



Damage Assessment and Reconstruction Planning in Poggio Picenze, following L'Aquila 2009 earthquake

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ABSTRACT

The April 6, 2009 earthquake caused extensive damage to the historical center of Poggio Picenze, a small village 15 km East of L'Aquila, where most of the buildings are made of local stones and are the result of centuries of incremental and often disorganized construction. This paper describes the ongoing experience of a group of researchers of the Universities of Chieti-Pescara. The research group is interdisciplinary and includes structural engineers, architects, city planners, conservation experts and geologists, and its main objectives are to define reference guidelines for the conservation, rehabilitation, and safety enhancement of the built environment. From the structural viewpoint, the focus is on two aspects, based on the results of the damage survey performed on many traditional masonry buildings and infrastructures: 1) development of guidelines for rehabilitation and reconstruction of buildings' aggregates (starting from an extensive survey on damage) and retrofitting of single buildings; 2) analysis of the implications of structural damage (e.g. collapse mechanisms) and retrofitting at the town scale, in the framework of a modern seismic-risk mitigation strategy that requires to allocate financial resources in such a way to guarantee at least a minimum urban structure (paths, roads, squares, etc.) after a major earthquake.

1 INTRODUCTION

Poggio Picenze, a village in the Abruzzi Apennines with about one thousand residents, is located at 760 meters above sea level. It is built on a South facing slope overlooking the impressive landscape of the L'Aquila valley, bounded by the Gran Sasso and Monti della Laga National Park to the North and by the Velino-Sirente Regional Park to the South. The mainshock of the April 6, 2009 L'Aquila earthquake) severely impacted the historical village centre, where seven casualties occurred, while the surrounding, new construction belt consisting mostly of reinforced concrete structures, suffered minor or no damage. Significant damage was also reported to the town Churches (among them the imposing Saint Felice Church) and in some older public buildings such

as the kindergarten and the elementary school, built between the two World Wars.

The present paper reports on the activities carried out in Poggio Picenze by a group of researchers of the University of Chieti-Pescara aimed at identifying guidelines for the reconstruction and requalification of the town historical centre.

Due to the inherent complexity of the task, a strongly interdisciplinary approach is being used, with the contribution of city planners, structural engineers, cultural heritage experts, architects, industrial designers, geologists.

1.1 The April 6, 2009 L'Aquila earthquake

The seismic event of April 6th 2009 confirms the high seismicity of the Abruzzi region, one of the highest of the Italian territory.

On April 6th 2009, 03:32:39 Italian hour, a strong earthquake measuring $M_w=6.3$ on the Moment magnitude scale struck the area around

L'Aquila, causing strong damage in Poggio Picenze, situated about 20 km from the epicentre. The peak ground acceleration (PGA) measured near the epicentre was up to 0.6 g, while the estimated PGA in Poggio Picenze is about 0.2 g on bedrock.

Past quake reconnaissance work shows the strongest damage in the NW-SE direction, according to the orientation of the seismogenic structure, i.e. the Paganica fault, with a relevant propagation toward SE and effects corresponding to the 9th degree in the MCS scale. For Poggio Picenze, the quake was estimated at 8.5 on the MCS scale.

2 SEISMIC EFFECTS IN POGGIO PICENZE

2.1 Seismic microzonation

In view of the reconstruction of the damaged areas, the Italian Civil Protection Department (DPC) has completed the seismic microzonation around L'Aquila.

Thematic maps developed from old and new data report homogeneous zones (microzones) from the seismic viewpoint (Fig. 1), classified according to three categories: stable zones, stable zones subject to local amplification effects, potentially unstable zones.

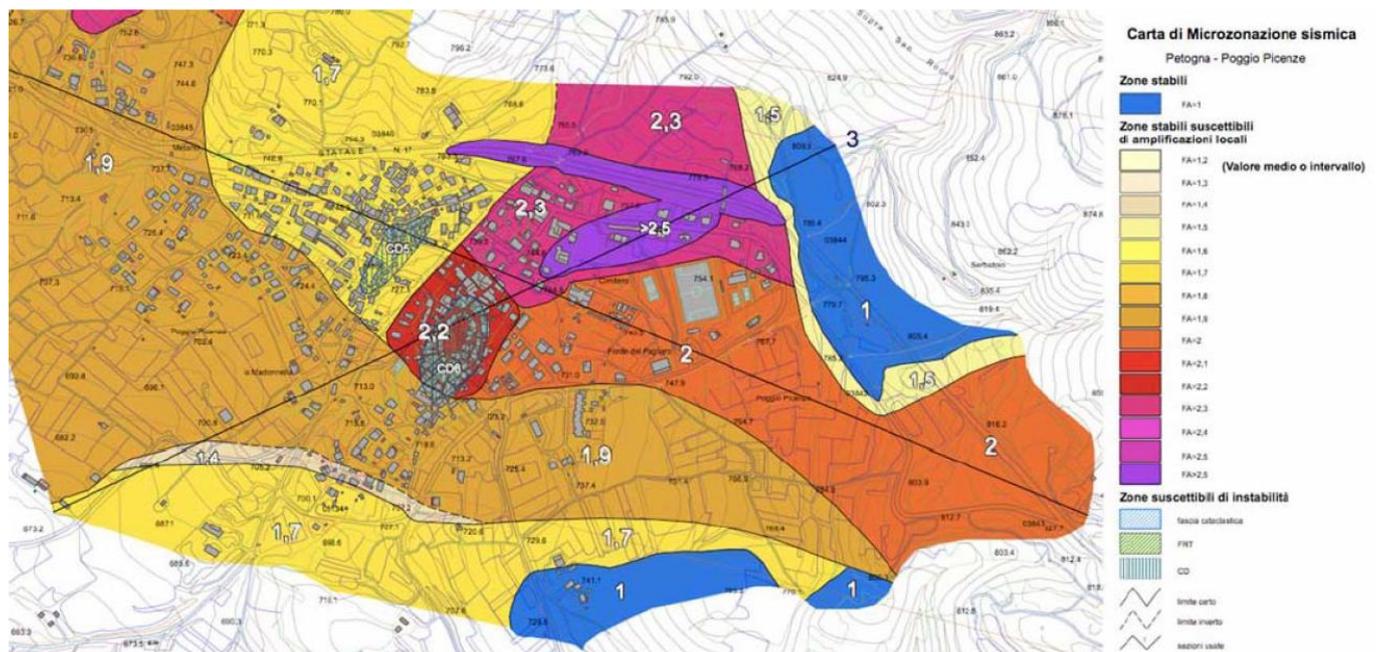


Figure 1. Microzonation map of the Poggio Picenze area (level 3) (Dipartimento della Protezione Civile, DPC)



Figure 2. Close-up of the results of the past-earthquake damage survey in Poggio Picenze

As shown in the map in Fig.1, the old (and central) part of Poggio Picenze can show significant local amplification effects due to the local geology; further seismic amplification is also possible due to topographical effects.

2.2 Damage survey

After the mainshock (April 6th 2009), an extensive campaign of speedy survey took place in order to access the damage suffered by private and public structures. Structures were classified based on the damage level (from A, corresponding to no damage, to E, corresponding to extensive damage or collapse).

The results of this survey, carried out by hundreds of volunteers (civil engineers, architects, geologists) coordinated by the DPC, were reported on the map section of Poggio Picenze (Fig. 2). The red areas clearly show that the two village oldest cores of are almost completely inhabitable and for this reason the old historical center has been closed off.

Outside the historical centre, which mainly comprises isolated reinforced concrete (RC) buildings, little or no significant damage was reported. On the other hand, some of the old masonry buildings outside the centre of Poggio Picenze, such as the St. Felice Martire Church, or older RC buildings (such as the elementary school and the kindergarten) suffered significant damage too.

2.3 Characteristics of the built environment

The historical centre of Poggio Picenze consists of two distinct cores; one develops around the ruins of the so called “castle”, with streets that follow topographic contour lines. The other core develops along the main axis of the ancient Roman Street “Claudia Nova”, with transversal and parallel streets arranged as a sort of comb.

The dwellings are very simple manufactures, aimed at satisfying primary needs. The building criteria and typologies mainly depend on the locally available natural materials, such as stones and wood. These materials are widely found in the historical centre.

Studies carried out on these buildings have shown that the main characters of the old town are those of a building (and cultural) heritage that uses basic traditional models with a very wide variety of variations, according to the original

needs of the inhabitants and changes during the decades.

It is for instance easy to recognize buildings that were initially conceived as stables or warehouses for tools or agricultural products, and were then transformed into dwellings.

For each structural element, the basic materials and their physical and mechanical properties have been studied and surveyed, together with typical craftsmanship and construction practices. Degradation and damage scenarios due not only to the seismic event, but also to the lack of maintenance and use were also recorded.



Figure 3. Corner toppling

3 STRUCTURAL BEHAVIOUR

3.1 Collapse mechanisms of macroelements

The study of the traditional building technologies for masonry structures indicate, in the most seriously damaged buildings, the absence of the box behaviour today required. This derives from the lack of connections between orthogonal walls, between walls and floor slabs or between walls and roof system.

Without a box behaviour, the seismic vulnerability mainly depends on the out-of-plane collapse mechanisms of the resisting

macroelements – e.g. masonry external walls or portions of them – rather than on the in-plane excessive stress state in the masonry (e.g. Speranza, 2003).

The structural vulnerability is in such cases evaluated using data mainly related to the geometric configuration of the building macroelements, by means of the so called kinematic approach to the limit analysis of equilibrium. The approach basically consists of analysing all the possible collapse mechanisms of macroelements and then individuating, by means of limit conditions for each mechanism, the smallest multiplier of the reference horizontal forces that activate the out-of-plane mechanisms.

The following figures show some of the collapse (or damage) mechanisms observed in Poggio Picenze.

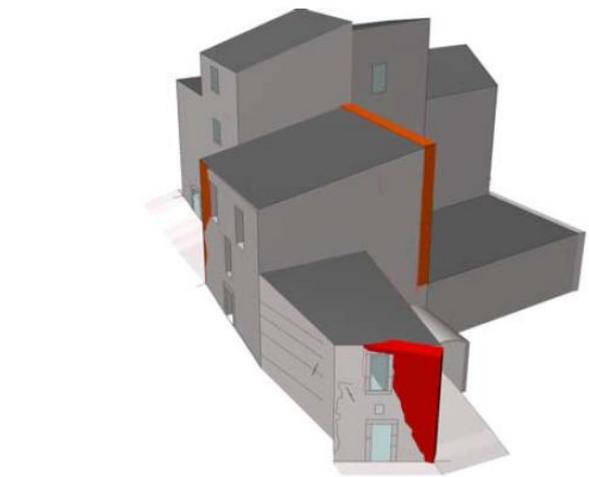


Figure 5. Partial toppling of an external wall



Figure 4. Vertical “bending” of a wall



Figure 6. Damage due to excessive shear stress

3.2 Collapse due to excessive in-plane stresses in the walls

When out of plane collapses of macroelements are avoided due to effective connections between walls (e.g steel chains or corner connections), the

strength of the buildings depends on the masonry strength. Figure 6 report typical cracks due to excessive shear stress, observed in P. Picenze.

3.3 Floor slabs and vaults

Damage to floor slabs and vaults was also frequently observed (samples in fig. 7.)



Figure 7. Damage due to floor slab and vault collapse



Figure 8. Historical center perimeter

3.4 Building aggregates

Historical centers are often made of interconnected, multilevel, masonry cells that share common walls. The structural behavior (namely, the analysis of the possible collapse mechanisms) must be evaluated considering the entire building aggregate (or simply *aggregate*, in the following), that can be defined as an assembly of structurally connected dwellings detached or isolated from other structures or aggregates.

The sketches in figures 3, 4, 5 show typical situations.

4 URBAN PLANNING FOR RECONSTRUCTION

Immediately after the earthquake, the local administration and the academic group working with it have started planning future activities. More specifically, the following items are judged central to the future of Poggio Picenze:

- rebuilding and reopening the old town, with possible changes in building destination (for example from private dwellings to economic activities);
- giving new life to old traditions and opening of new businesses;
- driving the rebirth of the town as part of a territorial plan based on the attractiveness of the surroundings, the current infrastructure, the existing economic activities and the relation between the different small towns and the main urban center, L'Aquila.

4.1 Historical center perimeter and building aggregate identification

The first concrete step toward reconstruction was the identification of the damaged historical center perimeter, as required by the reconstruction agency (or, in Italian, *Struttura Tecnica di Missione*).

This perimeter, reported in figure 8, clearly distinguishes the historical center where special rules need to be applied in order to assure a reconstruction process that respects the local building traditions and the pre-existing volumes. In the encircled area, in fact, the reconstruction cannot be performed at the scale of the single building or aggregate; according to recent guidelines for reconstruction, it has to be planned within a systemic approach, that should guarantee

a uniform quality and effectiveness of the strengthening and reconstruction actions from a structural, architectonic and town-planning point of view.

The next step, currently in progress, is the identification of the building aggregates that, as previously mentioned, can be defined as groups of dwellings belonging to different owners but connected from a structural standpoint.

4.2 Minimum Urban Structure

After the strong Italy (Irpina, 1980) earthquake in Southern Italy, city planners became aware that the mitigation of seismic effects cannot be guaranteed by reinforcing single building only. The problem has to be faced at the urban level, because a city is not simply the summation of buildings, but it works as a network of interconnected elements that include streets, electric power-lines, squares, aggregates, etc.

On the other hand, seismic risk can never be completely avoided, and therefore a community, particularly when dealing with an old, historical city center, must agree on the risk level it is willing to accept. A key factor is also represented by the financial resources that can be allocated to this specific task. The acceptable risk level is a dynamic parameter, that should be (and indeed is) periodically revised.

For given earthquake characteristics and intensity, on the other hand, buildings are more or less vulnerable depending on their aggregation (see Sect. 3.4), that in Italy is typically the result of continuous evolution growth and transformation of the urban texture.

An effective policy for reducing seismic vulnerability should consider and compare alternative assumptions of urban planning or urban transformation, without necessarily sticking to a faithful reconstruction of the pre-earthquake urban layout.

The first step is to clearly identify the functions and places or buildings that must be given priority in case of strong earthquake, such as hospitals, fire stations, town halls, schools, commercial areas and buildings with high occupancy. In a systemic approach, however, roadways and assembly areas, such as squares, must be kept functioning after a major earthquake. Closure of such communication infrastructure does not only hamper emergency



Figure 10. First draft of the minimum urban structure of Poggio Pienze

The dwellings of Poggio Pienze are characterized by very simple constructions that use basic traditional models with a wide range of variations, according to the original needs of the inhabitants and the changes during the centuries. The building criteria and typologies mainly depend on the locally available natural materials, such as stones, wood and sometimes straw.

For each structural element, basic materials and their physical and mechanical properties were surveyed and studied, together with typical craftsmanship and construction practices (fig.11).

Degradation and damage scenarios due not only to the seismic event, but also to the lack of maintenance and use were also recorded.

The main churches and monumental buildings were surveyed from the historical and structural point of view.

The Church of San Felice Martire (Fig. 12), built around the first half of the 15th century, was rebuilt and enlarged after the 1762 earthquake, with the same floor plan consisting of three naves separated by columns.

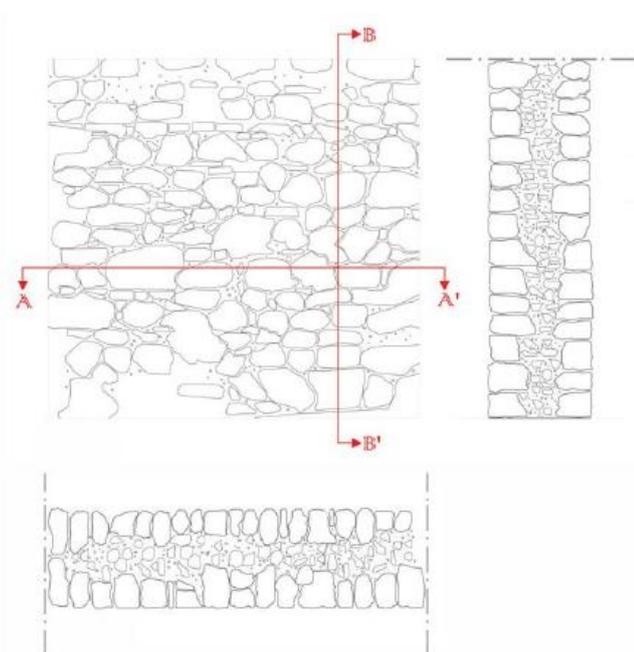


Figure 11. Example of irregular masonry wall



Figure 12. The Church of San Felice Martire

The facade in rubble stone was erected in 1924, after the 1915 earthquake. The

strengthening works of the bell tower, on the left side of the facade, date back to the same years.

The observed damage typologies include: toppling of the main façade (made of white limestone) and the consequent damage to several decorative elements; the expulsion of stones along the West side of the church; the breaking of the East side of the transept as a consequence of pounding.

The inner part of the church, decorated according to the baroque style, shows many deep cracks in correspondence of the barrel vault of the apse and the rubble stone walls of the side naves. Collapses were also observed in the dome and in the vaults (fig. 13) of the main and of the lateral naves.

Toppling was also observed of some of the walls of the bell tower, with expulsion of stones.



Figure 13. The Church of San Felice Martire

Palazzo Galeota (named after the Galeota family that has owned it for generations) is a massive building worth mentioning (Sepe *et al.*, 2010; Baldassarri *et al.*, 2010). It shows diffused damage both in the walls and in the roof, and has been heavily buttressed.

The so-called Medioeval House (fig. 14) is also worth mentioning: it is characterised by its distinctive mullioned window with two lights and ogive portal.

From the technological point of view, the historical buildings are mainly characterized by irregular masonry of natural stones, sometimes with the inclusion of bricks or even roof tiles (Fig. 11). At the lower building levels, masonry vaults are usually found, with a very elementary geometry (barrel vaults), while wooden floor slabs are more frequent in the upper levels.

Following past earthquake damage, several historical buildings have been periodically strengthened with traditional protection devices, such as wooden and more recently steel ties, that certainly limited damage due to the recent 2009 earthquake.

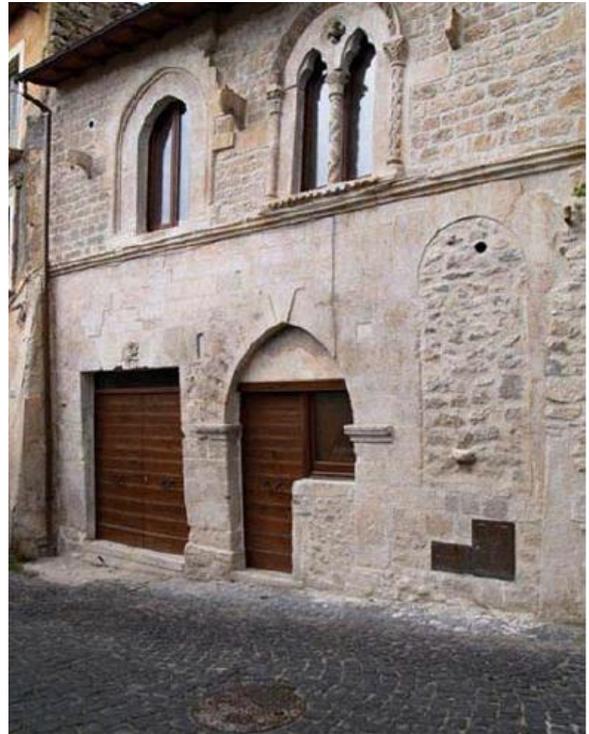


Figure 14. Medioeval House

The in-depth damage survey campaign that followed the April 6, 2009 earthquake has shown that without the above traditional, often non-engineered protection devices between masonry walls or wall corner strengthening, damage in Poggio Picenze would have been even more severe. Collapse mechanisms in Poggio Picenze were often due to rigid displacements (e.g. overturning, see Sect. 3.1) involving masonry macroelements (Sepe *et al.*, 2010), which can be prevented or delayed by simple and quick strengthening. Furthermore, the poor quality of the local masonry walls do not justify extensive and expensive retrofitting. One more constraint that needs to be taken into account when strengthening a historical building is the need to preserve historical characteristics and overall look. A softer approach may guarantee the connection between orthogonal walls by adding steel ties. This can lead to a more favourable "box behaviour". In some cases, the retrofitting of a historical building may also be used as an opportunity to eliminate recent, non-original additions (such as the plastering of an old façade) to bring the building back to a more original look.

Finally, some techniques commonly used in concrete buildings, may be downright dangerous, such as the substitution of a light wooden floor slab with a heavy RC slab. Many examples have shown that a heavier roof or floor slab may simply add mass and increase the seismic forces on the structure.

Another challenge is represented by the geology of the site. Preliminary microzonation analyses have shown large local amplification factors, and the existence of man-made caves under the city center, probably used as source of the building materials during the original building construction. There are examples of cave collapse following the 2009 earthquake, pointing to the need to further study the geology of the city center.

These and other typical situations are now being reported and explained in the guidelines for reconstruction, one of the main tasks the research group faces in the next months.

5 CONCLUDING REMARKS

The work performed to date by the interdisciplinary research group has gathered a large amount of data and has produced significant results both from the practical and the teaching point of view.

From the practical viewpoint, the research group supported the Municipality in the individuation of the boundary line (perimeter) encircling the town historical center, where the reconstruction cannot be performed at the scale of the single building or aggregate but, according to a recent Government Decree, has to be planned within a global approach.

This should guarantee a uniform quality and effectiveness of the strengthening and reconstruction actions from a structural, architectonic and town-planning point of view. At the same time, preserving the cultural and material identity of the place, or at least of its historical center, through this global approach, should allow a requalification of the village from

the touristic point of view, not unlike other small towns of the Abruzzi region, known world-wide for its natural beauties and mountain traditions.

Only the first steps have been taken in this direction, and additional, long lasting efforts are required – and indeed already planned – to complete the task.

Hopefully, this will change the disastrous earthquake of April 6th 2009 in a opportunity for making the Poggio Picenze territory safer.

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