ANNALI DI GEOFISICA, VOL. XXXVI, N. 1, April 1993

Seismic protection and conservation of the monumental heritage

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Abstract
The effects of the Irpinia 1980 earthquake on the monumental heritage and the following experiences of restoration have originated a deep awareness of the problems to be solved and of the need of substantial changes in the conceptions and the tecniques of the interventions.
The paper recalls some of the basic characters of restoration, reporting and commenting a number of case histories and general questions.

1. Introduction

The seismic problems attracted little, if any, attention in the culture of Structural Engineering in Italy in the years from the Second World War to the '70s; the few exceptions, though significant, do not modify this picture(1).

In the same period any reflexion on the masonry constructions, and hence on the material history of building from the remote antiquity to our times, is neglected not only from a technical viewpoint but even in a broader cultural sense.

This is an outcome of the positivistic aptitude permeating modern engineering, but probably in the first half of this century it is also connected to the influence of the futurist movement and of the great revolution of the rationalist architecture; in the '50s and '60s it is connected to the urgent needs of the post-war reconstruction and of the building expansion that has radically changed the size and the appearance of the Italian cities.

In such an atmosphere, the committment and the significant evolution of Engineering Mechanics and Structural Engineering in developing a theory and a design practice for the reinforced concrete, prestressed concrete and steel constructions, make the new materials enthusiastically accepted in the Restoration Charters of the '30s. In this connection, the work of Maiuri in Pompei and Paestum may be for instance recalled.

When the most dramatic problems of the reconstruction were over, the cultural and social traditions imposed the reconstruction of many monuments «*as they were*», saving their forms, dimensions and materials; the church of S. Chiara in Napoli (Gaudenzio dell'Aja, 1980) may be quoted as an example of this practice, that surely deserves further historical investigation.

In the meantime in the '50s and '60s, in Italy, a very intense development of techniques such as micropiling and grouting was experienced in the field of Geotechnical Engineering, specifically for the underpinning of ancient structures. The basic idea was to strengthen the soil mass, improving its low resistance, and to reinforce it by inserting tension resisting elements.

The ancient masonry structures are indeed made by nonhomogeneous, nonelastic, low-strength materials; their shape is three dimensional and often very elaborated; their dimensions are very large and sometimes indefinite, like in the conventual complexes or in the curtains of interconnected buildings; they are interested by a network of discontinuities, as the more or less degradated beds of malta. It is not surprising that such objects, so similar to weak rock masses, had been strengthened and reinforced by means of cement grouting and cemented steel bars (in geotechnical terms, «*nailing*»), that can be viewed in the authors' opinion as a natural evolution of the techniques developed in the field of geotechnics.

At a later time the structural engineers tried to place this approach «on a sound rational basis». The outcome of this attempt has been: the transformation of the columns and trabeations of the ancient Greek and roman temples into frameworks (see, for instance, Paestum temples, fig. 1); the transformation of the beautiful loggia of the Amalfi cathedral into a Vierendeel beam (fig. 2, Lizzi, 1981); the transformation of the masonry façades into frameworks by the systematic use of pretensioned cables, etc.

The seismic problems came to the attention of the engineers in Italy with the 1975 Friuli earthquake. In connection with the reconstruction of Friuli, new aseismic criteria for masonry structures were developed and circulated as recommendations or even regulations(2). They reflect the influence of two basic approaches:

– they have been developed for the small-stone masonry houses typical of the Friuli villages, and hence they include suggestions (like the use of the Pohr method or the limitation to no more than 7 m of the length of any room) that are far from being of general validity;

– they are heavily based on the aforesaid practices of strengthening and reinforcement by cement grouting and nailing (fig. 3) without any theoretical model or any systematic experimental investigation; in other words, with an approach in striking conflict with the theoretical and practical clarity of the design of the structures in reinforced concrete, prestressed concrete and steel.

This kind of strengthening or reinforcement is characterized by the lack of any experimental proof, in particular with respect to two of the most essential aspects of static restoration:

– the effectiveness of the intervention, that should be expressed and measured in quantitative terms;

– the durability of the intervention.

Furthermore, it alters the original structural

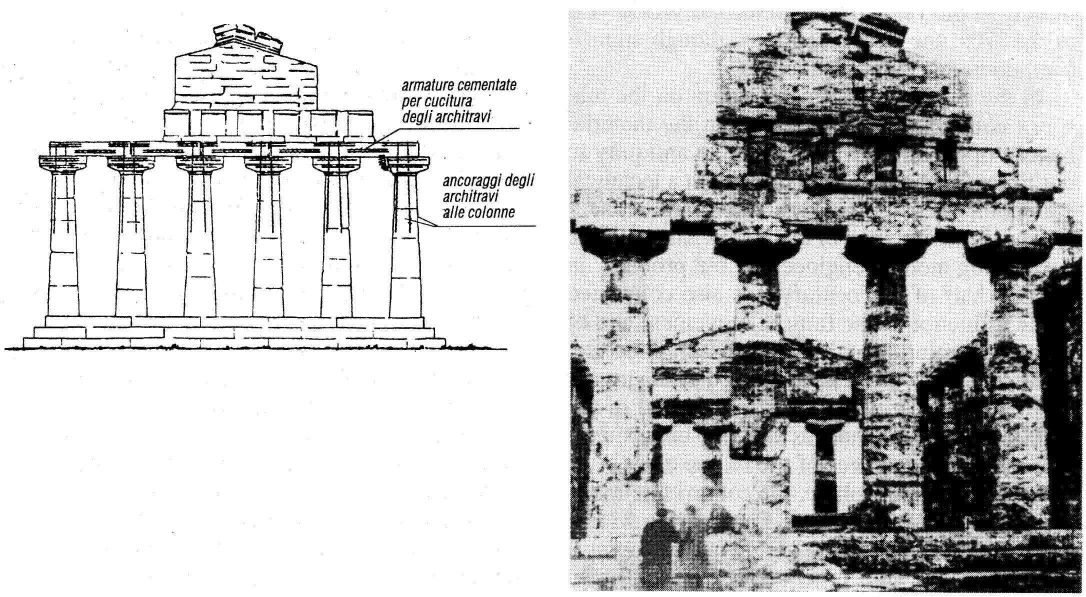
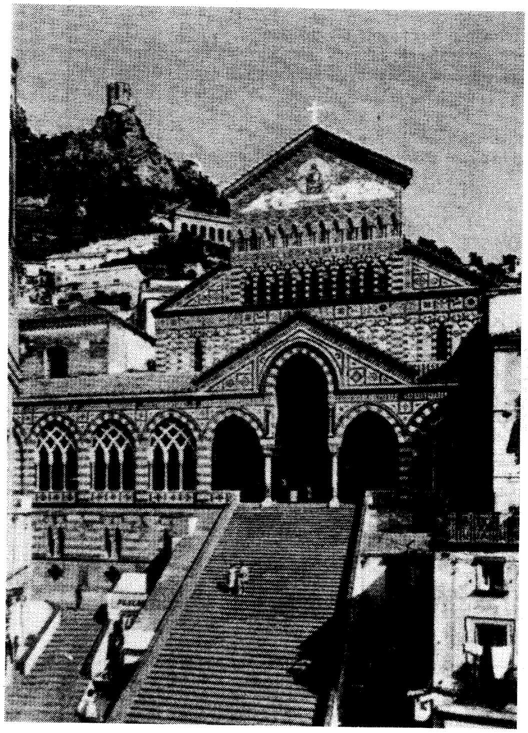


Fig. 1. Paestum. The Temple of Ceres (500 B.C.) and the scheme of reinforcement.



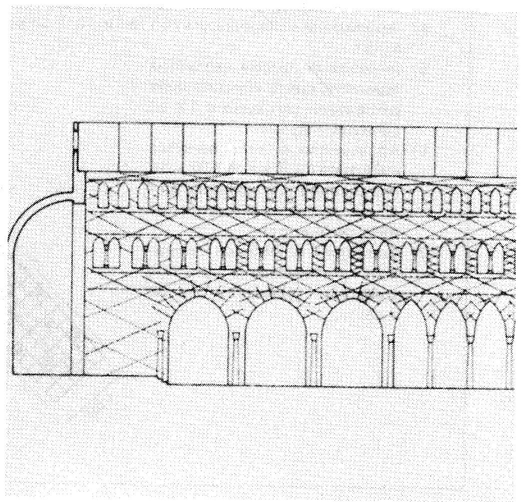


Fig. 2. Amalfi. The Cathedral and the scheme of nailing.

behaviour of the system; it is absolutely non-reversible and introduces material heterogeneities that modify in an irreversible way the material history and the structural body.

A similar development occurred in geotechnical engineering as applied to the restoration of ancient buildings and monuments, with a broad diffusion of piles (essentially micropiles) with reinforced concrete and steel structures connecting them to the ancient masonry foundations. It is obvious that the above comments fully apply also in these cases; furthermore, pile drilling irreparably damages the archaeological and historical remains that are often found below the buildings.

Processes of the same kind may be traced in other fields of engineering, such as the engineering of materials and the installation of services, though they are less significant, missing in these cases the historical continuity.

In other words, all the aspects of the engineering planet are involved.

2. The impact of the 1980 Irpinia earthquake

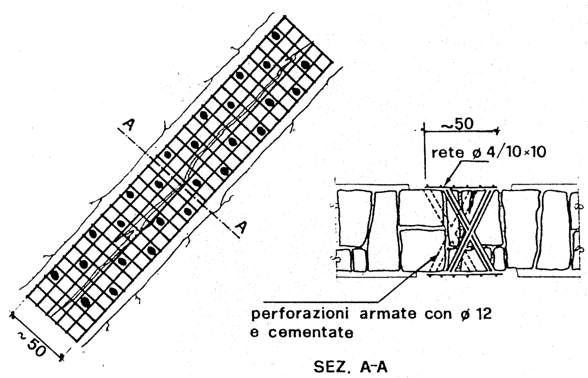
The Irpinia eartquakes occurred between November 1980 and February 1981, and struck a broad and densely inhabitated area. Their effects were felt, in particular, in the cities of Avellino, Benevento and Salerno, apart from Napoli and Potenza.

From the Irpinia earthquakes originated the new Ministry for Civil Protection, a number of special laws, the establishment of new bodies, like the Government Commissions, to deal with the seismic emergency, a powerful financial commitment of the State, a substantial revision of the seismic regulations. These are clear indications of the scarse attention paid up then to the seismic problems by the national conscience.

The same insufficient awareness could be found in education and research. Earthquake engineering had been practiced for hardly ten years; no attention was given to masonry structures, apart from few exceptions.

Lesione isolata - Metodo di riparazione per « iniezione » armata e placcaggio di superficie.

1) Togliere il vecchio intonaco mettendo a vivo la muratura per una striscia della larghezza di circa 50 cm a cavallo della lesione.
2) Pulizia e lavaggio della zona lesionata.
3) Sigillatura della lesione con malta cementizia con addittivi espansivi.
4) Perforazione della muratura con fori ø 40 ÷ 50 passanti inclinati alternativamente verso l'alto e verso il basso a 45°.
5) Iniezione di miscela cementizia espansiva, previa armatura delle perforazioni con barre ø 12 ad aderenza migliorata.
6) Applicazione di rete metallica elettrosaldata ø 4 ÷ 5 / 10 × 10 cm ancorata alla muratura mediante chiodi ed alle armature delle perforazioni.
7) Esecuzione di intonaco cementizio preferibilmente di tipo spruzzato (spessore minimo 3 cm.).



Lesioni d'angolo - Metodo di riparazione per « iniezione » armata.

1) Asportazione dell'intonaco.
2) Pulizia e lavaggio delle zone lesionate.
3) Sigillatura delle lesioni con malta cementizia.
4) Perforazioni delle murature (ø 40 ÷ 50 mm) con inclinazioni alternate.
5) Iniezione di miscela cementizia previa armatura delle perforazioni con barre ø 12 ad aderenza migliorata.
— Inoltre, eventualmente, sulle pareti non a faccia vista:
6) Applicazione di rete metallica elettrosaldata ø 4 ÷ 5 / 10 × 10 cm ben ancorata alla muratura - L = 100 cm. per lato.
7) Esecuzione di intonaco cementizio (spessore 3 cm) di tipo spruzzato.

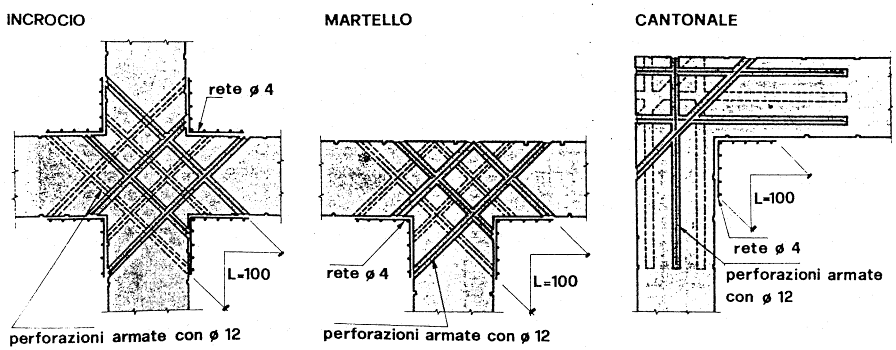


Fig. 3. A sample of the recommendations developed after Friuli earthquake for the reinforcement of masonry buildings.

Under these conditions, the answer to a widespread emergency could not be but a generalized application of that «technical practice of strengthening and reinforcement» developed in the previous years.

Thus, while the design of reinforced concrete and steel structures turned into a very sophisticated and elegant matter by the development and widespread application of computer algorythms, the masonry structures are dealt with on a completely empirical basis that, at its best, relies on the «static sensitivity» of a designer whose education is entirely inspired by the modern theory of structures and the rational architecture.

The aforesaid kind of intervention spreads rapidly everywhere, favoured by low-specialization contractors, scant prescriptions and very rewarding prices.

It has probably some positive effects on the common masonry buildings, that in Italy are still the large majority of the existing built heritage; but it turns into a brutal and distorting practice for the monuments and the monumental buildings.

Thus one could list plenty of underpinning by piles and micropiles; reinforced concrete footings and beams connected to ancient masonry structures; grouting and nailing; removal of wooden structural elements; steel roofs and covers; transformation of columns made by superimposed blocks into monolithic pillars; masonry walls sandwiched between reinforced concrete plates; thin reinforced concrete shells superimposed to powerful masonry domes and vaults, etc.

This general picture of cementification of the Italian monumental heritage is made still worse by the objective difficulty of checking the success of groutings and nailings, and by the lack of any prescription for material testing and static approval.

As a matter of fact, the technological evolution makes available a number of instruments and techniques for nondestructive testing of structures. Nevertheless, as is well known, the results obtained by such techniques have a scientific meaning and are of real use only if they can be interpreted in the framework of a consistent theoretical model; for the masonry structures, at the moment, such a model is largely to be developed. Even geotechnical testing is often viewed as a mere bureaucratic fulfillment.

This situation is by no means restricted to the regions hit by the earthquake, but it applies all over the Italian territory, irrespective of the seismic classification; the example of Rome is self-evident in this regard.

A generalized efficient opposition to this trend by the Government offices responsible for the architectural heritage was probably impossible, in an atmosphere of presumed certainty and cultural haughtiness of the structural engineers. Though completely in the dark about the ancient construction theory and practice, they imposed all their specialism, buttressing themselves with the support of the bureaucratic bodies and of the current juridical conceptions.

Only the Architecture Historians could have been in the position to play a significant role; but to this aim a «material» conception of Architecture would have been needed, instead of the dominant formalism if not the remains of a mere old-fashioned visibilism.

As a matter of fact, the problem has been raised within Structural Engineers at first, and later on within Engineering in a broader sense. It has been realized that Engineering has to acquire the sense of history, modifying its approach to the reality after almost three centuries, becoming aware of a continuity in its practice and rediscovering the constructional canons of the ancient works. To this aim, the cooperation of Architecture Historians, Archaeologists and Restorers is indispensable.

This new awareness has been strongly stimulated, at the theoretical and cultural level, by the Irpinia earthquake and by the following interventions; on the other hand, as could have been easily foreseen, it has difficulties in becoming an established and widespread practise, apart from a few examples.

Accordingly, it may be timely to review the recent investigations and research and the forthcoming programs in this field.

3. Research and studies

The subject of this section is strictly interconnected with all the studies of structural engineering carried out in Italy since the end of the Second World War, that is over half a century. Space limitations hinder a complete review; only the general trends will be thus outlined, apologizing in advance for the unavoidable omissions.

From 1945 to 1960 (but the dates are merely indicative) a general reformulation of the Mechanics of Materials and Structures (in Italian «Scienza delle Costruzioni») on the basis of the mathematical theory of elasticity is performed, focusing on the elastic beam but with some attention also to two-dimensional problems. The Theory of Structures (in Italian «Tecnica delle Costruzioni») achieves substantial progress in the analysis of plane frames and bridge structures, in the development of the theory of reinforced and prestressed concrete, in the design and construction of steel structures.

The design and technology of masonry constructions know a general obsolescence, while the wooden structures are dealt with only marginally.

This approach allows the training of well-educated structural engineers, ready to cope with the great questions of the reconstruction of the Country and the realisation of large public works, the network of highways may be quoted as an example.

This culture still represents the backbone of the training in the field of structural engineering in Italy.

On the contrary, the masonry structures are dealt with on a purely empirical basis, notwithstanding some isolated attempts (among others, Mastrodicasa, 1948; Guerra, 1951; Pagano, 1968). These exceptions, however, refer essentially to ordinary buildings.

It was in 1980 that the treatise of E. Benvenuto, representing the first organic and scientific reflection on the «Scienza delle Costruzioni», was published. This work strongly evidentiates the problem of a cultural continuity in the science of building.

The breach is open. Since then, a large number of studies and a huge amount of research have dealt with the built heritage in a different manner, with the aim of knowing it better and to save it.

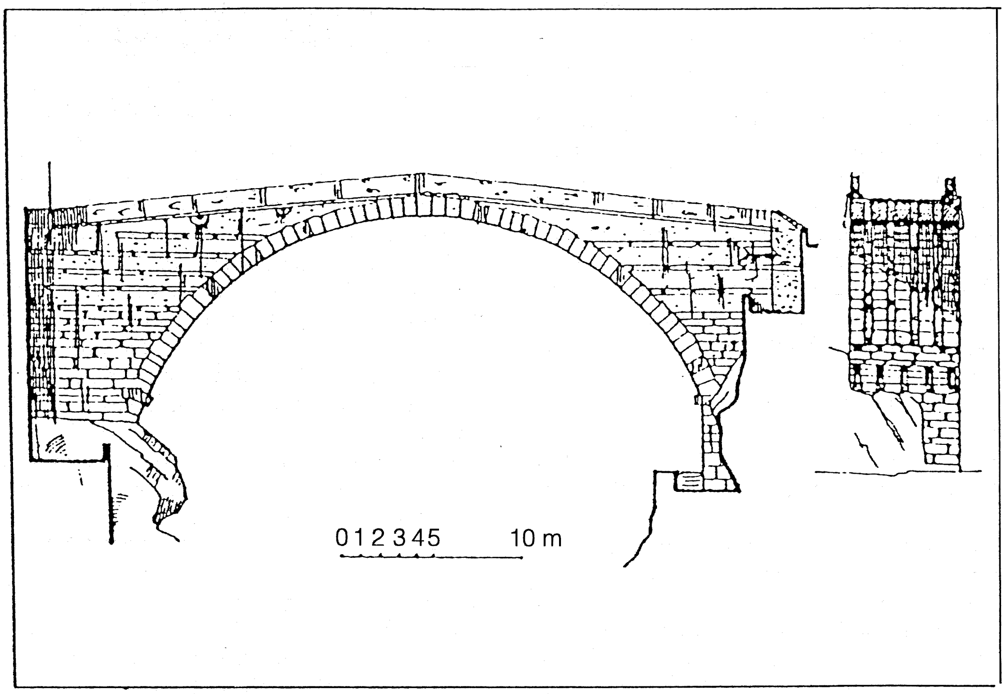


Fig. 4. The Roman Pont Saint-Martin on the river Lys.

Some things among many others may be recalled:

– the book published by the Technical University of Milano (Sacchi *et al.*, 1982) on the static and seismic behaviour of masonry structures, particularly devoted to brick masonry;

– the studies by V. Franciosi (Franciosi and Nunziante, 1983; Franciosi, 1986) on masonry arches; among them, the analysis of Pont S. Martin (fig. 4, Franciosi *et al.*, 1982);

– the Proceedings of the Conference on the State of the Art on the Mechanics of Masonry in Italy (Giuffré and Grimaldi, 1985);

– the volume on the «Technology, Science and History for the Conservation», edited by the Department of Constructions of the University of Florence (AA.VV., 1987a);

– the Seminar on the Protection of the Cultural Heritage from the Seismik Hazard held in Venice (fig. 5, AA.VV., 1987b);

– a number of papers by Augusti, Baratta, Corsanego, D'Agostino, Di Pasquale, Gavarini,Giuffré and many others(3), till the recent book by Benvenuto (1991) published by Springer Verlag.

Fig. 5. The cover of the Proceedings of the Venice Seminar, 1987.

On the other side, a different approach is documented by a large number of studies trying to develop a theoretical model of the masonry structures similar to the theory of the elastic body in the methodology and in the analytical formulation. Examples of this approach may be found in most of the references listed above, and in the work of G. Romano, M. Romano, Di Pasquale, Franciosi, Como and Grimaldi and many others(4).

Furthermore, many papers reporting case histories of strengthening and reinforcing have been published; the reinforcing techniques are qualitatively described in textbooks (Barbarito, 1984; Sarà, 1989; Rocchi *et al.*, 1991).

The nondestructive testing techniques have been developed to the point that many firms are available to perform these investigations and controls on a commercial basis. A leading role in this field and in that of monitoring is played by ISMES (Castoldi *et al.*, 1989), while the Universities are in arrears; perhaps this is the reason why the activity of this kind appears to miss a critical consideration, as recalled in a previous section.

Finally, the Italian National Research Council (CNR) promotes the research in this area through G.N.D.T. (National Group for the Defense against Earthquakes), that is engaged in theoretical and experimental investigations on masonry structures and on the vulnerability of the existing buildings; these investigations, however, do not specifically refer to cultural heritage. For these, the CNR (1991) has recently established an *ad hoc* committee, that has performed a feasibility study for a «Progetto Finalizzato» (oriented research project) on the cultural heritage.

Summing up, it may be concluded that two different, but often intersecting, research paths have been developed about structural analysis, restoration and reuse of the built heritage.

– The first one follows the classical rational approach of engineering, by searching a theoretical model capable of reproducing the behaviour of masonry structures, in the framework of the methods of Continuum Mechanics.

– The second one, though not renouncing to a scientific and rational approach, enlarge its horizons by basing its own methodology on the historical research and on the reflexion on the ancient art of building, trying to read it through the methods of modern mechanics, but having in mind the material history of the construction, its configuration and its evolution along the endless path of the different civilisations.

4. Regulations, worksite practice, attempts of safeguard of the built heritage

From the point of view of the regulations and laws, the first directions for the emergency interventions were issued soon after the Irpinia earthquake in the so-called «Ordinance 80»(5). The fundamental law of that period is, however, the Law 219(6), where all the «seismic culture» develope after the Friuli earthquake has been transferred.

It is the Law 219 that sets the imperatives of the seismic analysis of the masonry structures and of the «adeguamento», that is a modification of the structure such as to make it apt to resist seismic actions (or better to satisfy some form of analytical requirement).

In the meantime the classification of the national territory into seismically active zones is broadened, and a III category (low seismicity) is added to the existing I and II categories. All these undertakings are promoted by the Ministry of Public Works.

A very complete list of the existing regulations, updated to 1984, was compiled by Chiantini and Cipollini (1984).

In parallel to the normative process, the study of the vulnerability of the built heritage was undertaken, with special attention on the seismic vulnerability. A number of forms, intended for the rapid definition and survey of the vulnerability of a building, were proposed and some vulnerability surveys attempted. Among them, that of the Pozzuoli area affected by the bradyseism is exemplary.

In the field of Cultural Heritage, this approach has gradually extended, spread and finally merged into the recent proposal of a Law for the «Map of Risk».

The Ministries of Cultural Heritage and Civil Protection have established a «Committee for the Protection of the Cultural Heritage from the Seismic Risk», to whom the authors belong. It has gradually grown into a true Forum for the debate on seismic vulnerability and monuments, and in a broader sense on the methods of analysis and the technologies of intervention for the monuments.

The activity of the Committee, through a number of documents and some penetrating undertakings, points more and more towards the safeguard of the material identity of the history of the Architecture.

The relevant documents are(7):

– recommendations for the interventions on the monumental buildings in seismic zones (1986),

– directions for the undertakings and the behaviour to limit damages to the cultural heritage in the event of an earthquake (1986),

– emergency plan for the safeguard of the books heritage in the case of a calamity,

– emergency plan for the safeguard of the documents heritage in the case of a calamity.

Apart from some activities within the Ministry of Cultural Heritage, the undertakings of the Committee include the Venice Seminar (1987), the laying down of many pilot designs in agreement with the Regional Superintendences, the funding of Research Conventions with many Universities.

This can be grouped in the following research lines:

1. basic characters of the built heritage and settings tipology,
2. vulnerability,
3. behaviour and methods of analysis,
4. intervention technologies.

At present, a number of Conventions have been activated for a total of 10 MML.

The Committee has also opened a dialogue with the Ministry of Public Works on topics such as: the *ad hoc* regulations for the Cultural Heritage; the specifications and price lists; the training of specialized craftsmen and technicians; the revision of the register of contractors. The perspectives of these contacts seem to be rather good.

5. The present situation

The complex path that we have tried to trace out has undoubtedly deeply modified, from the cultural viewpoint, the problem of static restoration of the monumental heritage, and particularly that of its seismic protection.

The debate still needs further clarification about the meaning of the concept of safety in this context; some significant contributions may be found in Perego (1986) and ICOMOS (1991).

As it is obvious, studies and research will go on and deepen in all directions; it is very important, however, that what we have called the planet engineering is becoming more and more aware of the sense of history.

At the level of the intervention techniques, the battle appears still very difficult and it has to be realized that a widespread damage has already been done. Cases such as those of the Temple of Cerere, the Arch of Constantine, the Cathedral of Amalfi, the Baths of Caracalla, the Cathedral of Solofra are but a few examples.

On the other side, some «different» cases begin to exist: the Insula XIX in Pompei; S. Angelo dei Lombardi; S. Leucio, just to quote some of them.

Exemplary in this respect is the case history of the Leaning Tower of Pisa (Ministero LL.PP., 1971; Croce *et al.*, 1981; AGI, 1991).

Apart from its astonishing beauty, the Leaning Tower arouses throughout the world an intriguing curiosity and a special interest due to its somewhat misterious leaning and to the awareness that it is in danger of collapsing; the international geotechnical community has elected it as a sort of symbol of Soil Mechanics.

Since the beginning of this century, studies and investigations have been promoted by the Italian Government in order to verify the stability of the monument and take the appropriate conservation measures.

A number of Committees have followed one upon the other collecting historical facts, determining the shape, size and weight of the monument, monitoring its movements, investigating the composition and strength of the structure, determining the constitution and mechanical properties of the subsoil and ascertaining the regime of the groundwater.

The history of the Committees entrusted with the tower and suggesting safety interventions is almost as long and puzzling as the history of the tower itself. For the purpose of the present paper we will recall the intervention by the architect A. Della Gherardesca, who excavated in 1838 around the base of the Tower the so-called «catino», with the aim of uncovering the base of the monument that had sunk into the soil (the average settlement of the Tower may be estimated between 2 and 3 m). One century later, in 1935, cement grout was injected into the base of the Tower and the soil surrounding the catino, with the aim of sealing the water inflow. Both these interventions produced a sudden and definite increase in the rate of tilt of the tower!

In the early '70s, an international competition for stabilizing the tower was promoted by the Italian Government; five of the 27 proposals received were judged positively, but none finally won (fig. 6).

In the '80s a design group was established by the Ministry of Public Works, and produced a scheme of permanent stabilization works; nevertheless their proposal was not implemented.

In 1990 a new interdisciplinary Committee was appointed for suggesting and adopting stabilization and conservation measures; its members were restorers, art historians, mineralogists, besides structural and geotechnical engineers. The Committee is aware that the conservation and stabilization of the Tower of Pisa cannot be regarded merely as an engineering problem, as if the Tower were a smokestack or a silo; the integrity of the monument and its material and cultural history have to be safeguarded.

It is rewarding to realize how much these aspects are assuming an overwhelming importance in the public opinion, besides the approach of the experts; as a matter of fact procedures such as underpinning with micropiles or reinforcing the structure with steel bars cemented in holes or with cement grouting, that were seriously considered in the design proposals of a few years ago,

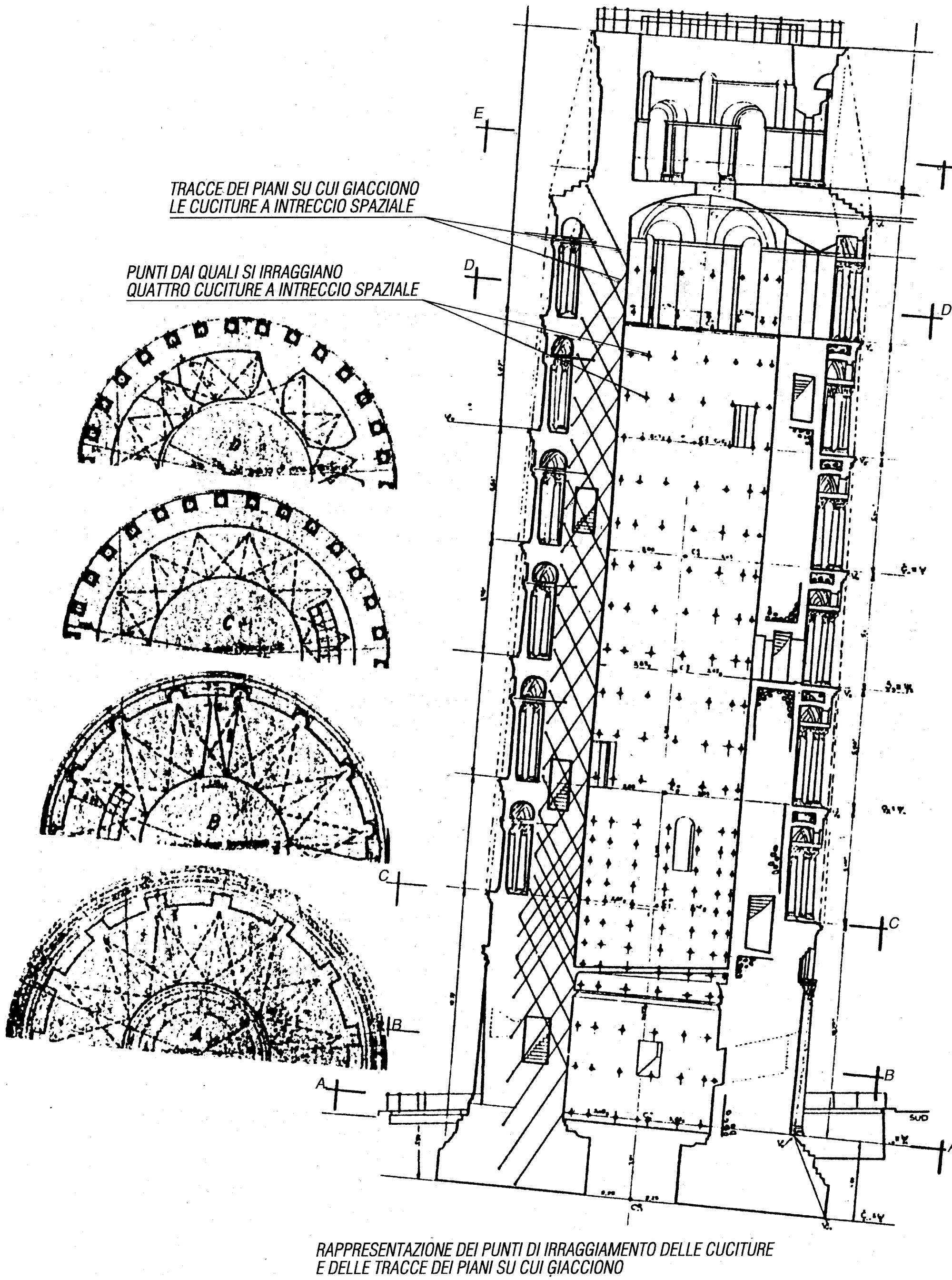


Fig. 6. A sample of the reinforcing measures suggested for the Tower of Pisa by some of the participants to the international competition.

are at present totally rejected. And from the engineering point of view this is a truly stimulating challenge posed by the ancient builders: the Tower has to be saved to the next generations without piling or grouting, without changing it into a different object, perhaps stable but embalmed, a sort of mummy.

At present, the Archaeological and Architectural Superintendences are progressively gaining confidence and begin to withstand the comparison with the technical requirements, true or presumed.

Monitoring, nondestructive testing and other testing are gradually spreading; care should be exerted to use them in a rational way, though they must however be encouraged.

The principal problem is probably to reach a situation where the responsibility of the monumental heritage is assumed entirely by the Ministry of Cultural Heritage, instead of that of Public Works; this would represent a turning point that would undoubtedly produce a positive reversal of trend. To this aim, a bold pronouncement of the Italian Academy is still missing.

In the archaeological sector, the problem is still more evident; accordingly, the time has come to rescue the archaeological areas from the prescriptions applying to other buildings, entrusting the Ministry of Cultural Heritage and the Superintendences.

Finally, it must be pointed out that the peculiar character of our Country and the importance of its cultural heritage is such to put it on the forefront among the industrialized countries; accordingly, little if any advantage can be expected from an international comparison.

6. Concluding remarks

The conservation of the immense built heritage, and in particular of the Italian monumental heritage, will represent more and more a problem in the next years; in fact such heritage is to be considered a truly outstanding chapter of the history of building and of the same human civilisation.

Engineering deserves a fundamental role in this connection; structural and geotechnical engineering are on the forefront. These branches of engineering should meditate upon their function and development, in continuity with the past and acquiring a true sense of History; this will transform structural and geotechnical engineers from mere technicians into leading actors of knowledge and evolution.

In this connection, it is believed that the birth of a «Cultural Heritage Engineering» is urgently needed from a cultural, scientific and educational point of view.

(1) The first revision of the Italian seismic regulations after the war is the Legge 25 novembre 1962, n. 64; a first broadening of the zones to be considered as seismically active occured with the Legge 2 febbraio 1974, n. 64. The revision of the technical regulations occurred with the D.M. 3 marzo 1975. The first papers about Earthquake Engineering after the war were published in the mid '60s (Castellani, 1965a, 1965b; Castellani and Grandori, 1965; Grandori, 1966).

(2) Regione Autonoma Friuli-Venezia Giulia: Recupero statico e funzionale degli edifici; Legge Regionale 20 giugno 1977, n. 30. Regione Autonoma Friuli-Venezia Giulia: Documentazione tecnica per la progettazione e direzione delle opere di riparazione degli edifici. Documento tecnico n. 2: Raccomandazioni per la riparazione strutturale degli edifici in muratura. Gruppo interdisciplinare Centrale, II Edizione, Maggio 1980.

(3) Some of these papers are listed in the references.

(4) Some of these papers are listed in the references.

(5) Ordinanza 6 gennaio 1981, n. 80. Norme tecniche e norme procedurali per la riattazione di fabbricati lievemente danneggiati.

(6) Legge 14 maggio 1981, n. 219. Provvedimenti organici per la ricostruzione e lo sviluppo dei territori colpiti.

(7) All these documents are compiled in the Volume of the Venice Seminar, 1987.

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