THE HISTORICAL CENTRE OF POGGIO PICENZE AFTER L’AQUILA EARTHQUAKE: BEHAVIOUR AND STRENGTHENING OF MASONRY AGGREGATE WALLS

Formisano Antonio¹, Fonti Roberta², Mazzolani Federico M.³

ABSTRACT

Poggio Picenze (Abruzzi region, Italy) was one of the most damaged small towns during L’Aquila earthquake. In particular, its historical centre was strongly hit by this catastrophic event due to different seismic vulnerabilities which have been investigated and discussed in the current paper. In the framework of this activity some case studies were carefully chosen and examined in relation to several chief features, such as soil, exposure and masonry setting.

The main aim of the study was to both identify and assess old masonry morphological characteristics, by comparing them with literature references, aiming at both fully understanding their response and implementing an effective and sustainable strategy of retrofitting interventions. Detected masonry features made difficult the damage analysis and the subsequent consolidation approaches to be used. In fact, no ordinary setting, small size stones having irregular shape and assembled with large parts of mortar, no regular flatten stone alignment and no transversal connection elements were recognised.

After that, different masonry failures due to three main seismic vulnerabilities of buildings placed in the Poggio Picenze were illustrated. After the identification of these collapses, the singular weak elements of damaged block masonry units were exhaustively identified and analysed with the final aim to design a useful retrofitting intervention.

Keywords: Historical centres, Building aggregates, Masonry apparatus, Headers, Roof maintenance and state

1. INTRODUCTION

The urban tissue of Poggio Picenze is composed of old masonry constructions, which represent the major part of the built-up. They were erected in aggregate condition following two different joint methods: the oldest constructions are placed around the peak of the hill, following the territory topography, whereas the youngest ones are located on both sides of the main street (See Fig 1). As a consequence, the wide spread housing typology is a construction composed by two differ levels in sequence overlapping a basement. This scheme, which is helpful for drop overcoming, is really vulnerable towards seismic actions, with often produce out-of-plane collapse mechanisms (see Fig. 2).

¹ Department of Structural Engineering, University of Naples “Federico II”, antoform@unina.it
² Department of Structural Engineering, University of Naples “Federico II”, roberta.fonti@unina.it
³ Department of Structural Engineering, University of Naples “Federico II”, fmm@unina.it
2. THE SEISMIC VULNERABILITIES

2.1. Generality
With reference to the Poggio Picenze built-up like representative case of the constructive practice of the Abruzzo towns, three primary seismic vulnerabilities have been detected:

– the ground response;
– structural alteration and maintenance, with particular attention to roof changing in terms of both geometrical scheme and materials;
– masonry apparatus.

In this paper the last two vulnerabilities have been considered and discussed.

2.2. Static problems: roof alteration and maintenance
After the earthquake it was noticed that constructions often failed due to either lack in maintenance of roofs or change of the coverage layers. In particular, information deriving from the knowledge of the original roof configuration showed that timber ties are generally hooked up by anchors to top panels outside (Fig. 3).
This valuable roof scheme was often replaced by dissimilar coverings, no effective during earthquake. As a consequence, four different roof conditions were noticed within the investigated city, they being classified into the following four categories:

A) Original roof scheme with no maintenance operations. Loosing of the original static capacity.
B) Roof structural configuration change. Materials and pitches slope are similar to the existing ones but different engineering details (absence of anchors) are noticed.
C) Roof alteration with material variation.
D) Roof pitch slope changing or roof scheme totally divergent from the original one.

These roof typologies are shown in Figures from 4 to 7, where a case study representative of each of the four categories is illustrated.
2.3. The masonry apparatus

The collapse mechanism derived from alteration of the original roof scheme (category D) is directly related to the masonry apparatus quality. In L’Aquila area the main masonry typologies are subdivided in two categories [2]:

1) The first masonry type is widespread within L’Aquila city and no in the neighborhood. The constructive scheme is based on stones having small size and irregular shape and assembled with no ordinary setting. As a direct consequence, total absence of headers is noticed and lack among either stones or within thickness mortar joints can be pointed out. Sometimes the stone irregularity is filled up by wedges elements. Regular flatten made in bricks and stretcher elements are present. This masonry type, which experienced a local mechanism under form of out-of-plane rigid block behaviour, is shown in Figure 8.
2) The second type is instead typical of the constructions within towns surrounding L’Aquila. This masonry apparatus is based on small size stones with no transversal section links, no stretcher elements, no bricks layers and no sufficient wedges elements (see Fig. 9). Therefore, due to the above lacks, a failure of the wall external layers occurs because of buckling phenomena.

![Figure 9](image1.png) **Fig. 9** A masonry panel detected in L’Aquila surrounding area and a second category masonry sample (1m x 1m) (b)

The masonry constructions of the urban tissue of Poggio Picenze match the second category (see Fig. 9); this mind that no rigid block behaviour can be expected during earthquake. In Figure 10 the failure due to buckling phenomena of the portion of a masonry panel not restrained by tie beams is shown.

![Figure 10](image2.png) **Fig. 10** Masonry failure due to the wrong assembling of masonry stones.

So, the illustrated deficiencies must be eliminated in order to guarantee a better seismic behaviour of the study masonry walls. Nevertheless, the better strengthening approach detection is really difficult. In order to define an effective and sustainable strategy of intervention, strictly connected to this masonry typology, a destructive in-situ experimental campaign on full-scale structural walls belonging to an existing building was planned, it being conducted from the University of Naples “Federico II” in collaboration with the University of Reggio Calabria (coordinator Michele Candela), the University of Perugia (coordinator Antonio Borri) and the University of Genova (coordinator Sergio Lagomarsino) [3-6]. This experimental research project was developed with the collaboration of the Municipality of L’Aquila. The test campaign was directed both to the identification of L’Aquila masonry panel mechanical parameters and to the behavioural assessment of panels under both dynamic and static conditions. In particular, static tests were performed to recognise the masonry collapse behaviour (in plane failure or out-of-plane one). Instead, out-of-plane tests were carried out under both “displacement-control”, with the possibility to apply displacements having alternate directions, and “force-control”.

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3. A STRENGTHENING METHOD FOR MASONRY WALLS

3.1. The proposed idea
Starting from the identification of masonry panel failure due to two principal defects, that is absence of transversal connection elements (headers) and no contact among stones, the University of Naples designed a traditional reinforcement strategy based on both placement of timber headers within the masonry thickness and replacement of mortar joints with wedge elements. The starting point of the study was the analysis of the masonry setting and its comparison with the “rules of art” for masonry panels. Later on, the strengthening idea was born from Abruzzo local constructive practice for old masonry buildings, where timber elements were widespread employed for connections of masonry walls. Therefore, some timber headers were placed within the panel thickness in order to obtain the mechanical interlocks of the two panel layers. To this purpose, the masonry set-up reading was important since the difference between the two panel faces allowed to define a unusual headers setting scheme, which is schematically illustrated in Figure 11a. The executive phases of the strengthening method foresaw the panel drilling with 4 circular holes (diameter of 200 mm) along the whole panel thickness, the setting of wooden headers with the regular stress condition re-established by wooden wedge elements and the replacement of mortar joints with stone wedge elements (Fig. 11b and c).

![Placement scheme of timber headers within masonry panel](image)

Fig. 11 Placement scheme of timber headers within masonry panel (a), executive phases (b) and detail of both timber header and stone wedge elements (c)

3.2. The out-of-plane test
The panel, having width of 2.10 m, height of 4.00 m and depth of 0.60 m, was before cyclically tested by means of a hydraulic jack under “displacement-control”, with the possibility to produce displacements in alternate directions, and then pulled out with the same jack in the final test phase. The pushing action of the jack, placed at a height of 2.25 m, was applied to the panel through a rigid box steel beam anchored to it by steel bars. The test set-up was arranged to take advantage of panel position in the building scheme (Fig. 12).

![Details of the test set-up](image)

Fig. 12 Details of the test set-up

The data resulting from experimental test, referred to the hydraulic jack position, are reported in Table 1, where it is apparent that the maximum obtained force $F_{max}$ corresponding to a displacement of 0.22 m is 1469 daN. In the table the pushing force is the load applied to the panel at the jack level,
whereas $M_o$ is the overturning bending moment and $M_s$ is the stabilizing bending moment. The achieved results were then compared to other results obtained from experimental tests on different panels (without reinforcement, reinforced with concrete headers, reinforced with injections), which presented both dissimilar geometrical dimensions and disparate jack application height. To this purpose, the maximum forces, and therefore the pushing actions, attained by each panel was homogenised each other with reference to a 1.00 m large masonry portion (see Fig. 13).

**Table 1** Strengthened panel response compared to the rigid block behaviour

<table>
<thead>
<tr>
<th>$F_{\text{max}}$ (daN)</th>
<th>$F_{\text{homol}}$ (daN)</th>
<th>Pushing force (daN)</th>
<th>$M_o$ (daN*m)</th>
<th>$M_s$ (daN*m)</th>
<th>Efficiency compared to a rigid block response ($M_o/M_s$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1469</td>
<td>1653</td>
<td>787</td>
<td>1574</td>
<td>1570</td>
<td>1</td>
</tr>
</tbody>
</table>

**Fig. 13** Comparison among strengthened masonry panels

By comparing the behaviour of the panel without reinforcement (Table 2) with the one strengthened by means of timber headers, it is possible to notice that performed intervention produces improvement in masonry mechanical interlock which, together with the wedge elements influence, allows to attain a total force four times more than the one of the original panel (see Fig. 13). In particular, the presence of stone wedge elements produce a strength increase two times than the one of the panel reinforced with headers only.

**Table 2** Unreinforced panel response compared to the rigid block behaviour

<table>
<thead>
<tr>
<th>$F_{\text{max}}$ (daN)</th>
<th>$F_{\text{homol}}$ (daN)</th>
<th>Pushing force (daN)</th>
<th>$M_o$ (daN*m)</th>
<th>$M_s$ (daN*m)</th>
<th>Efficiency compared to a rigid block response ($M_o/M_s$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>176</td>
<td>277</td>
<td>166</td>
<td>290</td>
<td>1373</td>
<td>0.21</td>
</tr>
</tbody>
</table>
4. CONCLUSIONS

The performed study has allowed to individuate the seismic vulnerabilities affecting the behaviour of masonry constructions within the smallest historical centres in the district of L’Aquila. In particular, the modification of building roof in terms of both constitutive materials and pitch slope and number represents one of the main failure cause. In fact, especially due to the lack of timber anchor able to make the roof-top masonry panels connection, many roofs collapsed under the recent L’Aquila earthquake.

The occurred masonry wall failures has allowed to implement their strengthening strategies based on the use of both connections among masonry layers and stone wedge elements. These interventions are used to guarantee both vertical and horizontal mechanical interlocks of masonry according to the “rules of art”, which are not fulfilled in many cases. This means that for L’Aquila standard masonry there is a wall part, proportional to the gap noticed in the experimental response between the original panel and the strengthened one, that during earthquake cannot be used to resist bending moment. Consequently, the pushing action necessary for panel overturning is reduced, as confirmed by the results of the performed experimental activity.

As a result, the reinforcement intervention deleted the gap between L’Aquila strengthened masonry response and the theoretic one for rigid-block. This gives us the significant information that it is really possible to reinforce into an effective way the L’Aquila old construction masonry.

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