoets the user specifies a single value for z_{eval}, guided by the 'Schematiseringshandleiding'. The application passes this value to the grass runup kernel. By default, z_{eval} is equal to the minimum level on the grass layer above the wave impact zone.

3.3 Strength

The basic parameter representing the strength of the grass revetment is D_{crit}, the critical value of cumulative overload. For D_{crit} only two values are known yet, depending on the level of damage considered:

$$D_{\text{crit,damage}} = 4000\ \text{m}^2/\text{s}^2 \quad (3.4)$$

$$D_{\text{crit,failure}} = 7000\ \text{m}^2/\text{s}^2 \quad (3.5)$$

D_{crit} does not depend on any load or strength characteristic.

In fact, two other strength parameters will also show to play a role in the failure mechanism:
- U_c, the critical wave runup front velocity along the slope
- α_S, the factor for decreased strength at transitions and objects

The value for the critical front velocity U_c is assumed to depend on the grass quality only.
The role of parameters U_c and α_S will be further discussed within the context of the hydraulic load.

3.4 Hydraulic load

3.4.1 Introduction

Notation

Within a stationary time interval it is convenient to define the level of interest with respect to still water level:

$$z = z_{eval} - z_{swl} \quad (3.6)$$

Where:
z Level of interest with respect to still water level (m)

Note that, from Eqn, (3.1) it is clear that:

$$z > 0 \quad (3.7)$$

Parameters pertaining to the specified level of interest will have 'z' as (extra) subscript in the formulae, but not always in the text.

The basic parameter representing the hydraulic load on the grass revetment is D_{load}, the cumulative overload.

The erosive load at z is determined by the front velocity U of the uprunning wave i. The following phenomena are considered not to contribute significantly to the erosive load:
- the flow down the slope;
- the transition in flow direction from upward to downward.

If the effective front velocity load $\alpha_M U^2$ of wave runup i at level z exceeds a critical velocity load $\alpha_S U_c^2$, the wave adds to the cumulative overload D_{load} at level z. The formula describing this process is:

$$D_{load,z} = \sum_{i=1}^{N} \max\left(\alpha_{M,z} U_{i,z}^2 - \alpha_{S,z} U_c^2 ; 0\right) \quad (3.8)$$

Where:
N Number of incident waves (-)
$U_{i,z}$ Front velocity along the slope of wave runup i at level z (m/s)
U_c Critical front velocity along the slope (m/s)
$D_{load,z}$ Cumulative overload at level z (m^2/s^2)
$\alpha_{M,z}$ Factor for increased load at transitions and objects, $\alpha_{M,z} \geq 1$ (-)
$\alpha_{S,z}$ Factor for decreased strength at transitions and objects, $0 < \alpha_{S,z} \leq 1$ (-)

The number of uprunning waves is assumed equal to the total number of incident waves at the dike toe N.

3.4.2 Front velocities in a single runup event

The maximum front velocity $U_{i,max}$ of runup event i having a runup height Ru_i, is described by:

$$U_{\mathrm{i,max}} = c_u \sqrt{g \cdot Ru_i} \tag{3.9}$$

Where:

$U_{i,max}$ Maximum front velocity along the slope of wave runup i at level z (m/s)
c_u Constant (-)
g Acceleration due to gravity (m/s^2)
Ru_i Runup level of runup event i with respect to still water level (m)

The value to be used for constant c_u within the failure mechanism model is, see (Van Hoven, 2015b):

$$c_u = 1.1 \tag{3.10}$$

The actual front velocity $U_{i,z}$ depends on the level of interest z. Between the still water level and 75% of the run up level it is advised to use the U_{max}. Between 75% and 100% of the run up level of a particular wave runup event, it is assumed the velocity decreases linearly (Figure 3.1).

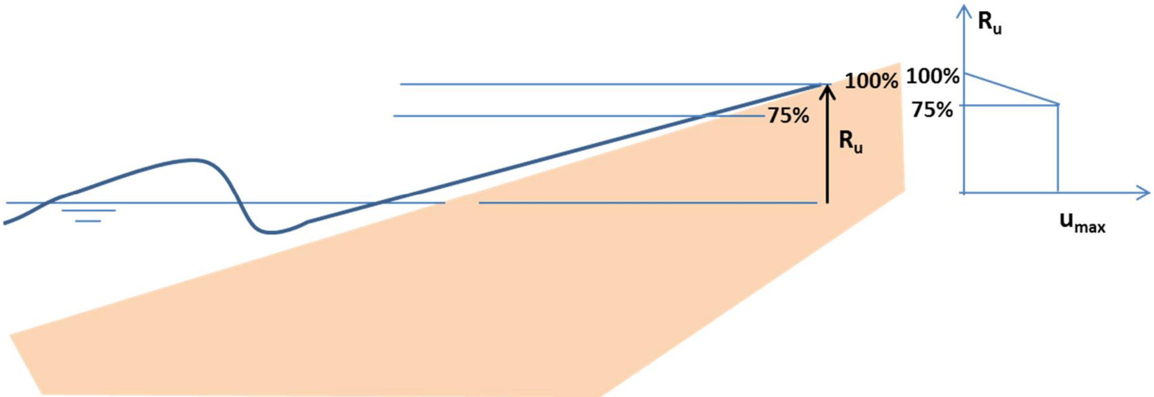

Figure 3.1 Front velocity of uprush of water U (m/s) in relation to the runup level Ru (m) for a particular wave runup event

The front velocity $U_{i,z}$, is then given by:

$$U_{i,z} = U_{\mathrm{i,max}} \cdot \max\left(0; \min\left(1; \frac{Ru_i - z}{Ru_i - 0.75 \cdot Ru_i}\right)\right) \tag{3.11}$$

or, slightly rewritten:

$$U_{i,z} = U_{\mathrm{i,max}} \cdot \max\left(0; \min\left(1; \frac{Ru_i - z}{0.25 \cdot Ru_i}\right)\right) \tag{3.12}$$

Substitution of (3.9) into (3.12) yields:

$$U_{i,z} = c_u \sqrt{g \cdot Ru_i} \cdot \max\left(0; \min\left(1; \frac{Ru_i - z}{0.25 \cdot Ru_i}\right)\right) \tag{3.13}$$

3.4.3 Runup levels within a single stationary event of N waves

The runup height Ru (m relative to the still water level) for a wave field reaching a dike is assumed to be Rayleigh distributed (disregarding any change in slope angle or roughness along the slope). With a calculated 2% runup height $Ru_{2\%}$, the probability function becomes:

$$P(\underline{Ru} > Ru) = \exp\left(\ln\left(0.02\right) \cdot \frac{Ru^2}{Ru_{2\%}{}^2} \right) \tag{3.14}$$

The probability function can also be re-written to calculate the runup level from a probability of exceedance P(<u>Ru</u>>Ru):

$$Ru = Ru_{2\%} \cdot \sqrt{\frac{\ln\left(P(\underline{Ru} > Ru)\right)}{\ln\left(0.02\right)}} \tag{3.15}$$

With this formula an approximation of all individual runup levels $Ru_{1..N}$ within a storm event condition can be given. If the wave runup levels $Ru_{1..N}$ are sorted in an increasing order, then the probability of exceedance of runup i of N waves is approximated as:

$$P(\underline{Ru} > Ru_i) = 1 - \frac{i}{N+1} \tag{3.16}$$

Substitution of (3.16) into (3.15) yields:

$$Ru_i = Ru_{2\%} \cdot \sqrt{\frac{\ln\left(1 - \frac{i}{N+1}\right)}{\ln\left(0.02\right)}} \tag{3.17}$$

With the given equations the cumulative overload (Eqn (3.8) and (3.13)) can be calculated for a given stationary hydraulic event of N waves and a calculated 2% runup height $Ru_{2\%}$.

3.4.4 The number of incident waves

The (actual) number of incident waves is based on the duration of the stationary event ΔT en the mean wave period T_m:

$$N_{actual} = \frac{3600 \cdot \Delta T}{T_m} \tag{3.18}$$

Where:
ΔT Duration of the stationary time interval (hr)
T_m Mean wave period (s)

Note that the factor 3600 is necessary due to the difference in units (hr versus s) between the two time parameters.

No scaling:

$$D_{load,z}\left(\text{no scaling}\right) = D_{load,z}\left(N = N_{actual}\right) \tag{3.19}$$

Scaling:

$$D_{load,z}\left(\text{scaling}\right) = \frac{N_{actual}}{N_{fixed}} \cdot D_{load,z}\left(N = N_{fixed}\right) \tag{3.20}$$

Just like the choice between 'scaling' and 'no-scaling', the fixed reference value N_{fixed} is an input parameter (actually a model setting) for the kernel. The value of N_{fixed} should lie between about 1000 and 10000.

3.4.5 The 2% runup level in a stationary event

The 2% runup level $Ru_{2\%}$ is assessed using the failure mechanism module for wave runup and overtopping at dikes. For the specifications of the input and output parameters the reader is referred to the functional design of the module for wave runup and overtopping at dikes, (Kuijet et al, 2015).

3.4.6 Cumulative load in a non-stationary storm event

A storm event is usually a non-stationary event. In the computation it is treated as a series of stationary events. For every storm event the value of D_{load} starts at 0.

$$D_{load,zeval,storm} = \sum_{i\Delta T=1}^{N\Delta T} D_{load,z,i\Delta T} \tag{3.21}$$

Where:
NΔT The total number of stationary time intervals within the storm event (-)
iΔT The index number of the stationary time interval within the storm event (-)

Note that z_{eval} has a fixed value for the entire storm event, whereas z can be different for each stationary time interval within the storm event (due to variation of the still water level z_{swl}), however, the point of interest on the slope remains the same.

3.4.7 Factor of Safety

The Factor of Safety at the end of a considered time step during a storm event $D_{load,zeval,cum}$ is defined as follows:

$$\begin{aligned} &if\ D_{load,\mathrm{zeval,cum}} \le \frac{1}{FoS_{\max}} \quad then \quad FoS = FoS_{\max} \\ &\qquad\qquad else \quad FoS = \frac{D_{crit}}{D_{load,\mathrm{zeval,cum}}} \end{aligned} \tag{3.22}$$

Where
FoS Factor of safety (-)
FoS_{max} Maximum value for the factor of safety (-)

$D_{load,zeval,cum}$ Cumulative overload at level z_{eval} (mNAP) up until and including the last considered time step (m^2/s^2)

The parameter FoS_{max} is an internal model setting and is primarily introduced to avoid dividing by zero. Its value should be set distinctly larger than 1, for example at 10.

The factor of safety at the end of the storm is defined as follows:

$$\begin{aligned} &if\ \ D_{load,\text{zeval,storm}} \le \frac{1}{FoS_{\max}} \quad then \quad FoS = FoS_{\max} \\ &\qquad\qquad else \quad FoS = \frac{D_{crit}}{D_{load,\text{zeval,storm}}} \end{aligned} \tag{3.23}$$

3.4.8 Composing a synthetic storm event[1]

Available:

- a time series of water level fluctuation during the storm event;
- a tabulated relationship between water level and wave conditions (height, period, direction), usually produced by a probabilistic computation (the so-called Q-variant).

At each time step where the water level is available, the corresponding value for the wave height, wave period and wave direction respectively is found by linear *interpolation* in the tabulated relationship. In cases where *extrapolation* appears to be required, the following rules apply:

- If the water level is more than 0.03 m higher than the highest water level in the tabulated relationship, then the input data is suspect and no computation should be made.
- If the water level is less than 0.03 m higher than the highest water level in the tabulated relationship, then the values at the highest water level in the tabulated relationship must be applied.
- If the water level is lower than the lowest water level in the tabulated relationship, then the values at the lowest water level in the tabulated relationship must be applied.

Next to the spectral wave period $T_{m-1,0}$ (which is provided as input) also a mean wave period T_m is required. This parameter is assessed using:

$$T_m = c_{Tm\_Tm-1,0} \cdot T_{m-1,0} \tag{3.24}$$

Where:

$c_{Tm\_Tm-1,0}$ Constant (-)

[1] *Note that this functionality may already exist and/or be shared with other failure mechanism descriptions.*

3.4.9 Creating a series of stationary time intervals[2]

The method for creating a series of stationary time intervals is illustrated in Figure 3.2.

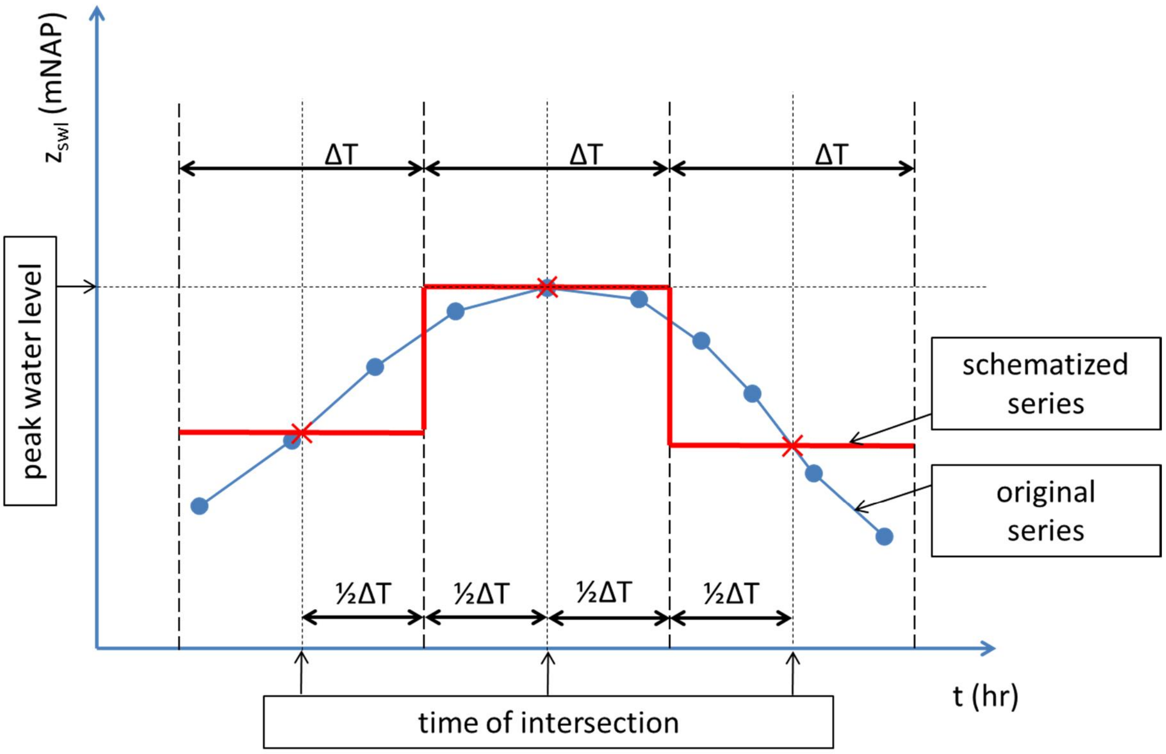

Figure 3.2 The concept of creating a series of stationary time intervals.

The method consists of the following steps:

1 Find the maximum water level $z_{swl,max}$ in the original time series.
2 Find the (first) time value $t_{swl,max}$ at which the water level reaches its maximum.
3 Generate a series of intersection time values with step ΔT that includes $t_{swl,max}$. Apply these time values as the central time values of the stationary time intervals.
4 Assess the value of the water level, wave height, wave period and wave direction at the series of intersection time values, using linear interpolation. Apply these values as the stationary values for the schematized stationary time intervals.

[2] *Note that this functionality may already exist and/or be shared with other failure mechanism descriptions.*

4 Software modules and data flow

4.1 Data flow diagram

See the intended data flow in Figure 4.1 on the next page.

In this diagram the following conventions apply:
- blue boxes contain data of other types of information
- yellow boxes contain a procedure or other sort of processing
- arrows indicate the direction of the data flow

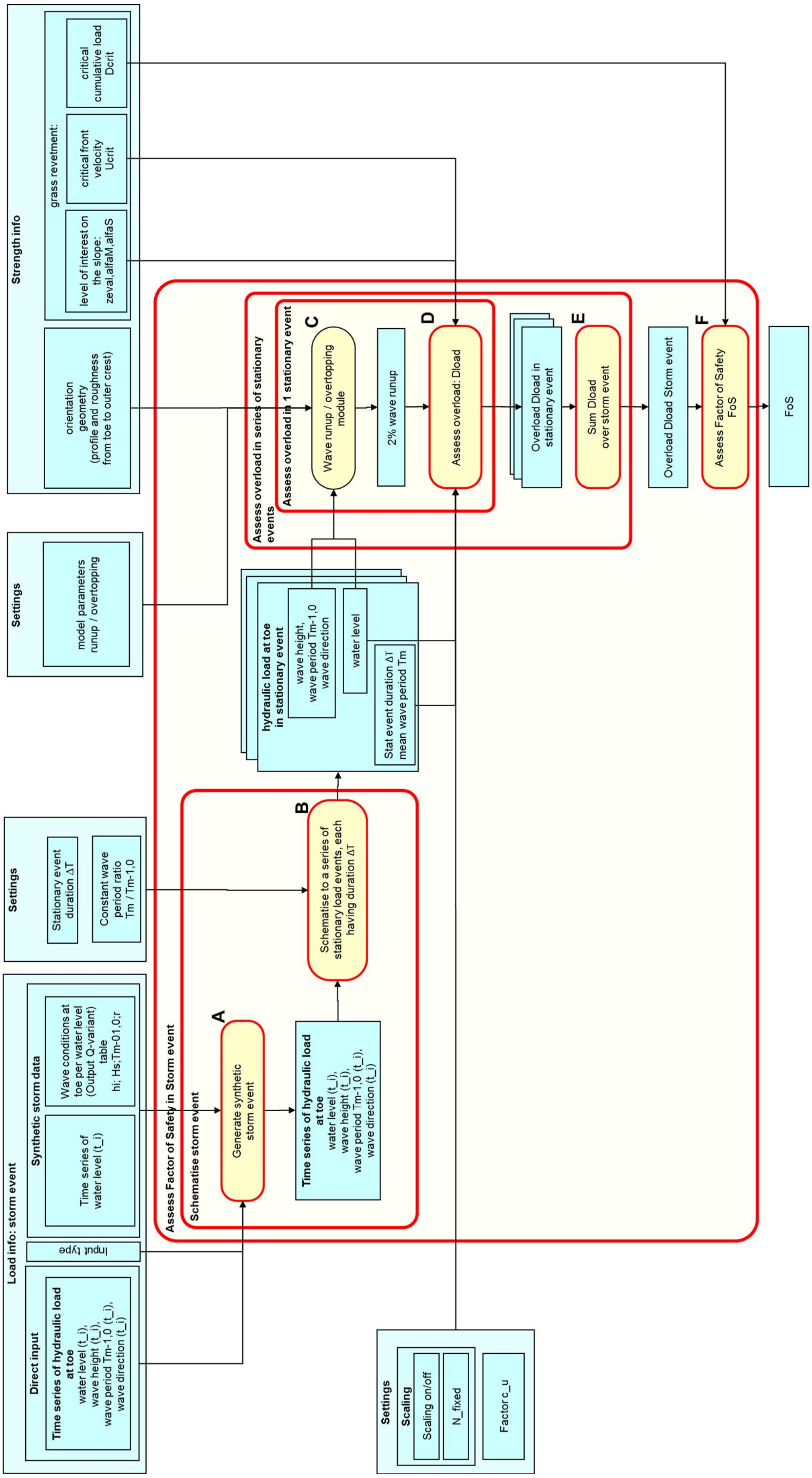

Figure 4.1 Data flow

4.2 Procedures

The procedures in the data flow diagram are labelled A through F. The link between these labels and the formulae in Chapter 3 is given in Table 4.1.

Label	Section(s)	Equation(s)
A	3.4.8	-
B	3.4.9	-
C	3.4.5	-
D	3.4.1; 3.4.2; 3.4.3; 3.4.4	(3.6); (3.8); (3.13); (3.17); (3.18); (3.19); (3.20)
E	3.4.6	(3.21)
F	3.4.7	(3.22)

Table 4.1 Link between procedure labels and sections and equations.

4.3 Input data

The storm event information must include the specification of the type of input, which is a choice between 'direct input' or 'synthetic storm data'.

Direct input basically consists of a table of a time series of hydraulic load at the toe, having the following columns:

t	hr	Time indication within a storm event
z_{swl}	mNAP	Still water level
H_{m0}	m	Significant wave height at dike toe
$T_{m-1,0}$	s	Spectral wave period at dike toe
θ	degN	Mean wave direction at dike toe

Synthetic storm data consist of two tables, having the following columns.

Table 1:

t	hr	Time indication within a storm event
z_{swl}	mNAP	Still water level

Table 2:

z_{swl}	mNAP	Still water level
H_{m0}	m	Significant wave height at dike toe
$T_{m-1,0}$	s	Spectral wave period at dike toe
θ	degN	Mean wave direction at dike toe

The second 2-table option is introduced to accommodate the hydraulic data available within the statutory safety assessment toolkit for The Netherlands (WTI2017).

In the synthetic storm data, the time series of the water level may be generated on the basis of a set of parameters like tidal range and storm setup, but this procedure is outside the scope of the present kernel.

Note that table 2 of the synthetic storm data does not contain time information. Instead, the water level is the key parameter.

The model settings for the storm event schematization are:

ΔT	hr	Duration of stationary time interval
$c_{Tm\_Tm-1,0}$	-	Constant, ratio of T_m and $T_{m-1,0}$

The strength information pertaining to the grass revetment consists of:

z_{eval}	mNAP	Level of interest on the outer slope
α_M	-	Factor for increased load at transitions and objects
α_S	-	Factor for decreased strength at transitions and objects
U_c	m/s	Critical wave runup front velocity along the slope
D_{crit}	m^2/s^2	Critical value of cumulative overload (one value)

For the wave runup computation the following information is required, see (Kuijper et al, 2015):

ψ	degN	Orientation of the dike normal
x	m	x-coordinates cross section (profile), $(x_1,..., x_m)$
y	mNAP	y-coordinates cross section (profile), $(y_1,..., y_m)$
r	-	roughness factor dike segments $(r_1,..., r_{m-1})$

In addition, the wave runup computation requires the following model settings, see (Kuijper et al, 2015):

$f_{run\text{-}up1}$	-	Model factor wave run-up 1
$f_{run\text{-}up2}$	-	Model factor wave run-up 2
$f_{run\text{-}up3}$	-	Model factor wave run-up 3
f_b	-	Model factor for breaking waves
f_n	-	Model factor for non-breaking waves
$f_{shallow}$	-	Model factor for shallow waves

Finally, the computation of the cumulative overload requires a choice between scaling and no-scaling. In the case of 'scaling', the next parameter is also required:

N_{fixed}	-	Reference number of incident waves (i.e. runup events) within a stationary time interval in case of scaling

Indepedently on the choice for scaling is required:

c_u	-	Constant (factor in relation between Runup level and Maximum front velocity)

4.4 Output data

The primary output of the computation is the Factor of Safety FoS for the storm event for the grass revetment at the level of interest on the outer slope.

In addition, all intermediate data as shown in Figure 4.1 (i.e. the blue data boxes within the overall procedure) should become available as (secondary) output.

This secondary output may exist of two tables.

Table 1:

t	hr	Time indication within a storm event
z_{swl}	mNAP	Still water level
H_{m0}	m	Significant wave height at dike toe
$T_{m-1,0}$	s	Spectral wave period at dike toe
θ	degN	Mean wave direction at dike toe

Table 2:

t	hr	Time indication within a storm event: end time of interval having the presented stationary hydraulic load
z_{swl}	mNAP	Still water level
H_{m0}	m	Significant wave height at dike toe
$T_{m-1,0}$	s	Spectral wave period at dike toe
T_m	s	Mean wave period at dike toe
θ	degN	Mean wave direction at dike toe
$Ru_{2\%}$	m	Runup level with respect to still water level, which is exceeded by 2% of the incident waves
$D_{load,int}$	m^2/s^2	Cumulative overload in the time interval having the presented stationary hydraulic load
$D_{load,cum}$	m^2/s^2	Cumulative overload up to this time within the storm event
FoS	-	Factor of Safety up to this time within the storm event

Note that the time indicators in Table 1 and 2 have different values, due to the (most likely) difference in time step between input time series and schematized time series.

5 Overview of Parameters

Symbol	Unit	Description	Valid Interval	Likely interval
c_u	-	Constant (factor in relation between Runup level and Maximum front velocity)	(0,∞)	[0.5,5.0]
$c_{Tm\_Tm-1,0}$	-	Constant, ratio of T_m and $T_{m-1,0}$	(0,∞)	
$D_{load,z}$	m^2/s^2	Cumulative overload at level z	[0,∞)	
$D_{load,zeval,cum}$	m^2/s^2	Cumulative overload at level z_{eval} until (and including) the considered time interval	[0,∞)	
$D_{load,zeval,storm}$	m^2/s^2	Cumulative overload at level z_{eval} after the entire storm event	[0,∞)	
D_{crit}	m^2/s^2	Critical value of cumulative overload	(0,∞)	
$D_{crit,damage}$	m^2/s^2	Critical value of cumulative overload, indicating the start of damage	(0,∞)	
$D_{crit,failure}$	m^2/s^2	Critical value of cumulative overload, indicating failure	(0,∞)	
FoS	-	Factor of Safety	(0,∞)	(0,10)
FoS_{max}	-	Maximum value for the factor of safety	(1,∞)	[2,10]
$f_{run-up1}$	-	Model factor wave run-up 1		
$f_{run-up2}$	-	Model factor wave run-up 2		
$f_{run-up3}$	-	Model factor wave run-up 3		
f_b	-	Model factor for breaking waves		
f_n	-	Model factor for non-breaking waves		
$f_{shallow}$	-	Model factor for shallow waves		
g	m/s^2	Acceleration due to gravity	(0, ∞)	[9.80,9.82]
h	mNAP	Still water level (=z_{swl})	(-∞,∞)	[-10,100]
H_{m0}	m	Significant wave height at dike toe	[0,∞)	[0,10]
N	-	Number of incident waves	[0,∞)	[50,50000]
N_{fixed}	-	Reference number of incident waves in case of scaling	[0,∞)	[50,50000]
$Ru_{2\%}$	m	Runup level with respect to still water level, which is exceeded by 2% of the incident waves	[0,∞)	
Ru_i	m	Runup level of runup event i with respect to still water level	[0,∞)	
r	-	Roughness factor dike segments (r_1,..., r_{m-1})		
T_m	s	Mean wave period at dike toe	[0,∞)	[0,25]
$T_{m-1,0}$	s	Spectral wave period at dike toe	[0,∞)	[0,25]
t	hr	Time indication within a storm	(-∞,∞)	[-100,200]

Symbol	Unit	Description	Valid Interval	Likely interval
		event		
U_c	m/s	Critical wave runup front velocity along the slope	(0,∞)	
$U_{i,max}$	m/s	Maximum front velocity along the slope of wave runup i at level z	[0,∞)	
$U_{i,z}$	m/s	Front velocity along the slope of wave runup i at level z	[0,∞)	
x	m	x-coordinates cross section (profile), (x_1,..., x_m)		
y	mNAP	y-coordinates cross section (profile), (y_1,..., y_m)		
z	m	Level of interest with respect to still water level	(0,∞)	
z_{eval}	mNAP	Level of interest	(-∞,∞)	[-10,100]
z_{swl}	mNAP	Still water level	(-∞,∞)	[-10,100]
α_M	-	Factor for increased load at transitions and objects	[1,∞)	[1,5]
α_S	-	Factor for decreased strength at transitions and objects	(0,1]	
ΔT	hr	Duration of stationary time interval	(0,∞)	[0.2,2.0]
ψ	degN	Orientation of the dike normal		
θ	degN	Mean wave direction at dike toe	[0,360]	

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