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Two-dimensional Modelling of Floodplains Inundation with Embankment Overtopping and Erosion

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A methodology for flooding simulation including overtopping and erosion of road embankments and river levees at large scale is presented. The emphasis is on the mutual effects of flooding over embankments and of embankments over flooding propagation, in the context of flood risk analysis for land use planning, river basin planning and civil defence. The methodology integrates an embankment erosion procedure into a two-dimensional flooding model. The model assumes that the flow field is represented as a set of triangular cells, whose bottom boundaries describe the ground morphology.

The hydrodynamic modelling is based upon the shallow water equations in the complete form, associated with the continuity equation written in the integrated form for each cell. Equilibrium equations are solved by a second order semi-implicit method, while continuity equations are treated according to a finite volume approach.

The embankment degradation routine assumes that an erosion process starts as soon as any embankment reach is overtopped. The implementation of the procedure requires that the computational grid must include cell interfaces along the embankment route. Of course, flows through these interfaces are assumed to be nil, unless the barrier is overtopped. Then, the flow over the barrier is evaluated by an overflow equation accounting for possible downstream tailwater effects. The embankment degradation is described geometrically by a rotation of the profile of the downstream slope around

its toe. The rate of the process is governed by assuming that the volume of additional erosion equals at each time interval the sediment volume corresponding to the solid transport capacity of the flow over the slope, as expressed by the Smart equation for steep slopes. The geometrical parameters of the cross section of the embankment are assigned initially for each elementary reach and are updated as the erosion goes on.

The erosion modelling procedure has been validated upon results of embankment overtopping experiments available in literature. The physical experiment has been reproduced by means of the mathematical model, thus determining the time progress of the embankment degradation at each reach.

A case study refers to the coastal plain of Irminio river in Sicily, Italy, where the flood propagation area is dammed by the transversal embankment of a coastal road, being interrupted only by the openings of two small bridges over two parallel branches of the river. The analysis includes a variety of flooding conditions, for several return periods and for an hypothetical dam-break accident.

The case study includes the comparison with the results obtained by simulation under a variety of simplified hypotheses: unerodible embankment, instantaneous erosion along with progress of overtopping and, finally, neglection of the erodible barrier. The comparison allows to realise the difference in the backwater effect upstream of the embankment. Of course, these results are consistent with the degree of stability of the embankment in the different cases. However, the differences between the model of sudden removal and the model of progressive erosion are really negligible. This is mostly a consequence of the very fast development of the erosion process, whose rate of progress can be determined anyway by the more accurate procedure.

The results of the applications lead to conclude that the simulation of catastrophic floodings including overtopping of erodible embankments requires to account for the erosion resulting from overtopping during the event. However, although the more accurate procedure is superior in theory, the duration of the erosion process is such short that the hypothesis of sudden removal of overtopped reaches as soon as overflowing occurs can be deemed quite reasonable too.