Experience in 3-D modeling tricks and fitting techniques in seepage and piping prediction in levee subsoil

A. Cavagni[1], S. Cremonesi[2], M.G. Tanda[3], M.D. Giliberti[4], L. La Torre[4], G. Zanichelli[4] & S. Pavan[5]

[1] *Graduate in Civil Engineering from the University of Parma, Italy*
[2] *Graduate in Environmental and Land Engineering from the University of Parma, Italy*
[3] *Department of Engineering and Architecture, University of Parma, Italy*
[4] *Department of Flood Risk Prevention and Mitigation-Interregional Agency of the Po River, Parma, Italy*
[5] *Interregional Agency of the Po River, Subsidiary office of Ferrara, Italy.*

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Levee failure due to flood-induced sand boils is one of the main causes that generate flood occurrence (Vergnani M. and Zanichelli G., 2002; Toth, 2004; TACFD 2002). It represents serious hazard for population and structures due to the difficulty in forecasting where erosion initiates.

The objective of this paper is to show how the 3-dimensional modeling can improve, in comparison with a 2-dimensional modeling, the evaluation of the failure probability (Lanubile and Tanda, 2016). That because the subsoil heterogeneity, the field measurements and the visual field observation of sand boils can be taken into account in the 3D approach.

We present two piping – sensitive subsoil case studies in Italy, along the Po river: Sacca di Colorno (Cavagni, 2017) and Caselle Landi (Cremonesi, 2017).

The analysis has been carried out using FEMWATER (Hsin-Chi, 1997) a 3-D Finite Element model, which is able to solve the saturated-unsaturated flow field both in steady and unsteady conditions. The embankments considered have been described by means of a detailed Digital Terrain Model with 1m grid. The heterogeneity of the foundation soil has been recovered on the basis of the existing investigations consisting of several boreholes and geo-electrical tomographies. These data have been processed by the graphical interface of the Groundwater Modeling System (GMS, 2017) software. The hydraulic parameters, when available, have been set at the values determined by field tests (Morreale, 2014) or at literature values (De Marsily, 1986; Van der Zee, R.A, 2011), on the basis of the geological description. The soil properties of the unsaturated zones have been represented with the Van Genuchten curves (1980) with parameter set in agreement with Carsel and Parrish (1988).

Both cases have been analyzed in unsteady conditions using the historical flood waves occurred in the Po river in 2000 and 2014; for these events records of the occurrence or not occurrence of the sand boils are available and they have been used as a check of the reliability of the soil heterogeneity identification and the hydraulic parameters (Ozkan, S., 2003).

In the Sacca di Colorno (Cavagni, 2017) case (Figure 1-a), the 3-D modeling gave new information on the plausible direction of the seepage flux that caused the formation of a big sand-boil, suggesting a new perspective for the remediation measures, since the existing hydraulic barriers, intended to prevent the sand boil formation, have been revealed as partially inefficient. In particular, the simulations pointed out that an unexpected, preferential flow direction origins from a gravel lens located downstream in the floodplain, that is saturated only for remarkable river levels.

In the Sacca di Colorno case, 2-D simulations carried out in previous studies did not notice the effect of the above mentioned gravel lens and suggested the design of hydraulic defense structures in the upstream and front side of the river. The 3-D modeling, with the overview consideration of the entire subsoil, can give information free of assumed flow direction as the ones unavoidable with the 2-D modeling.

In the Caselle Landi (Cremonesi, 2017) case (Figure 1-b), the 3-D modeling allowed a better definition of the design of the new hydraulic barriers to be realized in order to avoid the formation of

several, dangerous sand-boils. The 2-D simulations carried out in previous studies suggested the realization of an embankment with an extension involving the entire site while the 3-D simulation allowed a location and extent of the barrier optimized with regards to economic budget and hydraulic efficiency.

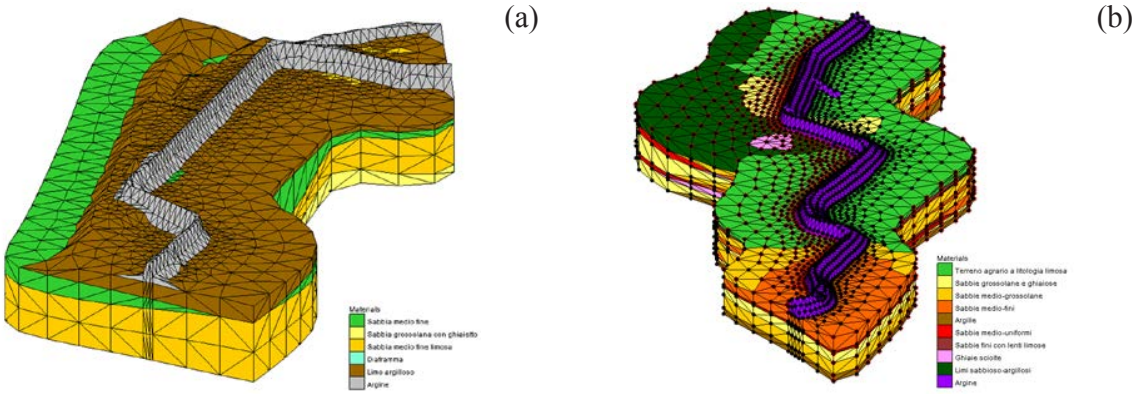

Figure 1. Computation grids for the (a) Sacca di Colorno and (b) Caselle Landi sites.

Finally, 3-D numerical models offer more reliable tools in flood risk management but a key role of the process is played by the detailed knowledge of the ground sediment structure and of the accurate geologic conceptual model.

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