2^{nd} Kerisel lecture: Geotechnics and Heritage

2^{me} Conference Kerisel: Géotechnique et Patrimoine Culturel

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ABSTRACT: Jean Kerisel (1908 – 2005) has been one of the first to apply his engineering skills to examining old buildings, such as gothic cathedrals or Egypt pyramids, with a different perspective. Nowadays the contributions of engineers to the important task of preserving the heritage is universally acknowledged; as an example, a number of cases in which Geotechnical Engineering plays an essential role is first reported. They include famous ones as the Leaning Tower of Pisa, but also common problems belonging to the everyday experience of geotechnical engineers.
The peculiarity of these problems, from the point of view of an engineer, is the requirement of respecting the integrity, besides guaranteeing the safety; such a requirement is analysed and discussed. It is argued that the development of a shared culture between engineers and restorers, archaeologists, art historians, architects is a necessary condition for a successful conservation. To become sufficient too, the conservation culture should be spread widely and become again a common sentiment amongst the majority of people.

KEYWORDS: heritage, conservation, integrity

RESUME: Jean Kerisel (1908 – 2005) a été l'un des tout premiers à proposer d'adjoindre le point de vue de l'ingénieur à l'étude des bâtiments anciens, tels que les cathédrales gothiques ou le pyramides en Egypte. De nos jours, la contribution des ingénieurs à la tâche importante de la préservation du patrimoine est universellement reconnue. On illustre d'abord un certain nombre de cas dans lesquels l'ingénierie géotechnique joue un rôle essentiel. Ils comprennent des cas célèbres et bien connus, comme la Tour de Pise, mais aussi quelques problèmes appartenant à l'expérience quotidienne des ingénieurs géotechniciens.
La particularité de ces problèmes, du point de vue de l'ingénieur, est l'exigence de respecter l'intégrité architecturale et culturelle des ouvrages, en plus d'en garantir la sécurité; on présente ici ce que cette exigence implique. On fait valoir que le développement d'une culture partagée entre les ingénieurs d'une part et les archéologues, les historiens d'art et les architectes de l'autre, est une condition nécessaire pour la réussite de toute intervention de conservation du patrimoine. Pour que cette condition soit suffisante aussi, la culture de la conservation du patrimoine devrait être largement répandue et le public devrait y être sensibilisé.

MOTS-CLÉS: patrimoine culturel, conservation, intégritè

1 JEAN KERISEL

When ISSMGE promoted a range of dedicated lectures, the Technical Committee TC301 - Preservation of Monuments and Historic Sites - immediately supported the idea of Yoshi Iwasaki to dedicate a lecture to Jean Kerisel.
Why Kerisel? In the early times he was principally known as Co- Author of a textbook on Soil Mechanics and of the "Tables de Butée et Poussée" (Caquot, Kerisel, 1948, 1949). At present, these tables are overcome by the availability of computers, but they have represented a simple and useful design tool for generations of geotechnical engineers. In the 1950' s Kerisel had been engaged in early research on large diameter bored piles (Kerisel, 1961), and designed the foundations of the Maracaibo Bridge in Venezuela with piles of a diameter of 1.35 m and up to 60 m long. When he was designated as the XV Rankine Lecturer, however, he selected the topic of "Old structures in relation to soil conditions" (Kerisel, 1975).
He applied his engineering skills to examining old buildings with a different perspective. An engineer's perspective in the field of Egyptology, for instance, led him to the publication of a number of books and of interesting theories about the Kheops pyramid (Kerisel 1987, 1991, 1996, 2005).
He promoted the Technical Committee on Preservation of Historic Sites of ISSMGE together with Prof. Arrigo Croce, and was its first chairman from 1981 to 1984.
When the writer invited Jean Kerisel to present the opening address at the first International Symposium on Geotechnical Engineering for the Preservation of Monuments and Historic Sites, held in Napoli in 1996 to honour the memory of Arrigo Croce, he was 88 years old, and he actually opposed to the invitation that "aging improves the quality of clays, but not that of men". But he finally surrendered and came to Napoli, gave a fine lecture on the Egypt of Pharaohs (Kerisel, 1997) and was awarded a degree of Doctor Honoris Causa by the University of Napoli Federico II.
As his son (Kerisel T., 2006) wrote, "Despite the infinite melancholy of old age, Jean Kerisel retained until the last his lucidity, youthful spirit and love of life. Among the favours granted to this exceptional man, the most precious was not to experience a twilight at the end of his long existence".

2 GEOTECHNICS AND HERITAGE

1 .1 Introduction

The importance of preservation of heritage could hardly be overemphasized. Croce (1985) believes that: "More than a shelter against the harshness of nature and the attacks of enemies, ancient monuments, buildings and settlements are a firm, long lasting, mutual bond between past and present, between man and environment”. In the late XVIII century Edmund Burke (1790), in his “Reflection on the revolution in France” claims that: “People will not look forward to posterity, who never look backward to their ancestors”. And Lenin urges, in the early XX century: “Citizens, don’t touch even a stone. Protect your monuments, the old mansions. They are your history, your pride”.

Professions such as restorers, art historians, archaeologists, architects and structural engineers are usually associated with preservation of heritage. But Geotechnical Engineering has also a very important role to play, because there are quite a number of monuments, monumental buildings, historical cities and sites affected by geotechnical risks of different types.

Let us quote some examples, taken mainly from Southern and Central Italy.

1.2. The Roman tunnels in the Phlegrean Fields

The Campanian sites East of Naples including Puteolis, Cumae, Baiae and the Lake Avernus, in the area of the so called Phlegrean Fields (Fig. 1), are universally known and admired for the beauty of the landscape bearing the sign of the volcanic activity, but also for the strong suggestion of legendary events (the entrance to the underworld through the Lake Avernus) and mythical figures (the hero Aeneas, founder of Rome; the poet and wizard Virgil) and for the abundance of monuments and ruins (Hamilton, 1776). The area has been inhabited since very ancient times. Cumae had been founded in the 8th century BC by Euboean Greeks, coming probably from the earlier colony of Pithecusae, on the nearby island of Ischia. The Greeks soon made Cumae the area’s most powerful city, then spread down the coast, founding Parthenopes in ca. 680 BC, Dikaiarchia (Puteolis) in ca. 530 BC and Neapolis, the “New Town”, in 470 BC.

Puteolis (the modern town is named Pozzuoli) was established as a Roman colony in 194 BC; it became the most important commercial harbour of the Mediterranean and the great emporium for the Alexandrian grain ships. In the middle of the Rione Terra, the acropolis of the ancient Puteolis, the temple of Augustus was constructed by the Greek – Campanian architect Lucius Cocceius Auctus. Strabo and other classical historians quote Cocceius as the author of the three major tunnels shown in fig. 1: the Grotta di Cocceio, the Crypta Neapolitana and, probably, the Grotta di Seiano also (Amato *et al.,* 2001). Crypta is the Latin word and Grotta the medieval Italian word for any underground space, both natural or man- made.

The main characteristics of the three tunnels are listed in Table 1. All of them are excavated almost entirely through the Neapolitan Yellow Tuff, that is indeed an ideal material for tunnelling being an easily excavated soft rock with a compressive strength ranging between 3 and 10 MPa and a friction angle of about 27°. The Phlegrean tunnels are by far the longest and most impressive tunnels of the whole Roman civilization; they are indeed unprecedented and unequalled engineering masterpieces.

The Grotta di Cocceio (Fig. 2) belongs to an outstanding complex of infrastructures conceived by Marcus Vipsanius Agrippa, deputy and son in law of Octavian (who will soon become the first Roman emperor Augustus) to connect the Lake Averno, shipyard of the fleet, to the stronghold of Cumae.

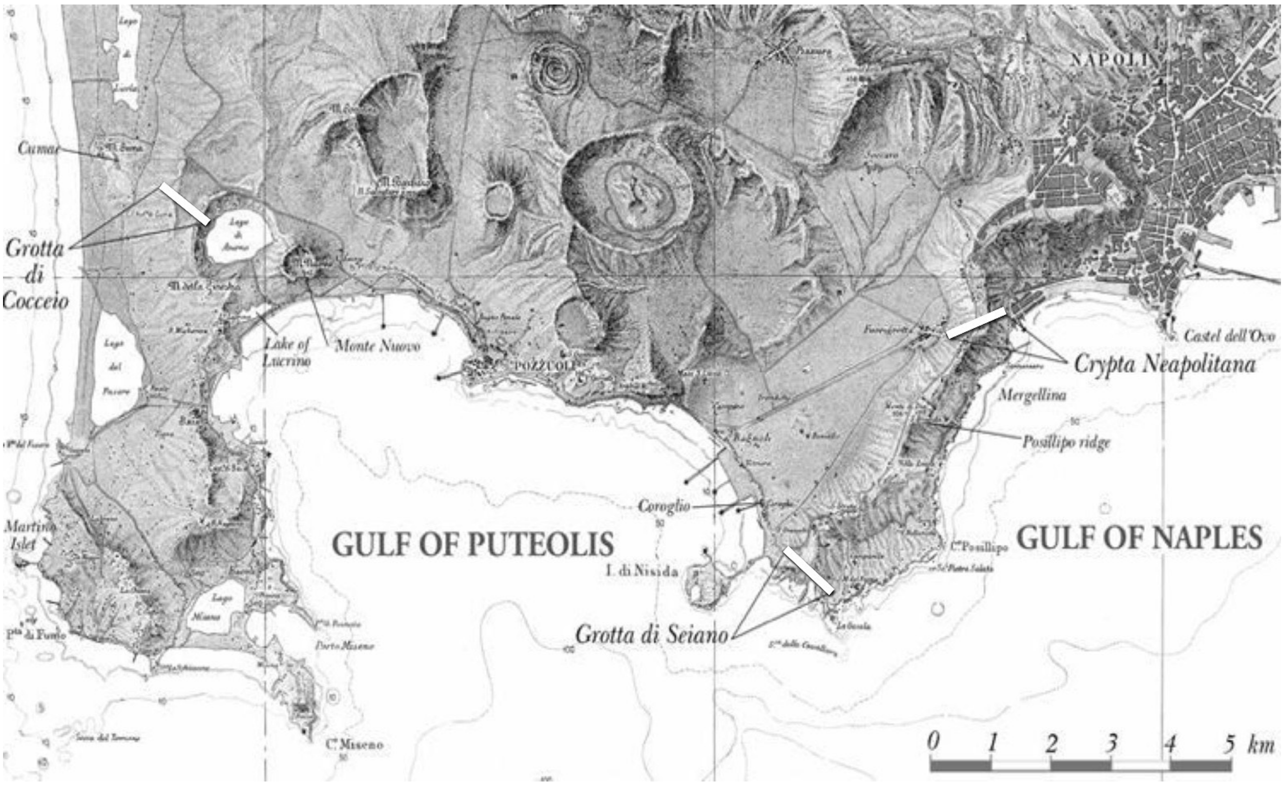

Fig. 1. The Phlegrean Fields in a map of the early X century

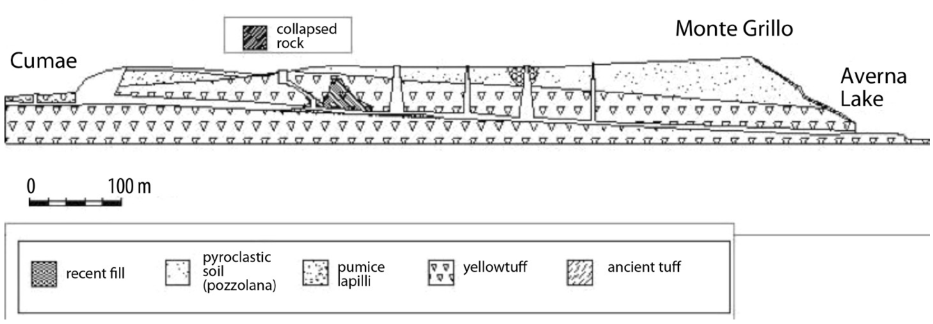

Fig. 2. Longitudinal profile of the Grotta di Cocceio

Table 1. Characteristics of the Cocceio's tunnels

Name	Length (m)	Width (m)	Height (m)	Ventilation or Lighting Shafts
Grotta di Cocceio	970	4.5	4.0 – 6.0	6 vertical, 2 inclined, 1 lateral
Grotta di Seiano	780	4.0 – 6.5	5.0 – 8.0	3 lateral
Crypta Neapolitana	711	4.5	4.6 – 5.2	2 inclined

In the Middle Ages Cumae gradually became a bandits and pirates lair, and therefore it was finally destroyed in 1207 to guarantee the safety of Napoli. The tunnel was abandoned and gradually filled by the sediments entering from the shafts; the two intakes were covered by landslide debris and the memory of the monument was lost. It was rediscovered in 1844 (Scherillo, 1858) and re-excavated in the following years by will of the king of Naples Ferdinand II Bourbon; it was opened in 1861 by the king Vittorio Emanuele II, just after the unification of Italy.

During the second World War it was used for the storage of explosives; in 1944 the retreating German Army blasted the explosives, producing at mid tunnel a huge cavity with a height of almost 40 m. After a stabilization intervention (Fig 3), the explosion cavity is now a further attraction for the visitors.

The Grotta di Seiano (Fig. 4) crosses the Posillipo ridge to connect Puteolis to the famous *Pausilypon*, a villa belonging to Vedius Pollio and later to the emperor Augustus. The eastern part of the tunnel is excavated through competent tuff and is hence unlined over a length of 144 m. The central and western parts cross slightly indurated pozzolana and very weak tuff; the sidewall of the tunnel in this section are lined with masonry in *opus incertum* and *opus reticolatum,* while the vault is lined with concrete *(opus cementicium*). The thickness of the masonry is around 0.5 m while that of the vault between 0.5 and 0.8 m.

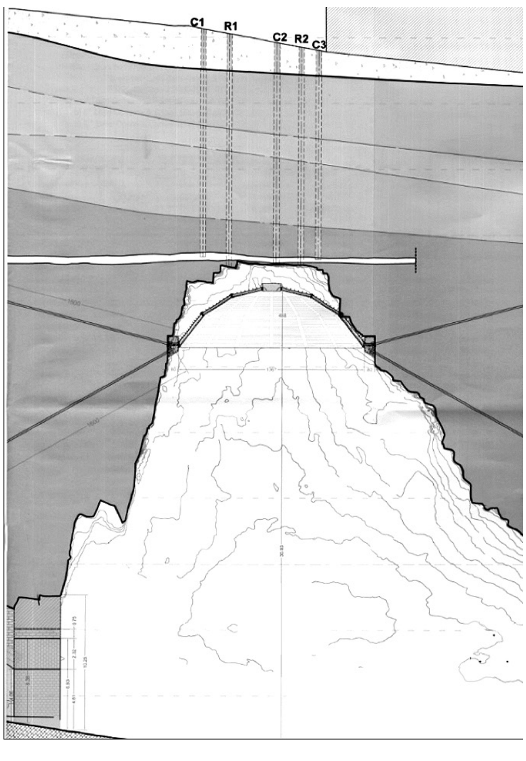

Fig. 3. Stabilization of the vault of the explosion cavern in the Grotta di Cocceio

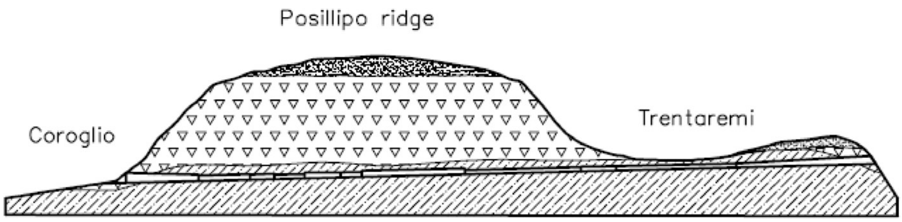

Fig. 4. Longitudinal profile of the Grotta di Seiano

In the centuries, both the entrances were covered by landslides debris and also the memory of this tunnel was lost. When the tunnel was rediscovered in 1840 it could be entered only by one of the lateral ducts; a number of collapses of the roof were found in the central stretch. The king Ferdinand II Bourbon became personally engaged in its reopening, committing the necessary works to Ambrogio Mendia, engineer and mathematician, Dean of the School of Engineering in Napoli (Lancellotti, 1840). The collapses were successfully restored after removing the debris, in spite of the difficulties connected to the occurrence of poisonous gases. The masonry lining was reinforced and thickened over a number of stretches, totalling around 250 m, and a total of 68 masonry arches were added. In the reinforced sections the width of the tunnel is reduced to 2.6 m (fig. 5).

At present the tunnel is regularly used to access the archaeological park of Pausylipon.

Reference to the Crypta Neapolitana (Fig. 6) may be found in Seneca (Epist. VI, 57, 1-2) and Petronius. It was excavated across the Posillipo ridge to make easier and faster the communications between Puteolis and Neapolis. In the Middle Ages, it was believed to have been excavated in only one night by Virgil, poet and wizard. Its present configuration is the result of a number of later interventions; it has been in use as a road tunnel till 1929. It is now interrupted by collapses of the vault in the central stretch and some interventions are underway to re-establish the free transit.

Modern Geotechnical Engineering is playing a major role in the recovery and conservation of these masterpieces of ancient Geotechnical Engineering.

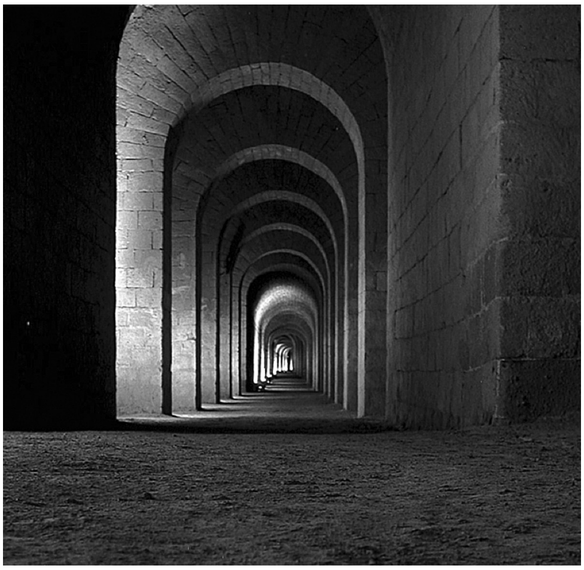

Fig. 5. The masonry arches added by Ambrogio Mendia in the XIX century

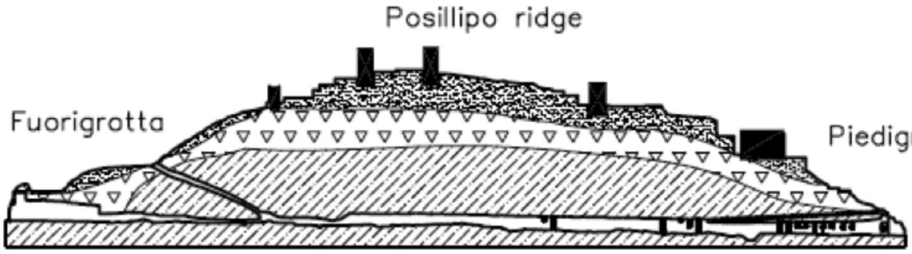

Fig. 6. Longitudinal profile of the Crypta Neapolitana

1.3. The retaining structures of the Vigna S. Martino

The Carthusian monastery of S. Martino (Candela *et al.,* 2013) was founded by the Angevins in 1325 in a dominant position over the city of Napoli and progressively enlarged and enriched. At the end of XVII century the architectural complex took its present form; in the meantime, the underlying slope of the hill was gradually converted from an impervious wooded steep crag into a succession of cultivated terraces retained by an impressive system of walls (Fig. 7) and provided with a network of drains, channels and water reservoirs conceived to store rain water for domestic use of the monks and irrigation and to laminate the floods following intense rainstorms (Fig. 8). It is still named "Vigna S. Martino" (S. Martin's Vineyard).

Fig 7. Bird's eye view of the Vineyard, with part of its retaining structures

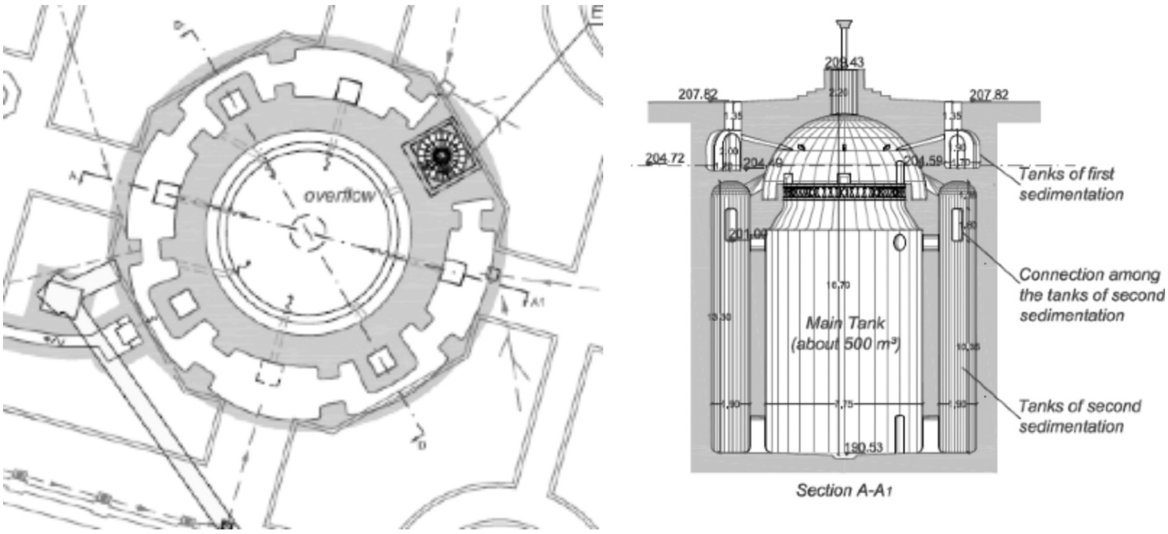

Fig. 8. The monumental tank of the great cloister of the monastery

The vineyard is at present bound to agricultural use and subjected to the laws to preserve landscape. It continues to be cultivated, but the maintenance of the system of retaining walls and hydraulic structures has been abandoned for a long time, and consequently the system is steadily deteriorating with uncontrolled water flow, concentrated erosion, collapse of some walls, landslides (Fig. 9). The survival of this document of the past is at risk; furthermore, the densely inhabited underlying built environment is exposed to a high landslide risk.

The urgently needed remedial works have been designed and works are going to start. The conservation of the system of retaining structures implies not only the repair of the various forms of degradation affecting them, but also their strengthening to comply with the more demanding requisites of the present seismic regulations. In general, the reconstruction of the outer facing of the walls to repair the effects of the erosion will be carried out with the same tuff masonry of the ancient walls, and cracks will be repaired by local demolition and suture. Some of the counterforts will be underpinned by micropiles, and some new counterforts will be added (Fig. 10). Finally, in the most critical spots ground anchors will be used, with special care to the connection between the anchor and the masonry (Fig. 11).

Fig. 9. Examples of deterioration of the system of retaining structures; left: detachment and fracturing of a counterfort; right: collapse of a retaining wall

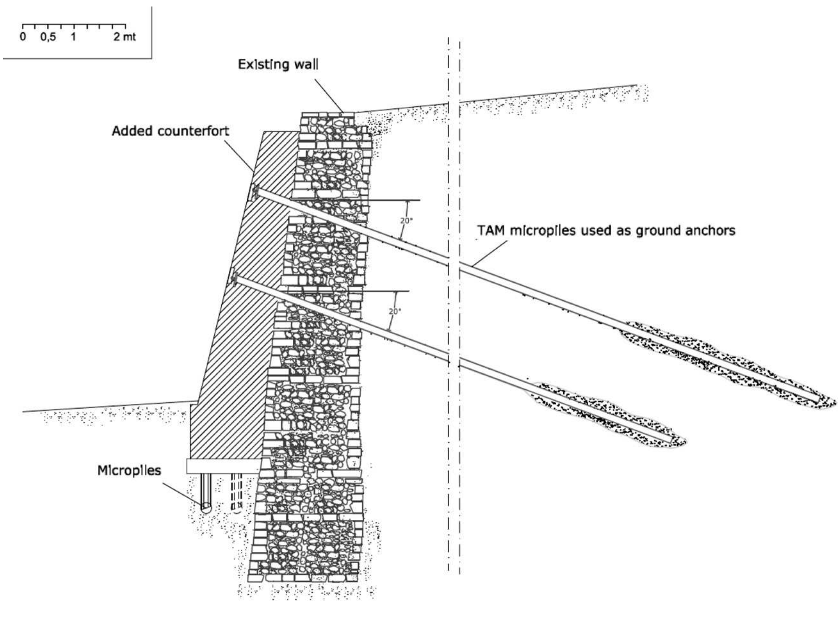

Fig. 10. Reinforcement of a retaining wall with a counterfort anchored and founded on micropiles

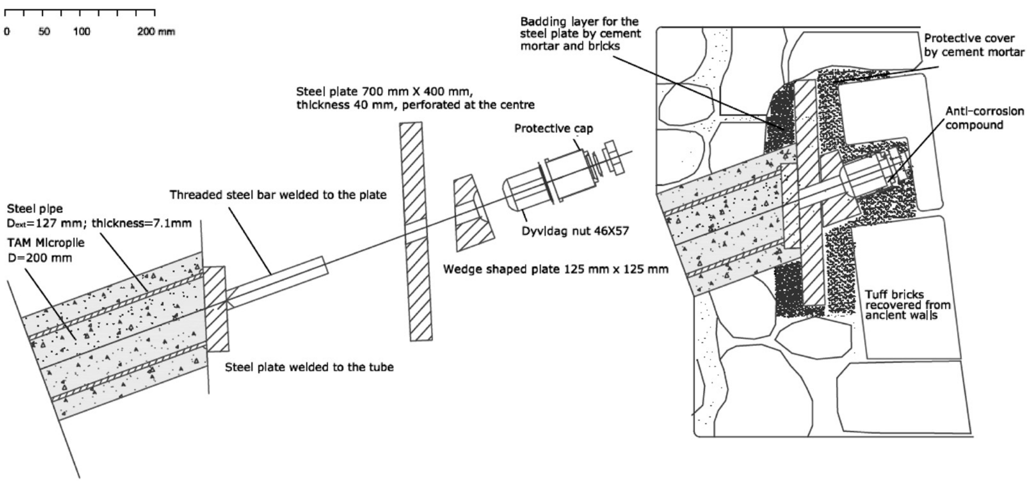

Fig. 11. Connection between the ground anchor and the existing wall

1.4. Coastal cliffs in the bay of Napoli

Via Krupp (Aversa *et al.,* 1997) is a pedestrian road built in the early XX century on the island of Capri, in the bay of Napoli, to connect the center of the island with the south shore (Fig. 12). According to Pane (1965): "It bears witness that a road can be a work of art, in the aesthetic meaning of these words".

The road is so well inserted in the natural environment, with its walls built up with calcareous stones, that it seems it has always been there.

Since the time of construction the risk of rock falls represented the main problem for the use of the road. In 1927 a maintenance program was started; a report of that year states that: "a man sitting on a kind of swing suspended by a rope and looking the rock face must be lowered from the top of the cliff in order to remove tottering stones or rocks with the aid of a bar or using explosives in very difficult situations*"*.

Since 1927 these operations have been repeated many times, and via Krupp was preserved for a long time. In 1978 it was decided to stop the maintenance program, considered too expensive and not guaranteeing a completely safe use of the road; since then via Krupp has been closed, except for short periods, and only now the Municipality of Capri is considering again the implementation of safety provisions.

A careful investigation including a structural survey of joints in the rock mass by terrestrial photogrammetry and a study of the trajectories of falling blocks leads to the conclusion that the possible protective interventions may consist in the removal of the smaller unstable blocks, anchoring the larger ones and implementing some protective barriers, located after the predicted trajectories of falling blocks and where they can be hidden by the vegetation. In any case, a modern version of the maintenance performed from 1927 up to 1978 with periodical inspections is mandatory.

Fig. 12. Capri: via Krupp

The village of Terra Murata (Walled Land) in the island of Procida, again in the bay of Napoli, is a settlement dating back to the X century and includes the Abbey of S. Michele and a number of other churches. These are exposed to the risk of collapse by the action of the sea, undermining the steep cliffs over which they were erected (Fig. 13). In the forefront of both pictures the remains of the cloister of Santa Margherita Nuova, collapsed due to the sea action in the early XIX century, bear witness of this phenomenon.

Castel dell'Ovo (Castle of the Egg: the strange name originates from the old legend of Virgil, poet and wizard, burying an egg below the castle. Until the egg will not be broken, the castle will stay safe) is one of the outstanding elements of the magnificent bay of Napoli (Fig.14). It stands over a small peninsula of Neapolitan Yellow Tuff, interested by a system of old cavities (in the Middle Ages the seat of a community of Basilian monks) and threatened by a system of fissures protracting in the overlying walls of the castle. The opening of the fissures is continuously monitored by displacement transducers; Fig. 15 reports some results over a period of two years. The influence of the yearly temperature fluctuation is evident, but no long term increase of the openings is evident (Russo, Viggiani, 2000).

Fig. 13. The village of Terra Murata in the island of Procida. (Let) view from the sea; in the background, at the right of the picture, the abbey of S. Michele. (Right) Birds eye view; in the forefront, the ruins of the cloister of S. Margherita Nuova

Fig. 14. Castel dell'Ovo, Napoli

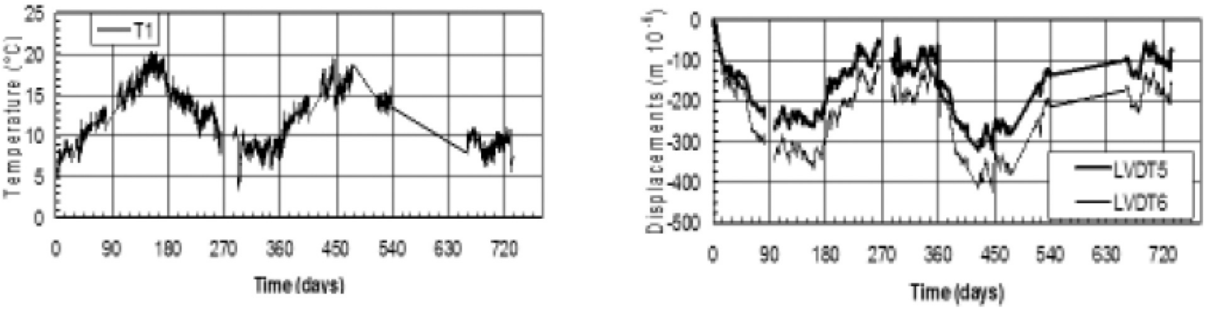

Fig. 15. Opening of fissures in the tuff below Castel dell'Ovo

1.5. Landslides

The town of Orvieto (Fig. 16), in the upper Tiber valley, rises on the top of a mesa formed by a slab of volcanic tuff overlying an overconsolidated clay formation (Tommasi *et al*., 2013). The flat topped hill delimitated by steep escarpments favoured human settlement. The town originated as an Etruscan centre in the IX century BC, was destroyed by Rome in 264 BC, but grew again in the Middle Age to a population of 20,000 inhabitants. Major buildings, infrastructures and churches were built during that period, including the Cathedral (Fig. 17), one of the masterpieces of medieval architecture in Italy.

The geotechnical problems of the modern city are mainly related to the stability of the steep rock escarpments. Collapses of the cliffs, often connected to landslides in the underlying clays, are reported since the XIII century; one of them, occurred in 1898, is shown in fig. 18.

The town is at present interested by a broad program of protective interventions; some of the provisions adopted are reported by Calabresi (2013). Monitoring indicates that the clay slope, in various areas of the hill, is still experiencing slow shallow and deep movements, which can be at the origin of new instability phenomena with significant damage potential to buildings and infrastructures. It is to point out that the situation of Orvieto is far from unique in Italy; similar problems affect for example other cities of the Tiber valley, as Civita di Bagnoregio, and of the Basento river valley as for instance Pisticci.

Fig. 16. Orvieto

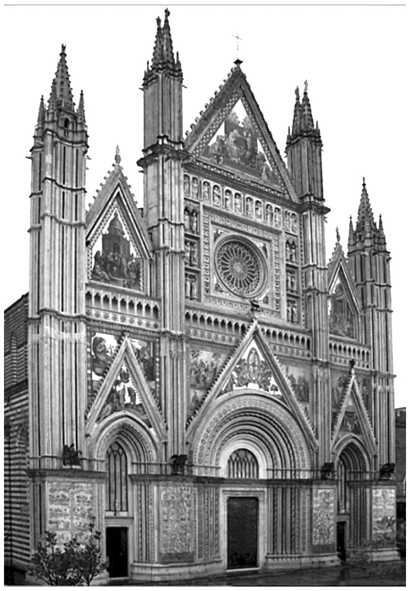

Fig. 17. The Orvieto Cathedral

Fig. 18. Orvieto; the collapse of a sector of the tuff slab in 1898. The arrows and the dashed line indicate respectively the crown scarp and the body of the previous landslide on the clay slope.

The gothic Cathedral of Agrigento, in Sicily (Fig. 19, Valore, Ziccarelli, 2013), was built in the XI century on the top of a hill, right on the edge of a steep slope 40 m high and with an inclination of 40° to 50° over horizontal. It has been repeatedly transformed in XIV, XVI and XVII centuries as a consequence of structural damages caused by differential settlement and seismic actions. Baroque superfetation has been added in XV century and partially removed in XX century. A massive still unfinished bell tower was added in XX century.

The behaviour of the cathedral has never been satisfactory; settlement, tilt, distorsions, partial collapses have occurred. Many interventions, including partial demolition and reconstruction, have been carried out in the last century. The most notable one was a massive underpinning by means of micropiles in 1976-1980. All these interventions have been unsuccessful and sometimes even detrimental; the cracks pattern observed after each intervention was a replica of the previous one. In 2010, a few years after the last intervention, the Cathedral had to be closed.

Recent geotechnical investigations have identified a large sliding mechanism of the underlying slope, involving the North aisle of the Cathedral and the adjacent stretches of the edge of the slope (Fig.20).

It is now evident that the preservation of the Cathedral requires the stabilization of the slope.

Fig. 19. The Agrigento Cathedral

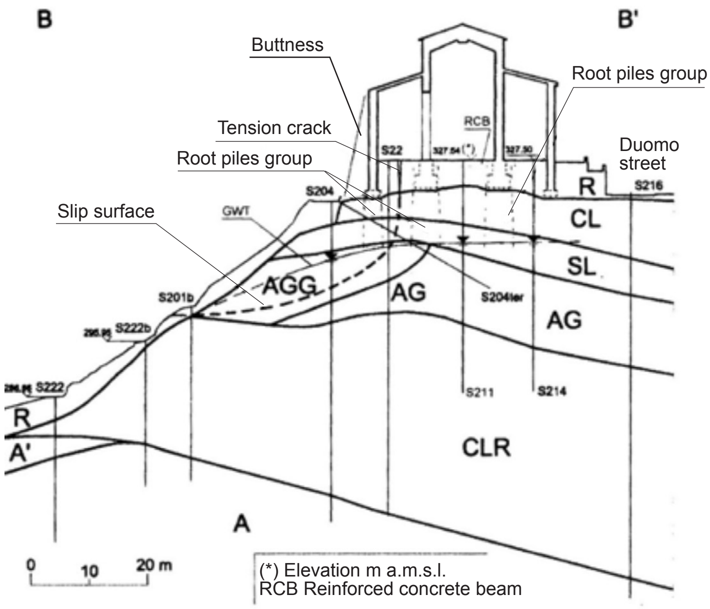

Fig. 20. Section through the Cathedral and its subsoil. R: made ground or topsoil; CL: upper soft calcarenite interbedded with sand; AG: grey clay; AGG: brown clay with secondary gypsum crystals; CLR: lower calcarenite with sand lenses; A: heavily overconsolidated grey clay; A': grey/yellowish clay with gypsum veins.

1.6. Foundations

The Colosseum, or Flavian Amphitheatre (Fig. 21), constructed in the 1st century under the emperors Vespasian, Titus and Domitian of the Flavian dynasty, is the largest amphitheatre ever built. It is the iconic symbol of the imperial Rome; they say: "as long as the Colosseum stands, so shall Rome; when the Colosseum falls, Rome shall fall; when Rome falls, so falls the world". At present, actually, the monument is partly ruined due to earthquakes and the continuous stone robbing during the Middle Age (one could argue that earthquakes and robberies have partly ruined the world also, in agreement with the ancient prophecy!)

The elliptical arena was a wooden floor with axes of 83 m and 48 m, covered with sand (arena is the Latin word for sand) and covering an elaborated underground structure called Hypogeum (Fig. 22), consisting of a two-levels network of tunnels and cages where the gladiators and animals where held before the contest.

The structure is founded on a gigantic elliptical ring beam (Fig. 23) with a width of 50 m and an average thickness of 12 m; at the extremity of the principal axes, four tunnels cross the foundation to connect the hypogeum to the exterior.

The subsoil has a complex geological setting, and the amphitheater is located above normally consolidated soils of the Labicano water stream, where the recent alluvial valley is carved into the middle Pleistocene alluvial and volcanic units and the overconsolidated clays of the Monte Vaticano Formation (Fig.24).

Fig. 21. The Colosseum today

Fig. 22. The Hypogeum

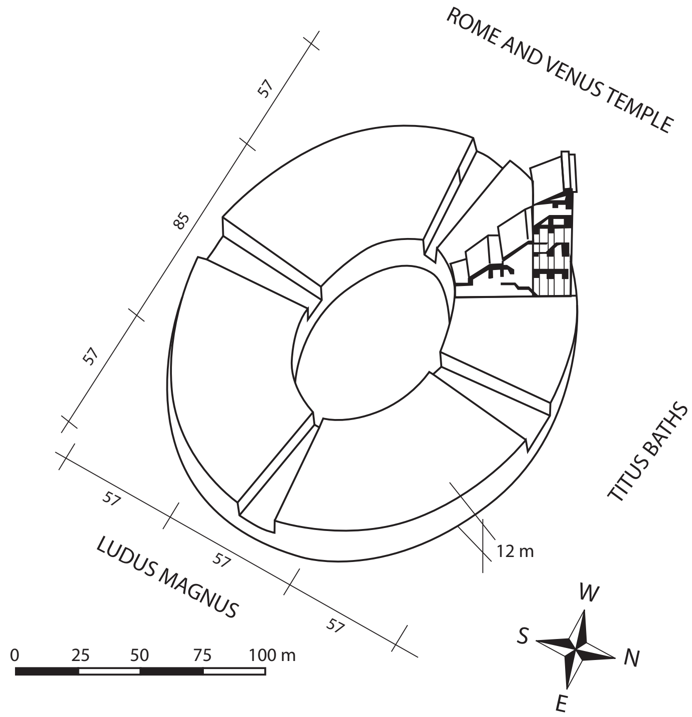

Fig. 23. Sketch of the foundation of the Colosseum

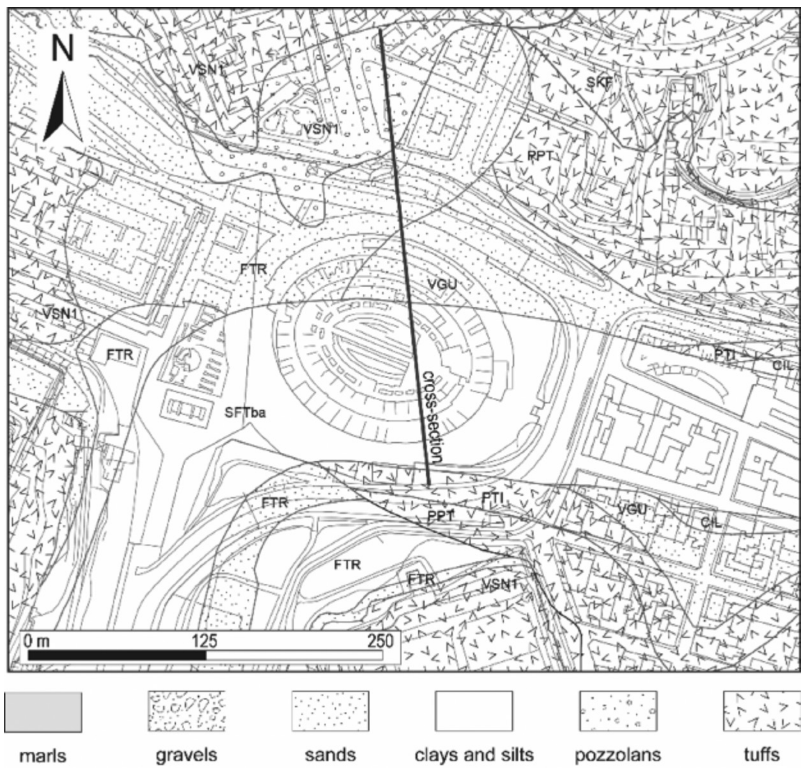

Fig. 24. Geological map of the environs of Colosseum. See fig. 25 for the legend

There is some evidence that a substantial differential settlement has occurred during construction. Furthermore, it is believed (Zezza, 1995; Moscatelli *et al.,* 2014; Pagliaroli *et al*., 2014) that local amplification effects due to 3D subsoil geometry and contrast of impedance have been responsible for the southern part of the monuments suffering severe damages and partial collapses (Fig. 25).

More detailed investigations have been planned to further clarify

this item, that could even be significant for the safety of visitors.
The Pantheon (Belardi, 2006) is a circular building (*rotunda*) covered by a hemispherical dome, with a porch with large granite columns connected to the rotunda by a rectangular vestibule (fig. 26). The dome, with a central opening (*oculum*) to the sky, two thousand years after its construction is still the largest existing unreinforced concrete dome with its 43.3 m inner diameter.
In spite of its simple geometry with a cylindrical wall and a hemispherical dome, the structure of the building is very complex. The wall is actually composed by 16 pillars connected to the dome by a system of barrel vaults and relieving arches (fig. 27).
Fissures and damages to the structure have been recognized and repaired many times in the past (fig. 28), so that a clear comprehension of their pattern is now difficult. According to Cozzo (1928) and Giuliani (2013) the foundation of the rotunda underwent significant settlement with statical problems when the construction of the cylindrical wall had reached the height of around 17 m; to cope with this problem, the foundation was connected to the nearby foundations of the *Basilica Neptuni* and underpinned at East and West (fig. 29). In any case, a differential settlement of 0.6 m in the north – south direction is evident. Geotechnical engineers are engaged in investigating the subsoil and the foundation of the monument thus contributing to the knowledge of its history.

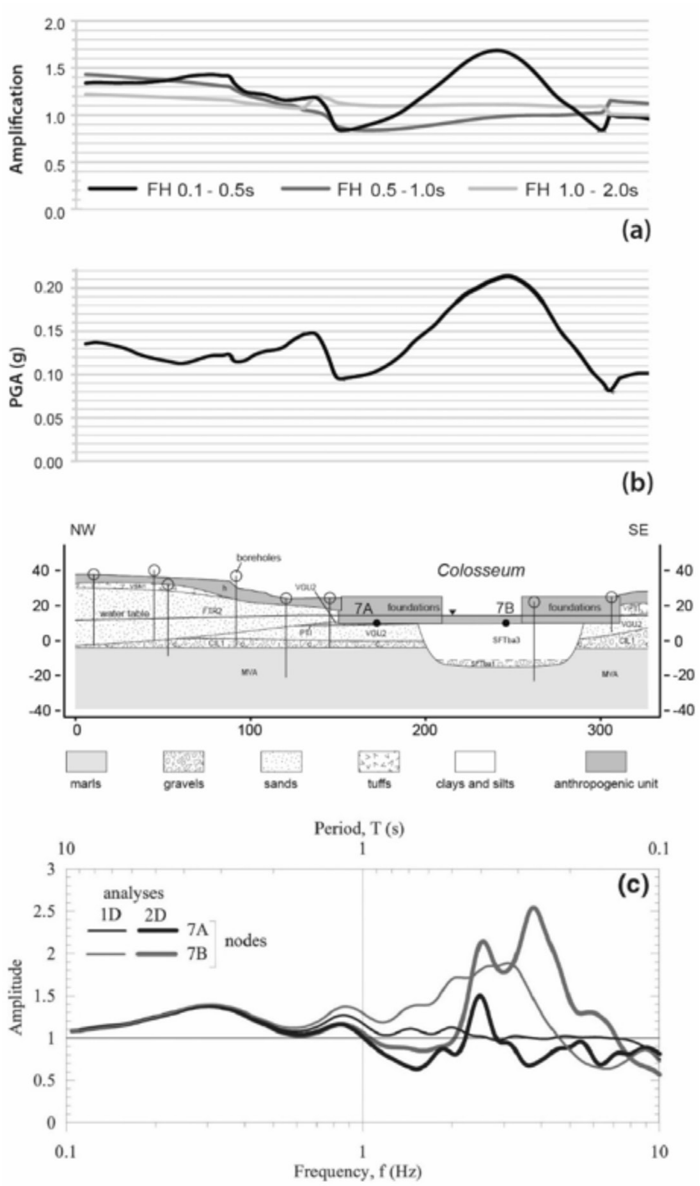

Fig. 25. The subsoil of the Colosseum: (a) Housner intensity amplification factors FH, (b) peak ground acceleration PGA, (c) amplification functions in selected surface nodes computed for cross-section #7 (modified after Pagliaroli et al. 2014). Legend of geological cross-section: MVA, Monte Vaticano Formation; CIL1, Santa Cecilia Formation; VGU2, Valle Giulia Formation; PTI, Palatino Unit; FTR2, Fosso del Torrino Formation; VSN1, Villa Senni Unit; SFTba, Tiber River Synthem: Alluvial deposits; h, anthropogenic unit.

Fig. 26. The Pantheon today

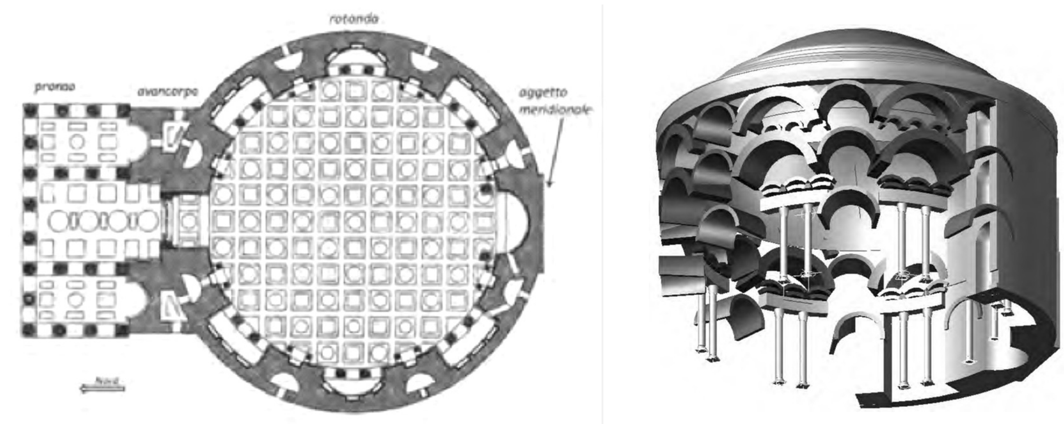

Fig. 27. The structure of the Rotunda

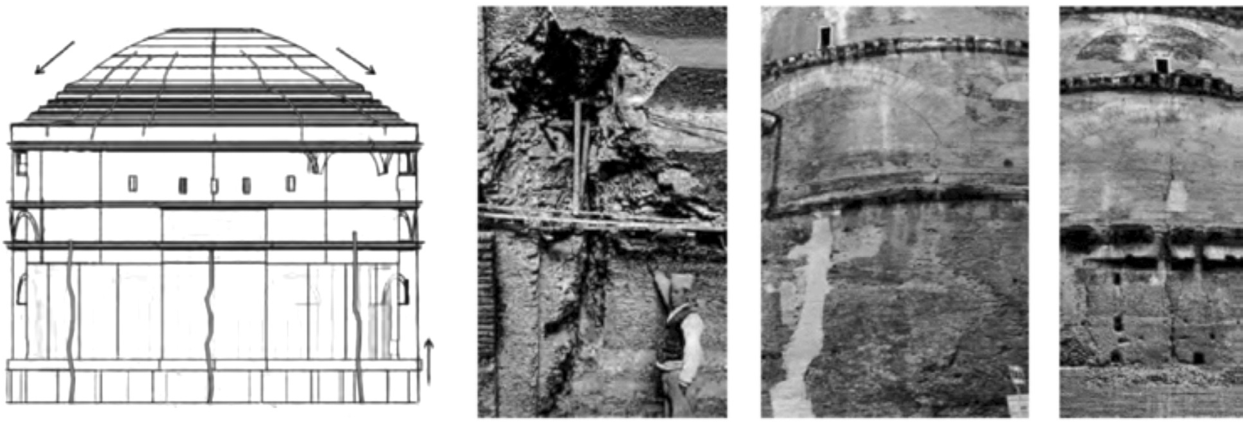

Fig. 28. System of fissures

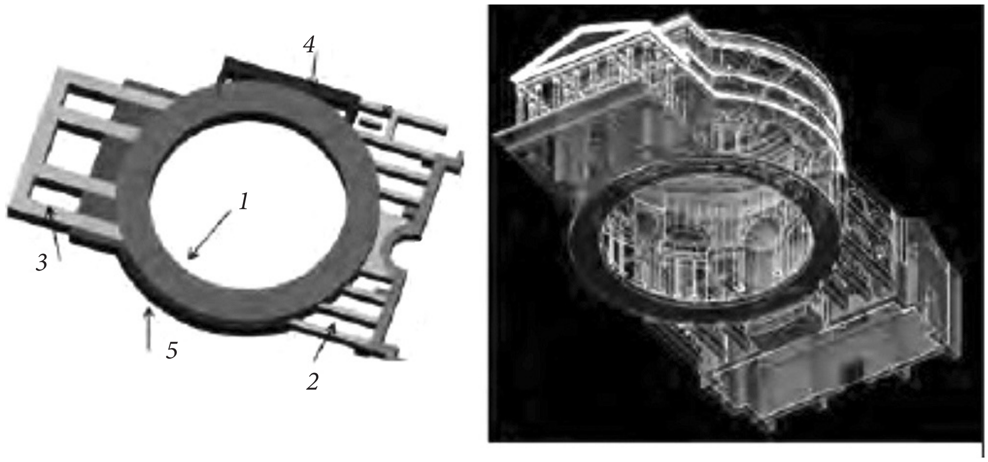

Fig. 29. Foundation of the Pantheon: 1) ring foundation of the cylindrical wall; 2) foundation of the Basilica Neptuni; 3) foundation of the porch and vestibule; 4), 5) thickening of the ring foundation

1.7. Deep excavations

The Guevara di Bovino palace in Napoli is a rich mansion in Renaissance style, dating back to the early XIX century. In March 2013 the western corner of the palace collapsed (Fig. 30), due to an accident occurred during the excavation of a nearby station of Line 6 of Napoli Underground.

The collapse was caused by the inrush of water and sand into the excavation through an unexpected discontinuity in the perimeter diaphragm (Fig. 31), uncovered by the excavation at a depth of 24 m, 22 m below the water table. It is estimated that some 2000 m^3 of water and 500 m^3 of sand entered the excavation in a few hours, before the hole could be plugged. The foundation soil of the collapsed corner was partly washed out and partly strongly decompressed; a careful investigation based on a fine mesh of CPT profiles, revealed that the effect was concentrated in a defined and limited area.

The foundation of the part of building to be reconstructed were initially conceived on micropiles, a solution almost invariably adopted in similar cases, while the remaining part of the building, the large majority, had to be left on its original shallow foundation. Later on, a careful analysis of the whole building under seismic action, revealed that the solution was far from ideal, introducing a significant heterogeneity in the dynamic response of the building. After a careful consideration of technical and economic aspects, it was finally decided to re-establish the original conditions of the subsoil by a program of compaction grouting controlled by cross-hole measurements of shear wave velocity, and revert to a shallow foundation similar to that of the remaining part of the building. It is to underline that this solution, selected as the best one from a technical point of view, is also the most satisfactory one from the point of view of the respect of the historical and material integrity of the palace.

Fig. 30. The collapse of the western corner of the Guevara di Bovino Palace, Napoli

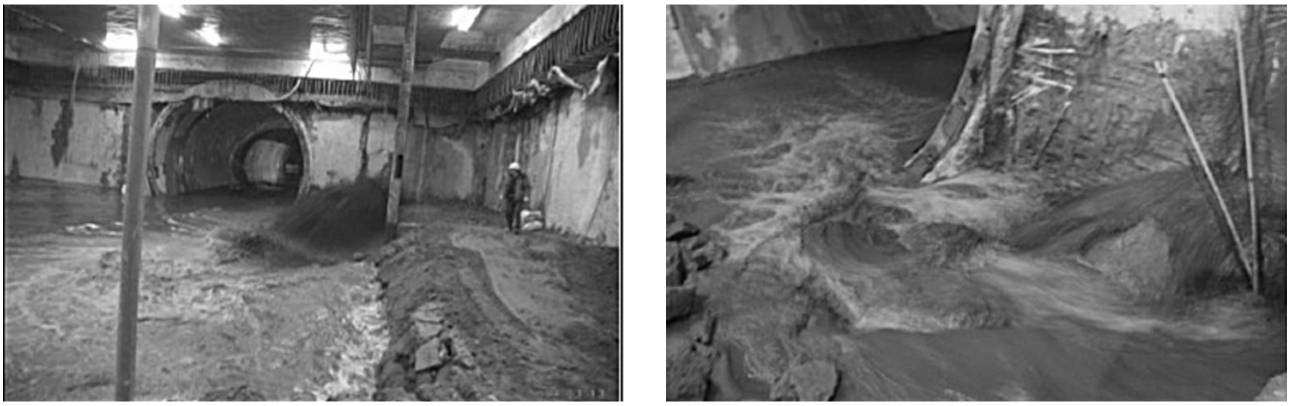

Fig. 31. The inrush of water and sand into the excavation

3 INTEGRITY

The intervention of the structural engineer on an ancient structure requires generally an approach markedly different from that adopted for new structures; the geotechnical problems of ancient structures, on the contrary, do not significantly differ from those of the new ones. This may be rather rewarding for geotechnical engineers, used to be the repository of all the uncertainties (Santucci de Magistris, Viggiani, 1977). But from the viewpoint of an engineer, in any case, the peculiarity of interventions on the heritage is the requirement of respecting the integrity, besides guaranteeing the safety. While the attainment of safety is relatively straightforward for a well trained and experienced engineer, the respect of integrity is a much more difficult matter.
The concept itself of integrity has many facets and is somewhat elusive; its comprehension, however, is a necessary prerequisite.
Its first and most obvious aspect is the formal, or iconic integrity: the external aspect, the image, the original form that should not be altered by the engineering intervention. For instance, in Fig, 32 a proposal for stabilizing the Leaning Tower of Pisa is reported. The Author of the proposal, formally submitted to the Authorities, claims to be stricken by the Art and in particular by the Tower, and suggests a hollow gigantic ”retaining statue”; inside it, an elevator would make easier for the tourists the visit to the monument.
Everyone can see that such a proposal does not respect the formal integrity of the Tower; unfortunately, however, the lack of respect is often much subtler! Furthermore, while being very important the formal integrity is not all, otherwise a copy would be as valuable as the original (fig.33).
Another important facet of the integrity is historical integrity; it can be illustrated referring to an example taken from the history of Napoli (Viggiani, 2013).
The church of Santa Chiara was founded in 1310 by the first Angevin kings Robert the Wise and Sancia of Mallorca as a double convent for the Poor Clares and Franciscans.
The church exceeded in scale any other church in the kingdom; it loomed over medieval Naples and still presides over the modern city. It was intended not only to host the tombs of the royal family but probably as part of a program to propose a Franciscan alternative to the authority of the papacy, by this time displaced to Avignon. The project of Santa Chiara, initiated soon after the arrival of Robert and Sancia in Napoli, reflected a new trend in the spiritual life of the kingdom, now strongly inclined towards the Franciscan and in particular towards the Spirituals. According to some historians, Santa Chiara was perhaps nothing less than

Fig. 32. A solution proposed for the stabilization of the Leaning Tower of Pisa

the setting for a brave and doomed attempt to reform the Church. Before 1943, the medieval interior of Santa Chiara was actually invisible, encased in a sumptuous baroque decoration that perfectly epitomized the defeat of the Franciscan party and the historical victory of the Rome papacy (Fig. 34). The original structure underneath the baroque decoration was revealed to modern eyes only on 4 August 1943, after American incendiary bombs caused a fire that burned continuously for 36 hours. The eighteenth century stucco was entirely destroyed and the medieval walls behind severely calcined. In keeping with the post-war preferences for streamlined design, and principally because of the cost and complexity of re-creating the magnificence of the baroque interiors, the church was reconstructed instead to an austere medieval shell, a loss still lamented by most Neapolitan lovers of the Baroque (Fig. 35).

This case introduces another aspect that may be disquieting for an engineer: the unicity of the solution of this kind of problems cannot be proven.

Another enlightening example of the elusiveness of the concept of historical integrity is that of Shinto shrines in Japan (Flora, 2013). Since the VI century the Japanese architecture is characterized by the use of wood; this implies periodical interventions of maintenance and substitution, a practice going on from centuries. The methods and techniques of maintenance are themselves an invaluable cultural heritage, and are strictly connected to the local religious and philosophical traditions.

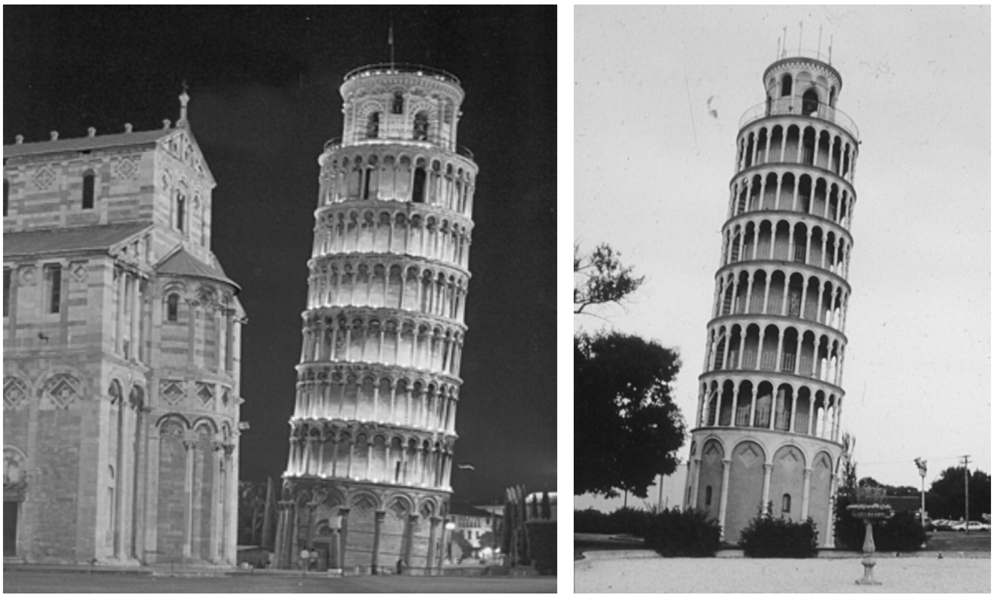

Fig. 33. (Left) The leaning Tower of Pisa; (Right) the leaning Tower of Chicago

Fig. 34. The interior of Santa Chiara: (Left) in 1939; (Right) after bombing in 1943

Fig. 35. The interior of Santa Chiara before the disruption (Left) and after the reconstruction (Right); has the historical integrity been respected?

Up to the mid of XIX century, the wooden Shinto shrines underwent periodically complete reconstruction, following the practice described above. Later on, for political and economic reasons, the periodical reconstruction was stopped for all the shrines except one. Nowadays, while the Ise shrine still keeps its ritual reconstruction every 20 years, the other ones are protected by law as architectural heritage. What is authentic in this case: the frozen material situation of the XIX century or the immaterial heritage preserved in the Ise shrine by the ritual periodic reconstruction?

A further facet of the integrity, particularly significant for engineers, is the material integrity. The materials, the construction techniques, the structural scheme are original features of a monument as significant as its appearance and history. An arch should not be transformed into a garland of stones hanging from a hidden beam; a direct foundation should not be transformed into a piled one, unless this is the only way to save it, and in any case at the price of a defeat. In some instances, the attempt of improving the safety by modifying the original structural scheme may even produce embarrassing results. The following quotation by Galileo's "Dialogues Concerning Two New Sciences" (1638) is very eloquent:

"And here I must relate a circumstance which is worthy of your attention as indeed are all events which happen contrary to expectation, especially when a precautionary measure turns out to be a cause of disaster. A large marble column was laid out so that its two ends rested each upon a piece of beam; a little later it occurred to a mechanic that, in order to be doubly sure of its not breaking in the middle by its own weight, it would be wise to lay a third support midway; this seemed to all an excellent idea; but the sequel showed that it was quite the opposite, for not many months passed before the column was found cracked and broken exactly above the new middle support (….). For it was observed that one of the end beams had, after a long while, become decayed and sunken, but the middle one remained hard and strong, thus causing one half of the column to project in the air without any support. Under these circumstances the body therefore behaved differently from what it would have done if supported only upon the first beams; because no matter how much they might have sunken, the column would have gone with them".

Finally, the harmony between a monument or a city and the surrounding wider landscape is another important aspect of the integrity to be preserved. Fig. 36 shows a quintessentially Italian landscape: Pienza in Tuscany, a small city founded by Pope Pius II in 1462 and still gloriously emerging from the surrounding landscape on top of a hill, in the Senese Val d'Orcia. The balance of countryside and cityscape is so admirably preserved that in 2004 the entire Val d'Orcia was included among the UNESCO sites.

Fig. 36. Pienza

The requirements of safety and use, in the majority of cases the Author has experienced, appear (and often actually are) in conflict with the respect of the iconic, historical and material integrity of the monuments. In almost all countries of the world conservation is looked after by an official trained in Art History or Archaeology. Generally, (*e.g*., this is the case in Italy), he has an absolute control on any action to be undertaken, and imposes constraints and limitations that sometimes appear unreasonable to the engineer. The engineer, in turn, tends to achieve safety by means of solutions which appear unacceptable to the official in charge of conservation, sometimes mechanically applying procedures and regulations conceived for new structures. With a misused word, we say in Italy that he tends to "cementify".

It is evident that some equilibrium has to be found. It is a deep belief of the author that a satisfactory equilibrium between safety and conservation, between engineers and professionals as restorers, archaeologists, art historians may be found only in the development of a shared culture. In the last decades, significant advancements have been actually registered in this direction between the realm of conservation ant that of engineering, and a number of associations, conferences, seminars have contributed to these advancements. ISSMGE is pursuing this goal in different ways; among them, the institution of the Technical Committee TC301 on Geotechnical Engineering for the Preservation of Monuments and Historic Sites.

4 CODES AND REGULATIONS

As an example of the relevance of codes and regulations on the conservation of heritage, the case of Italy may be reported. Long before Italian unification, the Italian states (Vatican, Kingdom of Naples, Venice, Grand Duchy of Tuscany, Lucca, Parma, Modena, Milan, etc.) formulated rules and set up public institutions to regulate and engage in this area of activity. Italy (as a unitarian state) was the first country to include the preservation of its landscapes and its cultural heritage amongst the founding principles of its Constitution. The widespread diffusion of cultural heritage and Italy's tradition of conservation are two sides of the same coin: the rules to safeguard the cultural heritage would not have been introduced without a strong civic sense of duty, triggered by the all-pervasive presence of monuments, churches, historic cities and villages; nor would that presence have been so robust and long-lasting without the guarantees provided by those rules over many centuries.

The roots of this civic, cultural and juridical culture are to be found in the spirit and tradition of the Italian cities, which, at least from the twelfth century on, had been developing a deeply held and highly sophisticated concept of citizenship, in which the monuments were the basis for civic pride, identity and a sense of belonging which were closely linked to the very idea of a well governed community. This is exemplified, for instance, by two documents. First, the decision of the Commune of Rome (1162) concerning Trajan's Column, which states, "In order that the public honour of the City of Rome is preserved, the Column shall never be damaged or knocked down, but must remain as it is for eternity, intact and unspoiled for as long as the world shall exist. Should anyone inflict or attempt to inflict damage on it, they shall be condemned to death and their assets confiscated by the treasury."

Second, the Constitution of the Commune of Siena (1309), according to which "those who govern the city must above all ensure its beauty and ornament, which is essential for the delight and amusement of foreigners, but also for the honour and prosperity of the Siena citizens themselves."

We come across very similar principles in hundreds of documents: beauty, decorum, suitability or *convenienza*, public honour, the common good or *public benefit*, for which the classical Roman formula *publica utilitas* was often employed.

Another significant example is that of the eighteen-year-old king Charles of Bourbon, who entered Naples to great celebrations in 1734, inaugurating a new era in the history of the Kingdom which was now once more independent after centuries of being a Spanish viceroyalty. He initiated the excavations in Herculaneum (from 1738) and Pompeii (from 1748), which produced an enormous quantity of new antiquities. This situation gave rise to Neapolitan legislation to protect the cultural heritage (1755), expressing the King's "profound regret" over the past export of antiquities from the Kingdom and establishing new rules to prevent it happening again in the future. Indeed, when Charles III became King of Spain (1759), in his new capacity he did not issue any provisions to safeguard artefacts there. Had his "profound regret" over the lack of protection for works of art in Naples vanished once he got to Madrid? No. In both cases, the monarch had not been writing the legislation personally, but expressing through it the civic and juridical traditions and practice of the place in which he was ruler.

In the following centuries one could trace the journey of Italy's conservationist culture, a process unique in its continuity and coherence from the Italian communes of the Middle Ages, through the legislation of the pre-unification states and then those of unified Italy, ultimately arriving at the Republic's Constitution. Article 9 of the Constitution (which came into effect on January 1st, 1948) states: "The Republic promotes the development of culture and scientific and technical research. It protects the landscape and the Nation's historical and artistic heritage." [in the original Italian : *La Repubblica promuove lo sviluppo della cultura e la ricerca scientifica e tecnica. Tutela il paesaggio e il patrimonio storico e artistico della Nazione*].

So far, the story is one of constant growth, from regulations in particular cities to the Constitution of a modern state. Unfortunately, this complex system of conservation (the most ancient and probably still today the best one on paper) is operating in an increasingly ineffective manner. The devastation of the landscape in Italy has become dramatic. The harmonious relationship between the Italian cities and their countryside, established over many centuries, is giving way to an uncontrolled urban sprawl, which is now home to a large amount of the population.

Although the conservationist laws remain in force and indeed are constantly improved (on paper), "derogations", "exceptions" and even "amnesties" (*condoni*) for the infringement of building regulations are continuously enacted. At the same time, conservation of the cultural heritage is undergoing a deep crisis caused by a lack of human and financial resources.

As a matter of facts, the development of a shared culture of conservation is a necessary, but far from sufficient condition. Immediately after the inclusion among the UNESCO sites, the area around Pienza was involved in a real estate project (fig. 37). The new settlement, the *Casali di Monticchiello,* were advertised as "your new home in a Unesco site". In other words, the UNESCO label, that the Val d'Orcia earned for its preservation, was immediately exploited for commercial reasons.

Montanari (2014) admonishes that the conservation of our cultural heritage depends much more on the importance that we attach it, than on laws, cultural politics, allocated resources or ministers. For all these factors to be effective, the conservation culture should be spread widely and become again a common sentiment amongst the majority of people.

Such a process can be eloquently evidenced by a brief quotation from Hegel's *Outlines of the Philosophy of Right* (1820): "Public monuments are national property, which, to be more precise, means that, just as with works of art in general when they are put to use, public monuments fulfil living and autonomous ends for as long as they are endowed with the soul of memory and honour. Once they are abandoned by the soul of memory and honour, however, they become in this sense private, anonymous and incidental possessions, as far as a nation is concerned, as with the Greek and Egyptian works of art in Turkey."

At mid XIX century the Pisan architect Alessandro Gherardesca, was appointed by the City Authorities to carry out some conservation interventions on the famous leaning Tower. He proudly claims (Gherardesca, 1838) that, thanks to Good, he was moved by love of his homeland and by the desire of saving the vestiges of the ancestral greatness.

The writer, borrowing from Martin Luther King, must confess he has a dream: that the international community of geotechnical engineers is able to find a similar spirit and contribute to the great undertaking of conserving the vestiges of the ancestral greatness!

Figure 37. Commercial exploitation of Val d'Orcia near Pienza

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