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Characterization and monitoring of a riverbank failure in a UNESCO World Heritage Site: the 2016 Florence (Italy) case study

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The impact of geo-hydrological hazards on cultural heritages represents a multi-disciplinary theme, which requires several different approaches. A complete analysis involves geotechnical, structural, and engineering issues and can lead to design adequate countermeasures. The Florence city historic centre, a UNESCO World Heritage Site since 1982, is crossed by the Arno River. The current riverbank morphology is the result of urbanization typical of centuries-old cities, which have mainly developed along the rivers to exploit the waterpower. In particular, the structure of the masonry riverbank is the product of a specific urban redevelopment approved in 1866 and completed in 1872 in the overall framework of the reorganization works carried out to let Florence be the capital of Italy. The vertical stone masonry retaining wall is anchored directly to the substrate of the riverbed with four rows of piles and the filling material is mainly compacted landfill. Buried subservices between the stone wall and the original riverbank and an arched vault culvert just adjacent to the buildings' foundations are also present. On May 25th, 2016, just few metres from the famous "Ponte Vecchio" bridge a portion of the of Lungarno Torrigiani road surface collapsed and the artificial riverbank was partially damaged by a cusp-shaped deformation without any shattering or toppling. The failure was approximately 4 m in height and 150 m in breadth (volume of about 1180 m3) via partial sliding of the underlying terrigenous layers towards the riverbed.

To identify the condition of damage of the involved structures, to define the causes of the failure, and to mitigate and preserve the cultural heritage site, a detailed analysis of this event was performed based on the integration of boreholes and geotechnical laboratory tests, remote-sensing techniques (i.e., terrestrial laser scanning), geophysical surveys (electrical resistivity topographies, downhole, and single-station seismic noise measurement), and stability analyses. The data obtained from these techniques were used to perform the limit equilibrium stability analysis of the slopes. Given the need to make the monitoring system immediately operational, remote instruments able to measure deformations from a station in the opposite bank were installed first. To monitor the crack pattern of the masonry embankment wall, also digital photogrammetry was employed together with the above-mentioned techniques.

The results show that both the aerial and submerged parts of the wall were deformed by the riverbank collapse without collapsing. Moreover, data allow to assess that the evolution of the studied failure is the result of the combination and interaction of two different dynamics. The first one is the riverbank failure, a typical destructive phenomenon during extreme hydraulic conditions, well known throughout the history of city, especially after the intense urbanization starting from 1175. The second factor is the continuous loss of water from the subterranean pipes of the aqueduct, which is a more recent phenomenon that developed from the capillary diffusion of the modern structure in every part of the city. Thus, the major cause of the collapse can be attributed to the loss of water from the local subterranean pipes.