



Morphodynamic Simulations with BASEplane

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BASEMENT Anwendertreffen



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Morphodynamic 2-D Simulations

Morphological changes in lateral direction

- lateral streambank erosion
- river bend morphology
- alternate bars



Thur, BHteam Ingenieure AG



Limmat, L. Vonwiller



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Fundamentals of Bed Load Transport

Bed load formula for uniform sediment d_{50}

- e.g. Meyer-Peter and Müller (1948)

$$q_b = \alpha \sqrt{g(s-1)d_{50}^3} (\theta - \theta_{c,\delta})^\varepsilon$$

Bed load formula non-uniform sediment σ_g

- grain size distribution with n grain classes (e.g. $n = 7$)
- e.g. additional hiding function ζ_i

$$q_b = \sum_{i=1}^n f_i \alpha \sqrt{g(s-1)d_i^3} (\theta_i - \zeta_i \theta_{c,\delta})^\varepsilon$$

- n sorting equations in active layer and update of sublayer



Local Bed Slope Effect $\theta_c \uparrow$

Critical Shields parameter θ_c

- user defined, e.g. $\theta_c = 0.047$
- transformed of Shields Diagram: $\theta_c = f(D^*)$

Adaptation of critical Shields parameter

- $\theta_{c,\delta}/\theta_c = f(\delta_l, \delta_t, \gamma)$
- arbitrary local bed slope $\delta = (\delta_l, \delta_t)$
- angle of repose γ
- approach of van Rijn (1989), Chen et al. (2010)

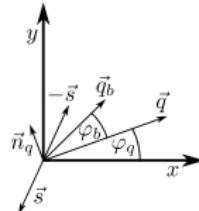


Lateral Bed Slope Effect

Bed load *direction* due to lateral bed slope

Approach of Ikeda (1982)

- $\tan \varphi_b = -N_l \left(\frac{\theta_c}{\theta} \right)^{M_l} \vec{s} \cdot \vec{n}_q$,
where $\vec{s} \cdot \vec{n}_q < 0$
- $1.2 \leq N_l \leq 2.4$
- $M_l \approx 0.5$
- additional (lateral) diffusion



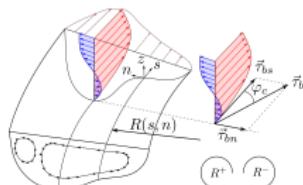
Bed Load Transport in River Bends

Bed load *direction* due to curvature effect

Approach of Engelund (1974)

- $\tan \varphi_c = N_* \frac{h}{R}$
- $N_* = f(C_f)$
- $N_* \approx 7$ (natural rivers)

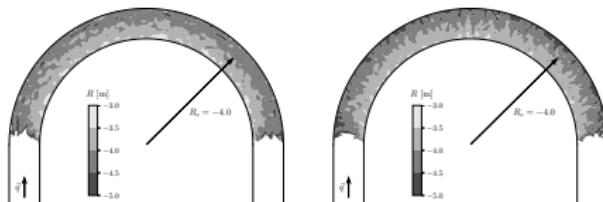
> need radius R



Estimation of Radius R

Local estimate of R based on

- lateral water surface inclination (left)
- velocity vectors using neighbor elements (right)

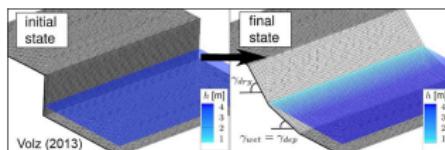


Bank Collapse

Sediment transport due to gravitational bank collapse

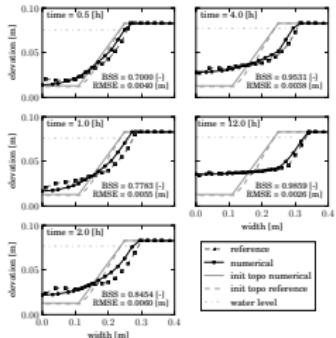
➤ Geometrical approach (Volz, 2013)

- critical angle for wet material γ_{wet} (\approx angle of repose)
- critical angle for dry material γ_{dry}
- $\gamma_{dry} \geq \gamma_{wet}$



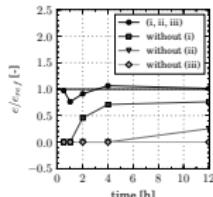
Lateral Erosion in Straight Channel

Laboratory experiments (Ikeda, 1981): (i) $\theta_c \downarrow$ (ii)  (iii) 



- uniform sediment d_{50}

- lateral erosion e/e_{ref} :



 (i, ii, iii) needed

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Erosion of Artificial Gravel Deposit

Laboratory experiments (Friedl, 2017): σ_g $\theta_c \downarrow$  

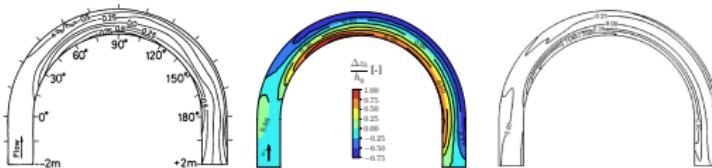


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Morphology in 180° River Bend

Laboratory experiments (Yen and Lee, 1995): σ_g $\theta \downarrow$  

- bed elevation change $\Delta z_b/h_0$ in 180° river bend



reference data of
Yen and Lee (1995)

present 2-D model

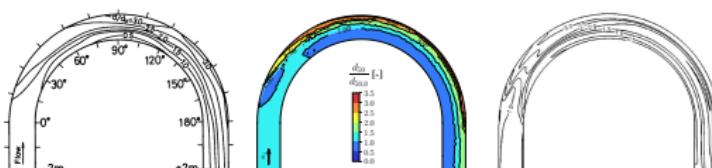
3-D model of
Fischer-Antze et al. (2009)



Grain Sorting in 180° River Bend

Laboratory experiments (Yen and Lee, 1995): σ_g $\theta \downarrow$  

- grain sorting effects (fining/coarsening) $d_{50}/d_{50,0}$



reference data of
Yen and Lee (1995)

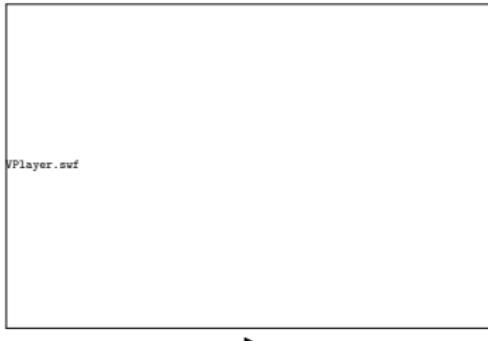
present 2-D model

3-D model of
Fischer-Antze et al. (2009)



Alternate Free Bars at Equilibrium

Free bar amplitude $A = z_{b,left} - z_{b,right}$

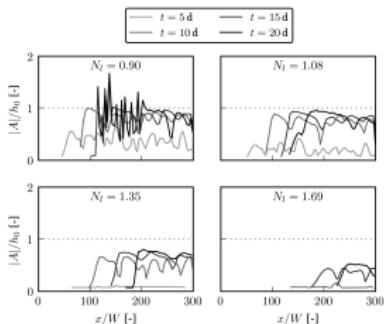


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Influence of Ikeda Parameter N_l on Bar Amplitude

- additional lateral diffusion
- total diffusion = numerical diffusion + lateral diffusion



Conclusion: Relevant Model Approaches

Modeling of streambank erosion

- bank collapse
- lateral bed slope effect
- local bed slope

River bend morphology

- lateral bed slope effect
- curvature effect

Alternate free bars

- lateral bed slope effect



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Thank you for your attention!



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References I

- Chen, X., Ma, J., and Dey, S. (2010). Sediment transport on arbitrary slopes: simplified model. *Journal of Hydraulic Engineering-ASCE*, 136(5):311–317.
- Engelund, F. (1974). Flow and bed topography in channel bends. *Journal of the Hydraulics Division ASCE*, 100(11):1631–1648.
- Fischer-Antze, T., Ruether, N., Olsen, N. R., and Gutknecht, D. (2009). Three-dimensional (3d) modeling of non-uniform sediment transport in a channel bend with unsteady flow. *Journal of Hydraulic Research*, 47(5):670–675.



References II

- Friedl, F. (2017). *Sediment replenishment by artificial gravel deposits and induced bank erosion in Swiss lowland rivers*. VAW-Mitteilungen (R. M. Boes, Ed.), Laboratory of Hydraulics, Hydrology and Glaciology (VAW), ETH Zurich, Switzerland (in preparation).
- Ikeda, S. (1981). Selfformed straight channels in sandy beds. *Journal of the Hydraulics Division-ASCE*, 107(4):389–406.
- Ikeda, S. (1982). Lateral bed-load transport on side slopes. *Journal of the Hydraulics Division-ASCE*, 108(11):1369–1373.



References III

- Meyer-Peter, E. and Müller, R. (1948). Formulas for bed-load transport. In *Proceedings of the 2nd Meeting of the International Association of Hydraulic Structures Research (IAHSR), Appendix 2, Sweden, Stockholm*, pages 39–64.
- van Rijn, L. C. (1989). Handbook. In *Sediment transport by currents and waves*, number Report H 461 in Delft Hydraulics. Delft Hydraulics.
- Volz, C. (2013). Numerical simulation of embankment breaching due to overtopping. Number 222 in VAW-Mitteilung. Laboratory of Hydraulics, Hydrology and Glaciology (VAW).

References IV

- Yen, C. and Lee, K. T. (1995). Bed topography and sediment sorting in channel bend with unsteady flow. *Journal of Hydraulic Engineering*, 121(8):591–599.