PRELIMINAR DAMAGE ASSESMENT OF MASONRY BUILT HERITAGE AFTER THE AMATRICE 2016 EARTHQUAKE

F. Brandi (1), N. Palazzi(2), L. Rovero(3), U. Tonietti(4)

(1) Student, University of Florence, Department of Architecture, francesca.brandi@stud.unifi.it
(2) PhD. student, University of Florence, Department of Architecture, nuriachiara.palazzi@stud.unifi.it
(3) Associate professor, University of Florence, Department of Architecture, luisa.rovero@unifi.it
(4) Associate professor, University of Florence, Department of Architecture, u.tonietti@unifi.it

Abstract

The paper consists of a descriptive report on seismic performance of the Built Heritage in Amatrice Valley (located in Central Apennines, Italy), hit by the Amatrice 2016 Earthquake of 24th August 2016. The report presents the outputs of a direct survey conducted in situ during a mission undertaken between the 26 August and the 28 August 2016. A preliminary seismic damage assessment of masonry Built Heritage is provided through a phenomenological approach, based on the description of images taken in situ.

The detected damages were classified according to four basic types: walls disaggregation, out-of-plane mechanisms, in-plane damages and non structural damages. The post-seismic survey sites visited and analysed are located along the Amatrice Valley, with reference to the following villages: Casale, Collalto, Collecreta, Collepagliuca, Cossito, Faizzone, Moletano, Petrana, Ponte a Sommati, Prato, Rocchetta, Saletta, San Lorenzo Flaviano, Sant'Angelo, Sommati, and Voceto.

Keywords: Amatrice 2016 earthquakes, Seismic vulnerability, Unreinforced Masonry (URM), Built Heritage

1. Introduction

The region between the Tronto Valley and the Sibillini Mounts, part of the Central Apennines (Italy), was subjected to a seismic sequence on August-October 2016 suffering high human loss and catastrophic damages to Built Heritage. Such terrible event put in evidence the need to activate prevention and safeguarding actions.

The aim of the paper is to provide a report based on a direct survey conducted in situ during a mission undertaken between the 26 August and the 28 August 2016. The report shows a preliminary analysis of the technical features and seismic behaviour of masonry Built Heritage hit by the Central Apennines 2016 seismic events. In spite of the claims by media, the Built Heritage in Central Apennines does not offer a completely homogenous scenario. It is important to underline that many constructive cultures follow one other starting from Sicilia up to Friuli as a function of the local environment, the economic state, the use of the building, the social requirements, the levels of technology, and finally the minor or major memory of previous earthquakes. It will need a deep and structured study on this matter. At present we try to understand, in this limited and local context, if and which different mechanical behaviours are detectable, and to connect them to the possible technical bases on which they are founded. The main issues with which we will face are: materials and implementation techniques of the walls, presence or absence of devices useful to achieve some level of *box behaviour*, measures and intervention that could have changed the masonry structural behaviour both as improvements that as weakening [1, 2, 3, 4, 5].

As starting point of this program we propose first results obtained by a phenomenological approach. The detected damages are divided and interpreted according to four basic categories: walls disaggregation, out-of-plane mechanisms, in-plane mechanisms and non-structural damages. In particular the study deals with the

Amatrice Valley, comprising Casale, Collalto, Collecreta, Collepagliuca, Cossito, Faizzone, Moletano, Petrana, Ponte a Sommati, Prato, Rocchetta, Saletta, San Lorenzo Flaviano, Sant'Angelo, Sommati, Voceto villages.

2. Central Italy seismic sequence of August-October 2016

The Central Italy seismic sequence of August-October 2016 affected an area stretching from the Tronto Valley and the Sibillini Mounts, portion of the Central Apennines. The first shock, Amatrice earthquake Mw 6.0, occurred in the early morning at 3:36:32 GMT on the 24th August 2016 (8 km, coordinates 42°42′50.4″N13°10′19.2″E), struck the zone between Accumuli and Arquata del Tronto villages. A largest number of aftershocks - 9000 up to the 16th September 2016 [6 - 9] have been recorded. This sequence of shocks culminated in the great event of 30th October with a shock of 6.5Mw, striking the zona between Norcia and Preci municipalities, at North of the first shock.

The seismic sequence interested a volume whose projection surface extending for about 50 km in Apennines direction between Ussita town and Campotosto Lake and about 15 km in the transversal direction. The dispersion of events sequence suggests the activation of faults system oriented in Apennines direction, characterized by some complexities observed by Istituto Nazionale di Geofisica e Vulcanologia, INGV: in particular, the activation of the Monte Vector fault segment and the activation of different structures antithetical dipping towards NE [8]. The main event of 24th August has been determined by slip of an extensional fault having strike= 156° and dip=50° SW.

The Macroseismic Intensity map of Fig. 1a, produced by INGV [8] shows that in Accumuli village the shaking intensity was 6.0, in Norcia 5.3 and in Amatrice greater than 4. The isoseismic curves in the Macroseismic map show: 1) significant destructive damages in area between Amatrice, Accumuli, Illica, Pescara del Toronto and Arquata del Tronto villages (MKS level IX); 2) heavily and moderately damaging (MKS level VIII, VII) in the areas in proximity of these villages; 3) slightly damaging (MKS level VI) in the zone comprised between Tronto Valley and the Sibillini Mounts.

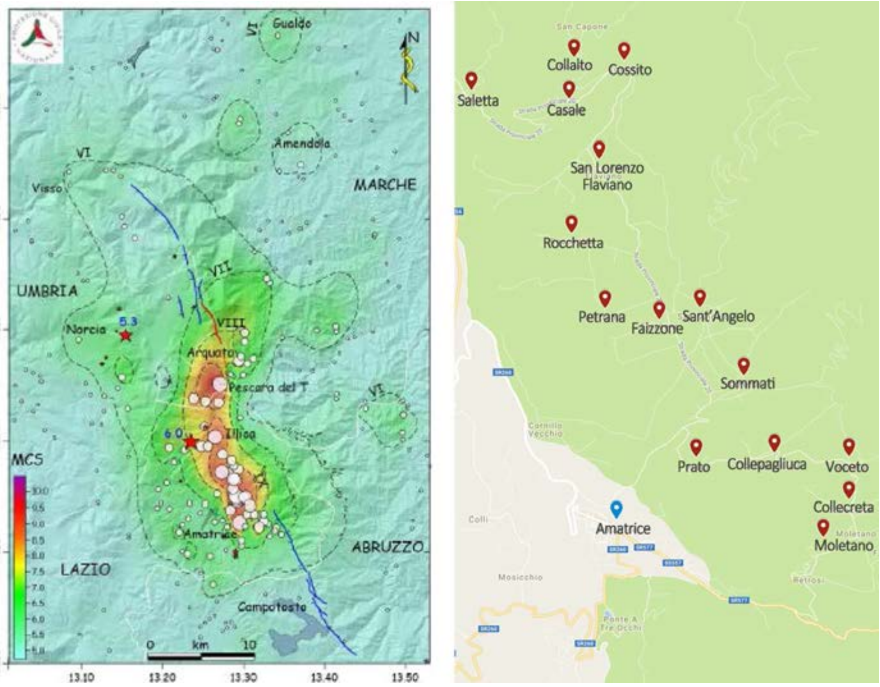

Figure 1– a) Macroseismic MSK intensity and isoseismic levels as proposed by Istituto Nazionale di Geofisica e Vulcanologia [8], b) Locations of visited sites during the mission took place between 26 August and the 28 August 2016 (Casale, Collalto, Collecreta, Collepagliuca, Cossito, Faizzone, Moletano, Petrana, Ponte a Sommati, Prato, Rocchetta, Saletta, San Lorenzo Flaviano, Sant'Angelo, Sommati, Voceto).

The MKS values are present in table 1 and are compared with strong motion peak ground accelerations obtained from reports of INGV, Istituto nazionale di oceanografia e di geofisica sperimentale (OGS) and the Analysis and monitoring of environmental risk center (AMRA). The values of spectral acceleration at T=0, maxima ground acceleration a_g (seismic hazard estimates for 10% probability of exceedance in 50 years), as defined by NTC 2008 Italian seismic code [10] are also reported. Table 1 shows the following data of 24th August 2016 shock: the magnitude Mw [8] the epicenter distance, the Peak horizontal ground accelerations and the Peak vertical ground acceleration, recurred by National Strong Motion Network [11] all data is currently being reviewed, in particular the data acquired by AQA stations, FCC, PRE and NOR); and of 30th October 2016 shock: the magnitude Mw [8], the epicenter distance; the Peak horizontal ground accelerations, the Peak vertical ground acceleration, recurred by Engineering Strong-Motion database [12]

Table 1 – Surveyed sites and intensities

Town	**Region**	**Seismic Zone a_g** **(NTC2008)**	24th August 2016 shock				30th October 2016 shock			
			Epicentre distance (km)	**Mw**	**PHGA (g)**	**PVGA (g)**	**Epicentre distance (km)**	**Mw**	**PHGA (g)**	**PVGA (g)**
Amatrice	Lazio	0.25/0.275	9,58	6.0	0.46/ 0.22	0.2	26.9	-	-	-
Accumuli	Lazio	0.25/0.275	0	6.0	-	-	19.3	6.5	0.42/ 0.38	0.54
Norcia	Umbria	0.25/0.275	14.25	5.3	0.33/ 0.38	0.21	5.4	6.5	0.48/ 0.36	-0.37
Arquata del Tronto	Marche	0.25/0.275	13.91	-	0.45	0.39	17.9	6.5	-0.28/ -0.19	-0.35

3. Preliminary assessment of masonry damage phenomena

The first shock of 2016 seismic sequence has produced severe and several damages aggravated by aftershocks of great intensity, with important partial and global collapses in Tronto Valley.

The predominant structural system of this area consists of unreinforced masonry (URM) ordinary buildings, and in many case such buildings show insertions of reinforced concrete (RC) elements, mainly floors and roofs, often characterized by a global collapse.

The greater part of local masonry heritage belongs to villages placed in mountain area, characterized by prevalent housing and rural use.

The Tronto Valley villages present important peculiarities in the construction techniques, result of a pre-modern culture based on local and tacit approach to knowledge.

The location and growth of villages urban structures are strongly influenced by the orography, as the country road (SP20) follows the level lines (isohypse) while the secondary streets are orthogonal to SP20. The villages develop along SP20 or secondary streets and then can show an urban arrangement both perpendicular and parallel to the mountain slope, so determining irregularities in plan and in elevation that cause an increase of vulnerability.

Generally, the bearing walls of buildings are arranged perpendicularly to the streets generating the aggregates.

Usually the aggregates have suffered an intense process of spaces saturation and clogging, using prevalently poor quality masonry. In fact, through the observation of masonries and prevalent failures of structures it was possible to survey that the fundamental requirements of a correct and efficient building technique (the “rule of the art”) are not respected both in primitive and clogging building cells.

The greater part of masonry buildings exhibits a weak wall consistency. Made by irregular stonework, constituted of pieces of different and little sizes (often pebbles), they cannot arrange horizontal layers and are not effectively transversally bonded.

It is anyway important to underline that quality masonry is not entirely homogeneous, since there are building implemented by a more efficient technique; sometimes the simple or partial respect of some requirements of the rule of the art can change the mechanical behaviour and allow an acceptable seismic response (that avoid collapses).

A rough synthesis of the carried out survey highlights the following main damage phenomena (associated to the well-known mechanisms) [13, 14]: walls disaggregation, out-of-plane damage mechanisms, in-plane damage mechanisms and non-structural damages. In the following sections, each damage type is described and commented [15], using the images taken during the mission. Each image is compared to corresponding image of street view-Google maps take before the earthquake.

3.1 Walls disaggregation

When the wall consistency is really weak, i.e. there is a compresence of almost all the typical weaknesses of irregular stone masonry, walls cannot activate any mechanism and collapse as a whole of incoherent material.

In particular, for walls made by irregular and size variable blocks, the scarce quality mortar, often in earth-lime, during the seismic event not guaranteed the effective contact between elements, the uniform transmission of loads and the cohesive resistance. Furthermore, the absence of *diatones* - blocks crossing the entire width of the wall - in rubble masonries (with pebbles) or in multi leaves walls causes the decomposition of the wall and does not allow a load distribution along the entire width of the wall even when the load bearing is on the wall edge.

These poor constructive techniques, within the absence of constant maintenance work, have led to predominant damages of disaggregation, heavily disruptive and destructive, considered the *zero mechanism* [16]. In Fig. 2 the walls disaggregation occurred in headpiece (Fig.2a-b), interlocking (Fig.2c) and isolate (Fig.2d-e) buildings. The masonry weakness is often aggravated by the presence RC interventions especially in gable roof that due to stiff and heavy, have slipped on poor masonry producing global collapses (Fig. 3a, b), as observed in [17, 18] after the 2009 L’Aquila earthquake.

Fig.2a - An abandoned building collapsed by disaggregation. The total absence of maintenance has exposed the interiors to atmospheric agents, causing an important deterioration of the masonry made of pebbles and mud mortar, Casale village

Fig. 2b- An isolated rural building subjected to a global collapse due to the disaggregation of masonry walls constituted by mud mortal and pebbles elements, Saletta village

Fig.2c - Two terraced dwellings interlocked between higher buildings with stagger floors, collapsed by disaggregation, Saletta village

Fig.2d – A three floors slender building located on an elevated slope characterized by *zero mechanism* due to poor and disaggregated masonry, Saletta village

Fig.2e - Rural warehouse has collapsed by disaggregation. The less of maintenance get worse the originally main weakness: the poor quality of the masonry made of pebbles and mud mortar, San Lorenzo a Flaviano village

Fig. 3a/b – Two isolated dwelling due to stiff and heavy RC glabe roof and floor sliding, have determined a global collapse of masonry structure, San Lorenzo a Flaviano village

3.2 Out-of-plane mechanisms

If wall masonry exhibits a sufficient consistency (size of the blocks not so different, some research of regularity both in the shape of pieces and in the stonework layers, better quality mortar, transversal mechanical behaviour guaranteed although by separated leaves the activation of the out-of-plane mechanisms occurs in absence of actual *box behaviour*.

The *first mode* mechanisms [19] is determined by structural weaknesses, detected in the whole Tronto Valley, as the lack of anchors, the absence of adequate connections between the additions, the presence of large openings in proximity of wall extremity, the absence or the inefficient presence of ties and bonds (Fig.4a, b, c, d, e, f, g, h). The crack patterns assessment on masonry buildings without *box behaviour* have confirmed that the seismic action has selected the most vulnerable masonry portions (characterized by independent behaviour) whose failure is due to a loss of equilibrium [20, 21, 22]. In fact the partial collapses of overturning together with the decomposition mechanisms have been more frequently recorded. The reasons, in the majority of cases, are detected in the scarce horizontal connections between orthogonal walls and between wooden roof and masonry, in the absence of tie rods and metal joins.

Fig. 4a- Out-of-plane mechanism due to material irregularity and local weakness of masonry wall determinate by the presence of a flue, Cascello village

Fig. 4b- A rural interlocked building shows horizontal arch mechanism inducing the overturn of the façade and the separation of external leave of remaining wall, Sommati village

Fig. 4c – Horizontal arch mechanism involved upper part of a three floors rural building, Sommati village

Fig. 4d- The building presents the activation of vertical arch mechanism due to lack of good connections between floor and masonry wall and to hammering of floor on rubble masonry, Faizzone village

Fig. 4e – The rural building shows the corner collapse depends on the presence of quoins, on the layout of the opening and spanning direction of the roof, Faizzone village

Fig. 4f – Composite overturning mechanism of façade due to the absence adequate quoins between the additions, to the presence of a big opening and of other opening in proximity of wall extremity, Cascello village

Fig. 4g - Composite overturning of the façade in the terraced aggregate, San Lorenzo a Flaviano

Fig. 4h- Example of masonry building with inadequate interventions of consolidation. Steel elements, at the second floor, hammered the rubble masonry wall determining the overturning of the all upper part of façade. The presence of ties has limited the collapse at the lower part of the façade, Rocchetta village

3.3 In-plane mechanisms

A significant number of structures in Tronto Valley showed a better *box behaviour*. These buildings are characterized by prevalently in-plane mechanisms due to shear and bending (Fig.5a, b, c). Such behaviour, the *second damage mode*, is achieved through devices that prevent the wall overturning so transferring the strengthening capacity to the transversal walls (that work in-plane). Sometimes an inadequate insertion of chains (Fig. 5a) shows a partial activation of overturning mechanism that doesn't reach the collapse.

The moderate damages normally suffered in this category have highlighted enough connection among the structural elements, able to guarantee an acceptable seismic response.

3.4 Non-structural damages

Fortunately, during the mission, some examples of buildings with non-structural damages were detected (Fig.6a and b) bring to light the use of efficient building techniques which respect the fundamental requirements of the "rule of the art".

Of course a quantitative survey of the real number of buildings, belonging to each damage category, has still to be done and the data is currently being reviewed.

Fig. 5a - The isolated building shows the partial activation of façade overturning which doesn't collapse because of the presence of a tie-rod, located at the second floor. Prato village

Fig. 5b - The terraced buildings show a good *box-behavior* characterized by diagonal shear cracks in upper level storey, mainly due to the ties at two levels (second and third floor), Sommati village

Fig. 5c – The isolated building shows both diagonal and vertical cracks; it exhibits tie-rods just at the second floor and corners bonds with regular and squared medium size blocks, Sommati village

Fig.6a, b - Terraced houses and isolated house with non-structural damage, Sommati and Faizzone villages

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