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Analysis of underseepage phenomena of River Po embankments

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Abstract

The Po River (Northern Italy) is the longest watercourse in Italy and over half of its length is safeguarded by major river embankments. Their stability is crucial for the local communities, being the Po River plain densely populated. Among all possible failure mechanisms, backward erosion piping at the interface between the bottom sandy aquifer and the overlying fine-grained soils has proved to be one of the most threatened phenomena. This paper describes the reactivation of a sand boil in a river embankment section in the Province of Ferrara, during the 2014 major high-water event. Detailed stratigraphic soil profiling as well as careful geotechnical characterization of the embankment and of the subsoil have been carried out on the basis of in-situ tests. Then, safety assessment of the backward erosion piping has been performed using simplified prediction tools and a preliminary 2D numerical model. Results are compared and discussed with the aim of providing some insight into the mechanism under investigation.

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Keywords: backward erosion piping; flooding; probability of failure; Po River; river embankments

1. Introduction

The Po River (Fig. 1), which flows eastward through Northern Italy, is the longest watercourse in the country and its drainage area forms a wide fertile flood plain. The Po Basin has a population of around 16 million (nearly ¼ of the

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population of Italy) and it is home to intensive agriculture and industrial activities, with a crucial role in the national economic development. The Po River is often subject to high-water periods. Therefore, over half of its length is safeguarded by major river embankments. Over the last centuries, such man-made water-retaining structures were progressively built and enlarged on a relative impermeable top layer that overlies a sandy foundation. A typical cross-section of the embankments is shown in Figure 2a. The extensive damage associated with a breach in such structures would result in very high human and economic losses.

Among all the Italian public bodies in charge for the Po River management, AiPo (Italian acronym of the Interregional Agency for the Po River) is the one who directly operates on the territory, acting on the control, monitoring, design, construction and maintenance of hydraulic structures in the whole basin. In addition, it provides a service for forecasting and monitoring the high-water events, as well as with an emergency management service. AiPo is also promoting new investigations and studies in order to detect one of the most threatened collapse mechanisms for Po River embankments: backward erosion piping. Final aims of the new investigations are: 1) the creation of a database of the most critical and recurrent piping phenomena; 2) the development of a methodology for the definition of an alarm threshold which correlates the river level during a high-water event to the piping initiation. The latter would be an important early warning system during such events.

Backward erosion is a sort of internal erosion and regards the detachment of soil particles, due to which shallow pipes develop at the interface of an aquifer and an impervious cover layer [1]. Seepage is the first step in the process leading to the collapse of the embankment due to backward erosion piping. It is induced by a hydraulic head difference H across the structure and a downstream unfiltered open exit is necessary for the occurrence of the phenomena [2]. The common exit type for backward erosion in the field is typically a hole, or crack patterns due to desiccation.

Once the first phase requirements are achieved, the initiation of backward erosion will take place when fluidization of sand near the exit point occurs (i.e. when the effective stresses are zero). This is clearly determined by the exit velocity. In a hole-type exit, flow lines will concentrate near the exit point, thus leading to higher flow velocities near it. In this sand boiling phase, the sand is lifted and dropped, but does not always imply transport of particles. When water head increases sufficiently to cause sand transport from the aquifer, particles settle in a ring outside the boiling zone, forming a “volcano” [2]. At this point, small pipes start to develop in the interface between the impermeable top layer and the sand.

Volcanoes, in Italian commonly named *fontanazzi*, are often formed downstream of Po embankments in response to a high increase in water river level. Ringing sand boils is a typical corrective action used in reducing hydraulic gradients [3] (Fig. 1b). The minimum height of the (sack) ring is limited to the height required to avoid sand transport, and therefore pipe development to the upstream level. Indeed, equilibrium is generally achieved and a further increase of water head would be required for the pipe to progress across the base of the embankment until it reaches the upstream level, thus eventually resulting in a widening of the pipe and river embankment failure. Such phenomena are typical of the medium low portion of the rivercourse, where the river is pensile during high waters.

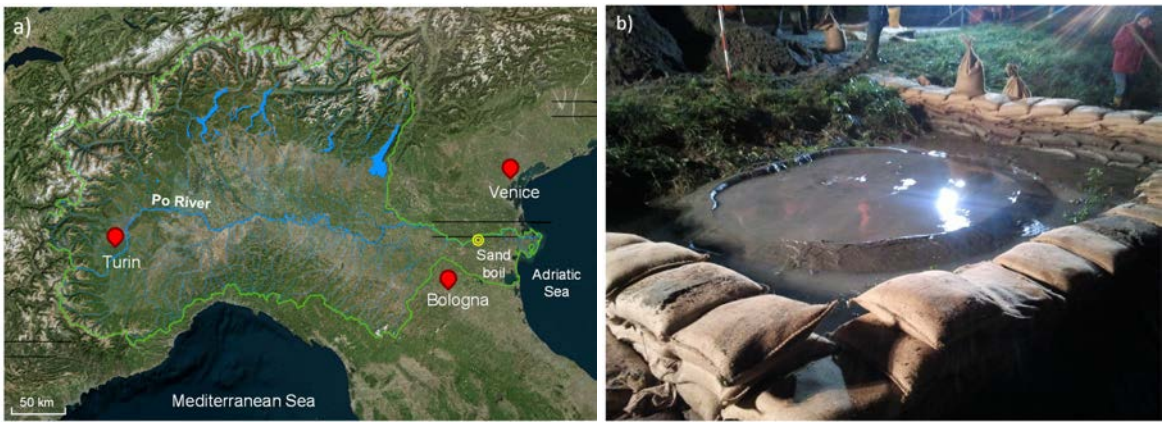

Fig. 1. a) Map of the Po River watercourse; b) sand volcanoe and sack ring (Courtesy of AIPo).