Memo

To
D-Geo Flow users

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Subject
Use of the 0.3D rule in D-Geo Flow

Introduction

Backward erosion piping often occurs in situations where a blanket layer overlies a sandy layer. Cracking of the blanket layer is required for flow to concentrate towards the surface and for release of particles towards the subsurface. The defect that is created as a result of cracking is gradually filled with a sand-water mixture, for which the density can vary. This slurry poses resistance for flow through the defect. The head loss in the defect takes up part of the total head loss across the levee and therefore reduces the head loss across the sand bed that may cause piping. The head loss in the defect depends on many parameters (Bezuijen, 2015), such as the flow through the defect, the density of the slurry, the thickness of the blanket layer and the size of the defect.

In the current safety assessment (Rijkswaterstaat, 2017) the head loss in the defect is accounted for through the 0.3D calculation rule. This means that the head loss in the defect is set equal to 0.3 times the thickness of the blanket layer, regardless of the density, flow and size of the defect. In the calculation of the stability factor for backward erosion, the critical head calculated with the Sellmeijer rule is compared to the head drop across the levee at critical conditions, corrected for the head loss in the defect:

$$F_p = \frac{\Delta H_c}{(h - h_{exit} - r_c D_{deklaag})} \quad \text{Eq. 1}$$

In which:

F_p	Stability factor for backward erosion [-]
ΔH_c	Critical head drop [m]
h	Water level with a probability of occurrence equal to the norm [m]
h_{exit}	Polder water level [m]
r_c	Reduction factor for resistance in the defect (=0.3) [-]
$D_{deklaag}$	Thickness of the blanket layer [m]

Since this head drop can be considerable for areas with thick blanket layers, it is necessary to take this into account in the ‘Toets op Maat’ as well. In D-Geo Flow the blanket layer and defect are physically simulated, which may raise questions of how to apply the rule. This memo illustrates how the 0.3D rule can be applied in D-Geo Flow.

Application of the 0.3D rule in D-Geo Flow

In D-Geo Flow the geometry and subsurface are modelled and a head drop curve is applied, after which the pipe development can be observed as function of the applied head in time. At some point the pipe has reached a critical value after which the pipe shoots towards the upstream side (the pipe growth is infinite when the equilibrium is exceeded).

This set up allows for the assessment of pipe progression in steady-state flow and in transient flow. For steady-state flow a critical head is obtained which is independent of the path towards this head (steep water level curve or flat water level curve). In this situation one could model the defect as a gap in the blanket layer without head loss and calculate the stability factor according to equation 1. However, for transient calculations it is more complicated. In a transient calculation the ‘critical head’, or head at pipe breakthrough depends on the steepness of the water level curve. As the head gradually increases, the head drop in the defect will also be increased, reducing the actual steepness of the head loss applied across the sand bed. If the actual head drop would be reduced afterwards, according to equation 1, the steepness of the curve is incorrectly modelled. For transient calculations, the 0.3D rule needs to be included in the calculation. This cannot be done by raising the polder water level by 0.3D, since this may result in flow towards the river when the river head is initially low, which is unrealistic.

It is therefore proposed here to include the 0.3D rule by using the heave boundary condition. The heave boundary is defined by:

$$p_i < P \Rightarrow Q_i = 0$$
$$Q_i > 0 \Rightarrow p_i = P$$

in which

Q flow (m^2/s)

p pressure (N/m^2)

P user defined pressure (N/m^2)

g gravitational acceleration (m/s^2)

This means that the nodes to which the boundary is assigned will be closed if the nodal pressure is smaller than the user-defined pressure P, but if the pressure is higher than the user-defined pressure P, water flow is allowed and the pressure will equal the value of P.

This boundary is suited for simulating the effect of the 0.3D rule, when applied at the exit point of the pipe below the blanket layer, since the resistance in the defect, represented by pressure P, will only be applied when the pressure in the node at the exit equals P. Flow towards the river is therefore prevented. There will be no need to physically model the defect when using this boundary.

To simulate resistance in the defect, for the entire period of simulation, the pressure P will be defined as:

$$P = \rho g(h_{exit} - z) + 0.3 D_{deklaag} \rho g \qquad \text{Eq. 2}$$

In which:

P user defined pressure [N/m^2]

g gravitational acceleration [m/s^2]

ρ water density [kg/m^3]

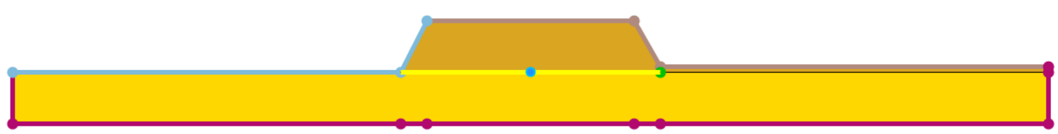
$D_{deklaag}$ thickness of blanket layer (m)

h_{exit} polder level [m]

z level of the heave boundary [m]

Example
In the following example the effect of the 0.3D rule is illustrated in D-Geo Flow using the heave boundary. The chosen example is a very simplified configuration, to illustrate the effectiveness of using the heave boundary for this purpose: a levee consisting of nearly impermeable clay (k=0.001 m/day) with a dike basis of 50 m on top of a sand layer of 10 m thickness with permeability of 50 m/day. At the downstream side a blanket layer of 1 m thickness is simulated consisting of the same material as the levee. The polder level is assumed to be equal to the downstream surface level.

The heave boundary can only be selected in ‘advanced mode’. In the ‘D-Geo Flow model properties’ window, the advanced mode can be selected. Boundary conditions were applied as illustrated in Figure 1, with the heave boundary assigned to the exit of the pipe only. Note that the defect has not been schematized, but is represented by the heave boundary.



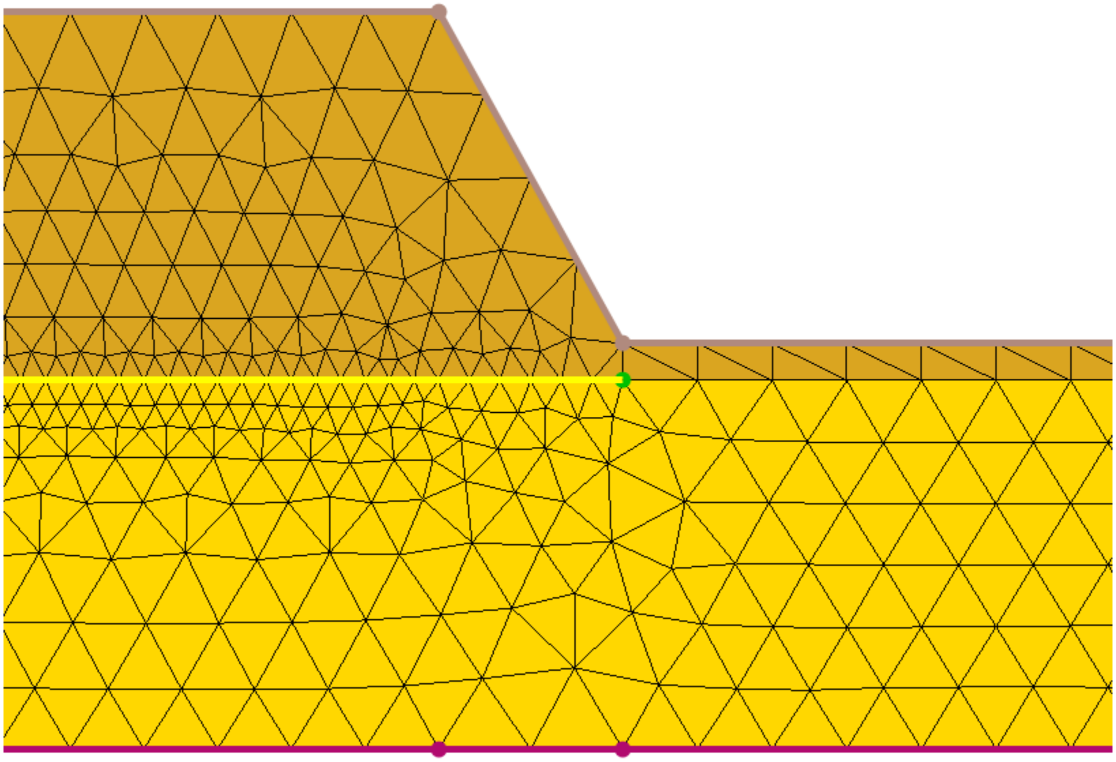


Figure 1: Boundary conditions in D-Geo Flow example (red: closed boundary, blue: submerging boundary, brown: seepage boundary and green: heave boundary)

For the head boundary a head of 0-10 m was applied in a time interval of 1 day. For the heave boundary a pressure was defined as:

$$P = \rho g(h_{exit} - z) + 0.3D_{deklaag}\rho g = 1000 \cdot 9.81 \cdot 1 + 0.3 \cdot 1 \cdot 1000 \cdot 9.81 = 12753 \text{ Pa}$$

which is equal to a head of 1.3 m.

After the piping calculation is conducted, the effect of the heave boundary becomes visible. Figure 2 shows the head along the pipe for different time steps. Since the number of time steps was set to 100, a calculation is performed each 0.10 m. In Figure 2 the first 20 steps are displayed, showing that the head drop remains constant along the pipe length until a value of 1.30 m, after which the heave boundary opens up, causing the head at the exit to remain at 1.30 and a head distribution along the pipe, indicating flow. It is noted that the head remains constant in the first step since the blanket layer has a very low permeability.

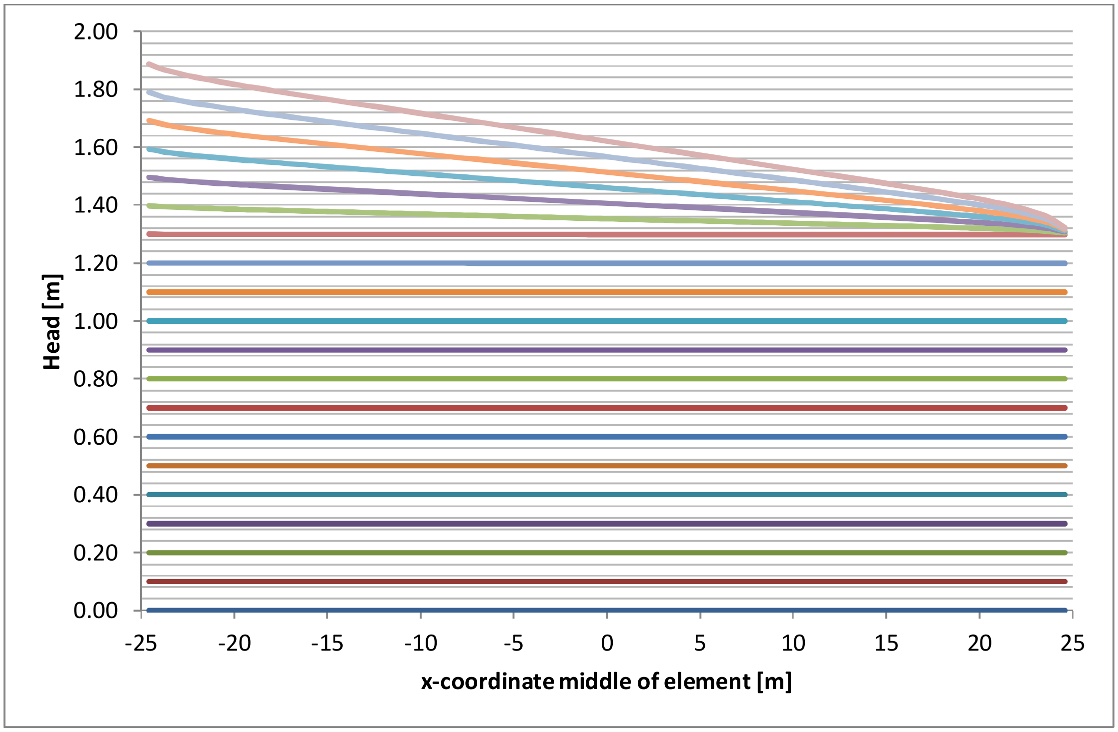


Figure 2: Illustration of effect of heave boundary for taking account of the 0.3D calculation rule

Bezuijen, A., 2015. Critical vertical gradients in piping - A preliminary sensitivity study concerning the 0.3-D rule. Deltares report 1220088-003-VEB-0001.

Rijkswaterstaat, 2017. Regeling veiligheid primaire waterkeringen 2017 Bijlage III Sterkte en veiligheid, Ministerie van Infrastructuur en Milieu.