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Detection and characterization of animal burrows within river embankments by means of coupled remote sensing and geophysical techniques: Lessons from River Panaro (northern Italy)

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ABSTRACT

The damage and the eventual breach of river embankments may be due to internal erosion and instability processes in the waterside and landside slopes. Beside the progressive degradation of soil properties, different types of macro-pores inside the levee body can influence its short- and long-term performance. Among macro-pores, burrows are a widespread form of biologic erosion of earthen structures potentially producing damage or even their collapse. In fact, animal burrows are erosion tunnels, which can lead to piping phenomena. Thus, the emergent risk connected to burrowing animals in earthen levees has to be tackled, given also the environmental changes driven by human activity and climate. Remote sensing and geophysical surveys can complement data from in situ investigation campaigns in the definition of the real-embankment model, as well as in the imaging of local defects which may influence its local and/or global stability. Several techniques were integrated in the study area of the Panaro River, where an active animal burrow was detected in spring 2015. Two campaigns were carried out: Survey-1, in June 2015, just after the relocation of the animals, and Survey-2 in December 2015, after the filling of the burrow with a cement-bentonite slurry. Here, we highlight the peculiarity of each method and the choice of an integrated multi-technique approach. The results allowed the known burrow, as well as two other tunnels, to be imaged in 3D, providing specific guidelines for the best integrated strategy to detect and characterize these macro-pores in a fluvial levee. The proposed approach can advance our knowledge of embankments in space and time, so that effective remedial actions in flood risk and wildlife management can be identified.

1. Introduction

Several scenarios or chain of events can lead to the progressive deterioration, the damage, and the breach of river embankments, which may be due to internal erosion and instability processes in the waterside and landside slopes (FEMA, 2005).

Beside the progressive degradation of soil properties, different types of macro-pores inside the levee body can influence its short- and long-term performance. Macro-pores are generally represented by cracks and fissures in the dike body due to natural consolidation and shrinking-swelling processes, to human and animal activity and to the presence of vegetation. Macro-pores may influence the performance of river embankments by increasing rainfall infiltration and inducing preferential and eventually deeper groundwater flow paths and irregular saturation degree. When the water level in the nearby channels increases, the heterogeneity due to the presence of macro-pores influences the final pore pressure distribution. If the pore water pressures would increase, the effective stresses and the shear strength would be reduced and macro-instability could eventually occur. Moreover, if the macro-pores somehow connect the two sides of the levee, the internal erosion can be accelerated until failure eventually takes place (FEMA, 2005; CIRIA, 2013).

Among macro-pores, burrows are a widespread form of biologic erosion of earth levees, embankments and dams that lead to an

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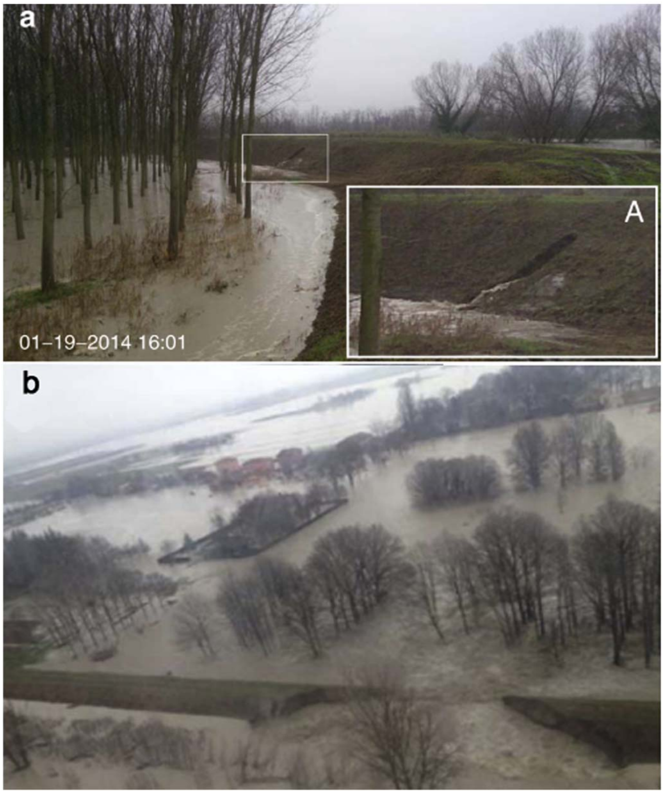

Fig. 1. a) Breach and b) failure of Secchia River embankments during the 19th January 2014 flood (after Orlandini et al., 2015 – a; D'Alpaos et al., 2014 – a, b).

increased risk during flooding events potentially producing structure damage or even its collapse. In fact, animal burrows are erosion tunnels, which can lead to piping phenomena; piping is in turn responsible to approximately half of the world's dam failures (Richards and Reddy, 2010). Moreover, Orlandini et al. (2015) and Taccari (2015) have recently shown how earthen levees disturbed by burrowing animals may fail causing disastrous floods, and have documented a possible animal-induced levee failure mechanism (Fig. 1, D'Alpaos et al., 2014; Orlandini et al., 2015). Besides these recent papers, case studies generally deal with management and maintenance issues, while relatively few studies were carried out to quantitatively assess the biological damage in earthen structures (Bayoumi and Meguid, 2011). Thus, the emergent risk connected to burrowing animals in earthen levees has to be tackled given also the environmental changes driven by human activity and climate (Orlandini et al., 2015).

In order to detect and characterize earthen structures disturbed by animal burrows, the pieces of information from direct, but punctual, investigation and monitoring campaigns must be complemented with indirect, but distributed, data from geophysical surveys, which can help in the definition of the real-embankment model with local punctual/linear/areal anomalies acting as defects which may influence its overall stability on the short- and long-term.

Several geophysical techniques have been applied on embankments and levees with different purposes. Most of the examples are related to imaging the internal structure and estimate the main stratigraphic and hydrogeological features (Panthulu et al., 2001; Cho and Yeom, 2007; Niederleithinger et al., 2012; Perri et al., 2014; Busato et al., 2016; Loperte et al., 2016). Some other papers focus on the detection of voids within the levee structure. In detail: Butler et al. (1994) applied resistivity and magnetic measures to detect badger burrows; Sheng Huoo et al. (2002) investigated the capability of GPR to detect voids with different size by means of laboratory tests; Kinlaw et al. (2007) analyzed the ability of GPR to find tortoise nests; Xu et al. (2010) used the same technique to detect subsurface voids inside dikes and dams. Di Prinzio et al. (2010) proposed the GPR as a standalone tool to detect burrows; Sentenac et al. (2012), as well as Jones et al. (2014) applied 2D and 3D resistivity measurements (ERT) to locate fissures in embankments, while Chlaib et al. (2014) and Samyn et al. (2014) considered the affordability of GPR in discriminating voids from water-filled cavities or metallic objects.

From the previously cited literature we can infer that the geophysical techniques most tested for the problem under examination are ERT and GPR, while some other methods are seldom reported to detect voids, not necessarily in river embankments, like gravimetry (e.g. Butler, 1984) and reflection seismic (e.g. Branham and Steeples, 1988; Deidda and Ranieri, 2005; Lorenzo et al., 2014). Thermal imagery has been proposed as a safety tool for detecting dam seepage (e.g. Deitchman and Loheide II, 2009) but no applications have been exploited to detect voids within flood control structures.

From the geophysical point of view, the detection of a "void" (i.e. any air-filled volume) in the subsurface is based on its physical contrast with the surrounding material. Such a contrast is very high for several physical parameters like density, electrical conductivity, electrical permittivity, seismic velocity. Each specific geophysical technique has its own advantages and disadvantages depending not only on the physical contrast, but, often equally important, on logistical issues, on achievable resolution, on target geometry and depth.

Remote sensing and several geophysical techniques were integrated in the study area of the Panaro River, where an active animal burrow was detected in spring 2015. In this area, two campaigns were carried out: Survey-1, in June 2015, just after the relocation of the animals, and Survey-2 in December 2015, after the complete filling of the burrow with cement-bentonite slurry. In the following sections we briefly highlight the peculiarity of each method, giving reason to our choice of an integrated multi-technique approach. The results allowed to image in 3D the known burrow as well as two others, providing specific guidelines for the best integrated strategy to detect and characterize such kind of structures in a fluvial levee. The proposed approach can advance our knowledge of embankments in space and time, so that effective remedial actions in flood risk and wildlife management can be identified.

2. Study site

We selected a portion on the inner flank of left levee of the Panaro River, where a European badger burrow was previously detected (Figs. 2 and 3c).The River Panaro is a water course tributary of the Po River (northern Italy) having a length of about 150 km and flowing in the Emilia-Romagna Region. The total catchment area is 1784 km^2, with mean annual precipitation of about 1017 mm. It flows through the central section of the northern Apennines down to the Po Plain. Upstream, the catchment is formed by a hilly zone, with sandstones and clayey marls, while downstream recent alluvial deposits outcrop. After the 1950s, in fact, a series of hydraulic works were carried out to reclaim plain areas and the River is now an almost artificial watercourse for long sectors of its course (Castaldini and Ghinoi, 2008).

In the study area, the present-day geometry of the embankment derives from subsequent enlargements of historical levees dating back to 4th–5th century A.D. The most recent works in this sector were carried out after the breach of Malpasso di Cà Bianca (11th November 1982, Fig. 2). Stratigraphic and lithological characteristics from the two boreholes are somehow variable, but the evidence of two or more levee bodies of different age and compaction was not found. Starting from the top of the levee (around 23 m above sea level - asl) 3 main units can be recognized. Unit 1 forms the top of the levee ad comprises layers of clayey silt and gravels. The levee body is composed by silt with sand (Unit 2). Underneath, Unit 3 is composed by clayey silt alternating with sand with silt in sub-horizontal layers and can be considered the natural soil at the base of the embankment.

Water table or partial saturation was found at − 8 m from the top of