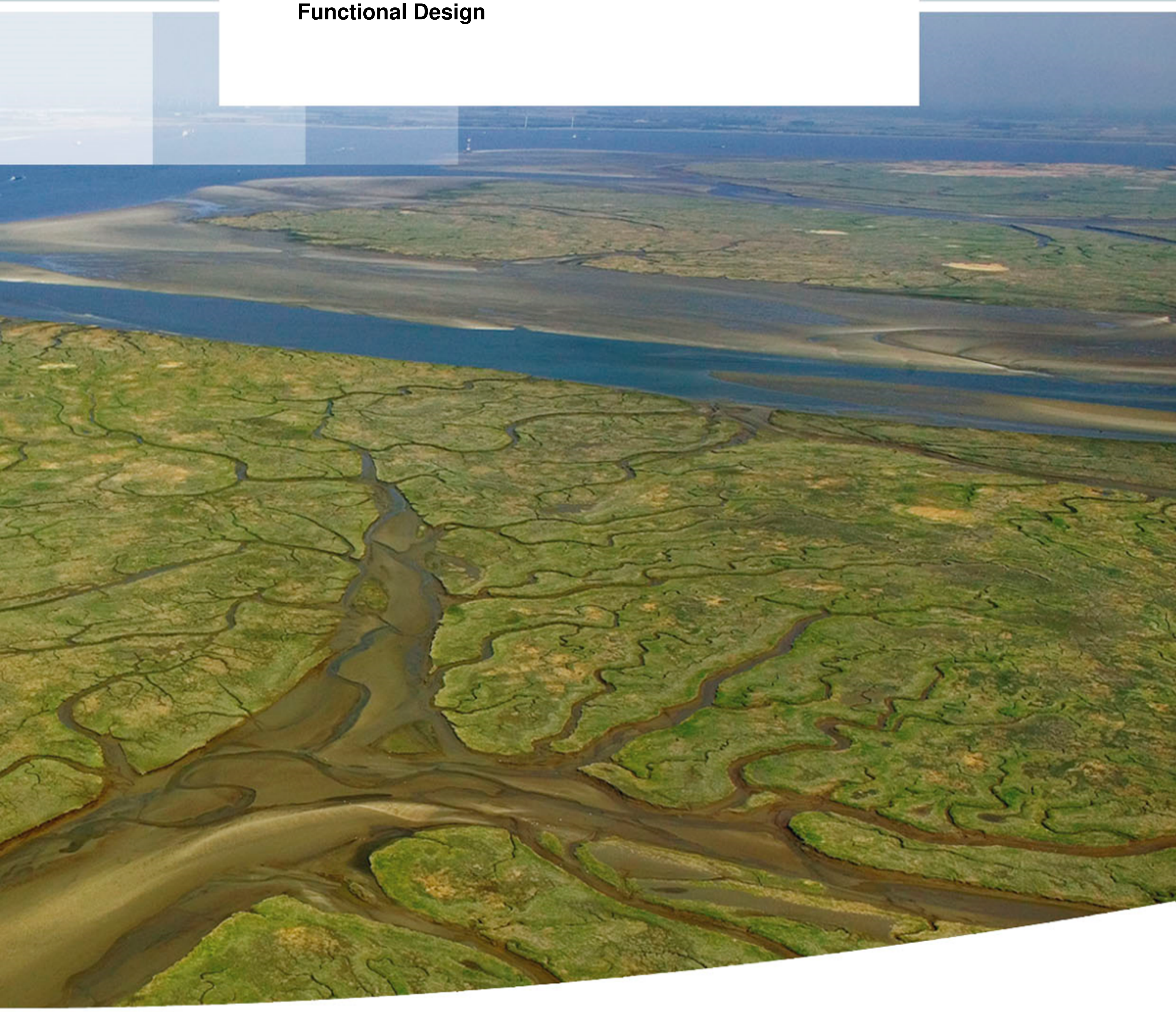
DAM Engine

Functional Design



DAM Engine

Functional Design

1210702-000

Deltares

Deltares

Title
DAM Engine

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Dike, safety assessment, design, software, macro stability, piping

Summary
This document contains the functional design for DAM Engine, a software module that computes the strength of a complete dikering with respect to several failure mechanisms, such as macro stability and piping.

Samenvatting
Dit document bevat het functioneel ontwerp voor DAM Engine, een software module die een gebruiker in staat stelt om voor een dijktraject berekeningen uit te voeren voor verschillende faalmechanismen, waaronder macrostabiliteit en piping.

References
Refer to chapter 4.

Version	Date	Author	Initials	Review	Initials	Approval	Initials
0.1	Jul 2017	Irene van der Zwan		Kin Sun Lam André Grijze		Maya Sule	

Status
draft
This is a draft report, intended for discussion purposes only. No part of this report may be relied upon by either principals or third parties.

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1 Introduction

1.1 Purpose and scope of this document

This document contains the functional design for the DAM Engine, a computational engine for the automated calculation of the strength of dikes. DAM was developed by Deltares with and for STOWA for all water authorities. This document describes requirements and functional design of DAM Engine. What will actually will be implemented depends on the requirements of the clients using this DAM Engine. If some functionality is not (yet) needed, then that part does not need to be implemented.

1.1.1 Future options

As mentioned above this document contains some options that will not be implemented in the first release, but are foreseen to be implemented in the near future. Therefore although sometimes a reference will be made to these options, these will not be described in detail yet.

That applies in particular to the following subjects:

- NWO module("Niet Waterkerende Objecten")
- WBI failure mechanisms (Piping, Macrostability)

1.2 Other system documents

The full documentation on the program comprises the following documents.

Title	**Content**
DAM Engine- Architecture Overall (The, 2017a)	Description of overall architecture of the DAM Engine and its components.
DAM Engine- Functional Design (this document) (Zwan, 2017)	Description of the requirements and functional design.
DAM Engine- Technical Design (The, 2017b)	Description of the implementation of the technical design of DAM Engine.
DAM Engine- Technical documentation (Doxygen, 2017)	Description of the arguments and usage of different software components, generated from in-line comment with Doxygen.
DAM Engine- Test Plan (Trompille, 2017a)	Description of the different regression and acceptation tests, including target values.
DAM Engine- Test Report (Trompille, 2017b)	Description of the test results (benchmarks and test scripts).
Architecture Guidelines (Kleijn *et al.*, 2017)	Architecture guidelines that are used by DSC-Deltares.

Table 1.1: *DAM Engine system documents.*

1.3 Document revisions

1.4 Document revisions

1.4.1 Revision 0.1

First concept of the document.

2 Non-functional requirements

3 Functional requirements

Main purpose of the DAM Engine The DAM Engine gets data from DAM Clients, combines this data to calculation input and make serially calculations with one ore more kernels and generates output.

3.1 REQ Data.Format

The DAM Engine has a defined format for the data input, so DAM Clients know how to arrange the input data.

3.2 REQ Data.Content

The DAM Engine has a defined content for the data input, so DAM Clients know how to arrange the input data.

3.3 REQ Data.Combination

The DAM Engine combines data per location when data is provide in GIS-files. Locations are defined by RD-coordinates. The design of this functionality is described in Appendix A.

3.4 REQ Data.Generation.Geometry

The DAM Engine can combine a surface line with a subsoil scenario. The result is a geometry, usable for the failure mechanism Macrostability.

3.5 REQ Data.Generation.Porepressures

The DAM Engine can combine the hydraulic data with a subsoil scenario. The result is a schematization of the pore pressures, usable for the failure mechanisms Piping and Macrostability. The design of this generation is mentioned in Appendix B.

3.6 REQ Calc.Type

The DAM Engine provides three types of calculations:

1 One-fold calculation: the input goes 'through' the kernel(s) and generates one main calculation answer (assessment);
2 Goal-seeking calculation: the input contains one variable and a desired outcome, the answer is the variable sufficient for the goal (design);
3 Time-lapsed calculation; calculations are made as time serie (operational).

More specified; the DAM Engine provides the following calculation types, so the DAM Clients can provide this functionality.

- Assessment general
- Assessment regional dikes
- Operational calculation from sensor data
- Design of geometry, given required safety factor: Design-Geometry
- Design of normative NWO-location, given dimensions of NWO and required safety factor: Design-NWO

3.7 REQ Calc.Assess.General

The DAM engine provides a Factor of safety. This may be one calculation or several. More than one calculation becames available when using several locations and/or several scenarios.

3.8 REQ Calc.Assess.Loadscenarios

The DAM engine must be able to calculate several load scenarios with different input data per location.

3.9 REQ Calc.Assess.Regional

For the assessment of regional dikes, DAM Engine must calculate several assessment scenarios (RRD-scenario). The design of this scenario selection is descriped in Appendix C.

3.10 REQ Calc.Operational.Sensor

The DAM Engine must be able to use sensor data as input for the generation of water pressures.

3.11 REQ Calc.Design.Geometry

The DAM engine must be able to generate new profiles (surfacelines) based on desired Factor of safety. This can be done by:

1 Raising the crest
2 Reducing the gradient of the slope
3 Shoulder development

The design of this geometry adeption is worked out in Appendix D

3.12 REQ Calc.Design.NWO

This will not be part of the first implementation of DAM Engine and therefor this paragraph has not yet been written.

3.13 REQ Failuremechanism

The DAM Engine provides calculations for following failure mechanisms, so the DAM Clients can provide this functionality.

1 Macrostability inwards;
2 Macrostability outwards;
3 Piping;

3.14 REQ Output.format

The DAM Engine has a defined format for the data output, so DAM Clients know how to present the output data.

4 Literature

Doxygen, 2017. *DAM Engine - Technical documentation, Generated by Doxygen 1.8.10*. Tech. rep., Deltares.

Kleijn, E., A. Grijze, H. Elzinga, S. Hummel and T. The, 2017. *Architecture Guidelines*. Tech. rep., Deltares.

The, T., 2017a. *DAM Architecture Overall*. Tech. Rep. 1210702-000-GEO-0005, version 0.1, jan. 2017, concept, Deltares.

The, T., 2017b. *DAM Engine - Technical Design*. Tech. Rep. 1210702-000-GEO-0004, version 0.2, mar. 2017, concept, Deltares.

Trompille, V., 2017a. *DAM Engine - Test Plan*. Tech. Rep. 1210702-000-GEO-0006, version 0.1, jan. 2017, concept, Deltares.

Trompille, V., 2017b. *DAM Engine - Test Report*. Tech. Rep. 1210702-000-GEO-0007, version 0.1, jan. 2017, concept, Deltares.

Zwan, I. v., 2017. *DAM Engine - Functional Design*. Tech. Rep. 1210702-000-GEO-0003, version 0.1, jan. 2017, concept, Deltares.

Appendix

A Data combination

A.1 Location

The locations are described with a name and RD-coordinates; a point element in GIS files. Each location is connected to a crosssection; a line element in GIS files.

The combination of data from GIS files is made based on these point and line elements. If the input data is available in a GIS file with line elements the data is collected at the intersection of the crosssection with the line element, see Figure A.1.

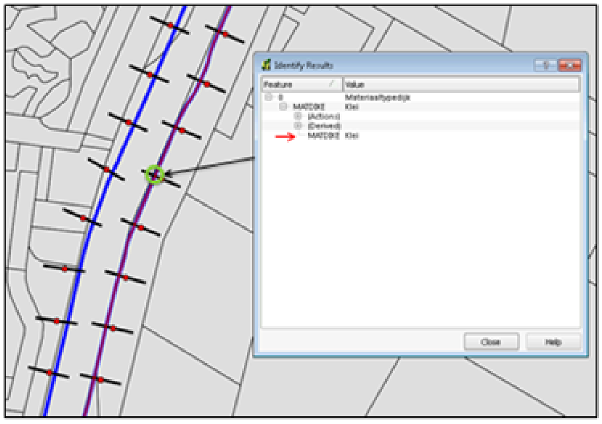

Figure A.1: *Data is collected from the line element at the intersection*

If the input data is available in a GIS file with area elements the data is collected at from the area where the location point is situated, see Figure A.2.

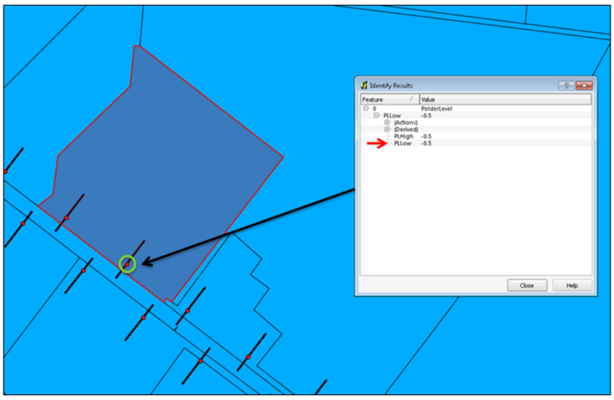

Figure A.2: *Data is collected from the area element where the location point is situated*

If the inputdata is not available in GIS files, all input data can be linked to each location via a table (csv-format).

A.2 Subsoil

The subsoil model is made up of the following elements:

- Soil segments
- Soil profiles
- Soil layers
- Soil materialparameters

A soil segment is located on a map and can contain several soil scenarios. A soil scenario is a combination of a soil profile and its probability. Each soil profile is build up from layers (1D-profile) or areas (2D-profile). A layer (or area) has the name of a material. And finally this material is described via soil type and several parameters (such as strength parameters). All is displayed in Figure A.3.

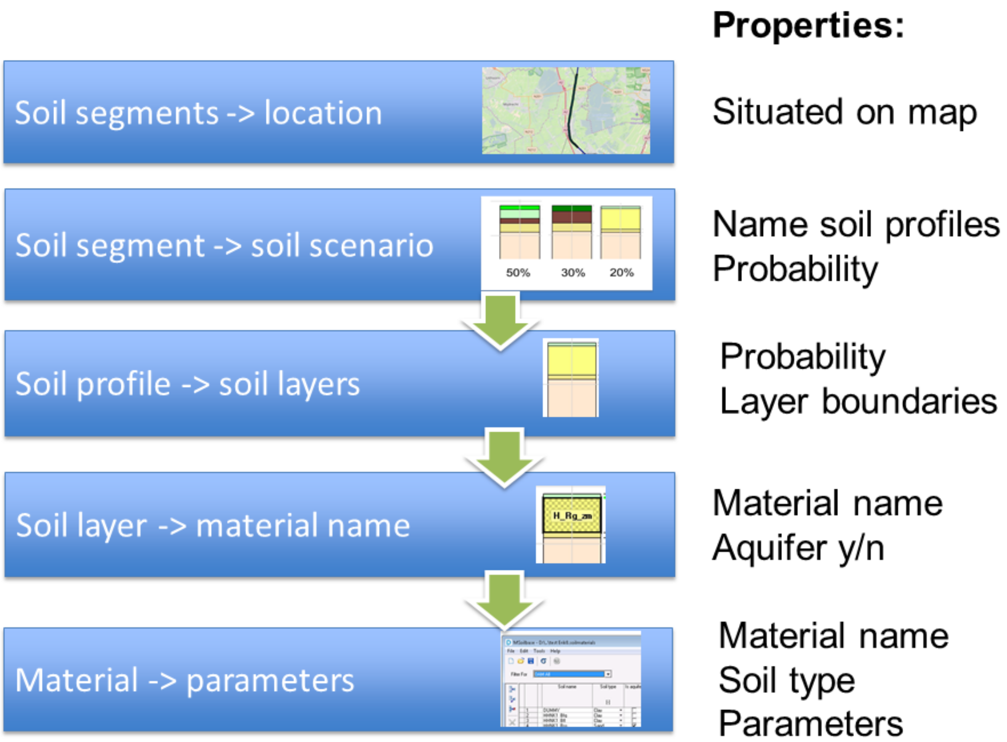

Figure A.3: *The elements of the subsoil model and their properties*

By linking the location to a soil segment, see section A.1, DAM Engine combines the location to the soil profiles of the soil segment. For piping calculations this is sufficient, for macrostability calculations a 2D-profile is necessary. This is described in section A.3.

A.3 Combination of surface line with soil profile

B Generation pore pressures

The DAM Engine can combine the hydraulic data with a subsoil scenario. The result is a schematization of the pore pressures, usable for the failure mechanisms Piping and Macrostability.

B.1 Conditions under which the automatic generation works

Under certain circumstances, the kernel must be able to produce the pore pressures in the geometry. If the following circumstances are met, the pore pressures will be schematized following the guidelines [Technisch Rapport Waterspanningen bij dijken (2004)] during a high water tide.

The requirements to automatically produce pore pressures are as follows:

- Minimum of one and maximum of two aquifers;
- The aquifers reach from one boundary to the other (CNS 8);
- The generator only works if the high water table is on the left side.

B.2 Procedure for schematisation of the pore pressures

The steps for the schematization of the pore pressures are:

1 The schematisation of the phreatic plane (see section B.3).
2 Initial schematisation of piezometric heads (see section B.4).
3 Checking for uplift (see section B.5).
4 Definitive schematisation of pore pressures (see section B.6).

B.3 Schematisation of the phreatic plane

There are currently two different approaches to the schematisation of the position of the phreatic plane: :

1 ExpertKnowledgeRRD
2 ExpertKnowledgeLinearInDike

The schematisation method can be selected by the user in the base data (attribute: PLLineCreationMethod). The schematisation method and the associated values can be defined at the location level.

The phreatic plane is referred to as Piezometric Line 1 (PL1).

B.3.1 ExpertKnowledgeRRD

The ExpertKnowledgeRDD method sets out the location of the phreatic plane at a maximum of 6 points: A to F. Figure B.1 lists these points. The level of the phreatic plane is defined by entering a number of vertical offsets relative to the outer water level or the ground level. Table B.1 lists for each point how it is determined/recorded. The location of the phreatic plane between the points is determined on the basis of linear interpolation.

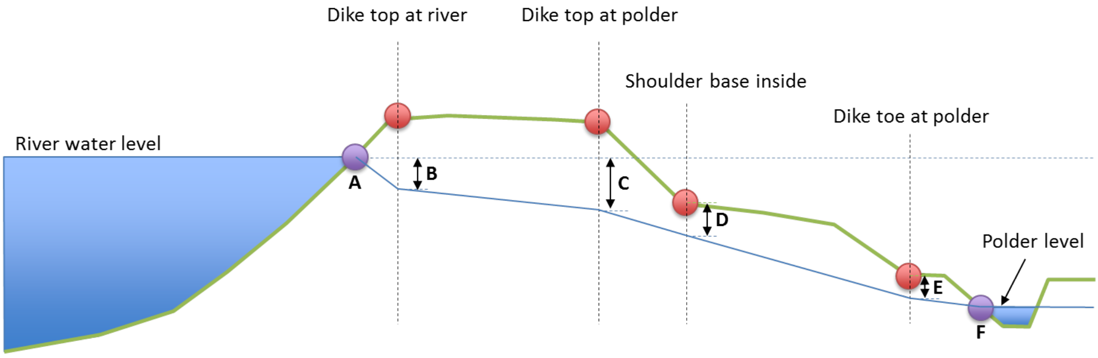

Figure B.1: *Schematisation Phreactic line (PL1) Macrostability inward using ExpertKnowledgeRRD*

Punt	Elevation determined by
A	Intersection of the water level with the outer slope (determined automatically)
B	Outer water level - stated offset
C	Outer water level - stated offset
D	Ground level shoulder base inside - stated offset
E	Ground level toe at polderside- stated offset
F	Intersection of polder level with ditch (is determined automatically).

Table B.1: *Parameters for each schematisation point used to locate the phreatic plane in the ExpertKnowledgeRRD schematisation option*

Lower levels relative to the reference point/plane are stated as positive values. When schematising a rise in the phreatic plane under the crest, the offset are stated as a negative value.

B.3.2 ExpertKnowledgeLineairDike

Here, the phreatic plane starts where the outer water level (Point A in Figure B.2 intersects the outer slope. It then continues in a straight line to point E and then to point F.

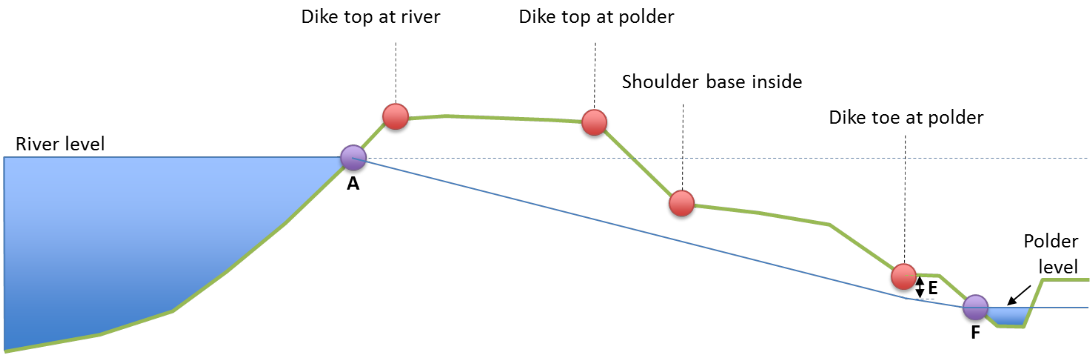

Figure B.2: *Schematisation Phreactic line (PL1) Macrostability inward using Expert-KnowledgeLineair*

B.3.3 Particular cases

The following checks are made:

Free water

The procedure must check that the phreatic plane along the dike does not extend beyond the slope. If this the case, the location is automatically adapted to follow the surface level one centimeter lower.
Free water at the polder side (right side of toe at polderside) is allowed.

No ditch, no shoulder

If there is no shoulder, point D will be omitted. If there is no ditch, the offset at point E will be continued with a limit of 1 cm below the surface line.

Phreatic line goes up

The procedure must ensure that the location of the phreatic plane is not below the stated polder level at points D and E as a result of the stated offsets. If this is the case, the location of the phreatic plane will automatically be matched to the polder level. In addition, the procedure must ensure that the phreatic plane at points D and E is not higher than at the preceding points. Point C may be higher than point B.

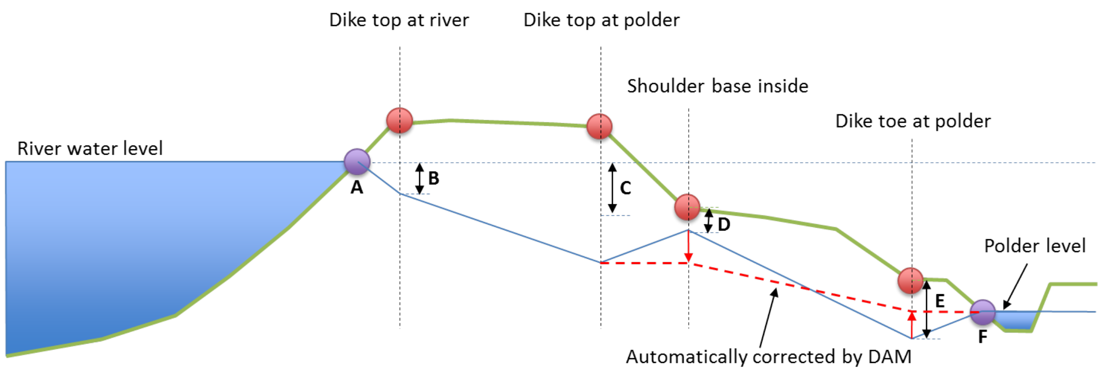

Figure B.3: *Adaption of phreactic line (PL1) when initial line would go up*

B.4 Initial schematisation of piezometric heads

DAM Engine can manage a maximum of two aquifers. DAM Engine also takes the penetration layer (TAW, 2004) into account. For the time being, this option works only with 1D soil profiles. If the calculations have to be made without a penetration layer, a value of 0 should be entered (attribute: PenetrationLength).

DAM Engine defines the aquifers from bottom to top (in the direction of the surface). A piezometric line (PL3) is assigned to the bottom layer (which is also an aquifer) (Figure B.4). The pore pressures in the penetration layer are schematised using PL2. PL4 will be allocated to any additional aquifer. Table B.2 gives an overview of the various piezometric lines and associated schematisation.

If several aquifers are stacked in succession one above the other, DAM Engine will allocate the same PL to all of them, assuming a hydrostatic range for the pore pressures. The separation between the aquifer and cohesive layer is then determined by the top of the highest aquifer in the stack.

For the purposes of the stability calculations, DAM Engine schematises the piezometric heads in the vertical direction using linear interpolation in the soft layers. A hydrostatic range is assumed in the dike body, the soil layers where the phreatic plane is located and the aquifers.

PL	Description
PL1	Phreatic line. For stability calculations with a stationary phreatic plane. The schematisation for PL1 is described in section B.3
PL2	The pore pressure at the top of the penetration layer. The PL2 is not affected by the piezometric head in the underlying aquifer and it is constant (in other words, there is no damping) over the entire width of the cross-section. The user enters the value for PL2 (attribute: HeadPL2), as well as the thickness of the penetration layer. DAM 1.0 uses the PL2 only if the thickness of the penetration layer >0 m. Note: at present, the use of PL2 is still limited to 1D soil profiles.
PL3	Pore pressure in the bottom aquifer. The value can be entered (attribute: HeadPL3). If no value is entered, PL3 is considered to be the same as the outer water level stated in the scenarios (see section 2.6). The value for PL3 at the inner toe (Figure B.5) depends on the stated damping factor (attribute: DampingPL3). This damping factor expresses the degree to which PL3 is damped to PL2. Zero means no damping (PL3 is constant). And the value 1 suggests full damping to PL2 (attribute: PL2). If no value has been entered for PL2, the polder water level will be used (attribute: PolderLevel). Beyond the inner toe, the PL3 declines to the polder level at a gradient to be stated (attribute: SlopeDampingPiezometricHeightPolderSide). The PL3 then matches the polder level. A value can be entered for the gradient of this PL slope. The default value is 0. This means there is no slope.
PL4	Pore pressure in an intermediate aquifer (if present). The schematisation for PL4 is similar to that described for PL3. However, PL3 should be read as PL4. Note: Both PL3 and PL4 use the same gradient for the slope of the PL line on the polder side.

Table B.2: *Overview and description of piezometric lines*

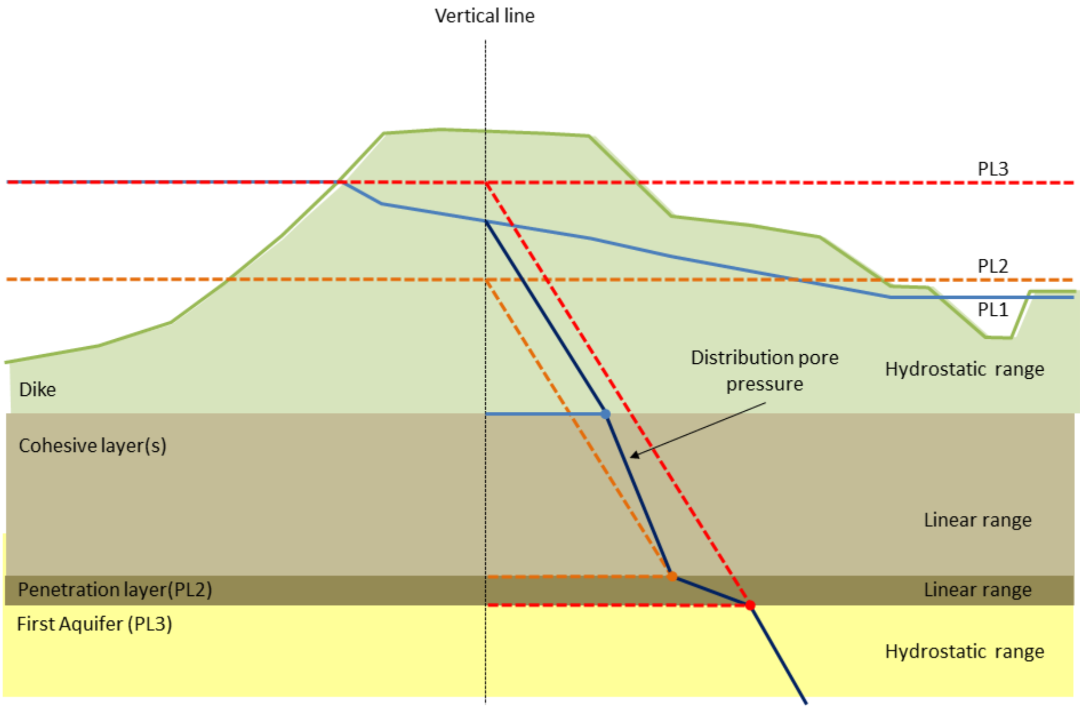

Figure B.4: *Schematisatie van waterspanningen in de situatie van één watervoerende laag*

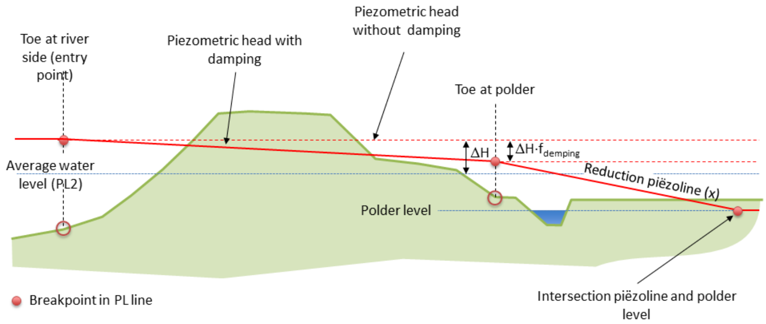

Figure B.5: *Gebruik van dempingsfactor (f) en reductie piëzolijn aan de polderzijde (X) voor schematisatie horizontaal stijghoogteverloop*

B.5 Check for uplift

DAM Engine makes calculations to see whether there is any uplift from the inner toe to the centre of the ditch bed. The formula from the VTV (2006) is used for this purpose, together with the initial schematisation for the piezometric heads (see section B.4)

$$opdrukveiligheid = \frac{\sigma_g}{\sigma_w} \tag{B.1}$$

If there is no ditch present, the calculations will extend to the edge of the cross-section. If uplift is calculated,DAM Engine lowers the PL3 or PL4 to a value in which uplift just no longer occurs, in other words to the point at which there is an unstable equilibrium(zie Figure B.6)

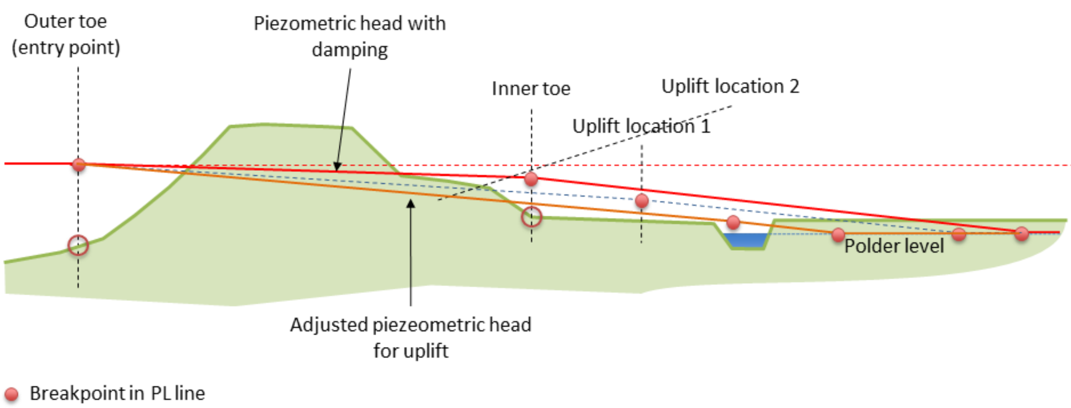

Figure B.6: *Lowering of piezometric head in the presence of uplift. DAM Engine checks for uplift starting at the inner toe and extending to the edge of the profile and adapts the piezometric head accordingly until an unstable equilibrium is attained.*

B.6 Definitive schematisation pore pressures

The definitive schematisation for the pore pressures is produced on the basis of the initial generation of the pore pressures and the check for uplift. This involves the straight-line interpolation of values in a horizontal direction between the various calculated tipping points in the PL lines.

C RRD scenario selection

For the assessment of regional dikes, DAM Engine must calculate several assessment scenarios (RRD-scenario) depending on:

- the type embankment (peat/other); green block in Figure C.1 and Figure C.2;
- the hydraulic shortcut (yes/no); brown block in Figure C.1, Figure C.2 and in detail in Figure C.3;
- the uplift situation (yes/no); purple blocks in Figure C.1 and blue blocks in Figure C.2.

This results in a variation of RRD scenarios, summed up in Table C.1

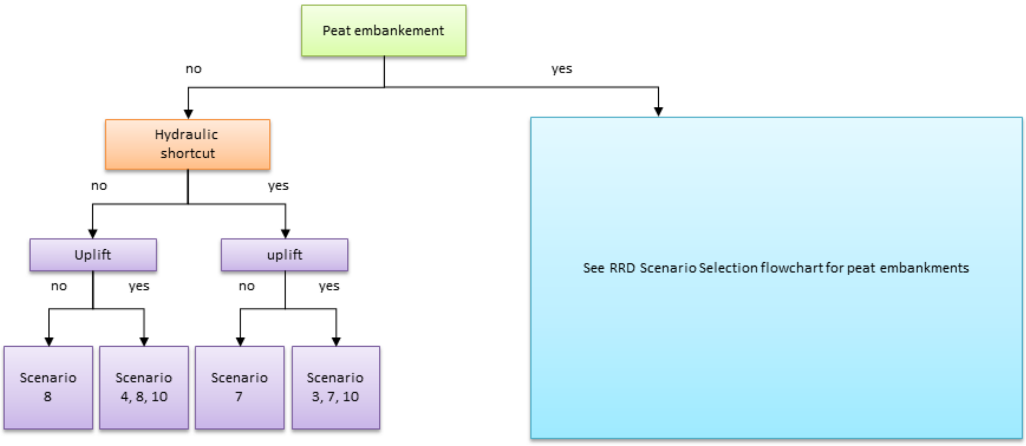

Figure C.1: *Flowchart of embankments other than peat*

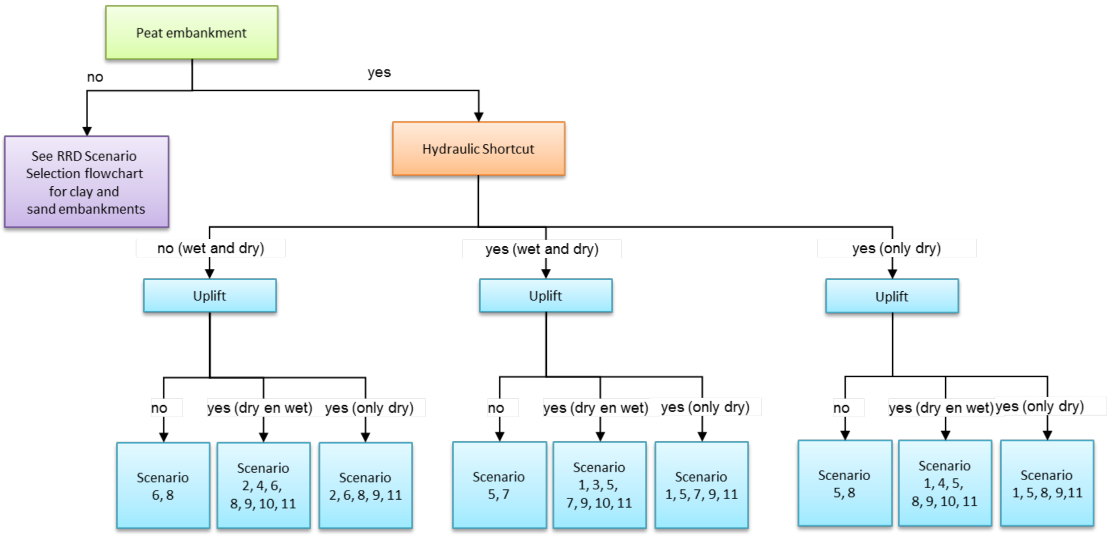

Figure C.2: *Flowchart of embankments of peat*

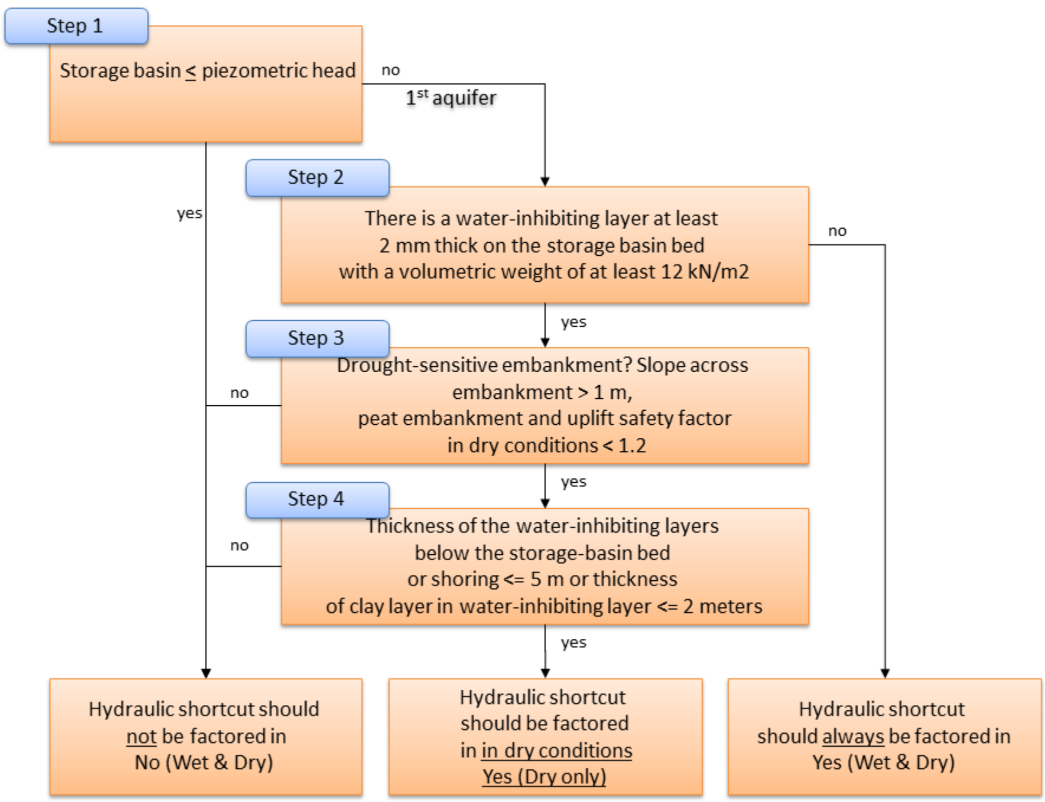

Figure C.3: *Flowchart of hydraulic shortcut*

RRD Scenario	Condition	Hydraulic Shortcut	Uplift	Model
1	Dry	yes	yes	Uplift
2	Dry	no	yes	Uplift
3	Wet	yes	yes	Uplift
4	Wet	no	yes	Bishop
5	Dry	yes	yes	Bishop
6	Dry	no	yes	Bishop
7	Wet	yes	yes	Bishop
8	Wet	no	yes	Bishop
9	Dry	yes/no	yes	Horizontal equilibrium
10	Wet	yes/no	yes	Piping
11	Dry	yes/no	yes	Piping

Table C.1: *RRD scenarios*

D Geometry Adaption

For the purposes of policy studies or determining impact scope or emergency measures, it can be useful to generate a profile that corresponds to the stated safety factor. DAM Engine can make automatic geometry adaptations for this purpose using a number of basic assumptions.

Automatic profile adaptation in DAM Engine consists of the following steps:

1 Raising the crest (see section D.1)
2 Reducing the gradient of the slope (see section D.2)
3 Shoulder development (see section D.3)

D.1 Raising the crest

During this step, DAM Engine checks whether the crest height complies with the required (in other words the stated) dike table height (DTH, attribute: DikeTableHeight).
If the crest height (the Z value for characteristic point Outer crest) is equal to or higher than the stated DTH, the profile will not be adapted. If the profile is lower than the stated DTH, DAM Engine adjusts the geometry and creates a new surface line based on the original slope gradients (α and β) and the original crest width (B), see Figure D.1.
The slope gradients, and the crest width, are determined on the basis of the following characteristic points:

- The outer slope gradient (α) follows from the calculated gradient on the basis of the outer toe and the outer crest line. If there is an outer shoulder, the outer slope gradient is determined on the basis of the top of the outer shoulder and the outer crest line.
- The crest width (B) follows from the distance between the characteristic points in the outer crest line and inner crest line.
- The outer slope gradient (α) follows from the calculated gradient on the basis of the inner toe and the inner crest line. If there is a inner shoulder, the inner slope gradient will be determined on the basis of the top of the inner shoulder and the inner crest line.

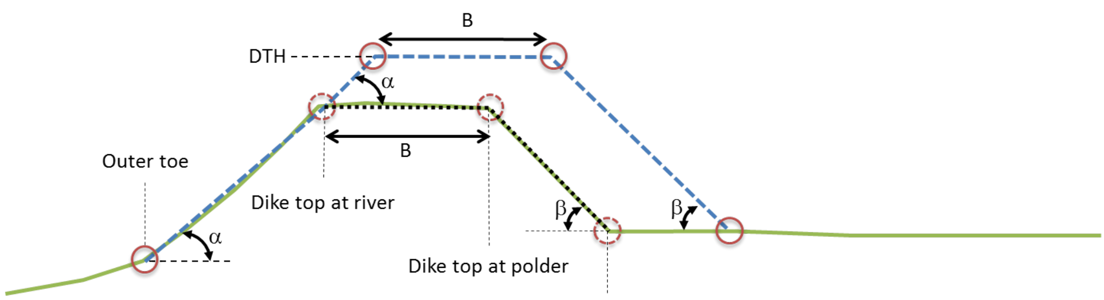

Figure D.1: *Adapted geometry for DTH*

The adapted geometry starts at the toe at riverside (outer toe) in the initial profile, see Figure D.2. If there is no inner shoulder, the toe at polderside (inner toe) of the adapted profile will be further away on the profile than the original inner toe, see Figure D.1. If the adapted geometry intersects with a inner shoulder, the top of the inner shoulder will be moved, see

Figure D.2.

In all adapted profiles, the geometry points within the adapted profile will be removed. The characteristic points will move in accordance with the adaptation of the geometry.

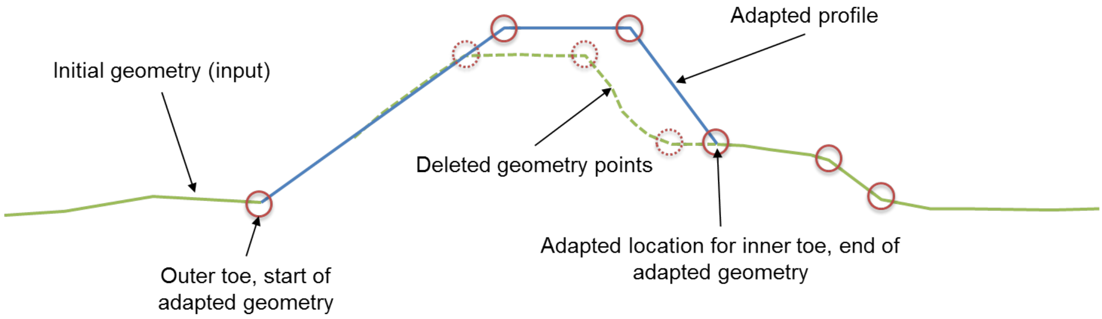

Figure D.2: *Adapted geometry by deleting geometry points*

If there is an outer shoulder, the adapted geometry will start at the shoulder base outside, see Figure D.3.

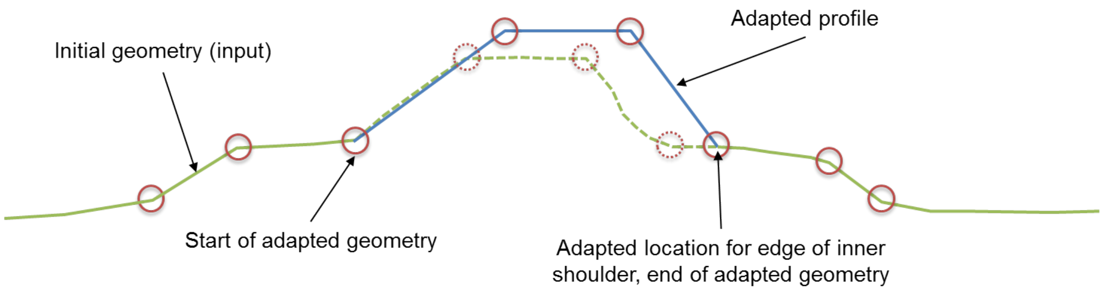

Figure D.3: *Adapted geometry when outer shoulder is present*

If the geometry adaptation results in the new dike base being so wide that the entire initial geometry is contained within the adapted profile, all the intermediate geometry points, including the characteristic points in the inner shoulder, will be removed, see Figure D.4.

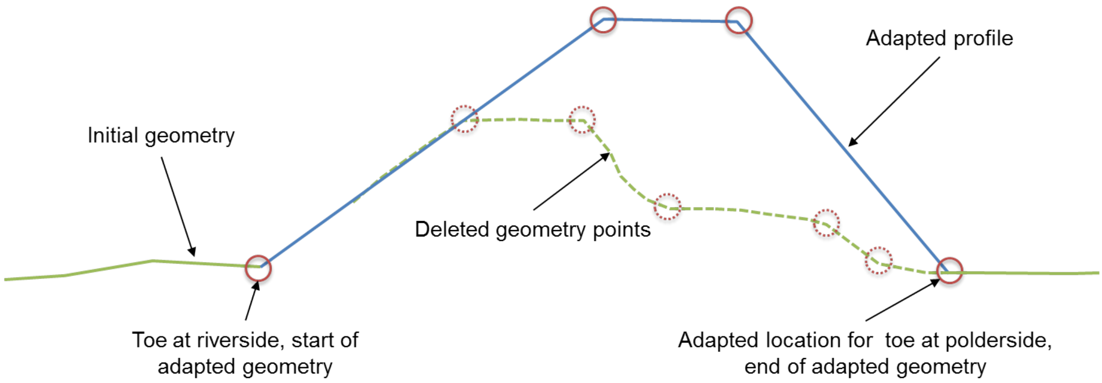

Figure D.4: *Adapted geometry with starting point for geometry of outer toe and larger dike base*

If there is a ditch in the profile, DAM Engine will move the ditch if the adapted inner toe is further away than the location of the inner toe in the initial profile. The ditch is moved along the unchanged part of the initial profile. If the ditch is moved, DAM Engine will maintain the original distance from the inner toe to the outer edge of the ditch (Δ). The original dimensions of the ditch will be maintained. See Figure D.5.

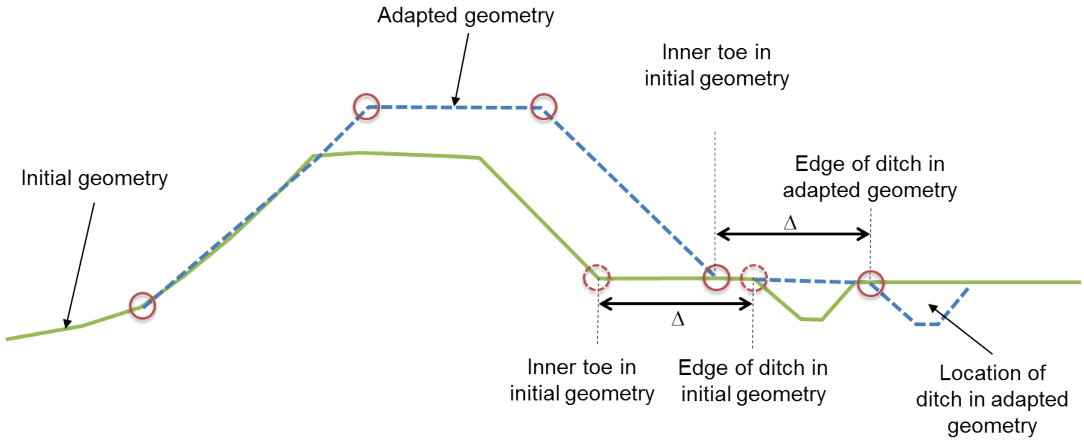

Figure D.5: *Moving the ditch*

D.2 Reducing the gradient of the slope

After the adaptation of the crest height in accordance with DTH (if necessary), DAM Engine will first carry out a stability calculation. If it should emerge that the exit point of the slip circle is on the inner slope and if the calculated safety factor is less than the stated safety factors, DAM Engine will (on condition that the profile adaptation option is on) reduce the gradient of the slope until the calculated safety factor $\geq$ required safety factor and the exit point of the slip circle is on the inner slope, see Figure D.6. If the exit point is no longer on the inner slope and the calculated safety factor does not comply with the desired safety factor, DAM Engine will generate a stability shoulder, see section D.3.

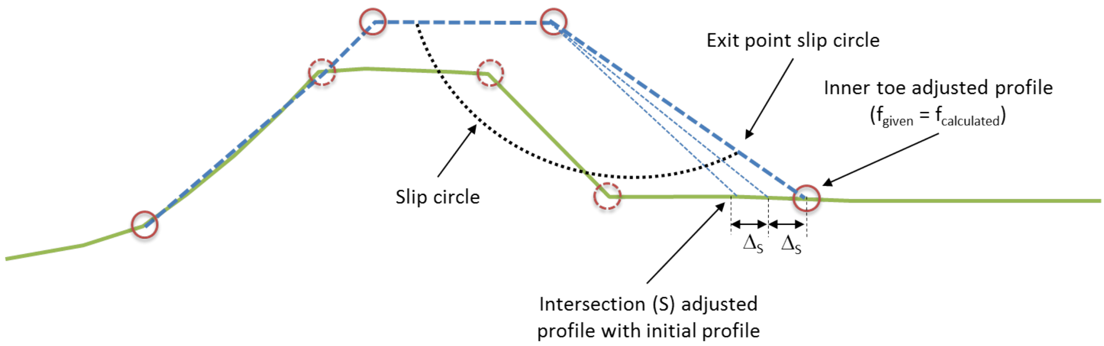

Figure D.6: *Iterative reduction of the gradient of the inner slope on the basis of the exit point of the slip circle*

D.3 Shoulder development

DAM Engine develops a stability shoulder iteratively as long as the slip circle does not intersect with the landslide slope (see section D.2) and the stated safety level has not yet been achieved. The maximum number of iteration stages is 200. This limit prevents DAM Engine getting stuck in an infinite iteration loop if the stated safety level is not achieved.

The algorithm used is based on moving the crest of the landslide shoulder in a straight line along an incline (α), see Figure D.7. The default value is 0.33 (1:3) but it can also be stated by the user (attribute StabilityShoulderGrowSlope).

The adaptation of the shoulder involves moving the inner toe in steps (Δ_S). The steps are in the horizontal direction and the standard steps are 1 metre in length but they can be changed by the user (attribute StabilityShoulderGrowDeltaX). Shoulder development stops when the calculated safety factor in the adapted profile $\geq$ the stated safety factor.

The inner toe is used as the starting point for shoulder development. If there is already a shoulder in the original cross-section, the crest inner shoulder point is used as the starting point. During shoulder development, the crest of the shoulder remains horizontal, as with the raising of the crest, see section D.1.

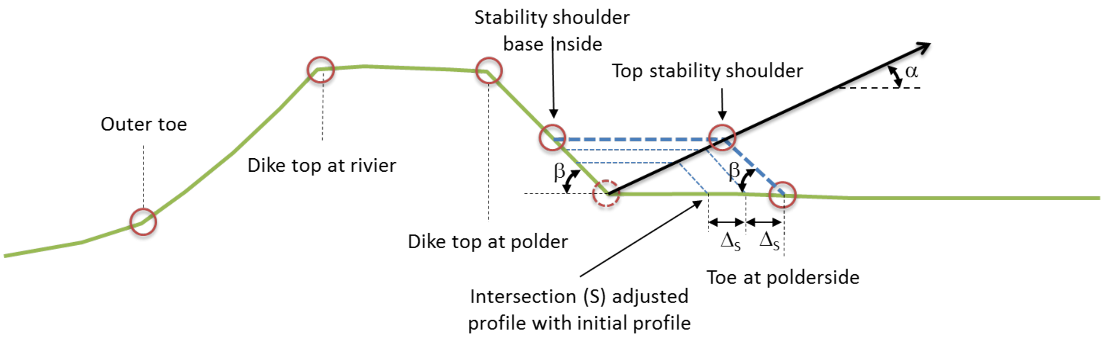

Figure D.7: *Iterative shoulder development for macrostability*