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Historical variables of seismic effects: economic levels, demographic scales and building techniques

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Abstract
During the analysis of the historical seismicity of Italy, territorial and social elements emerged that in the long term have strongly influenced the effects of the earthquakes. These elements are here presented as *historical variables* of the degree of intensity. The Italian context is characterised by a long and continuous history of housing, with profound historical and economic changes. The effects of the earthquakes are influenced by population density, the verticalism of the buildings – from the thirteenth century – and the building techniques. The latter have always been highly diversified, not only in the various historical periods, but also within the same time-span, on the same territory, because of the strong geographic differences which characterise the Italian area (coasts, mountains, plains, etc.). This contribution provides a synthetic assessment of these variables in relation to the seismic effects described in the historical sources. The authors expect to be able to better calibrate in future the evaluation of the seismic effects in relation to building characteristics.

Key words *historical demography – economic levels – building techniques – macroseismic intensity*

1. Introduction

The long-term analysis of Italian seismic history highlights territorial elements that *interact* so closely with the overall picture of seismic effects that they might almost be considered as historical variables of the degree of intensity. These elements are historical building techniques, economic levels and population size.

The attention of historical seismologists has sometimes focused on these themes, but a true school of thought has never developed, perhaps because wide-ranging instruments of synthesis have not been developed for the specific areas of investigation. Even though considerable research has been carried out in these sectors, the themes and research methods have a «centrifugal» tendency, which, with time, appears to have dismissed the possibility of providing instruments of synthesis capable of encouraging a multidisciplinary use of the available information on a large territorial scale and over a long period of time.

The relationship between economic levels, population density, building techniques and seismic effects is fairly evident in the analysis of strong earthquakes. Indeed, the term «construction» of the seismic disaster, has provocatively been used to indicate the negative convergence between an increase in population density and a decline in building quality, whereas the opposite term, «deconstruction», indicates the reverse tendency (Guidoboni, 1990).

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As is well known the effects of earthquakes on buildings depend on factors whose nature is diverse and often difficult to interpret. The damage caused is not only due to the energy of the earthquake but can also be attributed to the particular geological conditions of the site as well as to the structural and non-structural articulation of the building, its morphology, the type of foundations, the original building techniques, the alterations made through time, and the state of conservation and maintenance (closely related to the standard of living). We therefore have a group of mutual relationships and interdependencies which translate into the amplification or mitigation of the effects even in areas on, or very near to, the same site and between buildings constructed with the same building techniques and materials.

The problem is very complex and encompasses various disciplines. We aim to provide some ideas and suggestions of how to read the catalogue data, although we are aware that most of the themes require specific discussion.

2. Population

There are a number of high-quality studies of historical demography which are mostly regional or even local. During the preparation of the *Catalogue of Strong Italian Earthquake* (CFTI3) the aim was not to create a parallel database of demographic information (the resources available would not have been sufficient), but to absorb elements useful for the evaluation of seismic effects.

Descriptions from historical sources often include information such as the number of dead, and the number of destroyed or damaged houses. In order to be able to use this information, it must be compared to the total number of inhabitants and houses that effectively existed at the time the earthquake took place. Demographic data, such as the number of inhabitants and buildings in an inhabited centre or territory often allow an estimate of the territorial impact of an earthquake. Here we put forward elements inherent to the definition of population scales, with the aim of indicating themes that contextualise seismic effects. The problems with estimating the population figures differ from area to area and the complexity of the problem and the depth of the research is sometimes reflected in the contradictory estimates made by historians.

2.1. *Ancient Italy: a population estimate*

It is not possible to calculate statistical estimates for the ancient world; at most only probable data can be obtained. The figures handed down by historians were changed by late manuscript tradition, and they are therefore often inaccurate and must be rejected on the basis of historical evidence. Furthermore, the societies that existed in the past were both culturally and technically far too different from our current society to allow statistically reliable estimates. The calculations made by Beloch (1894, 1898 and 1903) are interesting because he put together data that, in some cases, appear to give reliable results (see Gallo, 1990; for the terms on the controversy see Seeck, 1897; Kornemann, 1897; Meyer, 1898).

As for the Roman age, public documents measuring the size of each administrative unit exist, although they are not proper land registers in the modern sense of the word. Unfortunately, most of the data do not allow reliable conclusions, due to the criterion used by the Romans to regulate the organisation of space. Roman administration was in fact entirely based on the cornerstone of citizenship (civitas). More precise data are available for the five-year censuses during the republican era, from 508 to 28 B.C.: out of 96 censuses 37 remain (Nicolet, 1979). However, though the list includes acceptable documentation, there are many obstacles preventing a thorough understanding of these data.

During the second century B.C. there was an increase in the free population (Gabba, 1972). Various attempts have been made to calculate the population of the Italian peninsula: Nissen (1902) suggested 16 million, whereas Beloch (1903) calculated 4 to 4.5 million city inhabitants, 2 to 2.5 million slaves, between half a million and a million foreigners and citizens of «Latin law», with at maximum a total of 7 to 8 million individuals divided as follows during the Augustan age: 1 million in Rome; 4 million in Central-Southern Italy, and 2 to 3 million in Central-Northern Italy (Salmon, 1974).

2.2. *Rome*

Rome is a special case in our knowledge of the ancient world. According to a tradition of studies which dates back to Beloch (1894) – the first scholar who concerned himself with the population of ancient Rome – ancient Roman territory developed from an original nucleus (*ager Romanus antiquus*) of about 154 km^2, which had an estimated maximum population of about 6500. Subsequent expansion brought the size of this territory to about 800/1000 km^2, which leads to the estimation of a population of no more than 35 000/50 000, limited to about 25 000 in the urban area. Considering that the census counted adult males in arms, it is probable that these data are actually reliable if extended to the allied population throughout Latium (Coarelli, 1988).

In the census of 393 B.C. Pliny records 153 573 freemen. As the territory controlled at that time reached 2000 km^2, this figure probably covers the entire population. According to a tradition going back to Livy, at the time of Alexander the Great (356 to 323 B.C.) there were about 130 000 to 150 000 citizens in Rome (or 300 000 to 400 000 inhabitants). During this period the city extended its territory to the whole of Latium (about 6000 km^2), and was six times larger than in the previous century. The area included within the so-called Servian walls (actually built in the fourth century B.C., although there is a sixth-century phase of which only a few stretches are known) measured 426 hectares and encompassed also the Aventine, the Capitol and the port of the Tiber. However, from the fourth century B.C. (when the Roman conquests began to engulf large territories) it is no longer possible to use the census data to calculate the population of Rome. In fact, in 336 B.C. the Roman territory extended over 5766 km^2, but in 290 B.C. it covered 17 320 km^2, and in 265 B.C. 24 000 km^2. The census data show that the territorial increase was clearly followed by the population increase included in the census, although wars and economic crises could determine even a sharp drop. Until 44 B.C. it is not possible to gain an estimate limited to Rome (when the grain distribution was extended to the plebeians and thus to practically all male adult citizens).

As regards late Christian and imperial Rome, Beloch (1894) was convinced that during the principality era (from the first to the third centuries) the population of Rome totalled about 800 000 inhabitants, while the end of the third century A.D. saw the beginning of a period of decline in the population. The crisis of the third century remains a problem since data for this period are scarce. The only available data regard the special distribution of wheat to the Praetorians and the plebeians by the emperor Septimius Severus to celebrate the tenth anniversary of his reign in the year 203. On that occasion 2 million *aureus* were distributed. At ten *aureus* per head, this gave a total of 200 000 beneficiaries. When compared to earlier data (Nicolet, 1989) this figure does appear to indicate a drop in the population.

In the absence of reliable statistics, these figures can only be considered extremely approximate, even with an excess of hundreds of thousands. But it appears reasonable enough to set the figure (which varied due to the frequent famines, epidemics, fires, etc.) at about 800 000/ 1 000 000 inhabitants during the late Christian age and the principality period. Mazzarino (1951) did not exclude an even higher calculation. Around the fifth century, especially after the sacking of Alaric in 410, the population of Rome underwent a sharp fall. With the passing of time, Rome has undergone considerable variations in population and seen profound changes in the use of urban space: elements that were connected to the role of Rome itself (fig. 1). These elements have been of considerable importance not only as regards the possibility of identifying any seismic effects in written sources, but they have also conditioned the typology of seismic effects in the urban area (Molin and Guidoboni, 1989; Guidoboni and Molin, 1995).

2.3. *The population of medieval cities*

From the thirteenth century the population of Italian cities begins to take on a definite

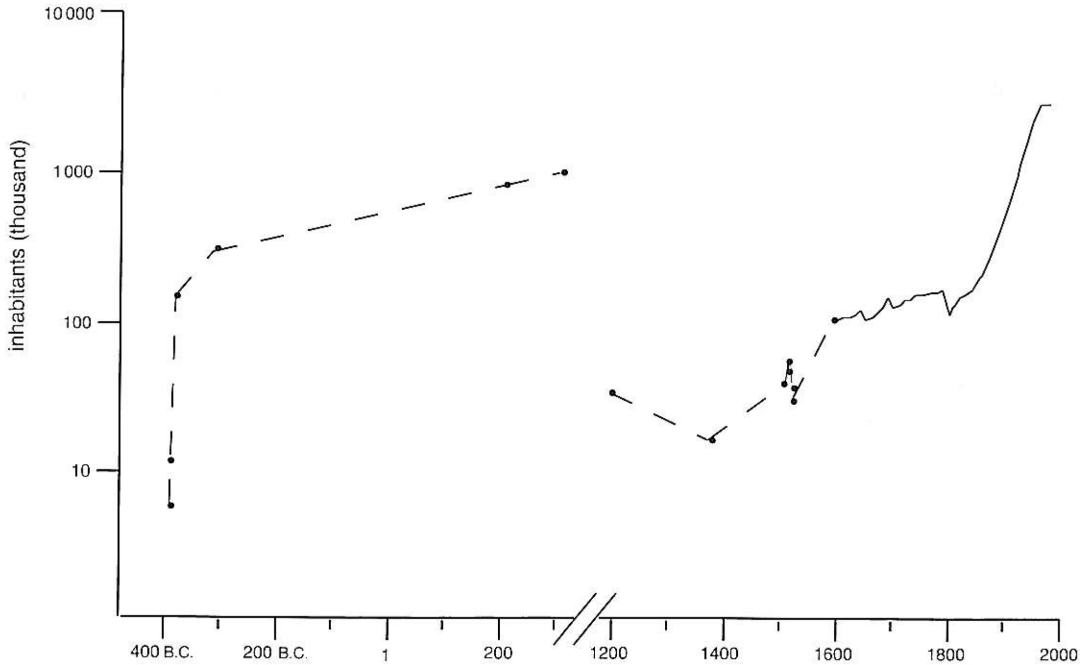


Fig. 1. Indicative progress of the population of Rome from antiquity till today (integrated and revised by Guidoboni and Molin, 1995).

quantitative profile in relation to the quality and quantity of available documentation. There are no true population data for the fifth to the tenth centuries and only sporadic data for the eleventh and twelfth centuries. Scholars have often suggested estimates based on indirect indicators. The complexity of the problems related to the definition of a «city» in itself, relative to areas and centres with very different economic development and territorial jurisdiction is the subject of a practically endless historiographic bibliography (for a rational general bibliographic picture see Ginatempo and Sandri, 1990; *La demografia storica delle città italiane*, 1982).

The peak in medieval population expansion came between the end of the thirteenth century and the first twenty years of the fourteenth century. The «stagnation» in the population is mainly attributed to the deaths caused by the great epidemic of the Black Death in 1348. There were also two large seismic disasters during these years, the effects of which clearly took place in a demographic context which was already much disturbed: the 1348 earthquake in Villach (the effects were felt in the Veneto region and in many Emilian cities) and the September 1349 earthquake in Central Italy (see in the CD-ROM).

At the time, the Italian urban landscape was one of the most developed in Europe as regards the large number of urban centres and high population density. In Italy as many as 11 cities had more than 40 thousand inhabitants (compared to 8 or 9 in Europe) and four of these Italian cities exceeded 80-100 thousand inhabitants. Therefore, the dense fabric and development of the Italian population during this period was exceptional and also explains the extraordinary wealth of documentation covering the history of the territory and urban events in relation to the effects of earthquakes.

The most densely populated cities were concentrated in Northern Italy and Tuscany. Central

Italy mainly featured small and medium sized cities. The south and the islands had a much less dense population pattern, with just two large cities, Naples and Palermo, which however fell within the European average. The development of urban centres obviously depended on trading routes (on land and by sea), the intensity of the trade and the general economic levels. The unrestrained growth continuing until about the mid-fourteenth century was followed by demographic crises that caused the population (mostly in medium and small towns) to shrink drastically. Italian cities underwent radical transformations between the end of the fourteenth century and the beginning of the fifteenth century, marking the onset of a general population crisis which was to hit vast areas of Central Italy with very different effects. According to Ginatempo and Sandri (1990), during the first half of the fifteenth century there were 35 Italian cities, out of a total of 145 localities, which had a minimum threshold of five thousand inhabitants. 43 cities had between six and ten thousand inhabitants, 10 between fifteen and twenty thousand, 11 between twenty and forty thousand, while only three cities (Milan, Genoa and Venice) had more than forty thousand inhabitants.

There was a network of settlements with fewer than five thousand inhabitants made up of towns and villages with a population between four thousand and just a few hundred inhabitants. Research into historical earthquakes has shown that it was this population range that was most frequently hit, in the internal Apennine areas, on different versants, in high valleys far from the cities, or along coastal borders which were scarcely populated in the past. Sometimes the towns were on Apennine ridges or located along the great transhumance routes, and their populations are often only remembered by sources thanks to the seismic destruction they suffered.

In general, the available historiographic data, summarised by an impressive research tradition into Italian cities, do not give a full account of the population extending from the countryside to the mountainous areas. Some regions are an exception, such as Tuscany, Emilia Romagna and Sicily, which have been studied in great detail, even in the lowest demographic scales.

2.4. *The ancient Italian states: the great censuses*

On the whole, from the seventeenth century onwards, demographic estimates tend to become more accurate, and sometimes one goes from indirect fiscal indicators based on «fires» or «mouths» (always influenced by exemptions, different estimations of minors and foreigners) to more reliable absolute figures.

The population census filtered through the territorial control of parishes generally begins in the seventeenth century. If it is ever possible to collect comprehensive and systematic data for the entire national territory, the great worth of this type of source would emerge, featuring even in the smallest hamlets and thus able to provide the overall scale of the residential network, an element of utmost importance in the definition of a seismic scenario. In the absence of a complete picture of these data, summary research has been carried out into the great censuses of ancient Italian states, which often however include non-homogeneous territorial annexations or are of little use to historical seismology.

Tax and administrative surveys carried out after destructive earthquakes often include separate data for direct estimates of the population and the amount of building property: these sources are sometimes unknown to historical demographers and should perhaps generate more converging interest.

We have used these links as far as possible and they may be found in this catalogue included in descriptions of effects by single location or in general outlines in the «demography» subset.

Figure 2 highlights the general population trends in the largest Italian cities from 1500 to 1700.

Figure 3 shows the Italian population trends from the mid seventeenth century to the nineteenth century in different geographical areas. This figure shows variations in the population percentage during the same period and the increases in population spanning the two centuries (Bellettini, 1980), an important element in relation to the economy and the building sector.

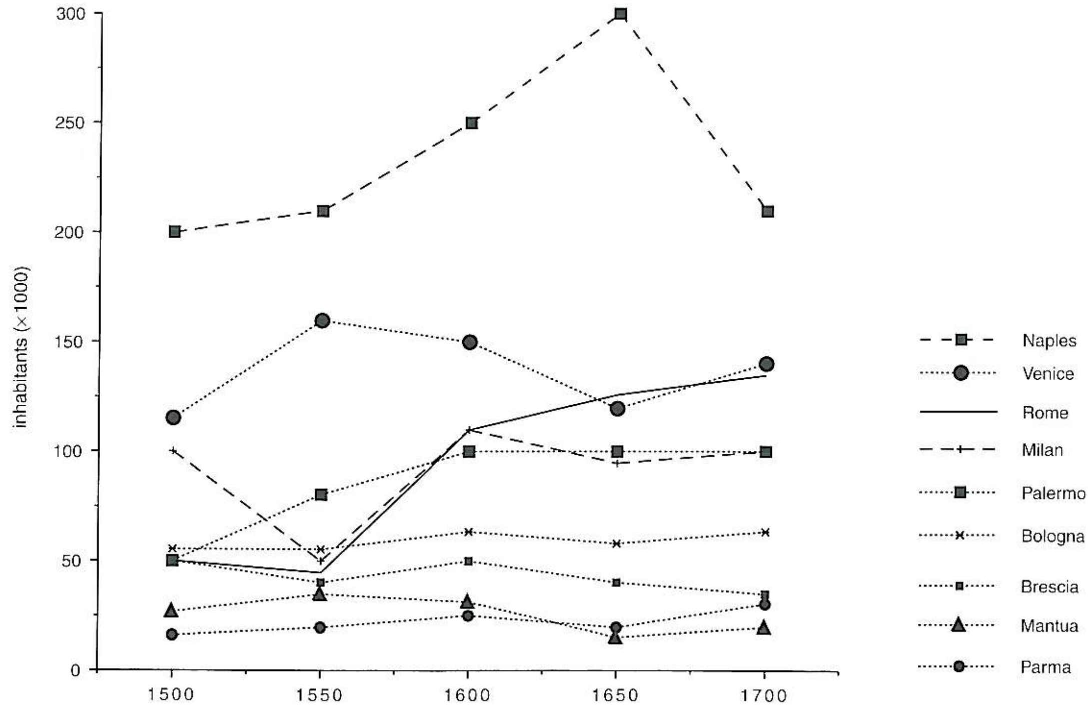
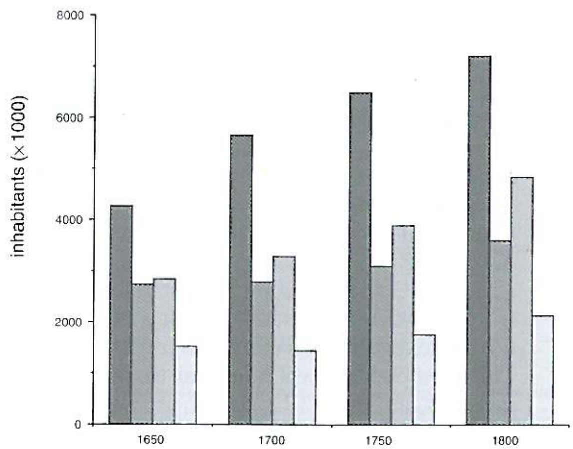


Fig. 2. Progress of the population in the major Italian cities from 1500 till 1700 (revised by Sonnino, 1980).



	1650-1700	1700-1750	1750-1800	1750-1800
Northern Italy	+33.0	+15.0	+10.7	+27.3
Central Italy	+1.4	+11.6	+16.3	+29.8
Naples reign	+15.8	+18.2	+24.3	+46.9
Sicily and Sardinia	- 3.8	+22.0	+20.3	+46.7

Fig. 3. Italian population from 1650 till 1800 by geographical area and variations in percentages for fifty years old (data elaborated by Bellettini, 1980).

3. Elements of historical building

As regards the building sector, Italy presents some very singular aspects compared to other European countries: more than half of its current architectural wealth is made up of historical construction, which has its roots in very ancient and diversified traditions.

As already mentioned, the history of building lacks general geographical or historical research, considering the vast amount of building with a local character and the single specialist or common typologies.

We would like to highlight the long-standing traditions and non-homogeneity in research, which still does not find a congruent evaluation in the use of macroseismic scales. Anticipating solutions is practically impossible at the current state of knowledge. Our intention here was to bring to light just a few aspects which we believe should not be overlooked in evaluating the effects of historical earthquakes, although the «linking» elements (including historical building techniques and macroseismic intensity estimates) have yet to be elaborated. Nevertheless, we believe that the general progress in historical seismological research is such that this topic will be seen as a research problem to be solved in the future.

We have tried to identify chronological sections where we can place building traditions and the character of the Italian housing landscape and which can implicitly be traced back to historical sources regarding earthquakes. We do not intend to highlight true breaks in history: on the contrary, we have tried to disclose the coexistence of different characters which joined older existing frameworks, showing reluctance to change certain types of construction, survival or very slow transformation, even in very different economic contexts. As we did for population, we have attempted to highlight some aspects of historical building which appeared to be more problematic for the evaluation of seismic effects.

Given the ancient character of the Italian habitational tradition and its importance through time, a brief explanation of the original elements of this building civilisation might be useful.

3.1. *Building and living in the ancient world*

The Roman building heritage is so far the best known of the ancient world. Thanks to recent important research carried out by Adam (1986, 1988, 1989b), the observational workshop set up in Pompeii (Maiuri, 1942; de Vos, 1982), and the recent interest of archaeology in the minor and ordinary buildings of suburban areas, we can outline the distinctive characteristics of this type of building and look at them in relation to the seismic effects.

Adam (1989a) observes that a close analysis of Roman building shows that although Roman builders had not invented everything about their art, they had the intelligence and opportunity not only to learn from local architectural techniques and customs, but also to select and improve them. The Romans drew their knowledge from Etruscan and Greek building techniques, and even from the most artless builders of Southern Latium. The most convincing examples of this surprising syncretism are linked to the two most exemplary techniques of Roman architecture: the barrel vault and the masonry.

It was by perfecting these two techniques and systematically applying them that the Romans gave a new impulse to architecture. The accessibility of this new art of constructing not only accelerated and encouraged the construction of public monuments, but also allowed more modest private buildings to have access to a new type of architecture; by using the same techniques they often had a final appearance similar to those of more luxury homes. But Roman building was not limited to these technical innovations alone.

It is known that Vitruvius' «De Architectura» mentions diverse building techniques for foundations and superstructures: besides the *opus testaceum* (the most frequently used technique in Rome) he recorded early historical techniques used by the inhabitants of ancient Italy, such as *opus latericium*: unbaked clay and straw bricks with a wooden core; and *opus incertum*: a bed of mortar into which irregular prismatic stones were placed (see also Marta, 1991).

Vitruvius, more interested in the large-scale monumental buildings, dedicated little attention to these poor-quality techniques and only mentioned the unbaked clay incidentally as the bonding agent used for foundations and superstructures. Archaeologists interested in Roman history have so far paid little attention to these elements, being more interested in important monumental and public building. However, it is in these highly perishable conditions, where materials such as stone, pebbles, earth, unbaked clay and wood were used, that minor building reveals its first archaeological testimonies in rural and urban settings.

The importance of the early historical building tradition continued to be a decisive factor even at the height of the Roman age. The tendency of earlier building techniques to persist perhaps prevented poor builders of ancient times from positively evaluating the effects of applying new techniques and materials on the duration and resistance of buildings. In ancient times there was probably some resistance towards using building techniques other than those codified by local tradition dating back centuries, even when they proved to be perishable, like adobe. Even in more recent times this cultural element may be seen in economically peripheral areas. Perhaps low economic vitality or economic levels of pure subsistence contribute to determining this picture. There still are no quantitative evaluations which allow us to have a more precise idea of the most common building typologies in various areas (Santoro Bianchi, 1995). According to Adam (1989a), to get an idea of the «innovations» introduced by the Romans to the former building panorama, we should look at Pompeii which has inspired most current knowledge.

Unlike those projects that allow us to note the considerable differences between luxurious houses and more modest dwellings by just looking at the plans, the building techniques at Pompeii do not differ, whether it be the noble *domus* or the most humble of shops. This, according to Adam, is perhaps the most democratic aspect of Roman civilisation: good quality architecture spread throughout the urban population on a large scale. Pompeiian builders had a particularly vast variety of building stone at their disposal (hard lava, porous lava, some types of tufa, white calcareous rock, marbles and bricks which had formerly been used as finishing material and which were widely used after the earthquake of 62 A.D.). Adam (1989b) wonders whether the choice of the Pompeiians to build with square hewn stones depended on their desire to achieve strength and visual attractiveness or rather maximum stability in the face of seismic risk. He believes that these preoccupations were probably all valid without it being possible to perceive a well-determined preference. What is certain is that the seismicity of Campania was known and that builders had probably had the opportunity to see for themselves that large blocks of *opus quadratum* resisted earthquake tremors much better than clay walls. The damage caused by the 62 A.D. earthquake shows that there was extensive damage to the walls, and that on the whole, the calcareous rock and tufa façades had resisted well. If this quality building technique was later abandoned in private dwellings, this was for practical and economic reasons rather than for technical ones.

Not by chance, the revolution in masonry techniques in Italy coincided with the end of the great campaigns of conquest of the second century B.C.: the wars against the Carthaginians (the Second and Third Punic Wars), the wars for supremacy in the Aegean (the victories of 197, 190 and 146 B.C.) and the war against Spain (victory at Numantia in 133 B.C.) fed the slave trade, supplying a great abundance of slave labour, which could be used for simple systematic building work.

The materials used to clad masonry surfaces were not shapeless stones or *opus incertum*, but regular stones with a squared surface and laid in 45° inclined arris-wise courses as in Rome. This layout provided a better interlocking as the edges were created by using courses of saw-tooth bricks or rectangular stones. In its initial, still irregular shape, this type of surface is known as *opus quasi-reticulatum*, later to become the elegant *opus reticulatum* of Augustan times which remained in use until 79 A.D.

The use of bricks, much earlier in Campania than in Rome, was to be seen for the first time in Pompeii at the end of the second century B.C. However, until 62 A.D. (the year of the earthquake, see this catalogue) the brick was used as an additional element along with stones to form *opus mixtum* which was used to finish off different types of masonry: in corners, or to level off horizontal surfaces. After 62 A.D., public monuments and private houses frequently employed great quantities of *opus mixtum* with almost industrial regularity and with extreme rapidity, to cover façades or to reinforce structures which had been damaged by the earthquake of that year.

In Rome, on the other hand, minor civil building appears to be of inferior quality. In this city, where most of the buildings were made of wood, the greatest threat was fire. Ulpiano (Dig. 1.15.2) records that fires broke out in Rome almost every day. Roman houses often collapsed even without earthquakes, as often proved by sources. This was due to static problems caused either by the inadequate construction of low class buildings or their state of dilapidation (Molin and Guidoboni, 1989). In the third century B.C. three-storey buildings were already very widespread in Rome and with the coming of the first imperial age houses reached such heights as to require the intervention of Augustus (Strabo 5.3.7). In fact, the emperor regulated private buildings by forbidding a construction higher than 70 feet (about 21 m). Despite this prohibition, a century later, Trajan was forced to renew and further limit the Augustan provisions, lowering the maximum height of buildings to 60 feet (about 18 m). Speculative building in Rome was widespread: the use of low cost materials and the maximum exploitation of the surface area led to the construction of buildings with a strong vertical trend, and created highly precarious accommodation (Carcopino, 1978). Juvenal (about 60-130 A.D.) describes Rome as almost hanging, leaning on «rafters as long and thin as flutes» and he adds «we live in a city which is almost entirely held up by slender props, the only remedy the administrators have for crumbling walls. And when they have filled up the gashes of the old cracks, they expect us to sleep peacefully under the threat of imminent collapse» (Juv. 3.190). There are a number of sources that clearly highlight the instability of many housing structures in ancient Rome. Evaluation of seismic events should take into account this particular urban context, although such sophisticated instruments of evaluation have yet to be developed.

3.2. *The different origins of the construction culture in Northern and Southern Italy*

Italy in the early Middle Ages is documented from the points of view both of written sources and archaeology. Thanks to careful historiographical work and medieval archaeology, now expert in building techniques, we now know the different building areas and the building elements that characterise Italian housing. It is worth mentioning here that due to the need to preserve still existent buildings the most thoroughly investigated period is the late Middle Ages.

It was halfway through the sixth century with the Lombard invasion that two distinct building areas began to take shape in Italy: *Longobardia* and *Romania* (territories which were subjected first to the Lombards and then to the Franks) and Byzantine territories. In Longobardia scattered rural settlements, organised into large farms prevailed: they were mostly made of wood, or even of other poor materials such as reeds, straw and dry clay. The building methods reflected the need to exploit locally available materials as much as possible: in large forest areas a lot of wood was used, just as roughly hewn local stone was used in the inner areas of the Apennines.

The widespread use of wood, which was more marked during the Lombard period than during the Roman period, had the advantage that it did not require skilled manual labour, since most peasants were also expert carpenters. Galetti (1989) observes that wood could in fact be the sole material to construct an entire building. Wooden poles were either placed directly on the ground, on a low wall or on planks and were vertically or horizontally joined. Or wood was used to construct the skeleton of the walls made of dry clay, or of clay and straw or of small stones. Written sources reveal that wood was also used as a roof covering (*scandolae*). These buildings were practical and popular because they could be dismantled and then reassembled elsewhere when the farming contract expired (similar houses can still be seen in some Alpine areas of Italy) (Galetti, 1985).

The cities in the Lombard areas had to a large extent lost their role as power centres capable of influencing the surrounding territory.

Humble houses built of wood and other poor quality materials stood alongside public, civil and religious buildings, which were still built with more solid materials such as stone that was often recycled from ancient buildings which acted as on-the-spot quarries (Cagiano de Azevedo, 1974; Ward-Perkins, 1984).

Central and Southern Italy was mainly under Byzantine influence, although scattered with important Frankish territories. There are different distinctive building techniques in urban and rural environments.

The rural environment was characterised by clusters of villages, made up of single-storey houses with roofs made of wooden planks (in the countryside the vertical development began only in the twelfth century, Toubert, 1973). The house walls were built with clay, or pebbles and clay, or brick fragments and mortar. Sometimes houses were built in this way right up to the main roof beam, and sometimes as far as the small wooden joists which formed the ceiling of the ground floor; the remainder was made of wood. Wood mixed with quality reused material was used in town housing. These elements have been uncovered during excavations in the inhabited urban areas of modern towns. Buildings made entirely out of wood, with walls made of wooden planks and horizontal beams, and with a straw roof covering can be found from the ninth to twelfth centuries in the Po valley (Brogiolo and Breda, 1985). However the element that most characterises the Italian countryside during these centuries is the castle, not built from new as in the north, but an addition to pre-existing settlements (Settia, 1979; Galetti, 1989). The peculiarity of this type of settlement, almost always built on high ground above the plains, on rocks, clay banks or schists, is still a characteristic of the inhabited Italian countryside.

In Central and Southern Italy, there was a greater use of reused bricks, especially in the lower parts of buildings, while the upper parts were made of tufa, a material which was lighter and present in large quantities. In areas lying in both Byzantine (later in fact becoming autonomous) and Lombard territories, there was an interesting coexistence of different materials and building practices, due to different economies and labour systems.

A common characteristic of building construction in early Middle Age towns was, however, the widespread use of cast-off material and early historical technology.

The problem with evaluating seismic effects does not only concern the quantitative and qualitative limits of sources, but also the little available knowledge on settlement characteristics, village networks, the territory as a whole as well as economic levels and lifestyles. Indeed, historical information is often concentrated around big cities, which are cultural centres and seats of political and territorial power. Only the monasteries have in some way shifted the traditional point of view through their *scriptoria* which recorded the most important contemporary events in chronicles and annals, leaving evidence of events involving territories beyond the urban context, that is villages and small isolated towns. These different territorial «points of view» have a determining influence on our current knowledge of the seismicity of the past.

3.3. *Urban and rural building*

As from the thirteenth century, with the tumultuous development of cities, alongside the consistent growth in population and the increased density of habitation, there was a further decline in safety levels as regards earthquakes. One of the elements emerging from this process of increased risk is the general use of increasingly heavy building materials. An additional feature was a marked vertical development of buildings, initially constructed in additional storeys made of wood, which were then stabilised by the use of heavy materials. Different chronological phases characterise many buildings in the same urban centre and traces of this situation can still be seen today in many smaller towns in Italy.

It may seem strange to say that this phase of greater urban development brought about a widespread decline in the standard of living conditions, with less safety, but the observations regarding this matter appear to reach the same conclusion. While the growth of Italian cities produced a new culture of trade and innovative economic forms, this growth also heightened the seismic risk, exposing a larger number of inhabitants and a building heritage with altered characteristics. The numerous highly destructive earthquakes witnessed during these centuries are probably related to this new tendency (see this catalogue).

An idea of the building of non-urban settlements has been gained from the study of the rural house in Italy carried out by the National Research Council between the Fifties and Eighties (see the research by Barbieri and Gambi, 1970 and references therein). Due to the different approaches to the subject by the different research groups, this research has produced a vast series of regional monographs that have outlined some general features of historical building.

Knowledge of rural building techniques significantly helps to outline the historical seismic scenarios, because the places affected by the most extensive damage are, for the most part, small towns or small rural settlements. In the larger towns, the building techniques (materials, geometry) and the urban characteristics (urban size, layout, the way buildings were grouped together) are the result of a more complex and differentiated urban and economic history.

4. Construction elements of the damage: some evidence

The descriptive outlines of seismic effects referred to in the different degrees of the MCS scale, and seismic scales in general, are far from being obvious during a practical application. This is due to different reasons: on the one hand there is the complexity and the variability of buildings, on the other hand the clarity of the descriptions in historical sources, conditioned by the author's point of view and the cultural language in a broad sense (administrative, narrative, naturalistic, etc.). The extent of the damage does not only depend on the materials employed and the way in which they have been put together to create a wall structure. It is also subject to other important elements such as geometry, structural details and the grouping of the buildings. Unfortunately, these aspects remain to a certain extent unexplored or are not considered by seismic scales.

4.1. *Geometry and structural complexity*

The geometry and complexity of a building and the way in which it is grouped with other buildings and therefore the grouping of the settlement as a whole, have contributed to creating a vast variety of settlement shapes, from the «courtyard» buildings of the plains to the hill towns of the Apennines. The great geometrical varieties and the ways in which buildings are grouped together have played an important role in creating seismic scenarios. In the case of towns clustered around a hill top, it is not rare – and indeed it is reported in sources – for the buildings at the top of the town to collapse onto those in the lower part, bringing about much more serious total damage than that directly caused by the earthquake. On the contrary, rural houses built on the plains over a large surface area, structured around a «courtyard», provided ample space between one building unit and another, favouring a type of expansion of the settlement and consequently less interaction between different buildings in the case of an earthquake.

4.2. *Vertical structures: walls*

The vertical structures of buildings are made up of load-bearing walls with a thickness varying from 10 cm for the poorest quality brick walls to 90 cm and more for non-residential defence structures. Wall structures, the way in which building materials are organised within a wall framework, may vary greatly, ranging from the superimposition of stone materials of different shapes and sizes without bonding material, to the wall made of squared stones or bricks well bonded with good mortar. Furthermore, there are mixed wall structures, particularly in humble urban buildings, with courses of pebbles intercalated with levelling bands made of bricks (see fig. 4).

Traditional vertical structures, built mainly to support their own weight as well as the weight of the roof, and at the most to resist wind action

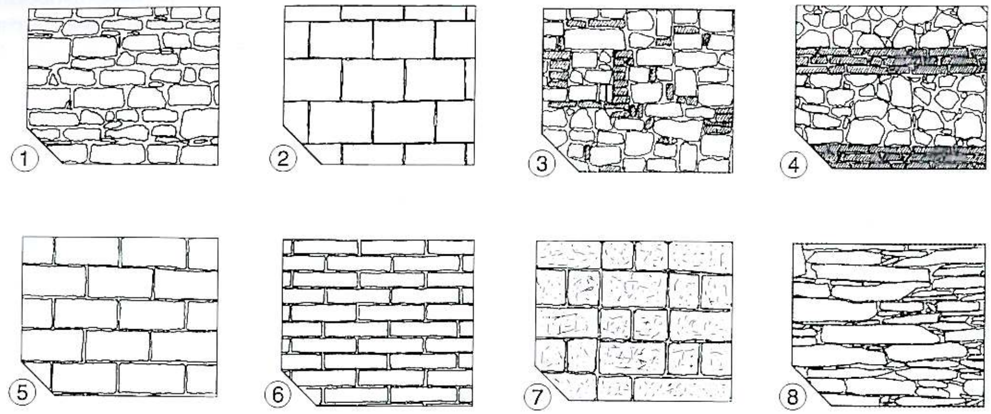


Fig. 4. Some typologies of building equipment of the Italian historical buildings. Stone materials: 1) in sub-horizontal strings and parallel, with divided ashlars with or without wedges; 2) in parallel and horizontal strings with ashlars; 3) irregular, in scaled blocks, with or without wedges. Various material: 4) in sub-horizontal strings, with ashlars or blocks and wedges; 5) strings of regularization with ashlars or blocks. Brick materials: 6) ribbed (in folio); 7) filleted. Earthy materials: 8) clay and straw blocks (elaborated by Parenti, 1988).

(the only horizontal force «in the project»), are particularly vulnerable to seismic effects when they have not been bonded horizontally, near the ceilings, with cordons of reinforced cement or tie-beams.

Over the past centuries, interior walls (whose sole function was to separate the various living quarters) were mostly constructed in poor-quality materials and building methods: brick-on-edge courses, reeds and plaster, wood, etc. The disintegration and collapse of these interior walls, which could even be caused by modest shocks, is sometimes reported by historical sources without specifying that these were dividing walls, or mentioning that the building was unfit for general use. Particularly detailed research is often necessary, though not always possible, in order to check these aspects. If the contextual information regarding building typology is not considered with enough attention, the intensity degree may risk being hugely overestimated. Even the relationship between the height and basic dimensions of the building, and the shape and depth of the foundations are important factors in determining seismic damage, but difficult to evaluate in relation to seismic scales.

4.3. *Horizontal structures: roofs and ceilings*

The shape, size, weight, materials and bonding materials used in horizontal structures (roofs and ceilings) have a great influence on the level of seismic damage to a building.

Historical sources and direct experience have often brought to light cases where buildings seen from the outside either seem intact or appear to have suffered limited damage, while on the inside the horizontal structures have collapsed, causing the death of the inhabitants.

Roofs and ceilings make different contributions to the extent of the damage and for this reason require different building measures. In general, they need to be horizontally bonded to prevent the seismic oscillations of the vertical structures of the building from causing the ceiling and roof trusses to collapse. Furthermore, following an earthquake, the so-called «pitched» roofs with their tilt can cause the load-bearing walls to lean outwards, and in some cases, collapse. There is also a great variety of roof shapes: double pitched roofs, found in most of Central and Northern Italy and in the Apennines; dome-shaped roofs or flat roofs typical of the Mediterranean building cultures.

The materials used for the roof structure and covering are other important elements determining the seismic damage. Very different roof-covering materials are used in Italy: ranging from the lightweight wooden roofing tiles used for mountain buildings (and also for Medieval constructions, mentioned before), over the roof tiles used for most brick buildings and also in large towns, to the heavy slabs of sandstone, slate, or schist used in Alpine and Apennine areas.

4.4. *Chimney stacks*

Chimney stacks often form a considerable part of damage to horizontal structures. Macroseismic scales make direct and highly specific reference to chimney stacks to classify effects of degrees VI and VII. The section of the flue extending above the roof can be distinguished in two categories, characterising size and importance when estimating damage: chimney stacks for internal flues and those for external flues. The former vary in shape, size and weight,

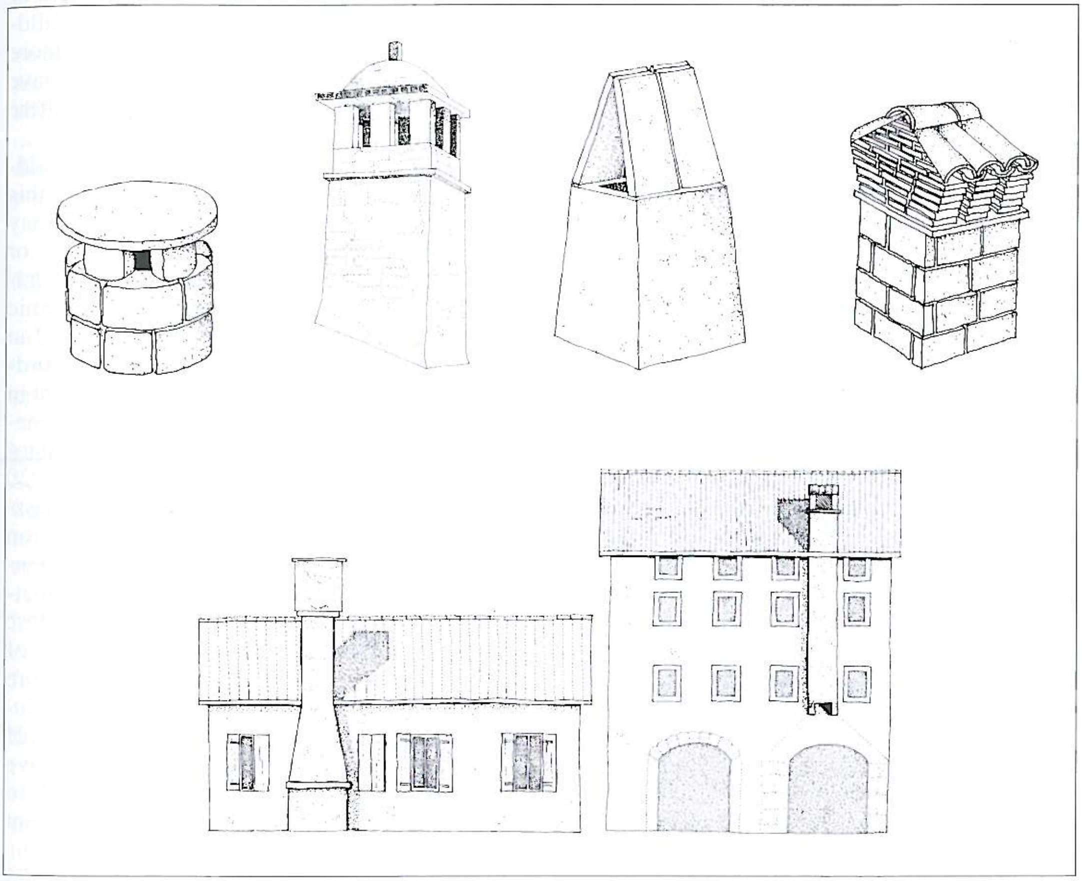


Fig. 5. MCS-degree VII indicates amongst other effects the fall of chimneys. As can be deduced from some examples reported here, its meaning may differ considerably: from the fall of almost leaning slabs, to the collapse of parts of the walls and the roof, in the case of big outer chimneys, typical for the Venetian and Eastern Emilian area.

but are generally small and have therefore a modest impact on the seismic damage to a building. Chimney stacks for external flues (typical, for example, of the Veneto region and the area around Ferrara) are generally large in size and rise in some cases even several metres above the roof. If they fall they can cause even the partial or total collapse of the roof below. When describing these collapses, historical sources often show a certain emphasis in defining roads littered with rubble due to the collapse of these chimneys (fig. 5).

Other building elements also deserve particular mention for their influence on seismic damage. These include doors and windows and their relative lintels or vaults, wooden or iron tie beams and truss rods, whose presence or absence can considerably influence the seismic response of a building.

5. Marginal historical endurance in seismic areas: some observations on the minor building panorama

From a geographical point of view, Italy is the country with the greatest variety of landscapes in relation to distance. This means that within restricted areas there are great differences in geomorphology and surface geology. It may be said that construction features have become consolidated historically and spread through a close relationship with the territory, the economy and local cultures. Over time shapes, materials, sizes and the way in which buildings are grouped together have determined a great variety of building types, true local languages. This variety of contexts demonstrates the complexity with which seismic effects are distributed within a settlement.

According to the experts, the extent of seismic damage is mainly governed by the poor quality of the materials employed, badly executed building elements and details, asymmetrical buildings, the grouping together of the buildings, and so on: elements that can be found in nearly all building types. However, building materials and the state of preservation play a particularly important role in «constructing» a seismic disaster.

It can be said that the static function of the stone, brick or clay constructions in the mountains or along the coast, in urban centres or in the countryside, depends on load-bearing walls of variable sizes. However, building materials change radically according to the characteristics of the surrounding territory, thus directly influencing the quality of the building. Very often, the user of seismic catalogues is not given a full view of the considerable variety of building situations in relation to a certain historical seismic scenario. In an attempt to highlight some aspects of this subject, and without of course claiming to be systematic, we have indicated some elements of historical building (many of which are still present in the contemporary building panorama) which were certainly much more widespread in the past. These elements have interacted with other typologies, for which there is a lack of quantitative research.

The quality and state of conservation of buildings is generally linked to economic levels: this relationship is not a determining factor but may be taken as a general trend that can increase or decrease the qualitative level of a building complex. If we compare the stages of economic development in Italy to those of other European countries (Rostow, 1978), we see that, according to economists, the industrial development in Italy only began in the last decade of the nineteenth century. It is acknowledged that technological maturity was established between 1920 and 1940, but the period of widespread mass-consumption only began in 1950. This situation is historically similar to that of Japan (to mention a highly seismic country), but differs greatly from the situation in the United States. These elements, indicators of the standard of living, of a greater need for housing safety and of a more complex urban culture, have had a strong influence on the quality of the reconstruction of buildings after a strong earthquake, and have also generally created different responses to earthquakes from a social and institutional point of view.

The rate of development of the *per capita* product in Italy from 1861 to 1970 (Rostow, 1978) shows that even during the stage of general economic consolidation there were periods of considerable economic decline. During these fluctuations it is reasonable to suppose that less qualitative consideration was given to building property, particularly during maintenance or renovation (see the 1931-1934 and 1935-1939 periods).

More attention to building techniques and greater awareness of their contribution to the various types of seismic damage might perhaps encourage a more complete use of historical seismic information. This might include the direct use of the type of damage, or the creation of scales of intensity which are more flexible in relation to the descriptive content of historical sources from different epochs and historical contexts.

The following observations indicate the presence of particular building types in seismic areas, whose endurance may have had a considerable role in seismic effects. These elements are not always referred to in sources, even when direct, and may instead be reconstructed through parallel research.

5.1. *Brick, stone, adobe brick: area and superimposition*

As is known, the brick house is part of a proper construction culture in Italy; it is both very ancient and widespread and represents the best known and most studied type of building. Scattered throughout the flat areas or concentrated in the populous villages of the plains, the brick house is also a distinctive historical feature of the mid-hillside landscape, from the small village to the city. It is obviously found in less hilly areas, where the earth can be worked more easily and where at least some flat land can be found.

Buildings in stone are also very widespread throughout Italy. This is a noble construction type, generally synonymous with ancient building quality, found from the mountains to the mid-hillside. The use of stone generally determines simple structures, shapes and grouping systems (Rodolico, 1953). The low resistance of stone to traction and thus also to flexion often means that the weight of the above wall has to be prevented from resting directly on the lintel, especially if this has a considerable span; stratagems such as relieving arches or even simpler devices such as triangular elements are therefore used to deviate very heavy loads.

The elements used in stone buildings do not require particularly specialised techniques: the stone buildings typical of mountain areas, in Central Italy for example, were made from local material. Where there were no major quarries because of the required size and capacity for quarrying and the value of the material, there were usually smaller excavations near the towns and the products were almost exclusively used for local requirements.

The peasants themselves collected or quarried the stones and lay them without any particular assistance; the stone was either squared using simple tools or left completely coarse. The stones were then selected: the best (the most even and square) were used in crucial areas such as corners and jambs, lintels and hearths, while less regular elements were used for the walls. In the Central-Northern Apennines, for example, stone was mainly used to form the wall structure. The different ways of working the stones produced different types of surface and construction systems: the most widely used method was the cavity wall and less frequently the even-structured solid wall. Cavity walls were formed by two stone walls with an inner cavity filled with various materials, pebbles, earth, stone and brick rubble. The outer wall of the building was very rarely plastered, while the inner wall was nearly always plastered with lime and sand. The surfaces had a more or less even masonry structure, according to the shape of the elements used and the finish of the building elements.

It is worth mentioning however that, alongside these «quality» materials, even in the same town buildings could be found with different types of surface structures:

– Unworked stones and pebbles of different sizes held together by a large quantity of mortar (particularly in isolated houses on rises).

– Very roughly hewn stones of different sizes.

– Unevenly squared and different-sized stones.

– Stones squared into the same shape and size (usually for the most prestigious buildings).

While the use of mixed masonry, stones and pebbles (sometimes with bricks) is even today typical of isolated houses on mid-hillsides, the use of dry masonry is typical of temporary mountain shelters (shepherds' houses) or annexed buildings, enclosures, stores, etc.

5.2. *The adobe brick house in Italy*

Perhaps less known is the adobe brick building, still found in some areas of Central Italy and obviously much more widespread in the past. Found in farming settlements on marginal ground or justified by particular contracts on the management of the land, this type of building is an indicator of a somewhat archaic village economy.

Could the presence of raw clay in seismic areas of Italy have influenced the overall picture of the effects drawn today from historical sources? This question is doubly interesting since on the one hand, these houses are considered the worst as regards seismic response (class A in the MSK scale, in the 1964, 1976 and 1981 versions and in the recent revision of the European Macroseismic Scale edited by Grünthal, 1998); on the other hand they were proposed as anti-seismic constructions after the 1915 earthquake and as a rapid and economic system for rebuilding the hit areas (see the 1915 earthquake in Avezzano in the CD-ROM).

There are no accurate statistics regarding this type of building through time in the various parts of Italy. We are therefore dealing with this problem in interlocutory terms, offering just a few elements to throw some light on this aspect of historical building, which we believe could have interacted in the past with the effects of earthquakes, along with other numerous known elements.

In areas where materials such as stone and wood were scarce and therefore had to be transported from a distance, and bricks required processing and firing in kilns and thus were not economical, there was nothing left but earth with which to build low-cost housing in a short time.

The numerous clay houses still found today in the Abruzzi region date back to the early nineteenth century, when a large labouring class was formed. The use of clay to build houses often reflects the need for a construction built with limited family resources, usually located in an isolated position. The drawbacks of this type of housing, such as damp, annual maintenance, a brief life span (often around 50 or 60 years) have gradually led to its abandonment in favour of more long-lasting and wholesome buildings. However, there is no doubt that this type of building was very common in many areas of Central and Southern Italy.

The clay was usually reinforced with dry straw. This material reacted in two ways: on the one hand it acted as a rigid structure to increase the resistance of the material, and on the other, it offered protection, though only partially, from damage due to water leaking through, as the vegetable fibres encouraged the evaporation of excessive water thereby limiting the effects on the clay. An inconvenience of the use of vegetable materials that cannot be overlooked is the risk of rot and parasites.

The shape and size of clay houses remains more or less regular. They normally extend lengthways and are built up along the shorter side (the distance between the walls is about 4 and a half meters to easily support the standard size of the trusses used for ceilings and roofs). While, due to technical requirements, the shape tends not to change, the various areas of the house can be constructed in different ways.

The roof covering of adobe brick houses was generally made by the same building technique used for stone and brick houses. The roof was almost always double pitched and the timber roof trussed construction was clad with bent tiles. Different structures were used between the trussing and the bent tiles. A grille made of reeds covered with earth was mainly used, and this sometimes included an additional layer of straw. It was occasionally built in fired bricks, sometimes decorated with simple designs. A substantial and very visible difference between adobe brick houses and other stone or brick houses was the larger overhang of the eaves, protecting the walls from the great damage caused by rain water.

An additional storey required intermediate load-bearing ceilings, normally made using the same technique as for the roof covering. Horizontal structures, such as ceilings and the frame of the roof covering, were generally constructed from natural materials such as wood, reeds and straw, used together with brick elements or alone. Adobe brick houses were found where the use of timber was very limited, either because of building traditions or because locally there were no large woods.

Ceilings were generally formed from a structure made of large trusses (usually roughly hewn trunks of oak or chestnut) which were inserted into the masonry. A second series of rafters with a smaller section rested on this structure. The floor was made out of flat hollow terracotta bricks or wooden planks which were placed directly on this double structure. The second structure was often made from a reed grille embedded in plaster or clay. The actual flooring was laid on this structure (masonry was occasionally reinforced using a cage made of reeds or wooden poles embedded in plaster which also contained stones and rubble).

Whatever technique was used to build the walls, the foundations were similar. According to ancient tradition, a continuous furrow was first dug (ranging between 50/60 cm in depth and width) around the entire perimeter of the house. The drainage system was then formed with a layer of bricks or crushed stones about 30 cm deep and a layer of clay on top.

A mixture of earth, shredded straw, water and finely crushed stone was fairly widely used by Abruzzi peasants to build their low-cost houses in open countryside. The mixture of earth was shaped in moulds or simply hewn into clods and laid by the peasant according to procedures handed down through generations. The «hoe» technique was the simplest: a piece of the mixture was detached using a hoe and was then handled and rolled until it took on a more even shape. These blocks were laid without being dried first, one on top of the other in layers, with each layer left to dry for five or six days. Then one applied another layer on top, taking care to wet the layer beneath so as to bond the two together. The masonry surfaces were then smoothed over with a spade.

The mixture used to build the walls directly over the foundations was prepared in a specially dug pit or within the perimeter of the building. In the first case the pit was small and the peasant worked the mixture with a spade until it reached the right consistency. In the second case, oxen were made to walk over and over the mixture while water and other elements were added until the right consistency was reached. The adobe brick house was very common in Central Italy, Calabria and Sicily.

6. Underground dwellings, isolated houses and temporary homes

Much of the Mediterranean area, southern and insular Italy has a considerable historical heritage of villages built within tufa, sandstone or limestone rises, which can still be seen today. These settlements were founded in very ancient times and have often been in such constant use that modern housing has been built on top and literally rests on these extraordinary «warrens» dug out through time. Today these rock dwellings have a gradual and double-sided fragility. One is their own chemical-environmental condition that causes the structure to deteriorate. The other is induced by the subsequent increase in vulnerability of the housing built above.

Besides the artistic quality of some of these buildings and their valuable testimony of very ancient settlement cultures, we would like to consider them from the point of view of seismic effects. Rock dwellings cannot be considered indicators of seismic effects: indeed, historical sources do not give data regarding these dwellings and, if they were to mention them, they would not provide the information about seismic damage required by macroseismic scales. Underground dwellings therefore remain in a grey area, where no seismic effects are known to us.

Their existence is little known and rarely reported by sources. During his on-site survey to study the effects of the 1857 earthquake in Basilicata, Robert Mallet observed that some inhabitants of Iscalonga, in the Doria-Pamphilj feud, wearing pelts (it was winter), lived in underground caves and passages which could only be located if smoke came out of an opening at ground level, indicating that there was a room underneath. This area was identified as unknown ground on the cartography by Rizzi-Zannoni. Less than one and a half century separates us from this description which is hard to include in the historical contexts reported by many seismic scenarios, reconstructed through written sources. Even so, material culture reveals to us traits of dwelling civilisations which have been present over many centuries and about which we know very little today.

These are not the only problems for the evaluation of the seismic effects: a very common circumstance, in all areas of Italy from north to south, was the isolated house and temporary homes, built on arable land or near pastures. In some cases the phenomenon is so widespread that it is a problem; for example, when the isolated houses are so common that they prevent the evaluation of seismic effects over a fairly large area. This is the case of the Acese area where the slopes of Etna were cultivated using this type of settlement. The peasants mainly lived in villages, but inhabited isolated houses on a seasonal basis. These houses were roughly repaired by the owners to keep the costs as low as possible. The 1818, 1865, 1879, 1889, 1894, 1911, 1914 earthquakes (see in the CD-ROM) feature this type of situation.

Collapsed buildings are recorded by sources in a general and summary manner and have no accurate or macroseismic classification for three reasons:

– They cannot be clearly localised.

– The damage to a single building is not foreseen by the MCS macroseismic scale.

– It is impossible to apply the conventional scale (A, B, C, D, E; see in more detail Ferrari and Guidoboni, 2000, this volume) that we have drawn up to evaluate the damage to single structures, since there are no elements of comparison with specialist architectural types.

The change in settlement situations and the settlement network itself may mean that more developed settlements are found today in these «grey areas». We would therefore like to point out that it is important to bear in mind the whole context for indications of seismic hazard on the basis of data over the long term.

7. Towards a «carefully considered» relationship between the evaluation of seismic effects and settlement characteristics

In our opinion, the elements we have summarised here reveal the importance of opening up the research to specific multidisciplinary contributions, for a more accurate definition of the historical variables that influence the evaluation of seismic effects. New quantitative elements could perhaps encourage the formation of a macroseismic scale that takes into account the peculiar settlement cultures distinguishing the different areas, and that better evaluates the response of the buildings to seismic disasters, not only in Italy but also in other Mediterranean countries. We feel that, at present, the margin of uncertainty in the cases described here is rather high and that it requires drastic simplification. The use of the EMS98 scale for historical earthquakes, often called for, could perhaps actually be applied if the data regarding historical building were approached organically and according to area and epoch, instead of through abstract construction types.

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