Available online http://amq.aiqua.it
ISSN (online): 2279-7335

Alpine and Mediterranean Quaternary, Vol. 31 (Quaternary: Past, Present, Future - AIQUA Conference, Florence, 13-14/06/2018), 59 - 62

https://doi.org/10.26382/AIQUA.2018.AIQUAconference

QUATERNARY URBAN GEOLOGY AND FOUNDATIONS OF HERITAGE BUILDINGS: A FEW OUTSTANDING CASE HISTORIES FROM ITALY

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ABSTRACT: In this paper we analyse the urban geological setting of three outstanding Italian cities, under the UNESCO patronage, in order to define the relationships between subsoil setting and historical building foundations. Geological features play a key role on this topic and their knowledge is fundamental for any conservation project.

KEYWORDS: Urban geology, Holocene, cultural heritage, building, foundations

1. INTRODUCTION

Most of the main historical cities has been settled in plain areas, close to a river or to the sea, on Quaternary deposits. In these areas, the ground is often constituted by recent unconsolidated, cohesive and granular, alluvial or paralic deposits, more or less thick and with complex sedimentary and lithological assemblages and with hiatus and heteropies. During time geological hazards like floods, subsidence and earthquakes, can severely damage or even destroy heritage buildings. In this context, urban geology, devoted to the study of the recent geological aspects, underground geological setting and geotechnical properties, plays the main role due to its great influence on the foundation, ensuring stability and durability of the heritage buildings. In this paper, we outline the role played by the urban geology for a few selected Italian outstanding cities in the foundations behaviour of their main heritage buildings. Namely we analyse the case histories of Firenze city centre, Venezia and Pisa; they all are UNESCO Human Cultural Heritage sites.

2. CASE HISTORIES

2.1. Firenze

Firenze was settled by the Romans in the II Century B.C. in a natural territory with swamps, marshlands and a river with a large bed within which it flew with braided channels. First the Romans reclaimed the plain for agriculture through the Centuriazione, whose imprinting is still deeply marking the territory as cadastral parcels and ditches and drains. During its history Firenze has been expanding, reclaiming the flood territory all around. The Firenze-Pistoia basin has been developing since the Piacenzian, dismantling the Zanclean low energy surface; this recent geological evolution, according to the allostratigraphy criteria, resulted into continental clastic deposits grouping into three UBSU (Briganti et al., 2003, Coli & Rubellini, 2013) including:

- Synthem of the Basin: lacustrine, alluvial and fan deposits; Piacenzian-Gelasian.
- Ancient Deposits: river-bed gravel of the paleo-Arno; Late Pleistocene.
- Recent Deposits: river-bed and alluvial deposits of the Arno river and tributaries, with swamps and marshlands in the plain; Holocene.

In the historical city centre area, the Recent Deposits of the alluvial bed of the Arno River directly lie on the bedrock; here, below a few meters of archaeological layer, the Recent Deposits are constituted at top by around 2 m of over-bank sands and silty-sands and below by river-bed deposits mainly made of pebbles and gravels, from clean to silty, with layers and lenses of locally graded sands; they are referred to a fluvial subaerial environment where the Arno River braided unconstrained in its alluvial bed, but periodically flooded large portions of the plain.

In the city centre there are two sites of main interest: the religious complex of the Cathedral with the Brunelleschi's Dome, the Baptistery and the Giotto's bell tower, and the civil complex of Palazzo Vecchio and Uffizi Gallery; here the subsoil sequence is (Fig. 1):

- Historical archaeological layer (V-XII century A.D.), about 3-4 m thick, corresponding to Roman and Early Medieval buildings ruins and debris.
- About 2 m of silty-sand of banks and overs-banks.
- About 12 m of river bed gravel.
- Bedrock, at around 17 m depth below the street datum in the Cathedral area and around 10-12 depth below the street datum in the Palazzo Vecchio area.

The Recent Deposits of the Firenze area display good geotechnical properties, gravels fall into the GW/GP fields of the USCS (ASTM 1988) and sands into the SP/SW fields. Sands and gravel have Vs = 120 m/s and Vs = 400 m/s, respectively. Gravels are most calcareous, dense and self-sustaining, with ϕ = 37°+/- 6°, as statistically deriving from 203 NSPT data from the whole city centre area. The archaeological debris have NSPT data ranging from 5 to 7. The water table is stable at about 7 m below the ground datum, with a seasonal excursion of about +/- 1.5 m and in equilibrium with the Arno River,

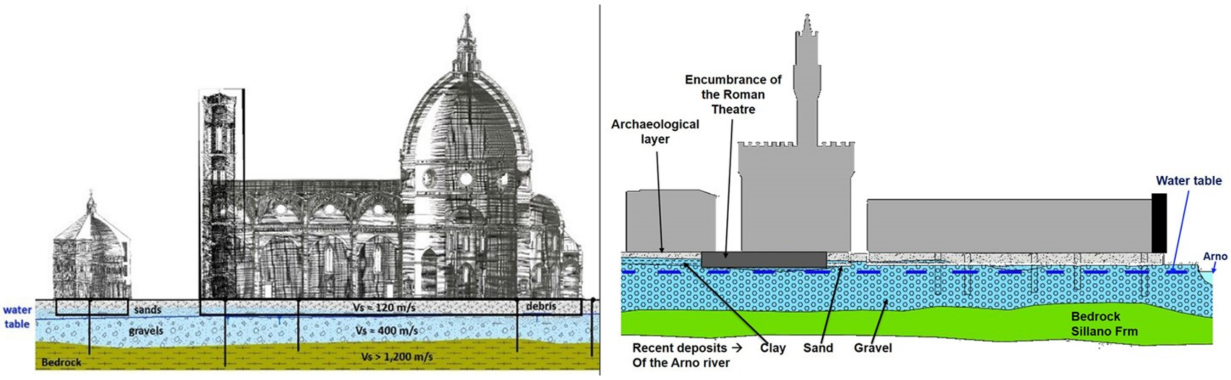

Fig. 1 - Schematic subsoil setting of the main historical buildings at Firenze.

which in turn is kept on level by a barrage downstream the historical city. The foundation of the main historical buildings of Firenze date back to the XIII century and is constituted by massive bodies of mortared stones, with a high quality mortar. They are 6 m depth and rooted into the gravels, right above the water table.

2.2 Venezia

Venezia is located in a complex foreland setting near the pinch-out of both the South alpine and the Apenninic wedges, which developed during Serravallian-Messinian ad Early Pliocene times, respectively. The present-day Venezia area was reached by the north-Adriatic turbidite system during the Early to Middle Pleistocene, due to the north-eastward shifting of the Apenninic fore-deep (Bassan and Vitturi 2003). The Holocene-Pleistocene transition is marked by the *Caranto*, which is an over-consolidated layer of sand and clay mixture considered to be the last continental unit before the Holocene (Flandrian) transgression, that progressively submerged the "Würmian" palaeoplain and the *Caranto* itself, here interpreted like a hardground (Bonardi & Tosi, 1994). The early Holocene sediments are represented by a discontinuous level of silt and sand, often with chaotic structure mixed with shelly marine-lagoon sands due to the sediment redistribution operating by the sea currents on the clasts supplied by the rivers descending by the Alps. Venezia is placed on the recent lagoon deposits, the water table is at the sea level about 1÷1.5 m below the streets datum and therefore all the sediments are saturated. During the Quaternary, the lagoon underwent some discontinuous phases of alternating marine transgressions and regressions, as a result of which both marine and continental sediments coexist (Fig. 2) (Zezza, 2008 *cum bib*).

Both recent lagoon and fluvial Pleistocene soils display bad geotechnical features: for cohesive layers c_u values range between 16÷400 kPa, for granular layers ▯ values range between 5°÷35°; Vs values are around 265 m/s. Cohesive layers display very high compressive and plasticity indexes, only the *Caranto* layer, has a certain grade of stiffness. The lagoon deposits present a typical soil profile characterized by the presence of the following type of sediments, according to USCS (ASTM 1988): 35% sands (SP, SM), 35% silts (ML), 25% clays, (CL), 5% soils with relevant organic matter (MH, OH, PT). Therefore, both cohesive and granular soils are subject to compaction due both to natural factors and to

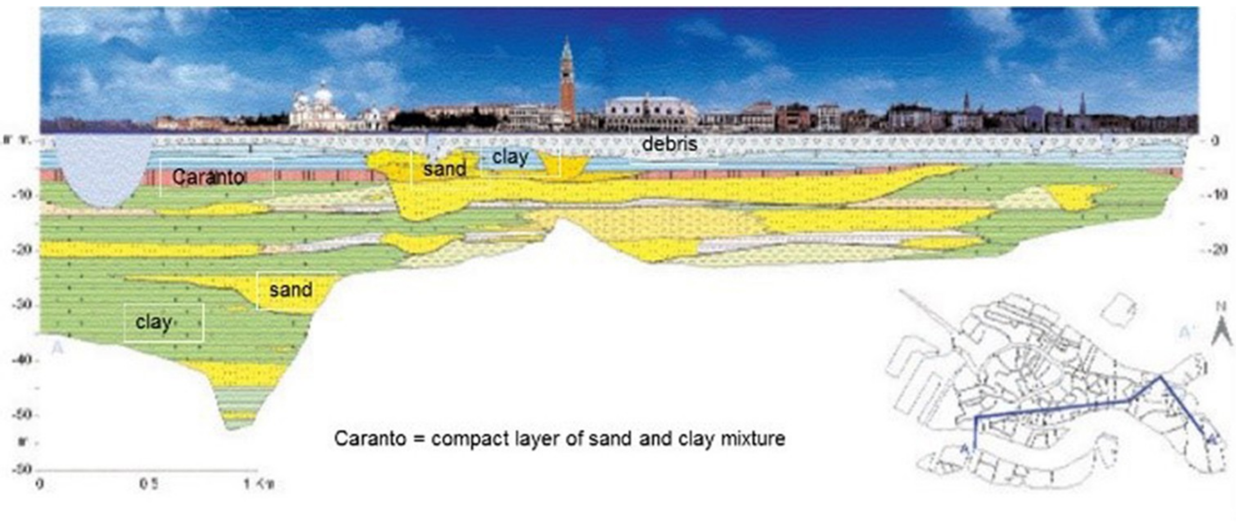

Fig. 2 - Subsoil geological setting of Venezia along a cross-section (after Zezza 2008).

the load of the city buildings. In the city area that resulted into a subsidence rate of around 0.6 mm/y, with subsidence differentiated through the city according to the local subsoils setting. In Venezia buildings foundations consist of a complex system based on the interaction of wood, water and soil. Because surficial soils have a low lift capacity, ancient builders used wooden poles in order to improve the geotechnical properties of the first layers and transfer the load to the below *Caranto* layer where poles had been rooted. This type of foundation is called "indirect foundation" (Biscontin et al., 2011).

2.3 Pisa

Pisa was settled by the Etruscans in the VII century B.C. on the coastal plain, at the confluence of Auser (ancient Serchio) and Arno rivers, close to the coast as a harbour. Later on, the sediments supplied by the Arno and Serchio rivers and beach sand cordons moved the coast west away from Pisa. The Pisa plain is the top of an inner inter-montane basin developed since Late Tortonian, which development had been controlled by normal faults on the eastern side. Above Messinian to Pleistocene deposits, the recent Holocene deposits consists of fluvial and paralic clastic sediments supplied by the incoming rivers, most the Arno and the Auser rivers. In particular, the city of Pisa lies above a deep paleo-valley eroded by Arno River during the last low-standing of the "Würm Ice-Age" into Pleistocene and Pliocene marine deposits. Later on, the paleo-valley was infilled by down-lap Arno river fluvial sediments from east and on-lap marine sediments from west, in a complex relationship of paralic environments: estuary, lagoon, coastal plain, bay-head delta, floodplain, fluvial channel; these recent infilling and the top sediments are mainly constituted by sands and clays (Fig. 3) (Aguzzi et al., 2005, 2007; Amorosi et al., 2008; Sarti et al., 2015).

The soil of the Pisa area presents a certain grade of over-consolidation that had been mainly attributed to the effects of ageing and, to a minor extent, to mechanical over-consolidation, due to erosion-re-deposition processes and water table fluctuation; all are soft soils with bad geotechnical properties. The Leaning Tower has ring-like shallow foundation, rooted up to 2 m below the ground datum, right above the water table (MLP 1971). Walls and foundations were made in wall-bag mode, with mortar of no very good quality; in the year 1935 the foundations were reinforced by grouting and with a concrete outer ring. Under the overburden of the Tower, subsoil has been undergoing progressive viscous-plastic deformation, which resulted into a vertical settlement of 2.5 m and symmetric rotation of the Tower, the leaning rate before the recent conservation works was of around 1.5 mm/y. This natural process had been helped by the pumping out water, since the 1950's, with subsidence of the whole Pisa plane. In order to stop/ reduce the increasing leaning of the Tower which was becoming critic, in the 1965 the Ministry established a

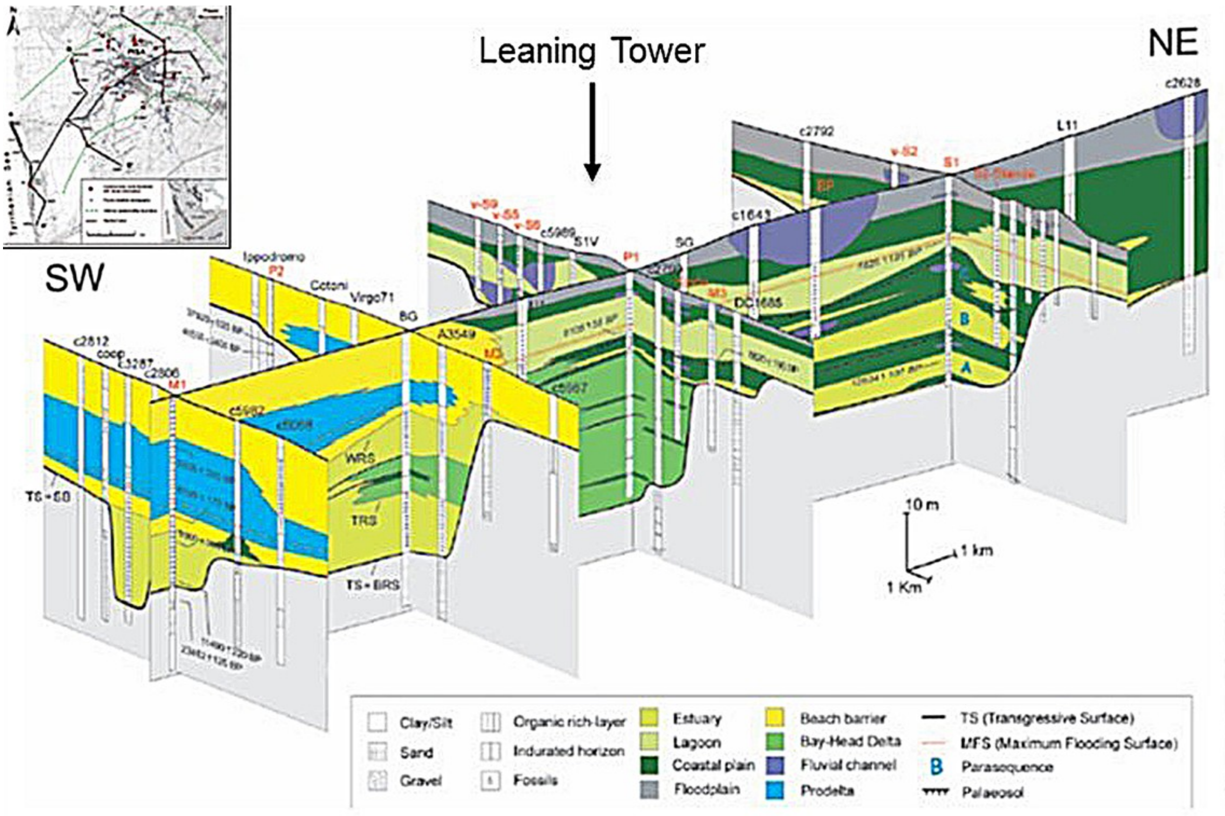

Fig. 3 - Subsoil setting of the Pisa area evidencing Arno paleo-valley during the last "Ice-Age" (after Amorosi et al. 2008).

National Scientific Committee (NSC) that proceed to soil sub-excavation below the upright side of the Tower; the works were executed in the year 2000-2001 by means of 41 drill-holes. These works allowed to achieve a gain of 0.5° of back-rotation and to put on safety the Tower for the close future.

3. REMARKS

When we have to address a problem of conservation for ancient historical buildings first of all we must acquire a historical and technical full knowledge of the monument, and of its detailed geological and subsoil setting, foundations and materials and original building techniques. Only after we have achieved these goals we can design conservation interventions in the full respect of the monument authenticity and integrity. The interventions must be carried out with the in-depth knowledge of the geological and depositional characteristics, and with knowledge of the stratigraphic sequences, the geological model and the type of depositional events in the period that goes from the last glaciation to now.

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Ms. received: April 30, 2018
Final text received: May 28, 2018