CASENTINO (AQ): A SEISMIC IMPROVEMENT PROJECT FOR MASONRY BUILDINGS

Caterina Carocci¹, Margherita Costa²

ABSTRACT

The paper illustrates the analysis carried out on an aggregate in Casentino (Sant'Eusanio Forconese Municipality, AQ) one of the historic centres of the Aterno Valley struck by the April 2009 Earthquake. The study begins with a speedy analysis on the whole urban centre, conducted with the explicit purpose of collecting data both on the characteristics of the architectural heritage and on seismic damage suffered by it. One of the results of preliminary analysis is the selection of a sample aggregate on the basis of: (i) constructive features that may be considered salient and recurrent in the entire urban fabric, (ii) recent or historical transformations, (iii) variety and severity of occurred damages. The study of the aggregate is directly aimed at identifying consistent criteria for seismic repair and improvement in a perspective that includes the preservation of the character and the original structural behaviour of the historical buildings. The results of the aggregate’s analysis constitute the basis for the subsequent generalization of both the recurrent problems and the resulting design criteria.

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

1. INTRODUCTION

The paper illustrates the analysis carried out on an aggregate in Casentino (Sant'Eusanio Forconese Municipality, AQ) one of the historic centres of the Aterno Valley struck by the April 2009 Earthquake. This area is characterized by a significant seismic history documented since XIV century, which allows collecting specific data on the impact of historical earthquakes on historical buildings. In the specific case of the historical centres located in Aterno Valley, many signs and traces of past earthquakes are evident on the urban fabric. The observation of these evidences assumes significance in the examination of the effects of the recent earthquake and contributes at the formulation of the aggregate’s pre-earthquake vulnerability condition [1].

The study begins with a speedy analysis on the whole Casentino centre. This analysis is conducted with the explicit purpose of collecting data both on the characteristics of the architectural heritage and on seismic damage suffered by it. The work was developed in several stages: data collection (through the implementation of field surveys and systematic observations), subsequent processing and comparisons. After the identification of aggregates in the urban fabric; later on each aggregate was taken as a single object of analysis. By the aggregates’ speedy survey comparative considerations were derived in terms of overall organization (layout and elevation), level of maintenance and transformation and damage. In addition, observations on the whole urban fabric concerning the local construction techniques, the presence of historical anti-seismic interventions and repairs related to past seismic events are carried out.

Based on the results of the preliminary analysis, the study on a sample aggregate started following three consecutive stages (knowledge, interpretation and design) on the basis of a research methodology used repeatedly for assessing the vulnerability of buildings in the aggregate with regard to the definition of the intervention criteria for mitigation of seismic vulnerability. This methodology, inspired by the assumptions of the researcher Antonino Giuffrè, is for the first time is here used in

¹ Assistant Professor, Università di Catania, c.carocci@unicat.it
² Architect, PRIN 2008 research group member, Università di Catania, marghe.costa1@gmail.com
a post earthquake context characterized by a high level of seismic damage [2, 3]. The study of the aggregate is directly aimed at identifying criteria for both repair and seismic improvement in a perspective that includes the preservation of the historical buildings.

2. ANALYSIS OF THE HISTORICAL CENTRE

The analysis carried out on the Casentino historical centre began with on field surveys which started already in the aftermath of the earthquake. Following a substantial preparatory work of data collection and mapping, on field surveying was conducted in August and October 2009. The work of data processing was realized during 2010. The historical centre of Casentino was sparsely inhabited and only in recent years the rehabilitation of some buildings as vacation houses started. A substantial part of the urban fabric was therefore occasionally used, unused or abandoned, resulting in low, if not absent, level of maintenance. In addition to the lack of maintenance, observation highlighted the presence of a wide range of transformation interventions some of which presumably played a negative role in respect of the seismic action.

2.1. On field survey and identification of aggregates and Architectural Units

The first operation carried out was to define the perimeter of the historic centre and preliminarily identify the aggregates to analyse. For each aggregate, a systematic observation and recording of a series of data, to the photographic documentation and to the subdivision in buildings (Architectural Units) was carried out (number of floors and internal courtyard, collapses, and crack patterns, presence of anti-seismic historical devices) (Fig. Na).

The results of the speedy analysis highlights some critical issues that must be resolved in the reconstruction phase, for example the identification of the aggregates taking into account the widespread presence of arches and built volumes overpassing the public streets: the choices made during speedy survey should be revised after a more attentive remarks on the degree of interaction due to the added volumes who currently connect together aggregates (Fig. 1b).

Fig. 1 (a) Aggregates and Architectural Units; (b) volume connecting street's opposite facades

2.2. Construction technique and damage

Collaterally to the analysis conducted on aggregates, specific analyses have been carried out concerning the local constructive technique and damage. These two issues were investigated by carrying out of specific observation campaigns conducted at the scale of the buildings (Architectural Units) proceeding where possible also to the observation of the interior of the houses.

The contemporary study of construction techniques and damage, together with information about the maintenance and transformation condition of buildings, is directly functional to the identification of the causes at the origin of a certain level of damage. The correlation of such information (even if coming from a speedy observation) allows for an evaluation of the vulnerability in the urban fabric before the 2009 earthquake; in this way it could be possible to verify the correspondence between expected damage and what the earthquake actually produced.
2.2.1. Local constructive technique

The analysis has investigated the constructive quality of the components of the buildings (masonry walls, roofs and horizontal structures) and their assemblies.

The masonry texture analysis, aimed at gathering information on the mechanical quality of the walls, was made following an extensive observation of external facades and sections (in case of collapse) and then selecting 12 samples to be analysed in more detail (Fig. 2a).

This analysis - carried out by the survey and compilation of a “board” – highlights a good presence of textures with large and medium size stone elements (in comparison with the thickness of the wall) located to make a good transversal connection; in some cases, however, the wall textures are made by the use of medium and small size elements.

In these cases, to expose a judgment about the quality of masonry texture, further studies are needed; these last were realized in too few cases so that any generalization is impossible [4, 5].

Masonry walls are systematically tied together by the use of tie rods; this type of connections can be observes both as “radiciamenti” (wooden elements placed during the construction of the wall in the middle of its thickness) and as metallic tie rods; all are identifiable from the outside for the presence of keys (Fig. 2b).

The first type is related to the a local anti-seismic construction technique came into use after the 1703 earthquake and the second one is related to a good practice for repairing the effects of subsequent earthquakes (the last in chronological order is the earthquake of 1915, the so-called “Avezzano Earthquake”).

Further data concerning the earthquake awareness in the local constructive technique is the common use to tie the upper part of the walls using the wooden structure as chains thus creating an effective constraint in the buildings' weakest area.

The other elements of the building in Casentino are: rough stone vaults (in most cases barrel vaults) systematically present in the ground level, while at the intermediate levels of the buildings wooden floors and brick vaults are the most spread structures.

Often the intermediate floor wooden structure was replaced with new ones (for example using metal beams and vaulted or flat brick elements) in some cases these transformations are related to repairs realised after the 1915 earthquake. In such cases often that replacement intervention is associated to the reconstruction of masonry wall portions identifiable by the presence of brick layers in the wall texture.

The repairs realised after historical earthquakes are spread in the whole urban fabric. These interventions are implemented as a repair or replacement of building elements (floors, roofs, masonry portions, etc.) or as additions of elements aimed to improve the capacity of the building (or the wall) to overcome a future earthquake without collapsing.

The most common are - in addition to tie rod – buttresses, increasing of wall's thickness and arches placed between external facades of front buildings to prevent their possible outside movement. These last structure were later on used to construct addition volumes of the buildings, so realising the peculiar overpassing volumes on the public streets (Fig. 2c).

Fig. 2 (a) Some of the masonry samples in Casentino; (b) metallic tie rod; (c) anti-seismic historical intervention

2.2.2. Post earthquake damage condition

As previously introduced, the observation of the external facades’ damages has been extended to the entire historical centre, while for about a 30% of the buildings was also possible to carry out the
investigation into the interiors. The collected data permit a rather precise evaluation of the damage suffered, both in relation to the extension and the level and also in relation to the quality of the damage itself.

The analysis aimed to suggest the causes that have produced the damage; an additional result of the damage examination is the highlight of the contribution provided by the historical seismic devices to the stability of the walls and the possible relationship with the condition and maintenance and transformation of the buildings.

Concerning the first item – presence of historical seismic devices – it is possible in general to say that their presence played a significant role to prevent the mechanisms' starting, at least in their evolution in collapse.

For the second item – concerning the level of maintenance and transformation of the buildings – the situation is more complex; it is clear that the collapsed wall portions are regularly not maintained, if not abandoned, thus confirming the lack of maintenance as negative factor in the structural seismic behaviour of the building. Not so clear is instead the role of transformation interventions present on the buildings (Fig. 3).

The classic distinction between “first mode” and “second mode” mechanisms has been articulated to reflect the forms that the damage has taken more frequently on Casentino buildings. For example the overturning of the external wall occurs frequently in forms that involve the entire wall or on the contrary only its upper portion (last level); the external wall damage mechanism can involve any portions of its transversal walls (in relation to the degree of connection characterising the angled or hammer walls) or involving only the upper portion of the cornice (often in the case where there was a negative contribution of wooden trusses).

The “second mode” mechanism (ie, “shear mechanism”) is interpreted as impossibility of activation of “first mode” one, due to the presence of effective connections between the converging walls; such a connection allows transferring seismic forces acting on the front walls to shear walls and, in this way, overcoming the seismic action with deep diagonal cracks in the walls each other effectively connected.

![Fig. 3 Casentino damage mechanisms map; it is the result of the systematic observation and identification of different damage mechanism present into the urban fabric](image)

### 2.3. Results and selection of the sample aggregate

The results of the study phase extended to the whole historical centre are: the systematic knowledge of its configuration, of the construction technique that produced it, of the damage condition due to the last earthquake.

On this comprehensive knowledge is based the following stage of analysis devoted to a single aggregate selected to represent the recurring problems in the built context. In fact, the study conducted on the sample aggregate is the basis for the preparation of a guide document to be used for the reconstruction intervention in Casentino historical centre.

The selection of the sample aggregate is therefore guided by the presence of features considered salient and recurrent in the built context, in terms of construction technique, recent historical transformations and, ultimately, variety and severity of damage.
3. THE SAMPLE AGGREGATE ANALYSIS

The sample aggregate presents a varied damage condition which includes portions of buildings affected by collapsing and walls with significant crack patterns. Signs and traces of historical transformations, and many recent transformations, characterize its present state. Furthermore, its localization in the context of the centre together with the conformation and orographic layout allow to represent a substantial part of the features found in the other aggregates (Fig. 4a). Finally, an additional reason for the choice has been linked to the possibility to carry out systematic survey entering into the buildings.

3.1. Critical survey

The first stage of analysis, devoted to the material consistency study on the aggregate investigates – through the "critical reading" [6] – both its present configuration and evolution/ transformation process, and the quality of seismic damage. To this end a survey was drawn to scale 1:100 showing the entire aggregate; in addition to geometric information, all data relating to the constructive elements (horizontal elements and roofing) and presence of historical seismic devices where collected. To the punctual recording of the construction methods were also added data concerning wall addition by analysing arrangement of facades, those relating to the conservation status, and promptly those relating to the damage caused by the earthquake of 2009 (Fig. 4b). Thus was constructed a comprehensive framework of knowledge that has been subsequently used as a basis for the processing of interpretation illustrated in the following paragraphs.

Fig. 4 (a) Sample aggregate; (b) aggregate’s critical survey

3.2. Evolution and transformation process and interpretation of the seismic damage

All information gathered in the cognitive phase is now used to express a synthetic judgment in relation to the aggregate’s seismic behaviour. This is equivalent to the identification of vulnerabilities and strengths on the configuration of the aggregate and individual architectural units that compose it. It should be noted that the core of this approach, recognizing the efficiency of the building or structural inefficiencies that have produced or amplified the damage, is related to the ability to articulate a qualitative judgment on the building on respect of the masonry “rule of art” [8].

3.2.1. Sample aggregate evolution process

The different phases, of construction history of the block, have been identified with assumptions supported by objective and dimensional data arising from the observation and survey (differences between the thickness of the walls, the presence of tapers, steps walls differentiated presence of superelevation, and parts added).

Fig. 5 Sample aggregate evolutionary history
Connecting the available data used in the form of “evidence”, a possible evolution process was formulated. The first step saw probably two aggregate separated by a path which, through successive additions was incorporated into the current configuration. Subsequently, the internal area of the aggregate was gradually occluded by volumes that have clogged the pre-existing cells, producing a deterioration of the liveability of houses (Fig. 5).

Alongside this significant change are the additions of superimposed level, in most cases realized using, materials and techniques different from the preexisting buildings. This reconstruction is aimed to the understanding of the mechanical behaviour of the aggregate. The identification of disconnection lines due to the evolution process and transformation allows to identify the weakest points, thus providing a fairly accurate indication of the location or concentration of the damage that the earthquake could have produced [8, 9]. This reading is used, not in order to forecast the damage (scenario of expected damage), but in order to reconstruct the pre-earthquake aggregate condition (pre-earthquake state of vulnerability), and thus to proceed to a comparison with really occurred effects (Fig. 6).

Fig. 6 Localization of vulnerability and resistance factors

3.2.2. Damage mechanisms activated by the earthquake of 2009

The identification of damage mechanisms due to 2009 earthquake is supported by the on field survey; some of them are visible as partial collapses, others as articulated crack patterns. After an initial assessment on the whole aggregate (location, type and form of the mechanism) (Fig. 7), the damage mechanisms were compared to the individual Architectural Units. To this last goal volumetric schemes to the scale of the Architectural Units were constructed in order to precisely describe the identified mechanisms. The presence of the damage mechanisms, in addition to highlight the seismic response explicated from the buildings, refers primarily to the position that the Architectural Unit occupies within the aggregate (interlocked, corner, head); the shape of the mechanism is instead connected to various factors related to vulnerabilities and resistances previously described. From the analysis of the identified mechanisms on the Architectural Units it appears that in cells placed the same position, the level of damage (and the form of the mechanism) varies depending on the different level of the state of maintenance and of the presence of systematic tie rods.

Fig. 7 Identification of damage mechanisms

1419
3.3. **Aggregate's project criteria**

3.3.1. **Comparison between pre seismic condition and damage**

Through the comparison between the pre earthquake condition and the post earthquake damage state it has been possible to highlight the factors (weaknesses and resistances) that have affected the seismic response of the aggregate.

The results of this comparison were used as the basis to design repair and seismic improvement interventions for the sample aggregate.

In the following we report a list collecting the sample aggregate's characteristics which played a role in the seismic response and that – in most of the cases – are spread in the Casentino urban fabric:

- The masonry walls are of adequate quantity and arrangement (the distance between the walls perpendicular to the facades are contained as well as the distance between floors); single exception being the occlusion of the courtyard;
- The thickness of walls at different levels are reasonable except for obvious irregularities in incongruous elevations;
- There is a certain amount of superimposed elevation made with materials and techniques not consistent with the original constructive technique;
- Some wall textures appear of poor quality
- There is a good number of anti-seismic devices such as tie rods, scarp walls and buttresses.
- An important portion of the aggregate is underutilized and abandoned and so resulting in lack of maintenance.

3.3.2. **The sample aggregate architectural design**

The repair and seismic improvement project is simultaneously aimed at improving living conditions and to preserve the historical identity of the masonry buildings; the approach is therefore finalised to the needs of safety and preservation using a synthetic design method.

It was found that the sample aggregate is completely occluded, and the internal cells do not have sufficient sources of light and air. The improvement of living condition coincides with removal of portions more precarious, i.e. those born from the process of internal occlusion of the court.

The reopening of the ancient path by means of the removal of the occlusion allows a real improvement of the housing conditions and simultaneously of the overall configuration of the aggregate (Fig. 8).

![Fig. 8 Creation of the new internal court through the conservation of the consolidated layouts](image)

3.3.3. **Repair and seismic improvement intervention**

Concerning the definition of the specific design for repairing the damage and improving seismic response, we list below the actions planned:

- New walls will be placed where needed in order to obtain a regular distance among masonry walls and restore the cells' arrangement. Particular attention will be given to the creation of the teething between the existing wall and the new one;
- Tie rods will be located systematically at every floor level. In case of new wall or in those to be disassembled due to too heavy damage, the tie rods will be placed during construction in the middle of their thickness;
- Repair of damaged masonry techniques will be realised with different techniques graduated by the damage condition;
- Improving of wall compactness will be introduced where necessary (to be decided after a proper analysis on the quality of masonry textures). In cases of proven mechanical failure, the intervention could be realised by disassembling and reassembling the wall.
– Where necessary, too damaged floors will be replaced according to the local construction techniques;
– Systematic remaking of the covers and the wall upper portions in order to realize reinforced masonry tie rods will be realised; the new wooden structures of the roofs will be realised not thrusting (Fig. 9).

3.3.4. Towards the guidelines for aggregates damaged by the earthquake of 2009
Downstream of the surveys conducted over the entire historical centre and the analyses realised on the sample aggregate, the preparation of an operative tool for defining projects aimed at safety and preservation of the built heritage can be produced by typing the recurring issues relating both to damage and to any critical points of the local construction techniques. The composition of an exhaustive list of problems will be accompanied by the following solutions presented in the form of performance to be achieved and general guidance on the types of programs eligible for the needs of security and conservation.

4. CONCLUSIONS
The experimental design of the sample aggregate in Casentino has retraced an analysis methodology finalised to defining consistent intervention criteria for historical built contexts. This experiment, however, which is based on a preliminary knowledge of the entire historical centre can be a useful guide for the study of aggregates in small historical centres damaged by the 2009 Aquila earthquake.

The procedure in fact defined the stages that allows to develop the project, starting from the critical reading of the aggregate in terms of constructive features and evolution and transformation process. In this context, the repair of the damages caused by seismic action and the improvement of safety that is necessary to provide to the urban fabric are the topics to be faced; these last are alongside to those of the necessity of preserving the identity of historical site which – in most small towns of L’Aquila – requires the ability to preserve from easy transformations the urban fabric composed of small and fragile buildings.

ACKNOWLEDGEMENTS
Authors thank Cesare Tocci (Università di Roma „La Sapienza”) who partecipated to the research work carried out in the two years after the 2009 earthquake, Sergio Lagomarsino and Serena Cattari (Università di Genova) and CNR/ITC which collaborated in the preliminary on field work. Arch. Concetta Borgia is the author of Fig. 1a. This work has been carried out under the Research Program PRIN(Italian National Interest Research Program) 2008.

REFERENCES


