L’AQUILA REGION MASONRY WORKS

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ABSTRACT

This paper presents the results of a study on masonry works’ quality carried out for L’Aquila city region, which was hit by the 2009 earthquake. In the aftermath of the earthquake many data were collected concerning the textures of a large number of masonry samples belonging to both monumental and ordinary buildings with different levels of damage. Making a preliminary systematic screening aimed at identifying significant occurrences and therefore permitting the choice of representative types of local construction techniques, several samples were analyzed, according to a methodology essentially referred to Antonino Giuffrè. In this way an interpretative framework of the technique of "making the wall" in L’Aquila architecture has been reconstructed, permitting, conversely, to highlight the inherent weaknesses and those due to the transformations that have influenced seismic response. The identification of the most common wall types, the analysis of their mechanical quality and the recognition of their associated positive and negative features constitutes a complex knowledge that proves to be a basic tool both for subsequent specialist in-situ and laboratory investigations (destructive and non destructive) and for defining appropriate intervention criteria for the reconstruction, restoration and repair of earthquake damaged buildings.

Keywords: Masonry work, Earthquake, Historical construction, Preservation, Seismic damage

1. INTRODUCTION

1.1. Reasons of the work

The earthquake does not strike randomly historical masonry buildings but selects, so to speak, only the poorest (or improperly modified) constructive situations, severely damaging them or even making them collapse, while well-designed and properly maintained buildings are not so heavily damaged that they can not be repaired. The "selection" made by the earthquake is a crucial information with a view to rebuilding what has collapsed and restoring what was damaged, because in the first case it can allow not repeating the mistakes that caused the disaster, in the second case it can suggest how to improve what has been revealed ineffective.

Unfortunately the reasons of a bad seismic behaviour neither are immediately recognizable nor can be easily bordered and, on the contrary, the overall structural response is determined by a wide range of factors which act some in the sense of resistance and others in the sense of vulnerability. Such a complexity has often led, especially for severe seismic damage scenarios, and in the impossibility of assessing the relative importance of different factors, to formulate unduly penalizing judgments about whole constructive contexts.

The objective of this work fits and is justified within this conceptual framework. Among the many aspects that may have contributed to the articulated, often dramatic, damage scenarios occurred during the 2009 L’Aquila earthquake, the only masonry work quality is examined in detail, in order to rationally define and circumscribe the role it actually played. This seems indeed necessary because the extent and severity of damages have encouraged many researchers to express strongly critical opinions about L’Aquila masonry technique, improperly interpreting as defects constructive peculiarities (not sufficiently known) and, thus, implicitly inducing the belief that the reconstruction and restoration will require the introduction of significant changes in traditional construction methods.

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This paper does not want to make the opposite mistake, saying in advance that collapsed masonry walls can be simply rebuild as they were, nor to suggest, at this stage, any constructive improvements. It just intends to provide a sufficiently broad knowledge support from which the problem of analysing the damages suffered by L’Aquila masonry works can be properly formulated and the question whether the walls can be kept as they are or what are the improving interventions they need can be answered.

1.2. Methodological references
The reference methodology of the work comes from the studies of Antonino Giuffre [1, 2]. This methodology consists of the following steps: (i) a preliminary screening is systematically carried out on a quite large number of historical centres, examining both ordinary and monumental buildings; (ii) significant recurrences in the local construction technique are identified and a sufficiently extended set of masonry types is selected; (iii) these types are then examined by comparison with the general requirements of the masonry “rule of art” (as codified in the nineteenth-century treatises [3, 4]) to which, following Giuffré, an explicit mechanical finalization is recognised. The preliminary results obtained by the application of this methodology to L’Aquila region masonry works appear to be encouraging: in fact, although with significant differences with respect to the classic rule of art, L’Aquila building technique allows obtaining comparable mechanical results.

2. STUDY AREA

2.1. Damages in masonry buildings caused by 2009 L’Aquila earthquake
The area most heavily struck by the 2009 seismic sequence extends for over 30 km along the axis of the Apennine chain involving several historical centres located both in the Aterno valley and on the slopes surrounding it.
This region is characterized by an important seismic history with a succession of numerous strong earthquakes for which documentations are available from about 1300. The earthquakes of 1461 and 1703 are rather similar to the recent one, as far as the recorded effects are concerned, while other minor events have however influenced the construction history of the centres located in the study area. The awareness of the repetitiveness of seismic events drove local builders to define, with the available materials, an explicitly anti-seismic constructive technique whose main features are recognizable as persistent characters of the area. Other common characters are typical of all centuries-old historical centres: the habit of re-using individual elements (stones, wooden beams) deriving from the collapse or disassembly of existing buildings, and that of modifying buildings (damaged or not) incorporating them into a new architectural arrangement (Fig. 1). The on field observations performed after the 2009 earthquake, with the aim of analysing local masonry technique for ordinary buildings (expressly excluding monumental ones) and formulating a mechanical judgement on their effectiveness, have been extended to a significant number of centres, including those most damaged, and have been performed in different periods.

Fig. 1 Examples of re-use of elements (left) and transformations that incorporate previous arrangements (right)

A preliminary set of inspections was carried out in the period April-August 2009. After selecting a restricted number of centres, a second set of surveys was conducted in autumn 2009 and spring 2010.
examining masonry walls with more detail and suggesting the first comparisons. In summer 2010 an eighteenth century palace, located in L’Aquila centre and deriving from the union of existing medieval and Renaissance houses, was surveyed studying several masonry samples certainly belonging to different epochs. Further surveys are currently in progress for another historical centre of the same area [5-7].

2.2. **Features of L’Aquila building technique**

Although the analysis presented in this paper is limited to masonry walls, it seems essential to situate it in the broader context of L’Aquila region construction technique, even if only briefly outlined, because such a comparison may help to highlight the characterizing features of local masonry work, emphasizing its effectiveness and/or precariousness, regardless of the countless other factors which may influence seismic behaviour of historical buildings [8]. In this regard, two aspects are worth underlining.

The most important fact, already previously mentioned, is the long earthquake tradition of the region which emerges from different circumstances: (i) the traces of damages caused by past earthquakes clearly recognizable in many historical buildings and entire towns (defects of verticality in walls, presence of re-use elements, etc.); (ii) the frequency of anti-seismic devices by means of which these damages have been repaired (buttresses, metal tie-rods, etc.) and of significantly transformed buildings after particularly violent earthquakes (witnessed, for example, by wall thickenings); (iii) and, finally, the explicit anti-seismic finalization of the whole L’Aquila construction technique which, after the disastrous 1703 earthquake, introduced and systematically applied, perhaps for the first time in the history of construction, a coherent set of technical solutions with the declared intention of increasing the earthquake resistance of traditional masonry constructions – from wooden “radiciamenti” (that run through the entire masonry structure, providing a system of connections much more effective than that offered by traditional metallic tie-rods) to the use of a “light” technology for particularly vulnerable building elements, such as balconies and ledges (Fig. 2).

But it is equally significant the progressive abandonment of traditional seismic foresight, witnessed by the decreasing regularity with which the rules developed after 1703 are successively applied and the undue extension of some of those rules whose outcome is the introduction of new forms of precariousness (e.g. the poor quality of wall thickenings, considered as mere aesthetic rather than structural devices, or the use of thin vaults on the upper levels of buildings). This process reaches its devastating fulfilment in recent times, in the second half of the twentieth century, with the massive spread of interventions completely indifferent to their negative effects on the seismic behaviour (e.g. the replacement of the original wooden or vaulted floors with concrete slabs), applied with the same ease to both ordinary and monumental buildings (the “restoration” performed on the church of S. Pietro di Coppito by Moretti in 1970 is emblematic [9]).

It is worth outlining that such considerations are essential to properly understand the influence of masonry works on the seismic behaviour of historical buildings: as a matter of fact, it would sound rather strange that a construction technique so refined from the viewpoint of seismic resistance could have blatantly disregarded the care of the most important structural element of the masonry building, i.e. the masonry wall – as it should be equally clear that even the best walls are not good enough to resist earthquake if a correct assembly of all structural elements is lacking.

![Fig. 2 Examples of different connection devices in L’Aquila region historical centres (wooden “radiciamenti” and metallic tie-rods) usually recognizable from the typology of external anchorages](image)
2.3. Study cases
This paragraph is devoted to briefly present some of the study cases on which more detailed analyses were performed. These are four historical centres and an eighteenth-century palace in L’Aquila.

2.3.1. Casentino
Before the earthquake, Casentino (municipality of Sant'Eusanio Forconese) was characterized by a generally poor state of conservation (mostly due to lack of maintenance caused by neglect) and at the same time by the sporadic presence of alterations due to recent re-use interventions. The damages have been severe, with partial or total collapses limited to a few units. The significant presence of walls without plaster and of limited collapses allowed observing in detail both masonry surfaces and transverse sections for the whole urban centre and made possible the choice of several masonry samples to survey (Fig. 3).

Fig. 3 Map of the masonry work samples analysed in Casentino

2.3.2. Ardinghelli palace
The analysis of the walls of Ardinghelli palace was performed in the framework of the preliminary phase of the reconstruction and restoration design of the building aimed at its seismic improvement. A detailed survey of 20 masonry samples, different for stone’s dimension and masonry work, has been performed and the results have been compared with those obtained by in situ investigations (such as sonic and flat jack tests) aimed at defining the mechanical parameters required by Italian code.

2.3.3. Villa Sant'Angelo
Villa Sant'Angelo is one of the historical centres more strongly affected by 2009 earthquake, with a 60% of collapsed buildings and an 80% of heavily damaged buildings. In such a situation, the analysis of masonry quality – and of the role it played in determining the occurred damages – appears to be fundamental in order to correctly define the reconstruction strategies. The whole historical centre has been carefully examined and about 30 masonry samples surveyed (the study was facilitated by the huge amount of damages that allowed observing inner parts of masonry walls).

2.3.4. Tussillo
Tussillo is characterised by an articulated damage scenario, with huge collapses only in a limited portion of the centre. As already observed for Casentino, the damage levels are strictly related both to the state of conservation and to the degree of transformation before the earthquake. The study of masonry works has been extended to about 10 samples, whose survey has allowed defining the transverse section of the walls, not in view.

2.3.5. Fossa
With respect to the other centres, Fossa is characterised by a significantly high building quality and, not by chance, the damage level is much less important (although in this regard, propitious site effects could have played an important role).
The study of masonry work is, currently, at a preliminary stage: about 40 samples have been collected and these will be compared in order to identify general families and successively thoroughly analyse them (Fig. 4).
3. ANALYSIS OF MASONRY WORKS

An illustration – not exhaustive but already significant of the different situations that have been surveyed – can be obtained from two of the cases presented in the previous section and related respectively to a palace (Ardinghelli palace) and a small centre (Villa Sant'Angelo). The masonry samples analysed in the two cases are localized in the maps of Figures 5 and 6: they are approximately 30 samples in the first case, and about 20 in the second one.

![Ardinghelli palace in L'Aquila: map of the surveyed masonry samples](image)

![Villa Sant'Angelo centre: map of the surveyed masonry samples](image)
3.1. Ardinghelli palace
Two typical situations have been recognized in Ardinghelli palace, both characterized by a maximum size of the stone elements of about 25-30 cm. The first is related to masonry works made of elements of almost similar size, disposed on regular layers and with well recognizable horizontal alignments (Fig. 7); the second is instead related to masonry works made of elements of different size and whose horizontal alignments are therefore not only less clear but also never coinciding with individual stone layers. Both types of masonry allows realising walls characterized by a different degree of transverse compactness, depending on the size of the available stone elements, on the overall thickness of the walls and on the manner in which inner stones are disposed (Fig. 8): these may in fact be located astride of the stone elements that realize, on a same layer, the two opposite surfaces of the wall, so as to "tighten" the elements themselves and ensure a sufficient transverse interlocking, even in the absence of a direct overlap (although partial) of the surface elements.

![Fig. 7 Ardinghelli palace: different stone arrangement in walls’ surface](image1)

![Fig. 8 Ardinghelli palace: analysis of wall section by removal some stone elements](image2)

3.2. Villa Sant'Angelo
Different situations can be recognised in Villa Sant'Angelo too, with respect to the stones dimension, compared with wall thicknesses, and to the foresight used in ensuring the transverse compactness. A first situation relates to masonry works with a certain number of elements of great size (i.e. elements whose maximum dimension is at least longer than half the wall thickness): this type of masonry allows easily to obtain a good transverse interlocking (Fig. 9 and Fig. 10a), but several cases have been observed in which the connection between stones disposed on opposite wall surfaces is absent or dramatically low (Fig. 10b). Other situations are more similar to those found in Ardinghelli palace and are related to masonry works made of average size stones with which an adequate transverse compactness can be however achieved by means of a proper arrangement of the elements, as already reported in the previous section (Fig. 11).

![Fig. 9 Villa Sant'Angelo: good arrangement of wall texture and presence of wooden chaining system](image3)
4. COMPARISONS AND FIRST REMARKS

The performed surveys suggest some preliminary remarks that, although requiring to be confirmed on a greater number of samples, nonetheless identify a trend that we think should not be completely subverted by the availability of more numerous data. Only a limited number of masonry works seems to be reportable to the classical interpretative framework set by the masonry “rule of art”, as it is delivered in the late nineteenth century treatises. In fact, since most walls are made of small size stone elements (if compared with the wall thickness) it is obviously impossible to fulfil some important requirements of the rule of art, especially the one which requires to connect the masonry (especially, but not only, along the wall thickness) by means of a sufficient number of large stones (“diatoni” and “ortostati”, according Vitruve’s definition). However, masonry works made with small and medium size stones cannot be simply defined as not respectful of the rule of art; it is more correct to say that they respect a rule somewhat different from the classical one but whose mechanical intent is the same – and can be always summarized in the wish of ensuring the transverse compactness and the horizontal layering of the walls. There is no doubt that this is a much more complex (and difficult to fulfil) rule, because the available material is “poor”, but in the same way it is more difficult to realize a rough stones wall than a squared stones one. Let us summarize this rule.

The stone elements are disposed in regular horizontal layers, using for the entire thickness of the wall, and for the different layers, stones of the same size and being careful (as far as allowed by the elements dimension) to overlap the stones belonging to superimposed layers (staggering them) as well as to interlock the stones belonging to a same layer (alternating the orientation, with respect to the wall plane, of the major dimension of surface elements: “diatoni” and “ortostati”). The interstices between the stones are filled with smaller stones and mortar and in the same way the joints on the wall surface are well filled too. Little stone elements are also used to retrieve the horizontality of the layers, when the masonry is made of stone element of different heights.
In these cases, the horizontality of the masonry work is recovered only after a certain number of layers and, although this circumstance leads to a less regular apparatus (with respect to the case in which all the stones have comparable size), nonetheless it demonstrates the presence of a constructive rule scrupulously respected.

It is worth explicitly noting that this kind of masonry work is very different from the so-called “sacco” masonry (characterised by a poor inner infill made of roughly laid small stones) which has often been invoked in the aftermath of the 2009 earthquake, pulling together in a single negative judgment most of the masonry works in the region of L’Aquila. The difference is just in the strict organization of the elements throughout the thickness of the walls, obtained by means of stones having the same size both in the surface and in the inner core of the wall itself.

In essence, the rule of art of L’Aquila region compensates the lack of a point transverse connection, such as that provided by “diatoni”, with a rigorous articulation of the masonry work in which the uniformity of stones size allows realizing a spread transverse connection, locally less effective with respect to the one due to concentrated “diatoni”, but at the same time broader and, therefore, probably, on average equivalent.

This last statement is, of course, at present, nothing but a working hypothesis: but the monolithic oscillations that these masonry works have been able to ensure in many cases (and that constitute an implicit judgment of mechanical quality) seem to suggest that it could not be completely arbitrary.

5. CONCLUSIONS

The observations that emerge from the on field surveys until now performed – and that are still in progress – are a crucial element of knowledge for the understanding of 2009 L’Aquila earthquake damages and, consequently, for the definition and calibration of consistent reconstruction and restoration strategies.

The mechanical quality that has been recognized in most of the masonry works examined suggests on the one hand to look elsewhere (site effects, incongruous transformations, material’s decay) for the reasons of often destructive seismic damage scenarios and, on the other hand demonstrates that the safe conservation of L’Aquila building technique can be rationally pursued.

The analysis must of course be deepened, however starting from detailed surveys of region masonry works and extending to other urban centres the mapping that in this paper has been presented with reference to a limited number of cases. Furthermore, to the experimental evidence lying in the observation of the monolithic behaviour exhibited by masonry walls during the last earthquake, it seems desirable to add other justifications of "mechanical quality" obtained by means of the usual tools of earthquake engineering, i.e. numerical and laboratory tests.

This is a study yet to plan but whose utility, in our opinion and on the basis of the preliminary results contained in this work, is indubitable.

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