Giornale di Geologia Applicata 1 (2005) 123 –130, doi: 10.1474/GGA.2005-01.0-12.0012

Natural hazards and cultural heritage in Florence: the slope instability story of *Monte alle Croci*

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ABSTRACT. Monte alle Croci was the scenery of many historical and artistic events since the Roman period and played an important role in the history of Florence. Some of these facts are connected with the slope instability of the area, firstly investigated by Leonardo da Vinci. The current urban layout, projected by Giuseppe Poggi when the city became the capital of Italy (1864-1877), is a response to these landslide problems. In this paper a review of the instability evolution throughout the last five centuries is presented and it is aimed to frame the present monitoring instruments. A large network of extensometers, inclinometers and piezometers is actually working, even if the data are not easily interpretable. Additional information is expected from some new instruments set up in 2002 and from the reconstruction of the past earth handling.

Key terms: Cultural Heritage, Slope Instability, Monte alle Croci, Hydro-geological Risk

Monte alle Croci in the artistic and historical events of Florence

The southern extremity of the historic center of Florence, on the hydrographical left side of the Arno river, is bordered by a series of hills, known as *Colli Fiorentini*, which yield an evocative panorama of the city with its artworks and monuments (FIG. 1).

Monte alle Croci (also known as *Mons Florentinus* in the period of Roman Empire and as San Miniato hill from Middle Ages) represents the most famous of these gentle heights, because of its significance landscape and its monuments of inestimable cultural, historic and artistic value.

FIG. 1 – Aerial view of Monte alle Croci.

According to an unverified chronicle, the area was uninhabited until 62 A.D., when a group of Christians, dispatched by St. Peter, settled and secretly built an oratory, nicknaming the hill *Elisbots*. More certain are the events concerning St. Miniato, the first evangelizer and Christian martyr in Florence. Victim of the persecutions of the Emperor Decius (249-251 A.D.), Miniato is thought to have been an Armenian prince: the legend narrates that, after his decapitation, he picked his head up, put it back on his neck and went to die in a cave on *Monte alle Croci*, where he had lived as a hermit and where later the church, that nowadays bears his name was built (BUSIGNANI & BENCINI, 1974; BARGELLINI, 1980).

The construction of the temple, one of the finest examples of pure Florentine Romanesque architecture, first started in 1018, thanks to Bishop Ildebrando, and continued until 1207. The façade was carried out in white Carrara and green Prato marble (12^{th}-13^{th} centuries); the interior contains an inestimable treasure of Renaissance masterpieces (FIG. 2). In the 14^{th} century, the contiguous *Palazzo dei Vescovi* (Bishops' Palace) was built and it was later converted into a monastery, with the joining of the cloister and other rooms, frescoed also by Paolo Uccello (15^{th} century). On the opposite side, the bell tower rises: the original, probably contemporary with the church, was damaged by lightning in 1325 and 1413, and fell down in 1499, and the building of the new one began in 1524 (GURRIERI *et alii,* 1988).

In this period, the same area saw the construction of San Salvatore church and San Francesco convent, an important Renaissance building completely rebuilt over a pre-existent little oratory (1419-1499) (LAPINI, 1900; BACCI, 1960). The façade of the church is both austere and graceful and designed with alternating curved and triangular tympani; the interior shows signs of an attempt to get away from the influence of Brunelleschi (FIG. 3) (GIUBBI, 1996).

FIG. 2 – Basilica of San Miniato and Palazzo dei Vescovi

In 1527, while the San Miniato tower was under construction, the area became a strategic point for the military defense of Florence: after the expulsion of the Medici family, a republican government was established and the attack of Charles V was looming up. In order to prepare for the siege (Florence withstood for ten months during 1529), it was necessary to fortify the hill and Michelangelo Buonarroti was commissioned to design the fortification that was rapidly built (FANELLI, 1973; BARGELLINI, 1980).

FIG. 3 – The interior of San Salvatore al Monte: on the arch some old restored cracks are evident.

With some differences compared to Michelangelo's original project, the bastions were built: they enclosed the basilica of San Miniato and the church of San Salvatore and teeply descended down to the Arno river.

The new defensive system integrated the big circle of walls that had contained the city since 1333: the old wall lapped on the hill, barely excluding it, and its construction was guided by a prediction of a fast growth, cut short by the Black Death in 1348 (BARGELLINI, 1980).

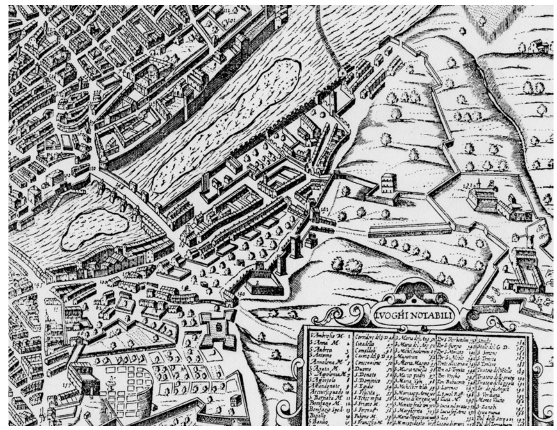

FIG. 4 – Particular of a 17th century city map (from BARGELLINI, 1980) with Palazzo Pitti, the wall system, San Miniato and San Salvatore.

After the 1529 engagements, the buildings of the area, damaged in different ways, were abandoned; the San Miniato complex became a fortress (with some modifications to the bastions at the end of 16th century), and the monks left the hill (FANELLI, 1973; GURRIERI *et alii,* 1988). Only in the San Francesco convent did the monastic life continue, even if in the solitude of the area, which at this point had been left outside the town planning (FIG. 4).

Until the 19th century, the hill remained untouched by building works; then, in 1865, the construction of the monumental cemetery (called *Cimitero delle Porte Sante*) started, immediately followed by the beginning of the city transformation works linked to the appointment of Florence as capital of the Kingdom of Italy. Indeed, between 1865 and 1876, *Monte alle Croci* was involved in a radical town planning intervention directed by the engineer Giuseppe Poggi. On the hill, Poggi designed the scenographic *Viale dei Colli* with its panoramic open squares, of which *Piazzale Michelangelo* is the most famous (FIG. 5) (POGGI, 1872; 1882; BARGELLINI, 1980).

The implementation of the project led to a general modification of the slope's profile. Some excavations and fillings involving impressive earth movements were carried out, in order to build new drainage systems and canalization which supplied water for the waterfalls and fountains, and to construct a series of earth retaining structures along the boulevard and on the *Rampe* terraces. A monumental staircase was built to reach the St. Miniato complex and a big loggia erected between the new *Piazzale Michelangelo* and San Salvatore.

Under this loggia, the Poggi's project foresaw the creation of an open-air museum with Michelangelo's *David* and some other sculptures, but this was never carried out: later, only a bronze copy of *David* was placed in the center of the *Piazzale* (BARGELLINI, 1980).

The last works date from the first half of 20th century, with the restoration of the San Miniato complex (1906), the transformation of the old factories into villas and the construction of some new elegant houses (1900-1920), the realization of a sports ground (1936), and the repairing of aesthetic damage caused by military engagements during the Second World War.

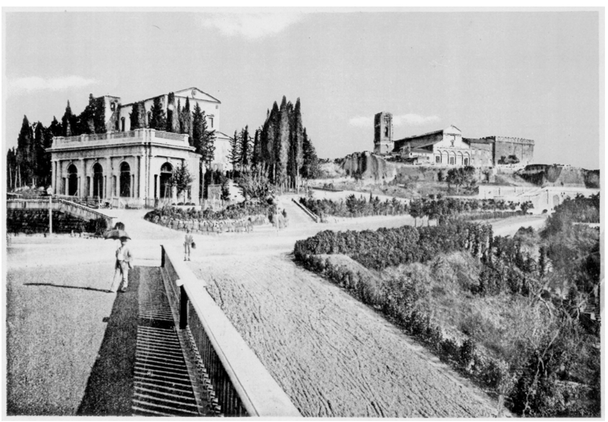

FIG. 5 – San Miniato, San Salvatore and Piazzale Michelangelo during the Poggi's works (from FANELLI, 1973).

The evolution of instability and the course of mitigation works

Historical studies concerning the slope instability phenomena on *Monte alle Croci* are plentiful and detailed because of the above-mentioned strategic, military and religious importance of this place. The unstable condition of the hill was already known in 1447 when Cosimo de' Medici forbade the friars of San Salvatore to enlarge the church, still under construction, because of the slope movements acting on the area (PULINARI, 1913; BARGELLINI, 1961).

At the end of the century, the validity of Cosimo's regulations was confirmed by considerable deformations in the San Salvatore complex: according to some chronicles both the church and the convent were seriously damaged, with a delay in the conclusion of the construction (MAZZANTI *et alii,* 1876), whilst in other opinions the entire monastery fell down and, considering the difficulties for the repair of original foundation, it was rebuilt closer to the church (CAROCCI, 1907).

In the same period, the San Miniato tower collapsed and, to assess the causes of the general instability of the area, a committee was charged to study the hill conditions, and, among others, Leonardo da Vinci was asked to take part (GURRIERI *et alii*, 1988).

As causes of instability, the studies indicated: a) the geological composition of terrains, namely the presence of beds of clayey marl easily softened by water; b) the groundwater rise in connection with intense and prolonged rainfall; c) the artificial undermining due to the exploitation of a clay quarry located in the lower sector of northern slope. However, no works were realized and new damage in San Salvatore was recorded in 1530 and 1536: as a consequence of that, a little reservoir was dug as a drainage system near the convent (BACCI, 1960).

In 1547, during a catastrophic flood, a landslide occurred on a hill adjoining *Monte alle Croci*, and several people died in Florence, thus shocking the city: the authorities temporarily prohibited any new buildings on the southern hills and the tower of San Salvatore was lowered by about 15 m, in the belief that the belfry load was responsible for the slope instability (GURRIERI *et alii,* 1988).

During the following decades, new cracks in the convent walls compelled the friars of San Francesco to carry out a lot of restoration works and, for a short period, to abandon the site. In 1652 a new landslide occurred on an undefined slope of *Monte alle Croci*, after a long period of heavy rainfalls; a technical board was given the task to study the causes and countermeasures (BACCI, 1960). They agreed with the conclusions of the 1499 committee; when several tests proved the superficial origin of waters, there was a general agreement in the mitigation strategies to be adopted for reducing landslide risk; these can be resumed as: a) building of a drainage system as a major restoration work; the plan of a very effectual drainage realized in 1652 is still available although no evidence of the work has been found on the ground; b) land use policies such as the suggestion of suitable agricultural practices or their constraint in some critical areas, limitations in construction of buildings; c) restoration of individual buildings (such as underpinnings, substructures, retaining walls) (BACCI, 1960).

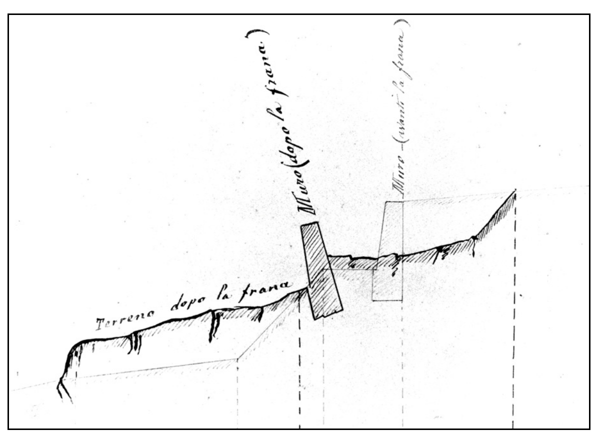

FIG. 6 –Poggi's original drawing of a landslide occurring during the construction of Piazzale (POGGI, 1872), showing the slope profile before (thin stroke) and after the event (thick stroke).

At the end of 17th century (1695), fresh damage occurred in the San Salvatore complex, and a new group of experts identified as triggering factors the weak ground with a considerable water content under the building foundations, the high gradient of slope, and the change of land use of surrounding fields, converted from woods into plantations. The structures were reinforced with the construction of some counterforts and the deepening of the church foundations by about 4 m (POGGI, 1872).

Some new damage was recorded in 1709, 1722, 1758, and, consequently, some light restoration works were carried out in San Salvatore (BACCI, 1960). The subsequent reactivation of instability, in 1853, led the local authorities to constitute a new commission, in which G. Poggi was involved: they highlighted the role of the subsurface water regime and prescribed a lot of interventions, which were never realized (POGGI, 1872).

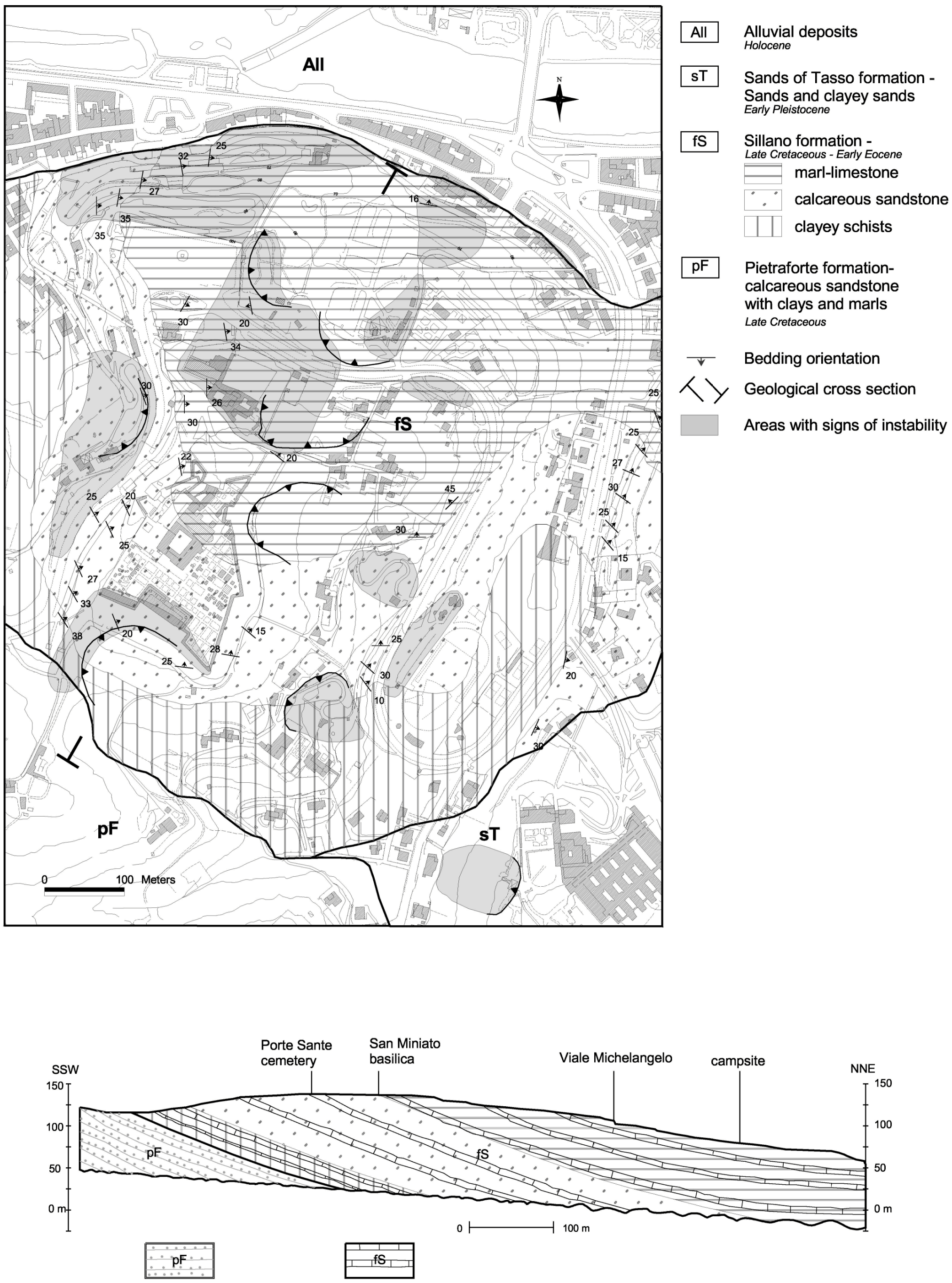

FIG. 7 – Geology and geomorphology map.

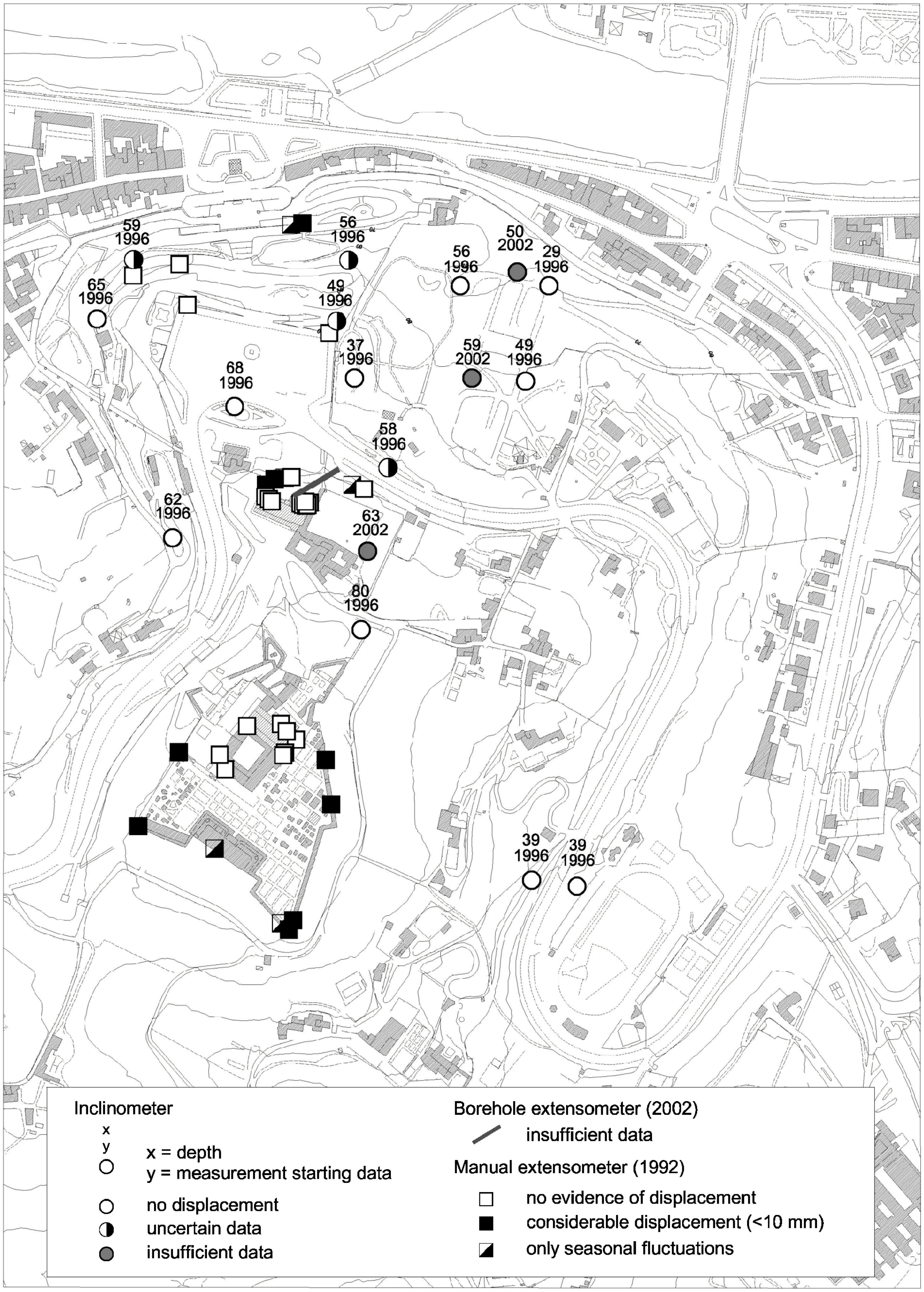

FIG. 8 – Underground and superficial field surveys.

Twelve years after, Poggi had started his project, and, being aware of the problems of the hill, he addressed the works to achieve a more stable layout (FIG. 6): in spite of this, in 1878-79, after heavy rainfall, several cracks opened in the San Salvatore complex and the San Miniato bastions, especially in some of the new structures, such as the loggia, the *Piazzale Michelangelo* retaining walls, and the buttress of the *Rampe* (POGGI, 1882; GIORDANO, 1884).

At once, the umpteenth commission was appointed: the experts, presided over by F. Giordano, carried out a complete geological investigation, still admirable for its thoroughness and precision, condensed in some detailed stratigraphic logs, deduced from the excavation of five wells, from 15 to 33 m in depth.

The inferred geological features were recognized as factors of instability, triggered by earth movements during the main road works: however, the commission had many doubts about the presence of a single, big and deep landslide, presupposing the overlapping of some independent small mass movements, even if, in any case, a connection between the crack systems of the San Salvatore complex and the *Piazzale Michelangelo* area was conjectured.

Again, a careful drainage system was proposed as an adequate countermeasure, together with the building of new breast walls and some directions about land use, such as the stopping of farming and a restraint on new constructions; the reinforcement with chains of San Salvatore church was projected and realized in the following years (GIORDANO, 1884).

During the 20th century, some damage in the San Miniato complex was recorded, but it was linked to the indiscriminate digging in the cemetery of *Porte Sante*: whilst there were emergencies of slope instability in 1973 and 1989, with the occurrence of new cracks in *Piazzale Michelangelo* and the San Salvatore walls, and, in the case of *Piazzale*, of a considerable sag (COMUNE DI FIRENZE, 1990).

Geological and geomorphologic settings

The rocks cropping out at Monte alle Croci belong to an allochthonous formation of the Group of Calvana (Cretaceous-Lower Eocene), as the *Sillano formation* (also named *Vallina formation*), constituted by shales with interbeds of limestone, marls and sandstones: in the area it is possible to distinguish three units, on the basis of the prevailing lithology (FIG. 7).

The rock layers are discontinuous and immersed in a clayey matrix, with a stratigraphical orientation of bedding parallel to the slope and dipping NE with angles of between 20° and 30°. The *Pietraforte formation*, constituted by cemented sandstones, borders the southern sector of the area, partially overlapped by Pleistocene lacustrine sands (*Sabbie del Tasso formation*) (FOCARDI, 1991; TADDEI, 1992).

The main geomorphologic feature is the presence of slope instability, that, as described, has been affecting the hill for a long time. The recognition and delimitation of landslides is extremely difficult due to the urbanization development of the entire hill during the century; the result of human settlement is the almost complete obliteration of evidence of past and present displacements (BERTOCCI & D'AMATO AVANZI, 1993; BERTOCCI *et alii,* 1995).

The available documentation emphasizes the presence of several surfaces which are potentially subjected to sliding (presence of soft clays, strongly fissured rocks) although clear failure surfaces have not yet been defined (GIORDANO, 1884; FOCARDI, 1991; BERTOCCI *et alii,* 1995).

According to some Authors, slope instability is due to the presence of a generalized translational sliding of the entire hill, affecting the slope facing the Arno River, promoted by the orientation of bedding strata, parallel to the slope (LOSACCO, 1957; COMUNE DI FIRENZE, 1990). According to others, landsliding is due to independent phenomena (BERTOCCI *et alii,* 1995; AGOSTINI *et alii,* 2002a; 2002b).

In the lack of conclusive data, the most significant representation of available information is the boundary marking of some areas where signs of superficial instability are present. The most important one, both for its extension and for the value of the involved or threatened buildings, is sited on the east side of *Piazzale Michelangelo*. This area is a wide valley, limited on the western flank by Michelangelo's bastions, partially occupied by a camping site; it presents a large potential source area including the zone of San Salvatore church and a portion of the *Piazzale Michelangelo*.

Site investigation and monitoring

The series of modern site investigations started with the works of Giordano's Commission, and continued during the 20th century with some drilling and structural deformation surveys. The more recent events (1973 and 1989) induced the authorities to arrange an extensive campaign of underground and superficial field surveys, in order to better understand the geometry, geology, geotechnical properties, causes, and possible evolution of phenomena (COMUNE DI FIRENZE, 1974; 1990).

Most of the instruments are still active (FIG. 8), even if the results of field surveys carried out in the past are often difficult to understand, especially comparing data with surface evidence. In particular, some inclinometric records show a certain difficulty for a correct interpretation due to a non-verticality of tubes as well as to their imperfect cementation in the terrain (AGOSTINI *et alii,* 2002a; 2002b; AGOSTINI & FANTI, 2003).

As a general rule, both inclinometers and extensometers have pointed to good stability for the highest portion of the hill where the *Basilica* of San Miniato is sited. On many of the monitored buildings, some seasonal fluctuations have been measured; such fluctuations sometimes show large differences and, in some critical cases, a marked trend, such as in the wall of San Salvatore church. In many cases slope instability is likely associated with a lateral pressure of terrains on the structures rather than to slope instability.

The data as a whole are interpretable as the result of a present condition of a general slope stability, that rules out the possibility that one or more deep landslides (slip surface

> 5 m) with notable velocity are active (of course, if inactive or extremely slow, they are undetectable by the inclinometers). On the other hand the existence of a set of surface earth movements, like soil slip, is conjecturable: this can explain the framework of the damage and cracks now observed.

It is very difficult to define the extension of these instability areas and their reciprocal relationship, and in this matter, a very significant area is the *Piazzale* and the *Rampe* below, where the Poggi project created a puzzle of filling material and excavation, with a steep gradient.

With the aim to reconstruct the pattern of debris thickness, a comparison between the topographic data, preceding and following the works, was carried out, using the very detailed information of the report of the Giordano commission and of the ample documentation of Poggi's project (FIG. 9) (POGGI, 1872; 1882; GIORDANO, 1884). Nowadays, the area seems the most critical in terms of geomorphologic hazard and risk for the city's cultural heritage.

In general, in order to establish the real dimension of the surface movements and, above all, to control the possible reactivation of bigger landslides, the continuation of monitoring surveys is necessary. In particular, new data offering greater explanation are expected from the recent instruments, like the deep inclinometers, surely well set up, and the sub-horizontal multi-basis bore-hole extensometer (AGOSTINI *et alii,* 2002a; 2002b).

Conclusions

Monuments and buildings sited on the hill of *Monte alle Croci* present damage of different degrees of severity (fissures, cracks, superficial displacements), part of which are due to mass movements.

As evinced from historical data, slope instability processes have occurred in different times involving, in particular, the zone presently in use as a camping area, as well as the church of San Salvatore and the adjacent convent.

In the past, a large slope movement from south to north, affecting the entire hill was hypothesized, but recent monitoring, stratigraphic and geomorphologic studies lead us to interpret the present instability phenomena as a series of independent and superficial slope movements distributed around the hill. This cannot exclude the existence of one or more deep landslides involving large parts of the hill, because, in the case of inactivity or very low velocity, the inclinometric survey (moreover not completely reliable) is unable to detect them.

In order to control the evolution of the area and, in particular, the possible reactivation of a general instability, the existing monitoring system, recently improved and integrated, will be used. However, at the present time a higher risk is determined by the evolution without control of the little debris slips, since many deposits of filling material are distributed on the slopes, in particular in correspondence of monuments and other cultural heritage sites.

The bulk of this material has poor geotechnical properties, and is the result of Poggi's works, as is shown by the situation of the *Piazzale* and *Rampe*. For this reason, an accurate monitoring and control is needed in order to avoid the occurrence of events that, even if of very low magnitude, can determine a very high risk, due to the precarious balance of the site, a unique balcony on the art and history of Florence.

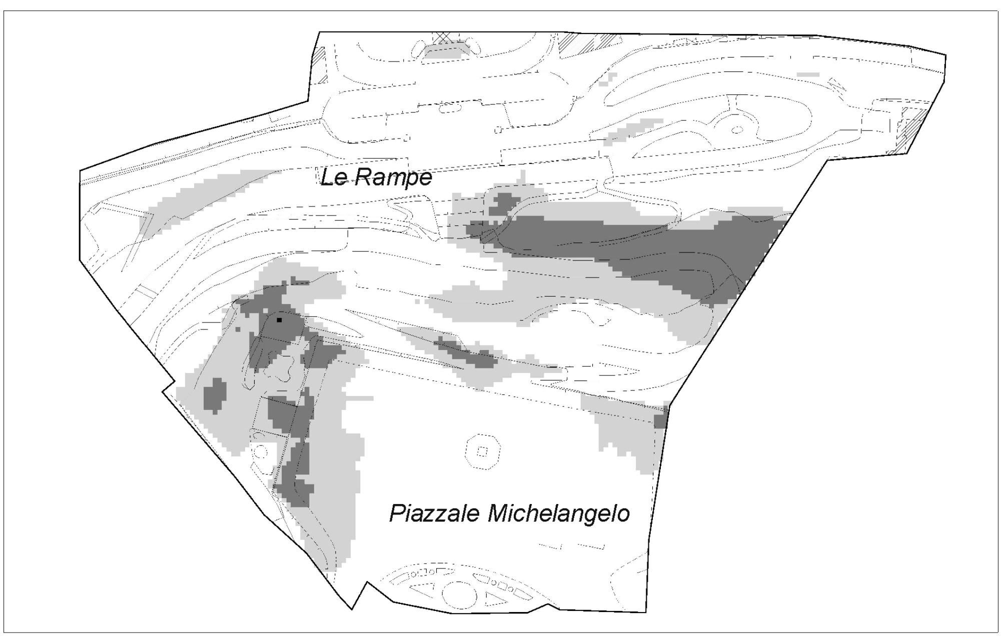

FIG. 9 – Thickness of filling material on the Piazzale and Rampe slope. White: no filling material; light gray: 1-3 m; dark gray: 3-8 m.

Acknowledgements

The Authors are grateful to Dr. P. Rubellini and Dr. M. Cecchi of the Municipality of Florence for providing data and for the organization of the site investigation.

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