DAM Engine

Functional Design

Deltares

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1210702-000

Deltares

Title
DAM Engine

Client	Project	Reference	Pages
Deltares - Geo engineering DKS	1210702-000	1210702-000-GEO-0003	34

Classification
-

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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	Jun 2018	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. (not available yet).
DAM Engine- Test Report (Trompille, 2017b)	Description of the test results (benchmarks and test scripts)(not available yet).
Architecture Guidelines (Kleijn *et al.*, 2017)	Architecture guidelines that are used by DSC-Deltares.
Overview of data used (Zwan, 2018)	Table with data used by DAM UI andDAM Engine

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 is to get data from DAM Clients, uses this data as calculation input and make serially calculations with one ore more kernels and generates output. This can be broken down to the next use cases:

Use case Design - UC Design
As a user I want to adapt the geometry until given safety for stability or piping is met.

Use case Operational sensors - UC Operational.sensors
As a user I want to make stability and/or piping calculations with the input from operational sensors.

Since most requirements are needed for multiple use cases, the requirements are classified per theme, not per Use Case. The themes are: data, calculation and output. The requirements per Use case are given in next table.

3.1 Data

3.1.1 REQ Data.Format

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

3.1.2 REQ Data.Content

The DAM Engine has a defined content for the data input, so DAM Clients know how to arrange the input data. The required data is described in xsd-files in https://repos.deltares.nl/ repos/ dam/ DamEngine/ trunk/ xsd. An overview of the required data for the engine in relation to DAM UI data is described in https://repos.deltares.nl/ repos/ dam/ DamOverall/ trunk/ doc/ DAM General/ OverviewDataUIAndEngine.xlsx. In this Functional design is referred to parameters mentioned in this overview by giving the *name*.

3.2 Calculation

3.2.1 Kernels

The DAM Engine provides calculations with the following stability and piping kernels:

1. Stability; kernel used by D-Geo Stability 18.1
2. *Stability; kernel used by D-Geo Stability 2019*
3. Piping; DAM-kernel piping
4. *Piping; WBI-kernel piping*

Italic printed functionalities are not implemented in DAM yet.

3.2.1.1 REQ Calc.Kernel15

The DAM engine can make stability calculations with the kernel of D-Geostability 15.1. The options used by the DAM engine are described in Appendix A.

3.2.1.2 REQ Calc.Kernel18

The DAM engine can make stability calculations with the kernel of D-Geostability 18.1. The options used by the DAM engine are equal to the use of the kernel of D-Geostability 15.1 and are described in Appendix A.

3.2.1.3 REQ Calc.DAMPiping

The DAM engine can make piping calculations with the DAM-piping kernel. The functional design of the DAM piping kernel is described in Appendix C.

3.2.1.4 REQ Calc.WBIPiping

The DAM engine can make piping calculations with the WBI-piping kernel. The functional design of the DAM piping kernel is described in **??**.

3.2.2 REQ Calc.Design.Geometry

The DAM engine must be able to generate new profiles (surfacelines) based on a desired Dike table heigth (DTH) and/or 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 described in Appendix D

3.2.3 REQ Calc.Operational.Sensor

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

3.2.4 REQ Calc.Design.Excavation

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

3.3 Output

3.3.1 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.

Van Geer, P., 2017. *WTI2017 Failure mechanisms - Kernel Piping, Requirements and Functinal Design*. Tech. Rep. 1220084-008-GEO-0001, version 7, definitief, Deltares.

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

Zwan, I. v., 2018. *Overview data DAM UI and Engine*. Tech. rep., Deltares.

Appendix

A Use of the D-Geo Stability Kernel

For stabilily calculation the DAM engine uses the kernel used by D-Geo Stability 18.1 This use is restricted to the options described in this chapter.

A.1 Model

The DAM Engine must be able to make calculations with following models:

- Bishop
- LiftVan (Uplift Van in D-Geostability)
- Horizontal balance

All models are available for inwards stability. For outward stability only Bishop is used.

The choice of the model is partly user-defined, partly automatic:
User can choose Bishop, Uplift Van or combination Bishop/Uplift Van.
User can not choose Horizontal balance, this is part of the RRD scenario selection, see Appendix B.

A.1.1 Combination Bishop/Uplift Van

The combination Bishop/Uplift Van give three results:

1. Bishop
2. Uplift Van (is made when *UpliftCriterionStability*) is higher than the uplift safety (see section E.5).
3. Normative result (lowest safety factor) of both.

A.2 Slip plane definition and calculation area

A.2.1 Grid generation

For the models Bishop and LiftVan a calculation grid must be generated. There are two options:

1. automatic generation
2. user defined generation

Ad 1 Automatic generation
See FD of Macrostability kernel.

Ad 2 User defined generation
The user defines the dimensions; number of gridpoints and distance between the points. The DAM engine defines the position of the grid depending on the characteristic points: For Bishop and for the left grid of LiftVan the left bottom corner is situated at the surfaceline in the middle of the crest (distance between outer- and innercrest). The right bottom corner of the right grid of LiftVan is situated above the most right x co-ordinate where uplift occurs. With the restriction that the left bottom corner can not be situated left of the x co-ordinate of the DikeToePolder.

A.2.2 Tangent lines generation

For the models Bishop and LiftVan a tangent lines must be generated.

There are two options:

1 automatic generation

2 user defined generation

Ad 1 Automatic generation
Bishop
-to described-
Liftvan
-to described-

Ad 2 User defined
For Bishop calcuations the tangent lines are generated automatic.

For LiftVan the user (client of DAM-Engine) must provide the distance between the tangent lines, *Distance tangent lines (UV)* . The lower tangentline is always situated 5.0 m below the upper geometry point of the lowest aquifer. The tangentlines are drawn with the given distance until the upper tangent line is situated above the Z;DikeToeAtPolder.

A.2.3 Calculation area

For the model Horizontal balance a calculation area must be defined:

Parameter	**Default value**
X co-ordinate left side [m]	x co-ordinate DikeTopAtRiver
X co-ordinate right side [m]	x co-ordinate DikeToeAtPolder
Highest slip plane level [m]	Z value PL4 or PL3 (when one aquifer present) at x co-ordinate DikeToeAtRiver
Lowest slip plane level [m]	Maximum Z value of top aquifer within calculation area
Number of planes in the slip plane level [-]	12

Table A.1: *Calculation area for horizontal balance*

A.3 Shear strength model

The DAM engine must be able to make stability calculations with following shear strength models:

- C-Phi
- Stress tables
- Cu calculated (with default inital surface level of D-Geo Stability; toplayer)
- Cu measured
- Cu gradient
- Pseudo values

This shear strength models are defined in the soil parameters per layer.

A.4 Zone Plot

The option of zone plot in D-Geo Stability is defined as the distinction of the slip circles in different zones; 1a, 1b, 2a, 2b, 3a and 3b.
DAM only uses zone 1 and zone 2. Zone Plot is used when*ZoneType* = ZoneAreas

The following settings for the Zone plot of D-Geo Stability are used by DAM:

- Dike table heigth: user defined : *DikeTableHeight*
- Dike table width: 3 m
- Start x co-ordinate restprofile: Xlocal;DikeTopAtRiver
- Boundary of design level influence at x: Xlocal;DSurfaceLevelInside
- Boundary of design level influence at y: maximal Y co-ordinate of surface line
- Required safety in zones: *RequiredSafetyFactorStabilityInnerSlope*

Calculation with zone areas is only possible for inward stability calculations.

A.5 Calculation options

D-Geostability offers different following calculation options. DAM uses the following settings:

- Requested number of slices: default D-Geo Stability
- Minimum circle depth: user defined: *MinimalCircleDepth*
- Minimum slip plan length: default D-Geo Stability
- Start value safety factor: default D-Geo Stability
- Minimum x-entrance used: default D-Geo Stability
- Maximum x-entrance used: user defined

The maximum x-entrance used is not directly user defined, but via Forbidden zones.

A.5.0.1 Forbidden zone

Forbidden zone is an option to define a forbidden zone for the entrance point of the slip plane. The forbidden zone is situated to the rigth side of a certain x co-ordinate. This x co-ordinate is defined by the *ForbiddenZoneFactor*. Xlocal;forbidden zone WF =(Xlocal;DikeTopAtPolder) + ForbiddenZoneFactor*(Xlocal;DikeToeAtPolder - Xlocal;DikeTopAtPolder) A forbidden zone is used when *ZoneType* = ForbiddenZone.

ForbiddenZonefactor	maximum x-entrance
0	x co-ordinate DikeTopAtPolder
1	x co-ordinate DikeToeAtPolder

Table A.2: *Forbidden zone factor*

In a picture:

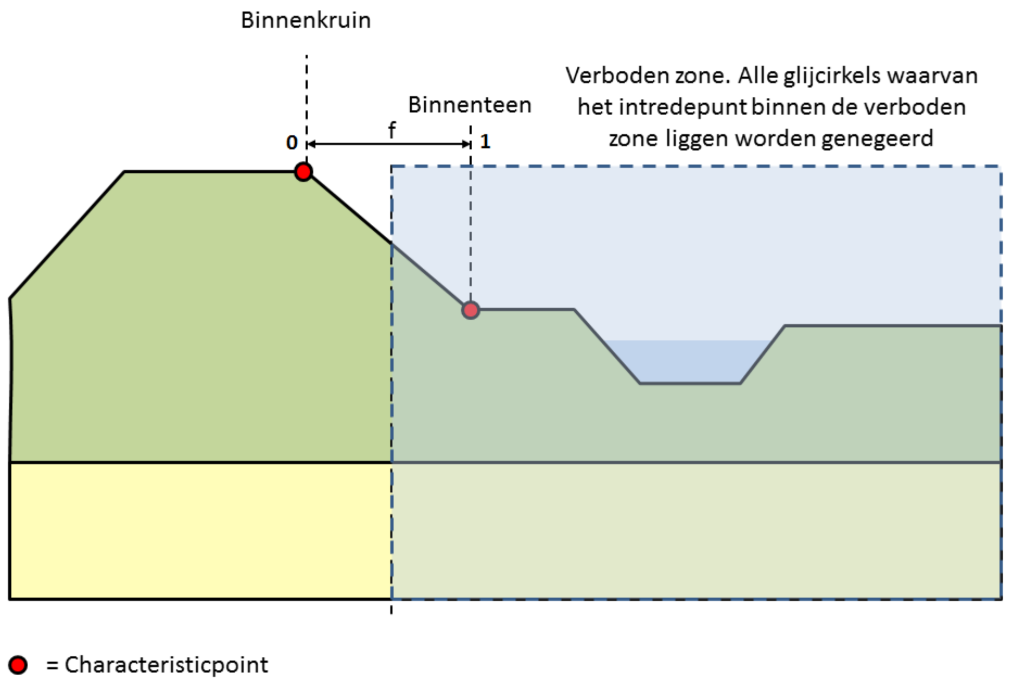

Figure A.1: *Forbidden zone factor*

A.6 Traffic load Degree of consolidation

The traffic load degree of consolidation is a material parameter. This may vary per location, per traffic load and hydraulic load. Therefore it must be possible to define the traffic load degree of consolidation per location.
In the UI the import of the traffic load degree of consolidation is done per material via soilmaterials.mdb and per location via csv-file or shape-file.

The hierarchy is:

1 Traffic load degree of consolidation per material.
For material types peat, clay and loam overwritten by:

2 Traffic load degree of consolidation per location.

So the Traffic load degree of consolidation of the material types sand and gravel keep the value from soilmaterials.mdb.

B Uplift calculation

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.

$$Upliftsafety = \frac{\sigma_g}{\sigma_w} \quad \text{(B.1)}$$

If there is no ditch present, the calculations will extend to the edge of the cross-section.

The check for uplift is done at every surface line point from DikeToeAtPolder to SurfaceLevelInside (from left to right).

The check for uplift has the following purposes:

- To decide if a LiftVan calculation is required, see section A.1.1.
- To generate the piezometric levels, see section E.5

C Piping

<chapter partialy in Dutch>

Voor piping kan gekozen worden uit de volgende opties:

1. Bligh
2. Sellmeijer 4 krachten model
3. Sellmeijer (VNK)
4. Sellmeijer revised(WBI)

C.1 Rekenregel van Bligh

Hier wordt gebruik gemaakt van de standaard piping regel van Bligh met een creep factor van 18:

$$L \geq H \cdot C_{creep}$$

C.2 Sellmeijer 4 krachten model

Hier wordt gebruik gemaakt van de regel van Sellmeijer zoals omschreven in de TR Zandmeevoerende wellen uit 1996:

$$\Delta H_c = \alpha \, c \, \frac{\gamma_p}{\gamma_w} \, tan(\theta)(0.68 - 0.10 \, ln(c)) \, L$$

waarbij:

$$\alpha = \left(\frac{D}{L}\right)^{\left(\frac{0.28}{\left(\frac{D}{L}\right)^{2.8} - 1}\right)}$$

$$c = \eta \, d_{70} \left(\frac{1}{\kappa L}\right)^{\frac{1}{3}}$$

$$\kappa = \frac{\nu}{g} k = 1.35 \, 10^{-7} \, k$$

ΔH_c het kritieke verval over de waterkering
γ_w het volumegewicht van water [kN/m³]
γ_p het (schijnbaar) volumegewicht van zandkorrels onder water [= 17 kN/m³]
θ de rolweerstandshoek van de zandkorrels [°]
η de sleepkrachtfactor (coëfficiënt van White) [-]
κ de intrinsieke doorlatendheid van de zandlaag [m²]
d_{70} 70-percentielwaarde van de korrelverdeling [m]
D de dikte van de zandlaag
L de lengte van de kwelweg (horizontaal gemeten) [m]

C.3 Sellmeijer (VNK)

De pipingberekeningen met het VNK model, een neuraal netwerk gebaseerd op het twee lagen model van Sellmeijer. Het model bestaat uit een grote collectie voorgemaakte sommen. De invoerparameters worden vergeleken met de invoer voor de voorgemaakte sommen en de uitkomst volgt door een interpolatie. In de eenvoudige toetsing wordt geen onderscheid gemaakt tussen een boven- en onderliggende zandlaag. Voor de berekeningen wordt de eerste watervoerende zandlaag uit het ondergrondmodel daarom gesplitst in twee lagen van gelijke dikte met dezelfde grondeigenschappen. De eigenschappen van Soil 3 zijn eveneens gelijk aan die van Soil1 en Soil 2. Het aanwezige verval is gedefinieerd door de buitenwaterstand verminderd met de waterstand bij het uittredepunt (polderpeil of maaiveldhoogte bij uittredepunt). De reductie van het verval met de term 0,3D, waarbij D de dikte van het slappe lagen pakket is, wordt verrekend op het kritieke verval, dus bij de sterkte kant.

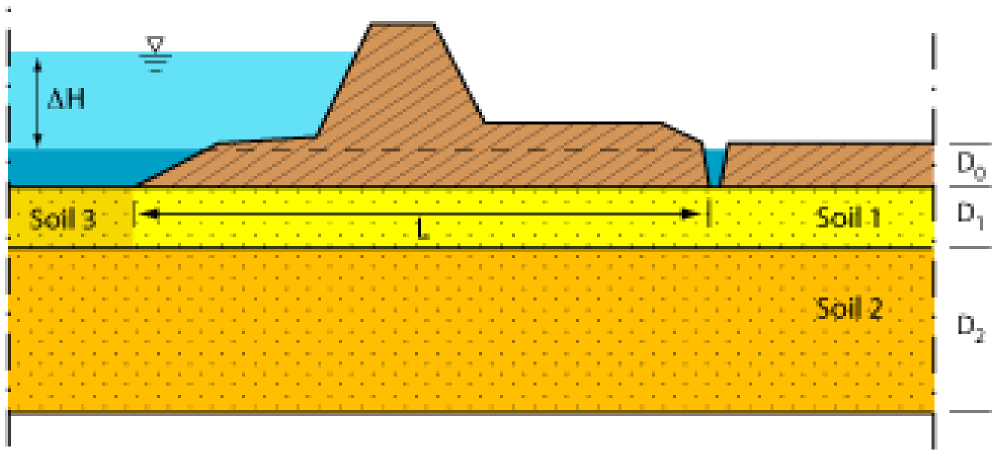

Figure C.1: *Schematisering ondergrond voor neuraal netwerk van Sellmeijer*

C.4 Sellmeijer revised (WBI)

Sellmeijer revised (WBI) consists of three sub failure mechanisms: uplift, heave and backward erosion.

For the determination of the exit point DAM determines the first uplift location, from the innertoe inwards, with the DAM-uplift calculation, described in Appendix B.

At this exit point DAM determines the three submechanisms via de WBI-piping kernel.

C.4.1 Uplift (uplift safety)

This function of the kernel is decribed in paragraph 3.3 in (Van Geer, 2017).

C.4.2 Heave

This function of the kernel is decribed in paragraph 3.4 in (Van Geer, 2017).

C.4.3 Internal erosion (backward erosion)

This function of the kernel is decribed in paragraph 3.5 in (Van Geer, 2017).

The submechanism with the highest safetyfactor is presented as the normative submechanism.

D REQDesignGeometry

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. The stated safety factor can be given for stability inward and for piping.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 adaption (see section D.3)

The order of the steps 2 and 3 of the adeption method is defined by *StabilityDesignMethod*. There are two options:

- Optimized Slope And Shoulder Adaption
  Apply slope adaption when slip circle exits in slope, conform section D.2, apply shoulder adaption when slip circle exits in polder (at right side of Dike toe at polder).
- Slope Adaption Before Shoulder Adaption
  First apply slope adaption starting with a given slope (*SlopeAdaptionStartCotangent*), stepping with a given adaption (*SlopeAdaptionStepCotangent*) until a certain given slope (*SlopeAdaptionStepCotangent*); only after that apply shoulder adaption.

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, *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.

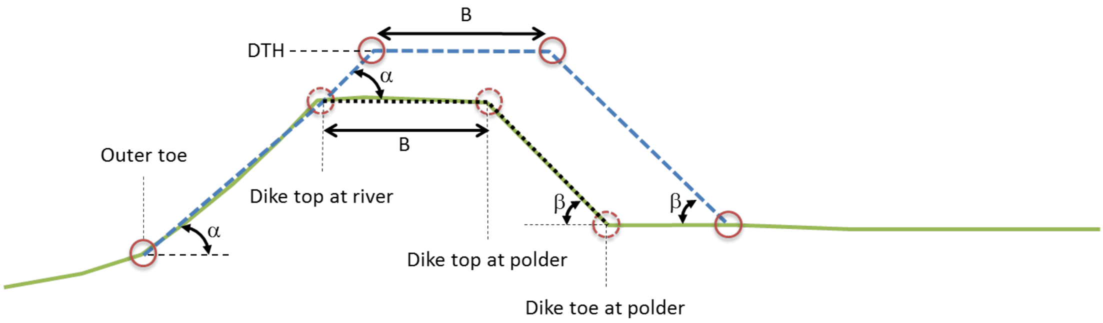

Figure D.1: *Adapted geometry for DTH*

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.

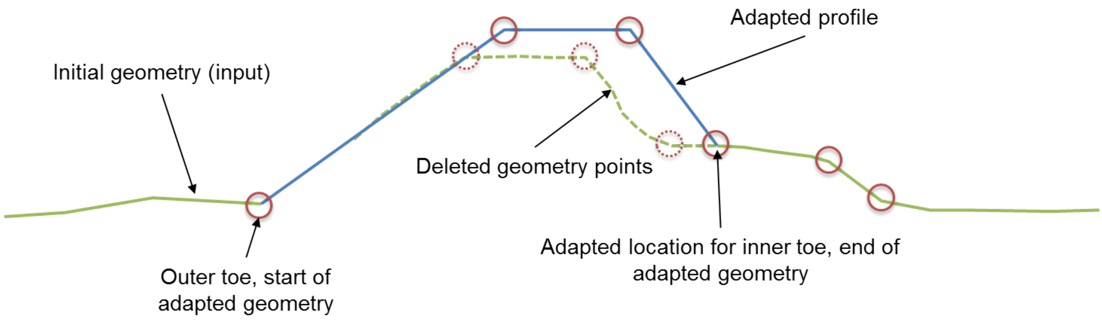

Figure D.2: *Adapted geometry by deleting geometry points*

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

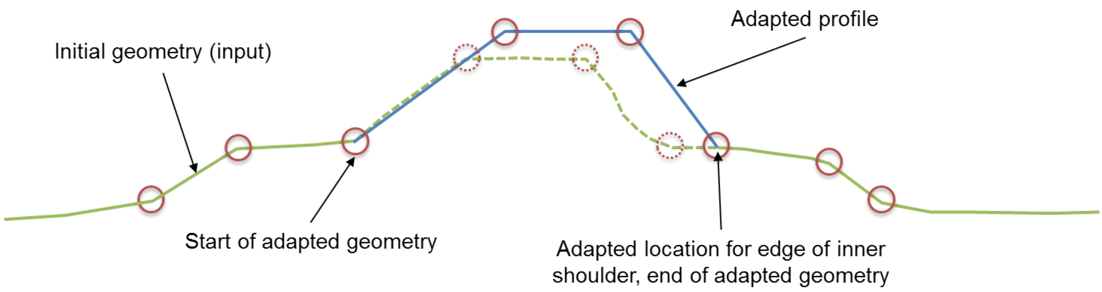

Figure D.3: *Adapted geometry when outer shoulder is present*

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.

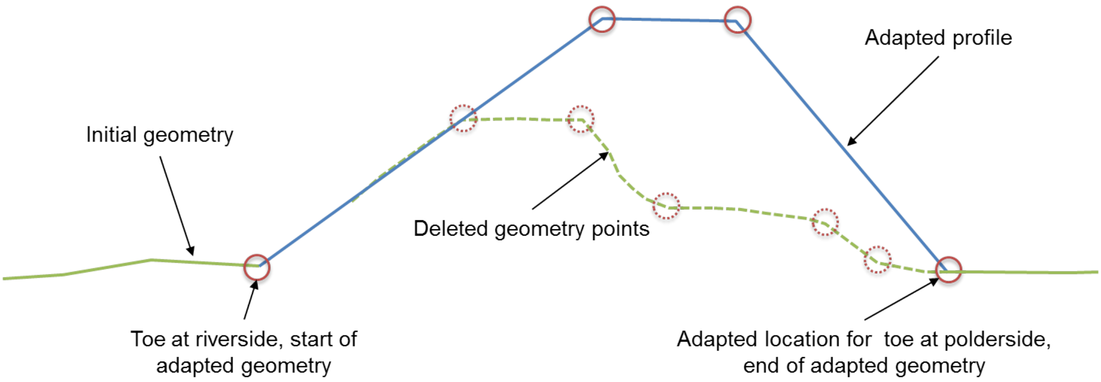

Figure D.4: *Adapted geometry with starting point for geometry of outer toe and larger dike base*

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.

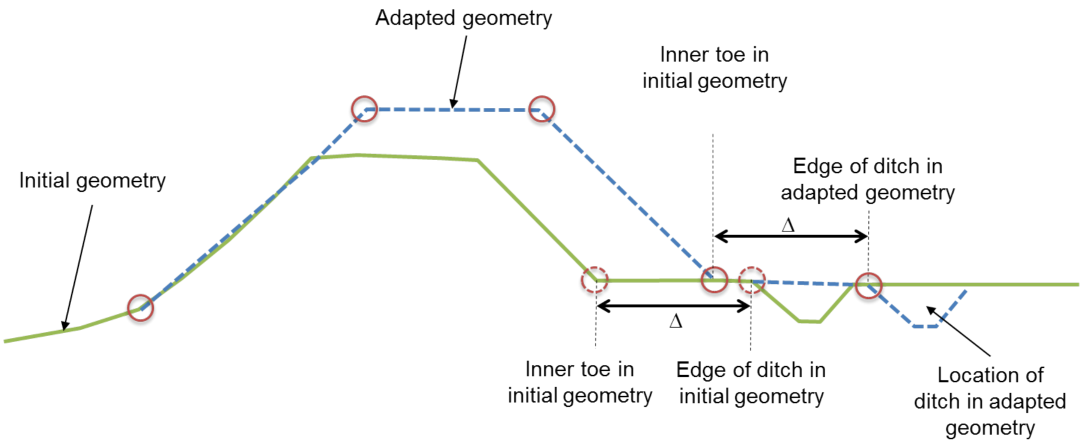

Figure D.5: *Moving the ditch*

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 **??**.

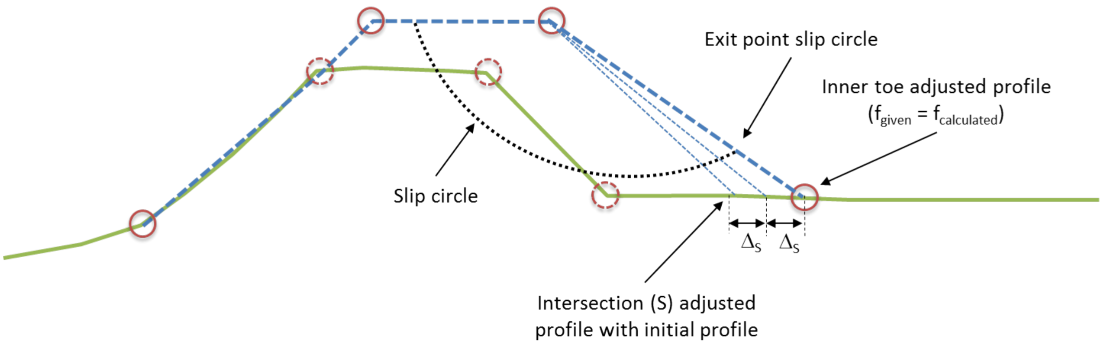

Figure D.6: *Iterative reduction of the gradient of the inner slope on the basis of the exit point of the slip circle*

D.3 Shoulder adaption

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.

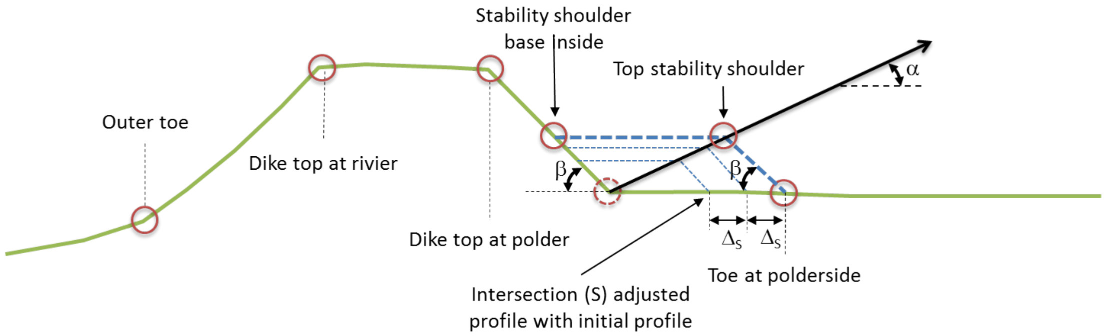

Figure D.7: *Iterative shoulder development for macrostability*

D.4 Restrictions use of design mode

In design mode a single stability model must be chosen; option Bishop/LiftVan is not possible.

E REQ 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.

E.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 conditions 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.

E.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 E.3).

2 Initial schematisation of piezometric heads (see section E.4).

3 Checking for uplift (see section E.5).

4 Definitive schematisation of pore pressures (see section E.6).

E.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).

E.3.1 ExpertKnowledgeRRD

The ExpertKnowledgeRDD method sets out the location of the phreatic plane at a maximum of 6 points: A to F. Figure E.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 E.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.

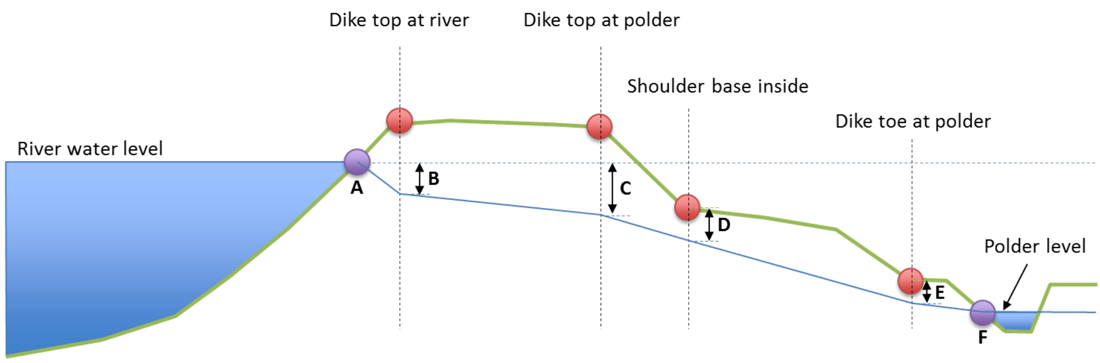

Figure E.1: *Schematisation Phreactic line (PL1) Macrostability inward using Expert-KnowledgeRRD*

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 E.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.

E.3.2 ExpertKnowledgeLineairDike

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

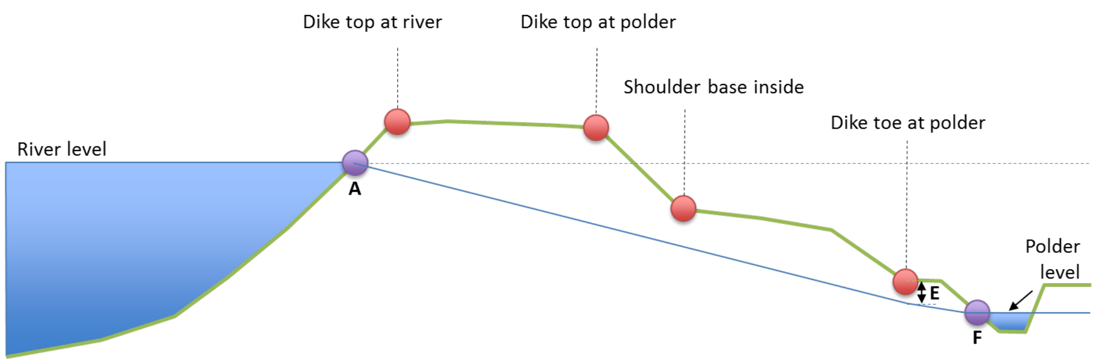

Figure E.2: *Schematisation Phreactic line (PL1) Macrostability inward using Expert-KnowledgeLineair*

E.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.

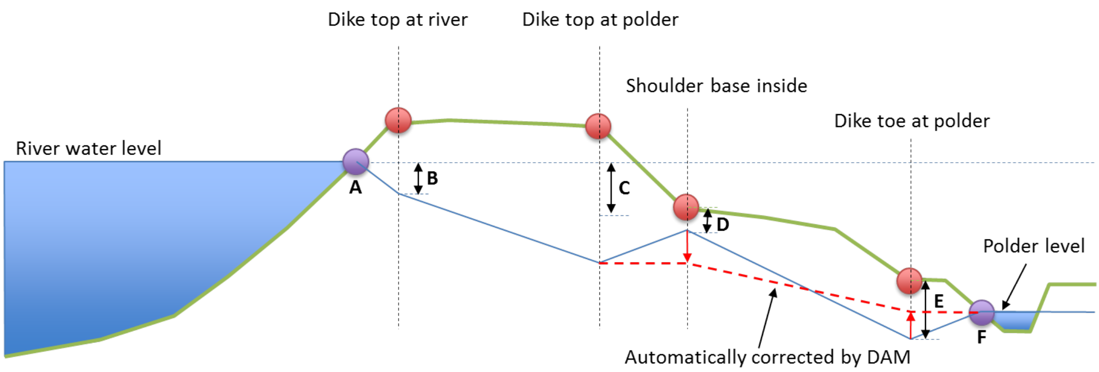

Figure E.3: *Adaption of phreactic line (PL1) when initial line would go up*

E.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 E.4). The pore pressures in the penetration layer are schematised using PL2. PL4 will be allocated to any additional aquifer. Table E.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 E.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 E.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 E.2: *Overview and description of piezometric lines*

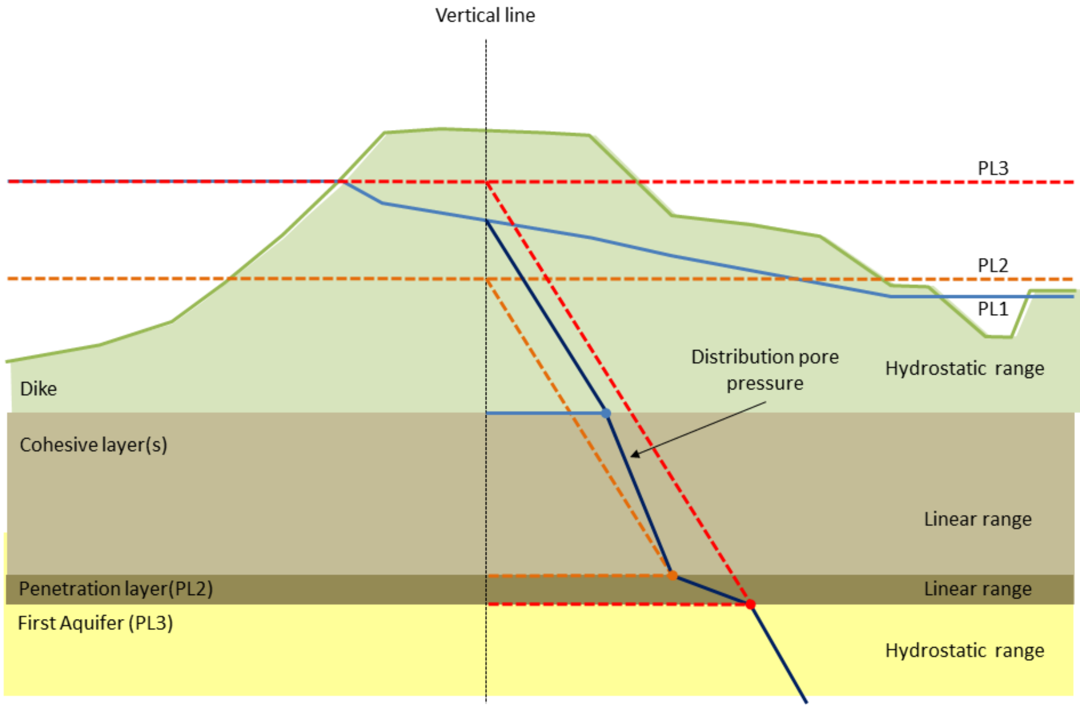

Figure E.4: *Schematization of the water pressures in 1 aquifer situation*

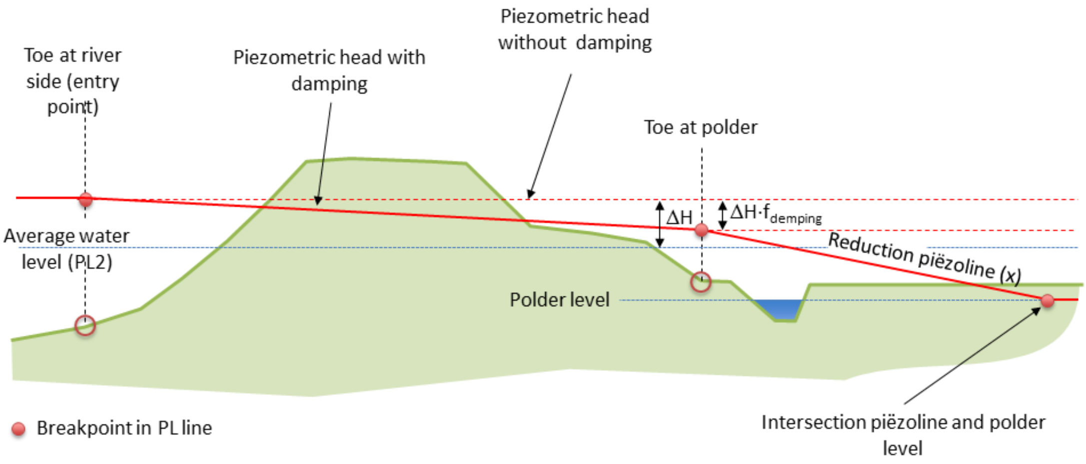

Figure E.5: *Use of damping factor (f) and reduction of piezometric level at polder side (X) for horizontal schematization of water levels*

E.5 Correction for uplift

The check for uplift is described in Appendix B

If uplift is calculated,DAM Engine lowers the PL3 or PL4 (if present) 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 E.6).

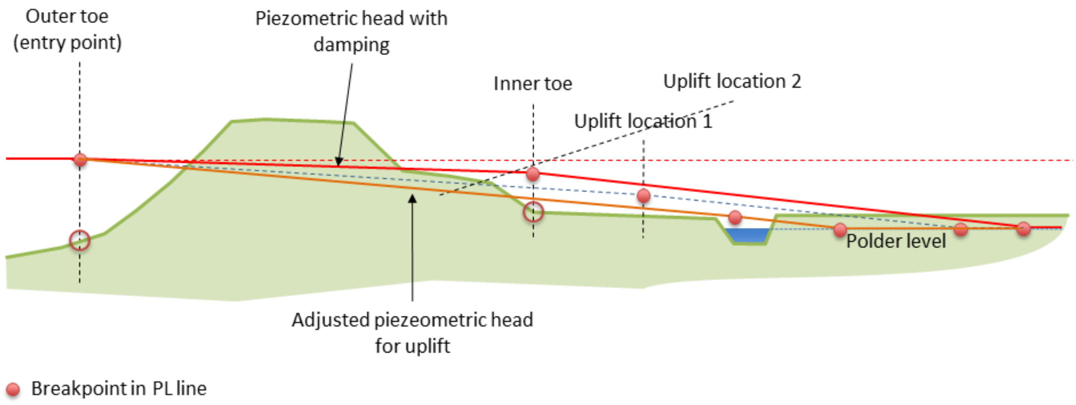

Figure E.6: *Lowering of piezometric head in the presence of uplift. DAM Engine checks for uplift starting at the inner toe and extending to the edge of the profile and adapts the piezometric head accordingly until an unstable equilibrium is attained.*

The PL3/PL4 continues from this point on with the specified slopegradient (*SlopeDamping-PiezometricHeightPolderSide*) until polderlevel with the condition that PL3/PL4 is always descending from left to right.

When a ditch is present Uplift is checked conform Bijlage 1 of Technisch Rapport Waterspanningen bij dijken (TAW, 2004), without the last bullit (thickness of layer under ditch is between the width of the bottom and width of the ditch). DAM Engine follows the flowchart of Figure E.7.

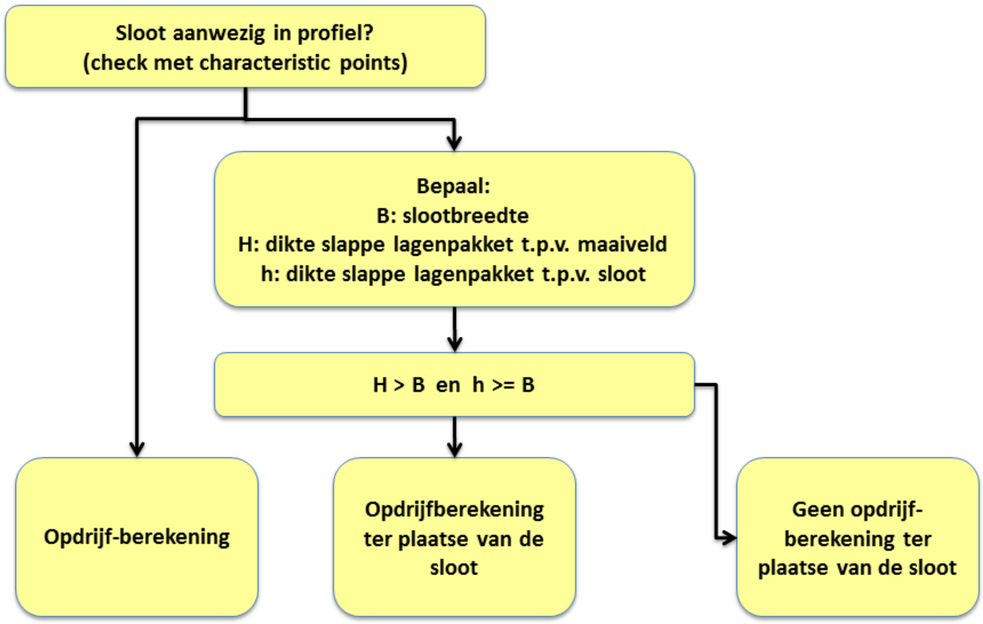

Figure E.7: *Flowchart check Uplift when ditch is present.*

Next figures are explaining the flowchart.

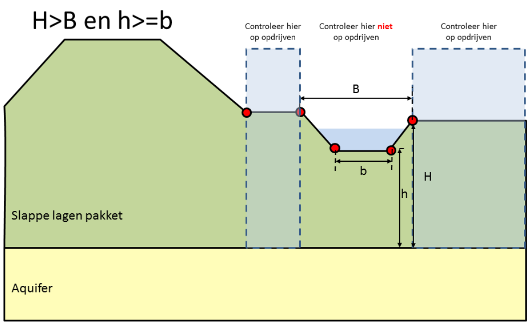

Figure E.8: *Uplift calculation when ditch is present, thicknes layer is larger than ditch*

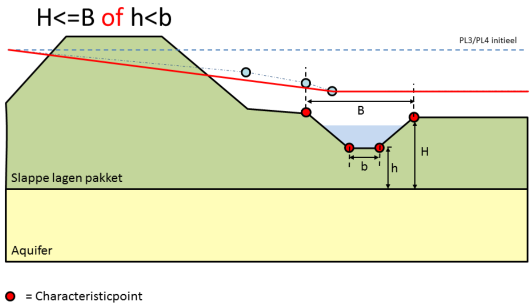

Figure E.9: *Uplift calculation when ditch is present, thicknes layer is smaller than ditch*

When uplift occurs at the location of the ditch it is possible that by deleting previous points of the PL line also uplift occurs between toe and ditch. While using the initial PL line, no uplift occurs. See Figure E.10. An extra check is made for uplift between toe and ditch ("Hier weer opdrijven"')

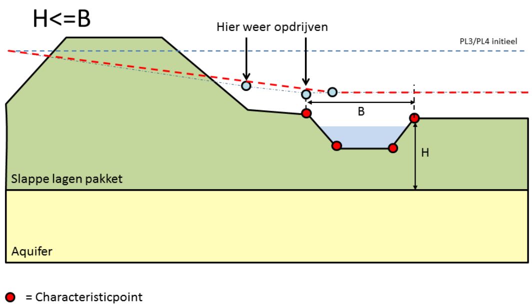

Figure E.10: *Uplift calculation between toe and ditch after uplift calculation at ditch*

E.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.