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Deposition-Erosion Criterion for Sediment Transport

Deposition-Erosion Criterion for Sediment Transport in Sewers based on Shear Stress Calculations

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The idea of the deposition – erosion criterion based on shear stress is that if the actual shear stress θ is below the critical shear stress value for deposition $\theta_{cr,\ deposition}$, i.e. if $\theta < \theta_{cr,\ deposition}$, then deposition will occur. If the actual shear stress value θ is in-between the critical shear stress value for deposition and the critical shear stress value for erosion, i.e. if $\theta_{cr,\ deposition} < \theta < \theta_{cr,\ erosion}$, then no erosion or deposition will occur and all suspended sediment is transported along the conduit. If the actual shear stress θ exceeds the critical maximal shear stress value for erosion $\theta_{cr,\ erosion}$, i.e. if $\theta > \theta_{cr,\ erosion}$, then erosion will occur.

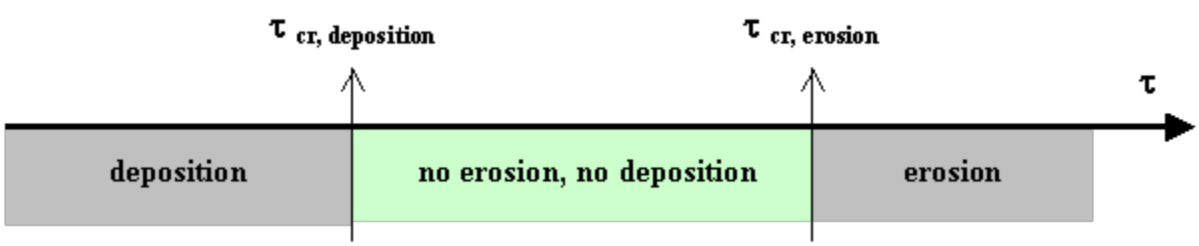

Figure 1: Illustration of the deposition – erosion criterion based on shear stress

Deposition - Erosion calculations can be made according to the following algorithm:

Calculation of the actual shear stress θ

The actual shear stress θ [N/m^2] can be calculated according to eq. (1):

$$\tau = \frac{\lambda_c}{8} \cdot \rho \cdot V^2 \tag{1}$$

where:
λ_c composite friction factor [-]
ρ density of water [kg/m^3]
V flow velocity [m/s]

Calculation of the critical shear stress values for deposition and erosion

Calculate the critical shear stress values for deposition according to eq. (2)

$$\tau_{cr,deposition} = \gamma_{deposition} \cdot g \cdot (s-1) \cdot \rho \cdot d_{50} / 1000 \tag{2}$$

where:
$\gamma_{deposition}$ deposition parameter [-]
g gravitational acceleration [m/s^2]
s specific sediment density [-]
ρ density of water [kg/m^3]
d_{50} sediment particle size [mm]

Calculate the critical shear stress values for erosion according to eq. (3)

$$\tau_{cr,erosion} = \gamma_{erosion} \cdot g \cdot (s-1) \cdot \rho \cdot d_{50} / 1000 \tag{3}$$

where:
$\gamma_{erosion}$ erosion parameter [-]
g gravitational acceleration [m/s^2]
s specific sediment density [-]
ρ density of water [kg/m^3]
d_{50} sediment particle size [mm]

Note: $\gamma_{deposition}$ can not exceed $\gamma_{erosion}$, i.e. $\gamma_{deposition} \le \gamma_{erosion}$

Calculation of the deposition / erosion rate q_s

If $\theta < \theta_{cr,\ deposition}$ then deposition occurs. The deposition rate q_s [kg/s] can be calculated according to eq. (4)

$$q_s = -\alpha_{deposition} \cdot \left(\frac{\tau_{cr,deposition} - \tau}{\tau_{cr,deposition}} \right)^{\beta_{deposition}} \tag{4}$$

where:
θ actual shear stress [N/m^2]
$\theta < \theta_{cr,\ deposition}$ critical deposition shear stress [N/m^2]
$\alpha_{deposition}$ deposition parameter [kg/s] ($\alpha_{deposition} \geq 0$)
$\beta_{deposition}$ deposition parameter [-] ($\beta_{deposition} \geq 1$)

Note:	$q_s \leq 0$ (deposition)
	$\alpha_{deposition} \geq 0$, maximal deposition rate (i.e. for θ equal to zero)
	$\beta_{deposition} \geq 1$

Care must be taken that no more sediment will be deposited than the amount of sediment that is carried by the flow. Therefore the deposition rate q_s is limited according to eq. (5).

$$q_s \geq -C_{old} \cdot Q \tag{5}$$

where:
C_{old} concentration prior to deposition – erosion calculations [kg/m^3]
Q flow [m^3/s]

If $\theta_{cr,\ deposition} < \theta < \theta_{cr,\ erosion}$ then there will be no erosion and no deposition. All suspended sediment is transported and therefore q_s [kg/s] will be zero and C_{new} will be equal to C_{old} (see eq. 6).

If $\theta > \theta_{cr,\ erosion}$ then erosion occurs. The erosion rate q_s [kg/s] can be calculated according to eq. (6)

$$q_s = \alpha_{erosion} \cdot \left(\frac{\tau - \tau_{cr,erosion}}{\tau_{cr,erosion}} \right)^{\beta_{erosion}} \tag{6}$$

where:
θ actual shear stress [N/m^2]
$\theta_{cr,\ erosion}$ critical erosion shear stress [N/m^2]
$\alpha_{erosion}$ erosion parameter [kg/s]

$\beta_{erosion}$ erosion parameter [-]

Note:	$q_s \geq 0$ (erosion)
	$\alpha_{erosion} \geq 0$
	$\beta_{erosion} \geq 1$

Care must be taken that no more sediment will be eroded than the amount of sediment that is stored in the bed. This is expressed by eq. (7).

$$q_s \cdot \Delta t \leq M_{bed} \qquad (7)$$

where:
Δt timestep [s]
M_{bed} sediment mass stored in the bed [kg]

The sediment mass that is stored in the bed M_{bed} can be calculated according to eq. (8).

$$M_{bed} = A_{bed} \cdot \Delta x \cdot \rho \cdot s_b \qquad (8)$$

where:
A_{bed} cross-sectional area of the sediment bed [m^2]
Δx mesh size [m]
ρ density of water [kg/m^3]
s_b bulk specific gravity [-]

The bulk specific gravity s_b can be calculated assuming a 60% void ratio (see eq. (9)).

$$S_b = \frac{s + 0.6}{1.0 + 0.6} \qquad (9)$$

Combining eq. (7) and eq. (8) results in an upper erosion limit expressed by eq. (10).

$$q_s \leq A_{bed} \cdot \rho \cdot s_b \cdot \frac{\Delta x}{\Delta t} \qquad (10)$$

Calculation of the resulting sediment concentration in the flow

The new sediment concentration in the flow C_{new} (i.e. after deposition – erosion calculations) can be calculated according to eq. (11)

$$C_{new} = C_{old} + \frac{q_s}{Q} \qquad (11)$$

where:

C_{old} original sediment concentration [kg/m^3]

q_s deposition - erosion rate [kg/s]

Q flow [m^3/s]

Six user editable parameters are introduced, three of which ($\alpha_{deposition}$ [kg/s] ; $\beta_{deposition}$ [-] ; $\gamma_{deposition}$ [-]) apply to deposition processes and three of which ($\alpha_{erosion}$ [kg/s] ; $\beta_{erosion}$ [-] ; $\gamma_{erosion}$ [-]) apply to erosion processes. An example of the application of these six parameters is shown in figure 2. Figure 3 shows an example of the deposition – erosion criterion in its most simple form, i.e. when $\alpha_{deposition}$ = $\alpha_{erosion}$, $\beta_{deposition}$ = $\beta_{erosion}$ = 1 and $\gamma_{deposition}$ = $\gamma_{erosion}$.

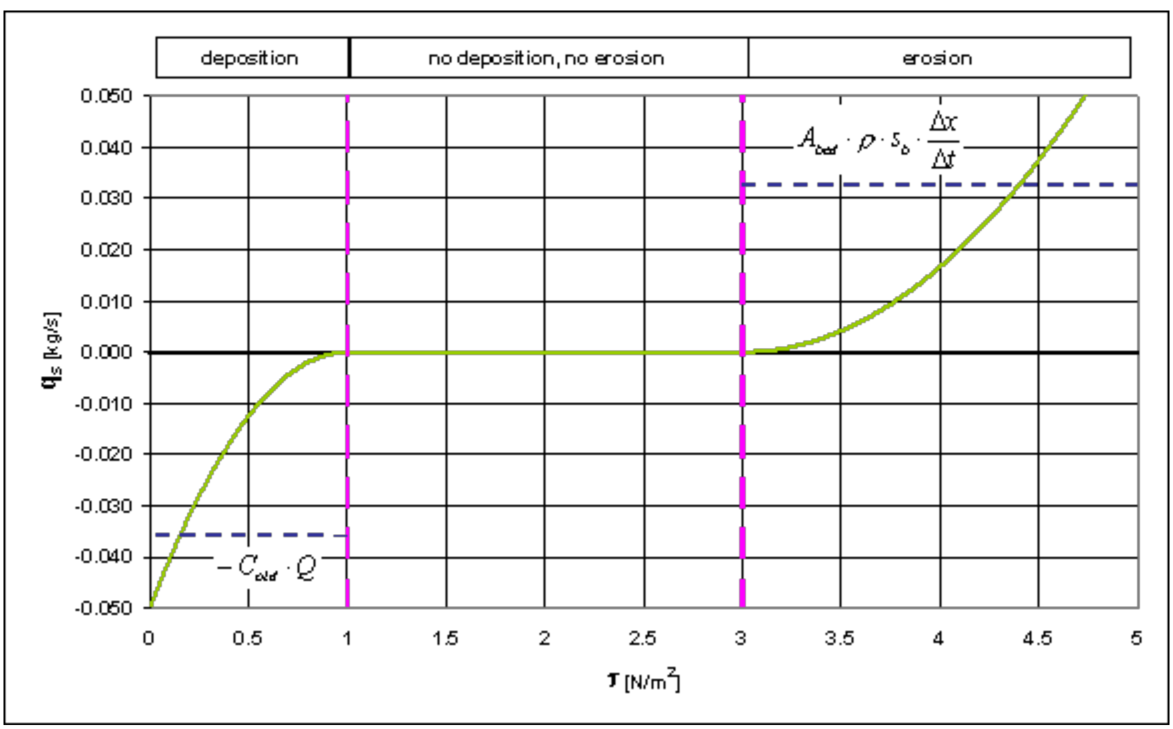

Figure 2: Example of the deposition – erosion rate criterion representing the deposition – erosion rate q_s as a function of the shear stress θ

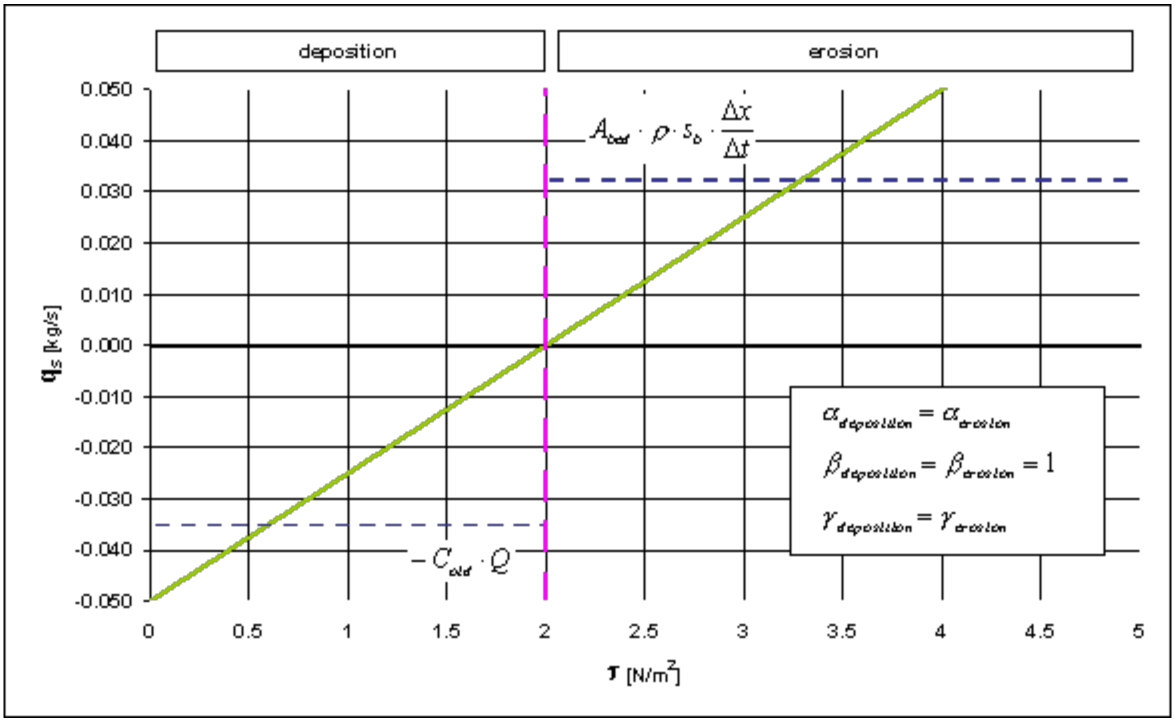

Figure 3: Example of the deposition – erosion criterion in its most simple form representing the deposition – erosion rate q_s as a function of the shear stress θ

Parent topic: Technical Notes
