SEISMIC PROTECTION OF EXISTING BUILDINGS IN THE ITALIAN EXPERIENCE

Maria Adelaide Parisi, Chiara Tardini
Politecnico di Milano, Department of Architecture, Built Environment and Construction Engineering

Abstract
The current Italian code for structural design treats extensively the issue of seismic protection of existing buildings. With an approach that may be considered innovative for a building code, the building must be first examined in its different characteristics, including the need for an accurate reconstruction of its history, in order to reach the best possible knowledge of its structural behavior. In coordination with the code, guidelines specifically devoted to the case of heritage buildings have also been developed. These documents have their roots in older regulations issued at different times during the course of the national history. The development of seismic codes is strictly intertwined with the sequence of significant earthquakes that hit the Country, as new codes were often issued as a consequence of a major seismic event, and with the advancement of earthquake engineering as a discipline. This research follows the path of the main Italian seismic regulations developed from the Country foundation to the present, starting with the Casamicciola earthquake of 1883. The focus is on indications for strengthening the existing building stock and for preserving the cultural heritage that may be found along the entire period considered.

Italy is a nation of ancient civilization and, at the same time, has a territory affected by a significant level of seismic hazard. As a result, damaging earthquakes recur frequently and take each time a toll from the large part of the building stock that was constructed without specific provisions for seismic action, among which are centuries-old cultural heritage buildings and monuments.

Currently, the structural design code has a large section on existing buildings subjected to earthquakes, with indications for seismic damage repair and for preventive strengthening that may be compulsory under particular circumstances. Other official documents deal with the more specific case of monumental buildings, like the relevant guidelines issued by the Ministry of Cultural Heritage. This is the result of a long development, where the sequence of seismic events, the birth and growth of earthquake engineering as a discipline, and the formulation of rules and regulations for building design are interconnected and develop along a path starting in a far past and arriving at our days. In the following, without aiming at a full historical reconstruction, some significant steps of this path are highlighted and will permit to track the origins of the present indications dealing with the care and preservation of the existing building stock. This historic outline is described with reference to three different periods. In the first, Italy, as a young, recently unified country, faces dramatic seismic events and sets a first approach to seismic protection; in later times, in Italy and worldwide formal seismic design codes are issued for new buildings at first and, eventually, for strengthening existing ones; more recently, performance-based codes are developed; greater attention to the built heritage has given rise to a wealth of documents, ranging from design codes to guidelines specific for different building types, as described in the following.

The new Country and the birth of the discipline

Short after national unification was reached, in 1861, Italy had to face a highly damaging earthquake that occurred on July 28, 1883 at Casamicciola, in the island of Ischia, gulf of Naples (Fig. 1). The earthquake occurred in the evening causing over 2300 victims, out of which almost 700 tourists. The site was a well appreciated resort for northern Europeans seeking milder winters. In the aftermath, the Government issued building regulations to be applied in the reconstruction.

The Royal Decree (Regio Decreto, 11 settembre1886, n. 212), regulating building repair and reconstruction, deals with existing buildings and with buildings of cultural value in particular. The approach is, however, one of very invasive or even destructive interventions, showing little sensitivity for cultural values of the past or, in any case, lack of knowledge on how to proceed with effective interventions, resulting in an extreme conservativism. At point 13 of the building regulation, giving prescriptions on restorations, vaults at storeys above ground had to be demolished and substituted with slabs. Vaults of churches were also to be demolished and replaced by solidly built slabs supported by a sufficient number of interconnected vertical elements. According to a publication of the National Seismic Service (Servizio Sismico Nazionale, 1998), an extensive demolition of buildings has been produced, as can be estimated from the large amount of debris recorded, which exceeded significantly what could be ascribed to the earthquake alone. This is an indication of the little consideration given to the conservation of existing buildings, especially of cultural value, that were present in the area.

Twenty-five years later, in December 1908, the even more devastating earthquake that hit the towns of Messina, in Sicily, and Reggio, in Calabria, facing each other through the Messina straights, found a more scientifically organized engineering community. The earthquake and the following tsunami killed over 80000 people, levelling down the two cities. A committee formed by academic scholars and practitioners in equal number was nominated with the task to define sound criteria for reconstruction that could also prevent seismic damage in the future. The most interesting result of the Committee work is in understanding that the major effect of ground shaking on buildings was from horizontal inertia forces, which could be taken into account in design with a statically equivalent force profile. Structural dynamics was not yet known, therefore the distribution chosen made reference to that used for wind, uniform for common building heights. Interestingly, an alternative was also devised in the now-called base-isolation of buildings. At the time, this intuition could not develop into a viable solution and was left aside, given the lack of knowledge of the dynamic behavior of structures and the absence of powerful computational tools. This approach became possible only after the development of computer technology. Indications given for new construction as well as for the repair and strengthening of buildings damaged but not destroyed by the earthquake were collected in the Royal decree, Regio decreto 19 aprile 1909 n. 193, regulating new construction and interventions in the area hit by the earthquake. Provisions for existing buildings appear milder, vaults are "tolerated" but their thrusts must be eliminated by tie-beams, an indication still given today. In the third chapter, "titolo III", on repair, point 31 in particular deals with heritage buildings, stating that "for repairing national heritage buildings of artistic, historical, and archaeological value, the modality must be decided case by case, considering their conservation only". This is a very different attitude compared with the 1883 case.

It is worth noting that at this time, and for many decades after, seismic building codes were issued only after the occurrence of an earthquake in the area interested by the event. The concept of seismic zonation will develop much later. Meanwhile, adding up these areas, a seismicity map, without reference to return periods or rates of occurrence, was slowly built, as shown in Fig. 2. The difference in color, or tone, indicates the contribution of subsequent events starting with the 1908 one, indicated by the darkest area. Other maps in Fig. 3 show the evolution toward a scientifically based zonation arrived later in the 20th century, with the 1984 version, until the current version, which covers almost all the national territory. The current map shown at the right hand side in the figure refers to an earthquake with return period of 475 years, internationally accepted as exceptional action for ultimate limit design in common building situations.

The many seismic events that hit the Country in the first half of the 20th century were usually followed by decrees regulating funds and technical indications for reconstruction. The insertion of metal ties to relieve thrusts and improve connectivity of buildings has been, and still is, indicated as an effective and simple intervention. Figure 4 shows the presence of tie rods with different restraint systems on the outer wall of a building in the Abruzzo region, each representing a different period. The bar-shaped restraint could date back to the 1915 Avezzano earthquake, while the plate is typical of much later times, like the earthquakes of the 1970's or 1980's. The arrow-tip restraint indicates the presence of an old timber tie.

National codes for seismic design

Older seismic regulations were enacted only in areas that had been declared seismic after being hit by a damaging earthquake. The start of what can be considered a modern seismic code giving general design rules not related to the consequences of a specific earthquake occurs in Italy much later, in 1962 as a first issue and in 1975 with a more dynamically correct approach. Two levels of seismic action were defined, as for zone 1 and 2, according to the newly issued seismic zonation of the national territory. This code deals with earthquakes in a modern sense, in line with the major international codes of the time: structural analysis can be performed considering a statically equivalent force distribution tailored on the first mode of vibration, regulated by the mass and grossly the stiffness distribution of the structure. A direct response spectrum modal analysis is also possible, although at the time the computational power and the necessary expertise were hardly available except to a small number of professional firms. The validity of this code has been practically extended, with minor updates and with a wider and wider use of dynamic analysis, till the issue of the next generation of codes in the 21st century. In the 1962 and 1975 code issues, no consideration was given to the problem of existing buildings and of heritage structures. This topic appeared for the first time with a coordinated and detailed treatment in the revised version of 1986.

In just over a decade, from 1968 to 1980, three major earthquakes occurred, in the Belice valley, Sicily, 1968, in the north-eastern part of the Country, in Friuli, 1976, and in Irpinia, Campania, 1980. In 1979 a damaging earthquake had arrived also in Valnerina, Umbria. The Friuli and Irpinia events reached about 1000 and 3000 fatalities, respectively. The devastation they produced made it clear and evident that no advanced design code could significantly reduce the seismic risk, if no provisions were taken also to reduce the vulnerability of the existing structures, particularly the older masonry dwellings that constituted a large fraction of the building stock (see Fig. 5). The amount of data collected from direct observation of seismic damage in these earthquakes and especially after the Friuli event gave rise to a large effort of studies on different related topics. Studies on masonry as construction material, the behavior of masonry panels under vertical and lateral forces, the concept of seismic vulnerability and the vulnerability index criterion for its assessment, as well as the first ad hoc computational methods, like the first simplified method for static nonlinear analysis of a masonry wall with openings under vertical and lateral forces, apt to assess its capacity under seismic action and, finally, criteria for seismic strengthening of masonry buildings, all stemmed from those ruins and from the simultaneous and synergic presence at the earthquake site of young researchers of different Countries (e.g., among others, D. Benedetti and V. Petrini from Politecnico di Milano, and Miha Tomasevic from Slovenia).

The Decrees issued by Regional Authorities with local indications for reconstruction, and particularly by the Friuli-Venezia Giulia Regional Authority (e.g. Legge Regionale 20 Giugno 1977, n. 30 - DT2), were strongly influenced by the first results of these studies and, in their turn, influenced the new issue of the national seismic code in 1986.

The 1986 code presents an extended section on existing buildings with some interesting points, stating, namely,

- when an increase of the seismic capacity of a building would be required;
- the possibility of two different approaches, that is, seismic strengthening and seismic improvement;
- what types of interventions could be performed, and which were highly advisable.

Because it was not possible to force the upgrading of privately owned buildings, it was decided to impose strengthening interventions whenever a building would undergo extraordinary maintenance, including a change of use, an increase of loads, etc. The rationale under this rule was that in a period of some years or even some decades a significant part of the building stock could be brought to a higher level of seismic capacity. This criterion is still present in the current code, with minor changes in the minimum increase of loads for which strengthening becomes compulsory, now a 10 per cent versus the previous value of 20 per cent.

An interesting point in this code was the distinction between strengthening and improvement. Strengthening intervention corresponds to a series of works that are deemed necessary to make the building capable of resisting to the same seismic action considered for the design of new buildings.

An intervention for seismic improvement consists in performing one or more works on specific structural elements with the aim at increasing the safety level without major changes in the global behavior. The distinction suited well the listed heritage buildings, for which invasive interventions could clash with principles of preservation, and which could need some upgrading of their capacity of response. A later document on restoration principles issued by the Cultural Heritage Ministry on October, 26 1999 (Testo unico delle disposizioni legislative in material di beni culturali e ambientali), officially declared the interventions for seismic improvement as part of the approved restoration criteria.

The two approaches have been passed on, virtually unmodified, in all subsequent issues of the seismic design codes.

The code presented also guidelines for the interventions that could increase the seismic quality of the buildings. The focus was on masonry, while only short notes were given for other materials. The suggested interventions were in line with constructional traditions, but also fostered large use of reinforced concrete elements, grouted bars, ring beams, etc., bringing often to increase stiffness and mass significantly, not always to the best.

Among the studies carried out starting with the Friuli earthquake, the seismic behavior of specific types of heritage buildings, and criteria for assessing their vulnerability, were developed. The damage suffered by churches directed the interest on pointing out the relationship between their peculiar structural characteristics and the damage occurred. It was observed how collapse most often would occur in specific building components, called macro-elements in the study, with recurring damage patterns. From this observation and from the analysis of data collected in the post-earthquake inspections came the definition of typical macro-elements, and first criteria for assessing the church vulnerability on their base (Doglioni et al., 1994).

A new generation of codes

The earthquake that hit central Italy in 1997, in the Umbria and Marche regions, acted as a sort of testing bench for the interventions that had been implemented following the 1986 code indications. In this earthquake, and later in the L'Aquila earthquake of 2009, it became clear that some interventions producing excessive increase of mechanical properties compared to the poor quality of the original masonry had been, themselves, fostering damage. This occurrence was not the rule and only applied to a few cases, yet it set the alarm for rethinking the indications in order to avoid such a behaviour. The same earthquake, arrived in an area particularly endowed with cultural heritage buildings, damaged significantly churches and historical palaces. After the first proposal for vulnerability assessment quoted above, the significant amount of studies that followed, and the experience acquired in this event gave rise to a more complete treatment of monumental buildings in seismic areas. For churches, and later for palaces, the main collapse mechanisms were formalized and a procedure to evaluate damage or, preventively, vulnerability of these structures was developed (e.g. Lagomarsino and Podestà, 2004). The procedure was adopted by the Civil Protection Agency for use in the post-event activities of damage recognition. It has been used during the L'Aquila earthquake of 2009 and the Emilia-Lombardia earthquake of 2012.

At the beginning of the new millennium, the earthquake engineering community was waiting for news. Also in view of the observations from the Umbria-Marche earthquake, a new seismic code was felt as necessary. At the same time, the Eurocode program was expected to issue soon a norm for seismic design. A new zonation of the national territory was also due soon. It arrived in 2006. Again an earthquake broke the spell. In 2002, the moderate earthquake of San Giuliano di Puglia killed the primary school children and their teacher in a badly constructed building. In March 2003, a new code, issued with an urgent decree, Ordinanza 3274, widely inspired by the Eurocode 8 draft for the design of earthquake resistant structures, was issued still in a temporary mode, as alternative to the current code. It would be finalized after a period of testing. The code was thoroughly different from the previous one, in line with the new generation of codes that were being published worldwide. It was intended as performance based, through a limit state approach, like the Eurocode 8, which was finally published in 2004. The Ordinanza dealt extensively with existing buildings, especially for masonry but also for non-ductile reinforced concrete. A new table of properties for different types of masonry was published for the first time after the one that had been supplied officially in 1980. For existing masonry buildings to be strengthened or improved, an analysis of damage mechanisms that may possibly develop became required. Directions were given for computations, based on limit equilibrium of elements involved, considered as rigid blocks. Another important innovation was the introduction of the level of knowledge for the building in exam, depending on the available data and on the amount of experimental tests that the designer intends to carry out on the structural elements. An additional safety factor is derived on this basis. A very detailed appendix reports recommendations for interventions. A milder approach with less invasive interventions, taking into account the experience from recent earthquakes, may be noted.

The 2003 Ordinanza never reached a final acceptance, because a new National building code (Norme tecniche per le Costruzioni), valid in seismic and not seismic areas, was prepared. It appeared in February 2008 and is currently in use. Within this code, a substantial section, section 8, is devoted to existing buildings, with a large part for buildings in seismic areas, basically corresponding to the text of the Ordinanza. Details for interventions are collected in the Commentary, presented in 2009, and in its appendices.

It is clear at this point that the importance of operating correctly on existing buildings and on heritage buildings in particular has been fully acknowledged, at least at code level, and that knowledge has significantly grown in decades of study, experimentation, and experience. For a complete picture, however, the documents issued by the Ministry of Cultural Heritage need be mentioned. A first issue, in 2006, was a guideline for assessing and reducing the seismic risk of cultural heritage (Linee guida per la valutazione e riduzione del rischio sismico del patrimonio culturale), and criteria for interventions, which made reference to the Ordinanza for technical aspects. Different approaches depending on the accuracy level to be attained were offered for vulnerability analysis, with reference to the concept of damage mechanisms in the background and within a simplified probabilistic framework. A new edition came in 2010, in order to be coordinated with the 2008 design code. This is a very rich and comprehensive document that well represents the state of the art in dealing with heritage buildings in a seismic Country, a long way from the first notes in the 1909 decree, but following the same spirit of consciousness and care.

Conclusions

The present Code for structural design has an important section concerning existing buildings. Within this section, and in the relevant commentary and appendices, detailed indications are given for seismic strengthening and seismic improvement interventions; preventive measures specific for cultural heritage buildings and monuments are available from the guidelines issued by the Ministry of Cultural Heritage. This is the result of a long path that lasted over a century, marked by the earthquakes that hit the Country and by a growing consciousness of the need of protecting the existing buildings and monuments in order to effectively reduce seismic risk and preserve cultural values.

Bibliographic references

Presidenza Consiglio dei Ministri, Servizio Sismico Nazionale, (1998) *Il terremoto del 28 luglio 1883 a Casamicciola nell'isola d'Ischia*, Istituto Poligrafico e Zecca dello Stato, Roma.

Doglioni F., Moretti A., Petrini V. (1994), *Le chiese e il terremoto*, Trieste: Edizioni LINT.

Lagomarsino S., Podestà S. (2004), Seismic vulnerability of ancient churches: damage assessment and emergency planning, *Earthquake Spectra*, 20(2), 377-394.

Lagomarsino S., Podestà S. (2004), Seismic vulnerability of ancient churches: Statistical analysis of surveyed data and methods for risk analysis, *Earthquake Spectra*, 20(2), 395-412.

Fig. 1 - Ruins of the Church of the Annunziata, Casamicciola - E. Matania.

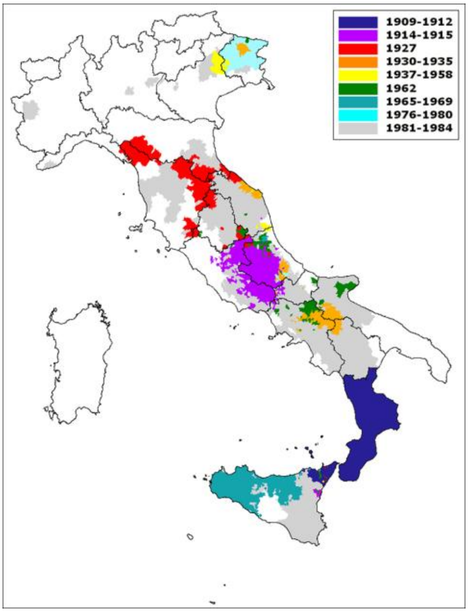

Fig. 2 - Seismicity map with areas hit by earthquakes from 1909 to 1984.

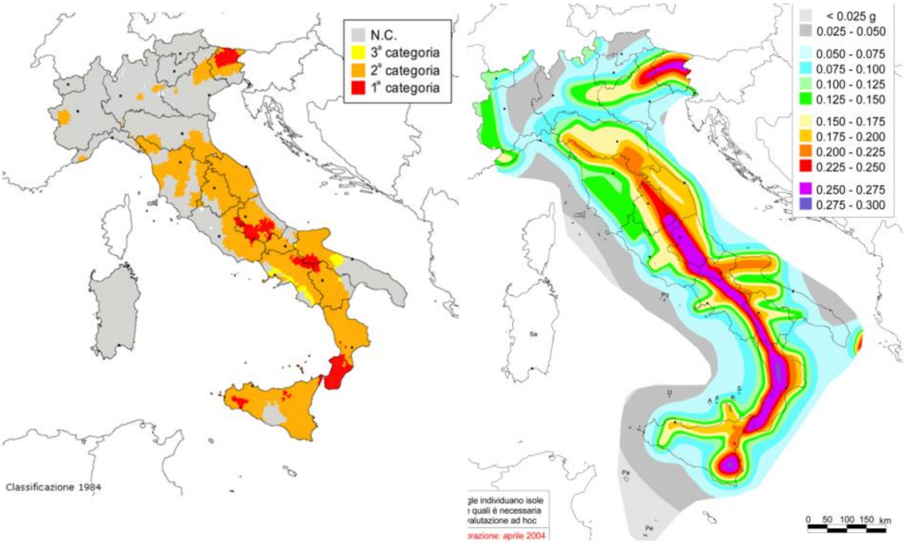

Fig. 3 - Seismic zonation in 1984 (left) and now (right).

Fig. 4 - Different tie rod restraints.

Fig. 5 - Damage in the Friuli 1976 earthquake.