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EARTHQUAKES IN CENTRAL ITALY IN 2016: COMPARISON BETWEEN NORCIA AND AMATRICE

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ABSTRACT

In this paper lessons are extracted from the comparison between the very different consequences that a set of earthquakes had on the neighbouring towns of Amatrice and Norcia during the 2016 central Italy earthquake sequence. The paper initially describes the prevention programs implemented in Amatrice and Norcia starting from the reconstruction after the 1860 Norcia earthquake. The earthquake intensities in Amatrice and Norcia during the 2016 Central Italy events were considering accelerometric recordings of the Italian Strong Motion Network. In the same municipalities, the damage has been assessed through site visits and analysis of the results of the post-earthquake safety assessment performed after the events. It was found that the differences in damage were essentially due to the strengthening of most houses in Norcia done during the previous decades. This is also likely to lead to a much faster recover of the economy and livelihood in Norcia, as Amatrice needs to be entirely rebuilt.

Keywords: 2016 Central Italy earthquakes; damage prevention; strengthening.

1. INTRODUCTION

On August 24th, 2016, a (moment) magnitude Mw 6.2 earthquake struck central Italy at 3:36 a.m. local time (1:36 a.m. UTC). The epicentre was close to Accumoli, a town between Amatrice and Norcia. This earthquake caused casualties in Amatrice (234), Accumoli (11) and Arquata del Tronto (49). Amatrice was the most hit town, with severe damaged buildings. More than 15 earthquakes with magnitude larger than 4.0 followed the main shock. Most of the constructions of Amatrice collapsed during the main shock, and the ones that did not collapse were so damaged that were unusable. From this moment onwards, the area withstood an intense seismic sequence, with up to 600 low-magnitude events per day up until the last days of October, when a new set of strong earthquakes occurred.
In the evening of October 26th, two events, a Mw 5.4, at 7:11 p.m. local time (5:11 p.m. UTC) followed just two hours later by a Mw 5.9 earthquake, at 9:18 p.m. (7:18 p.m. UTC), hit central Italy again. On October 30th, a third and larger earthquake, with a magnitude Mw 6.5 struck the town of Norcia, at 7:40 a.m., local time (6:40 a.m. UTC) with epicentre 6 km north of Norcia. This earthquake was the strongest to hit Italy since the 1980 Irpinia earthquake with Mw 6.9. Due to the events of October 26th, many people left their homes, afraid that a larger event could happen, and went to sleep in cars, campers or moved to shelters or hotels. For that reason, when the October 30th Mw 6.5 earthquake stroke and impacted the towns of Norcia, Castelsantangelo, Preci and Visso (nearly 8,000 residents), these were partially abandoned.

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Due to the vicinity of the epicenter the ground accelerations in Norcia were extremely high, with a value of the horizontal Peak Ground acceleration of 0.48g registered at the nearest seismic station (Station Code NRC, N=42.7925, E=13.0964; Luzi, 2016). Many constructions were damaged, but many others withstood the seismic actions with little or no damage and there were no fatalities.

Today, Amatrice is a ghost village, where no one is allowed to enter freely, as a direct consequence of the August 24th earthquake. In contrast, the town of Norcia, which felt the August and October earthquakes, being strongly hit by the last of the earthquakes mentioned, only suffered minor damage. How is it possible to explain the differences between Norcia and Amatrice? How come there were no casualties in Norcia? In order to find and document answers to these questions, a KnowRISK team, with members of Instituto Superior Técnico (IST), and Istituto Nazionale di Geofisica e Vulcanologia (INGV), together with a member of Instituto Politécnico de Setúbal (IPS) visited the affected zones during the last week of October 2016, while the seismic sequence was on going. Truthfully, the motivation for this field trip arose from the comparison between the different impact of the August earthquake in Norcia and Amatrice.

2. SEISMIC INTENSITY

A series of accelerometric recordings were obtained at several stations during this earthquake sequence. Figure 1 shows the spectra for horizontal accelerations recorded in stations located in Amatrice and Norcia for the earthquakes of 24th August and 30th October. At least for the E-W component, the spectrum recorded in Amatrice on the 24th of August was higher than in Norcia (left) so figure on the left shows also the 475 return period spectrum used in earthquake design in Amatrice. On the contrary the spectrum recorded in Norcia on the 30th of October was higher than in Amatrice. Hence figure on the right also shows the 475 year return period spectrum in Norcia. In the location of both Amatrice (AMT) and Norcia (NRC) stations the soil is Eurocode type B, and the 475 year return period spectra refer to soil B.

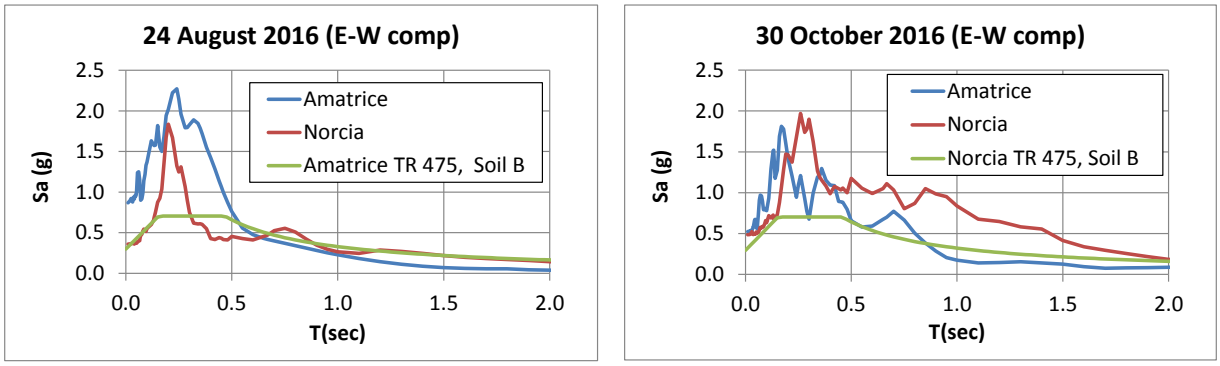

Figure 1. Response spectra for Amatrice and Norcia, East-West component. Left) 24 August shock. Right) 30 October shock. (Engineering Strong Motion Database, Luzi et al.)

Comparison of the recordings of the same event at different stations shows that during the August 24th event, in Amatrice, the maximum spectral acceleration was 2.27g for a period of T=0.24sec and in Norcia it was 1.9g for a similar period. Comparison of the recordings of different events at the same station show that in Amatrice the August 24th event was stronger than the October 30th event, at least up to 0.5 sec. On the contrary in Norcia the 30th October event was stronger. On the August 24th event the design spectrum was exceeded in Amatrice up to T=0.5 sec. On the August 30th event it was exceeded and up to T=0.80 sec in Amatrice and for all periods in Norcia. The return period of the spectral accelerations is shown in Figure 2 (left) where it can be seen that the return period is in the order of thousands of years in the high frequency range, well above 475 years shown in dashed red line.

Figure 2 (right) shows the ratio of Amatrice to Norcia spectral acceleration in function of the period of vibration for both the August 24th and the October 30th shocks. Once defined the parameter η as the average of the above spectral ratio on a period interval (Equation 1) the values shown in Table 1 are obtained.

$$\eta = \frac{1}{T_2 - T_1} \int_{T1}^{T2} \frac{Sa(T, Amatrice)}{Sa(T, Norcia)} dT \quad (1)$$

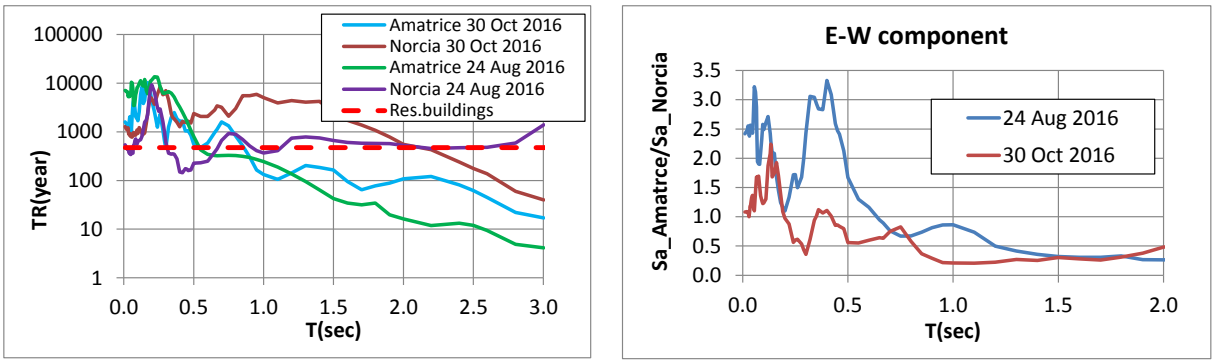

Figure 2. Left) Return period of spectral accelerations in Amatrice and Norcia, East-West component, 24 August and 30 October shocks. Dashed red line shows the return period (475 years) for seismic design of residential buildings. Right) Ratio of Amatrice to Norcia spectral acceleration, East-West component, 24 August and 30 October shocks.

Table 1. Average ratio of spectral accelerations in Amatrice and Norcia

T_1 (sec)	T_2 (sec)	η (Sa Amatrice / Sa Norcia on 24 August 2016)	η (Sa Amatrice / Sa Norcia on 30 October 2016)	η (Sa Amatrice on 24 August 2016/ Sa Norcia on 30 October 2016)
0.00	0.50	2.29	1.06	1.48
0.00	1.00	1.60	0.79	0.93
0.50	1.00	0.92	0.52	0.40

In Amatrice and Norcia, the most common building types are masonry buildings, 2 to 3 storey high, with natural periods in the order of 0.2-0.3 secs. Hence, considering also the elongation of the period due to seismic damage, we can conclude that the August 24th shock in Amatrice was about 2.3 times stronger than in Norcia, while the October 30th shock had about the same intensity in Norcia and Amatrice. The average ratio of spectral accelerations in the interval of periods T_1=0, T_2=0.5 sec in Amatrice for the August 24th E-W recording and in Norcia for the August 30th E-W recording is 1.48. Thus, when considering the effects of both shocks in Amatrice and Norcia the difference in seismic intensity reduces. Considering a wider interval of periods, T_1=0, T_2=1.0 sec, the average ratio of spectral accelerations in Norcia and Amatrice is similar (η=0.93).

The Amatrice earthquake produced higher spectral accelerations than the Norcia earthquake for periods below about T=0.45sec, therefore producing stronger effects in stiffer constructions, i.e. low-rise. The differences are stronger below T=0.2sec. Conversely, the Norcia earthquake produced stronger effects in more flexible constructions, in both Amatrice and Norcia' stock of buildings. It is important to point that although there are some differences in seismic intensities in Norcia and Amatrice, it is clear the large difference in building performance cannot be attributed to differences in seismic actions alone.

3. SEISMIC IMPACT

The result of the seismic crisis of August and October 2016 was the destruction of the historical core of Amatrice and a total number of 299 victims out of which 234 in Amatrice. On the contrary, in Norcia, despite damages in many houses and some collapses of historical constructions, as some of their exterior walls and churches, most of the houses were standing and, above all, no one died. Figure 3 provides a good comparison of the state of both villages after the earthquake.

Figure 3. Left) Amatrice after the August 24th earthquake. Right) Norcia after the October 30th 2016 earthquake

Most of Amatrice constructions collapsed or were severely damaged during the August 24th earthquake. Ordinary buildings had complete failures as well as civil protection buildings or buildings belonging to the cultural/educational structure of the town. The town structure was broken. For instance, the masonry wing of the Capranica elementary school collapsed and the RC wing was unusable. The RC new wing of the Grifoni Hospital was unusable. The Police Station as well as the Carabinieri and the Ranger Stations were unusable. The Roma Hotel was unusable and only one out of nine restaurants was usable. The supermarket was inoperative and 50% of agricultural activities were impractical. Due to extended damage, after the August 24th earthquake, the historical core of the town was closed to the general public, and could only be accessed under the supervision of the Italian fire brigades. This included the KnowRISK structural engineers that only got permission to visit the town when the fire brigades could receive them. The survivors of the earthquake had no alternative than to leave town and stay in hotels, in nearby villages or more far away, mainly in the Adriatic coast, while others went to live with relatives or friends.

Figure 4 - Damage in Norcia after the October 2016 earthquakes

Norcia was strongly hit by the sequence of October earthquakes, mainly by the one of October 30th. However, damage was much less extensive than in Amatrice. Some monumental constructions suffered partial collapses and several constructions inside town were damaged, a few ones strongly. Figure 4 shows some of those cases. The KnowRISK team was in Norcia three times, on the 26th of October, just four hours before the 5:11 p.m UTC earthquake, on the 28th October between the major earthquakes of that week, and on the 19th December. The photos shown in Figures 4 and 5 were taken

by the KnowRISK team on December 19th 2016, one month and a half after the major earthquake that hit the town.

In general, in Norcia, most constructions appeared, from the outside, to have no damage or slight damage, but there were also a few with parts in risk of collapse. In these conditions, any aftershock could lead to more damage, making it unsafe to walk on the streets. Therefore, the centre of Norcia was closed to the public, until conditions to safely use the streets could be re-established. This comprises essentially two conditions: i) all constructions in which there is partial risk of collapse onto the streets must be braced to avoid that risk, and ii) the seismic crisis must be over. Regarding the first condition, when the KnowRISK team visited Norcia in December 2016, together with members of the Italian fire brigades, those works of bracing unstable structures were going on in several parts of the town, which could take a few months to complete. Figure 5 illustrates some of those cases.

Figure 5 - Bracing of unstable constructions in Norcia by the fire brigades

The second requirement implies an extremely difficult decision. When the KnowRISK team visited Norcia and Amatrice by the end of October, two months after the major earthquakes of August that were followed by low intensity aftershocks until October, it was thought that the seismic sequence could be fading away. However the October earthquakes, as well as the ones that took place in January 2017, casted high uncertainties on the assessment of the situation from the seismological point of view. In this situation, it is likely that only after several months of lack of relevant earthquakes the crisis could be declared as finished.

From what the KnowRISK team observed, the fact that in Norcia there were no casualties is due to two main issues: i) Norcia suffered less damages than Amatrice, and ii) the population was on alert due to two earthquakes on the 26th of October. Although their magnitude was not large, these earthquakes were clearly felt by the population, causing some alarm among the people. They caused some minor damages, mostly non-structural. With the recent memory of the Amatrice events in August in their minds, many people left their houses to safer places. As a consequence, when the main earthquake took place on 30th October, at 7:40 p.m. local time, many people were sleeping on cars and not in their homes.

In order to compare differences in damage in Norcia and Amatrice, the results of the post-earthquake safety and damage assessment are analysed. The overall damage assessment database is not yet

available, but the results of usability assessment are known. Before 30th October, buildings were inspected with AeDES Form (Baggio et al, 2014). The October earthquake increased the affected area and led to the need of t many reassessments. Therefore, a quicker procedure was adopted making use of the FAST form (OCDPC n. 405, 2016), which is a short version of the AeDES form. If damage was detected, the building was additionally inspected with the AeDES form. In Amatrice, as well as in Accumoli and Arquata, the three most affected municipalities, the AeDES form was used for all buildings. The usability classification in the AeDES form can be summarized in: usable buildings (A), restricted use (B=usable after short term countermeasures and C=partially usable), and unusable buildings (D=to be reassessed, E=unusable, F=unusable for external risk). External risk occurs when elements from adjacent buildings may fall on the building under consideration or on its entrance. Typical examples are buildings close to damaged bell towers. The form also contains the classification to use when the external risk is not considered. The unusable buildings due to factors including external risk are given by the sum of the buildings that are classified as A_F, B_F, E_F, where, for example, E_F means a building unusable due to external risk that remains unusable when the external risk is removed. This allows a more efficient management of the results of the inspections and a more precise analysis of the intrinsic building features. The classification of the FAST form can be summarized in usable and unusable, even if different terms were used in order to avoid misinterpretation with AeDES classification. Table 2 shows the percentage of usable buildings (A), restricted use (B+C), and unusable buildings (D+E+F) in Norcia and Amatrice before and after the 30th October earthquake, informing which form was used. Table 3 shows the same data when external risk is not considered. However, since the FAST form does not contain the usability classification when external risk is not considered, the latter cannot be evaluated for Norcia after the 30th October earthquake.

Table 2. Usability classification in Amatrice and Norcia considering external risk

Date	**Event**	**Form**	**Municip.**	**Number of buildings**	**A (%)**	**B+C (%)**	**D+E+F (%)**
20/10/2016	24/08/2016	AeDES	Amatrice	3,171	31.5%	9.7%	58.8%
20/10/2016	24/08/2016	AeDES	Norcia	1,742	54.8%	9.5%	35.8%
01/11/2017	24/08/2016 + 30/10/2016	AeDES	Amatrice	3,884	34.1%	10.0%	55.9%
28/02/2017	24/08/2016 + 30/10/2016	AeDES + FAST	Norcia	2,318	62.2%	37.8%	

Table 3. Usability classification in Amatrice and Norcia excluding unusability due to external risk and considering only structural and non-structural damage

Date	**Event**	**Form**	**Municip.**	**Number of buildings**	**A+A_F (%)**	**B+B_F+C+C_F (%)**	**D+D_F+E+E_F (%)**
20/10/2016	24/08/2016	AeDES	Amatrice	3,171	40.6%	12.7%	46.7%
20/10/2016	24/08/2016	AeDES	Norcia	1,742	62.1%	10.8%	27.1%
01/11/2017	24/08/2016 + 30/10/2016	AeDES	Amatrice	3,884	43.4%	13.2%	43.4%

From Table 2 one can see that before the 30th October 2016 earthquake the percentage of usable buildings in Norcia (54.8%) was about 1.7 times more than in Amatrice (31.5%) and that the percentage of unusable buildings in Amatrice (58.8%) was about 1.6 times more than in Norcia (35.8%). The assessment after 30th October, resulting from both the increase of damage due to new shocks and the completion of the survey, did not change significantly these figures.

Considering the intrinsic features of the buildings alone disregarding the external risk (Table 3), it is possible to observe that the building stock show less vulnerability (usable buildings in Amatrice increase from 31.5% to 40.6% and in Norcia from 54.8% to 62.1%) but the proportion between Norcia and Amatrice remains similar to the one obtained including the external risk.

The comparison between the damages caused in Norcia and Amatrice shows profound differences. Since the earthquakes themselves cannot explain these differences, they must be attributed mainly to differences in vulnerability between both towns.

Both in Norcia and Amatrice, most constructions are/were old, built in periods in which earthquake resistant design was not enforced in codes of practice, and therefore it is thought that original constructions were vulnerable. Regarding seismic design, Amatrice was placed in zone 1 (high risk) in 1915 as a consequence of the Avezzano earthquake. In 1927 the seismic zone was changed to zone 2 (medium risk) and finally in 2003 became again zone 1. At the present time, the 475 year return period PGA on stiff soil is 0.259 g. Norcia was located in zone 2 (average seismicity) in 1962. Similarly to Amatrice it changed to zone 1 in 2003. At the present time, the 475 year return period PGA on stiff soil is 0.255 g.

Norcia has been coping with earthquakes through times, sometimes with vast consequences. Nowadays, Norcia has a safety culture regarding earthquake risk, due to several reconstructions of the city's buildings that took place after strong events. The first example is the reconstruction after the M 5.7 1859 earthquake, regulated by guidelines drafted by two experts sent by the Pontifical State. These experts linked damage with the building architectural features. The reconstruction carried out at that time was able to save human lives when the 1979 Valnerina M 5.8 earthquake happened. The Valnerina reconstruction, regulated by Regional Law 50/80 (L.R. n. 50, 1980), was implemented through interventions on "comparti", groups of buildings or blocks where the interventions had to be jointly designed. In 1997, another earthquake happened in Umbria-Marche, where Norcia is located. Following this earthquake Law 61 was issued on 30/03/98 (L. 61, 1998). Governmental contributions (ranging from 360 to 750 €/sqm) were provided for repair and seismic upgrading with a minimum safety level of 65% of the full retrofit. According to Umbria Region Observatory on the 1997 reconstruction (http://www.osservatorioricostruzione.regione.umbria.it/canale.asp?id=101), in Norcia municipality there have been 534 requests of financial contribution of private residential buildings, out of which, 531 were considered eligible (about 20% of the buildings in the whole municipality). Higher priority was given to houses where people lived permanently, with second houses receiving a lower priority. The main strengthening techniques used in Norcia consisted in i) confinement of masonry walls by a layer of mortar with a pre-fabricated steel welded mesh inside, in both faces, connected by steel bars at a given spacing (Figure 6), and ii) introduction of iron ties connecting parallel walls in order to prevent the out-of-plane movement of exterior walls to the outside of the construction.

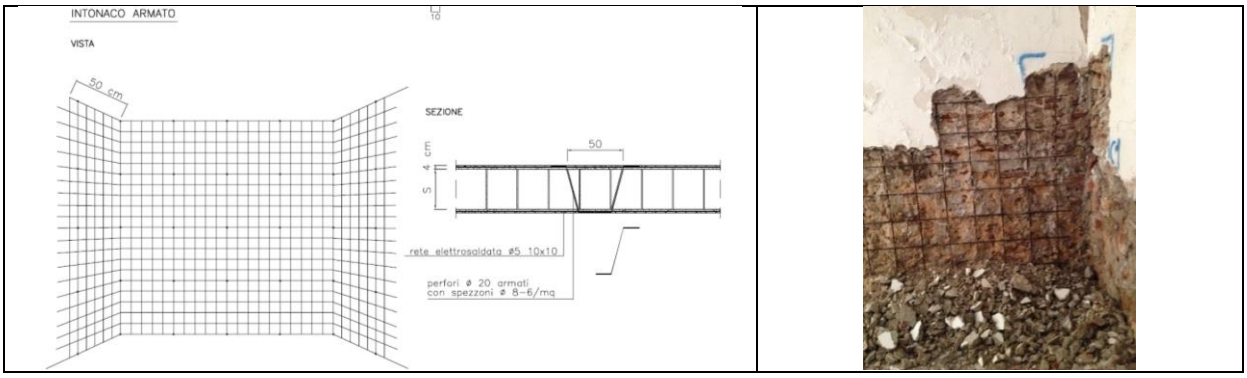

Figure 6. Left) Sketch of masonry confinement by steel mesh and mortar. Right) picture from a real case.

Amatrice, as well, was affected by the 1997 Umbria-Marche earthquake but to a lesser extent due to the greater distance from the epicentre. The reconstruction in Rieti Province, where Amatrice is

located, was regulated with a different legislative act (OMIDPC 2741, 1998), with lower contributions and lower safety performance requirements with respect to Umbria and Marche Regions. Financial contributions were provided for building repair and upgrading with a minimum safety level of 50% of the full retrofit. Private buildings contributions were set to about € 200-380 per square meter with owner cofinancing ranging from 25% to 50% according to the damage level. The number of private buildings that received financial contribution in Amatrice is not known to the authors. However, an upper estimate of upgraded private buildings is 50, based on 1997 unusability. Amatrice was slightly affected by the 2009 L'Aquila earthquake and no significant reconstruction program was implemented. After the 2009 earthquake, almost one billion euro in seven years was allocated from the Government for the National Seismic Prevention Plan through article 11 of the L. 77/09 (L. 77, 200). In Amatrice, there were no applications for public buildings and only 11 applications for private buildings. From the 11 mentioned, 9 applied for local strengthening and 2 for seismic upgrading. From these, only one building was located in the historical core of Amatrice. Also note that Norcia made no applications probably due to the fact that buildings were already upgraded after the 1997 Umbria-Marche earthquake.

4. RECOVERY

In Norcia, many buildings in its centre were in safe conditions after the earthquakes of October 2016 and could be used if people could access them, allowing the revival of the local economy. In Amatrice, this did not happen. In fact, the lack of conditions for people to safely walk through the streets is a major factor hindering economic recovery. Also, the longer the period in which the centre of the town is closed, the higher becomes the probability that some people will never return, compromising the recovery of the city.

The Italian government declared that the affected towns would be completely rebuilt. However, that will take years, completely modifying the livelihood of the population. Even if the streets and constructions are rebuilt keeping the same architectonic and urban characteristics as before the earthquake, the urban environment may be different, such as stores and urban dynamic, as people will be different. It cannot be taken as granted that the culture, traditions and other factors that are part of the identity of Amatrice before the earthquake will be re-established in the future.

Although there can be locations where the damage is such that resuming living conditions is faster than in Amatrice, as it is the case of Norcia, the large amount of damage may cause traumas and psychological effects that may eventually induce similar effects on the population. As an example, the KnowRISK team got acquainted with several inhabitants of Norcia during the three visits allowing a closer involvement with the reality of the recovery process, including economic, social and psychological aspects of the situation. As it has happened in other earthquakes, in other countries, after several sequences of earthquakes, the population starts questioning whether they should stay or move to a less earthquake-prone region of the country. There is no straight answer to this. Nevertheless, in zones with a high seismic risk, to increase the resilience of local communities it is important to continuously oversee the quality and seismic resistance of the constructions, as well as promoting the prevention of non-structural damage, in order to reduce economic damage, both in the buildings themselves and on their contents as well, and to reduce the likelihood of people being injured or killed".

4.1 Amatrice

In Amatrice, many buildings had to be demolished due to partial or total collapse or because were not repairable. In many cases they were also affecting roads and public areas. After August 24th, 314 buildings have been demolished and debris removed. Temporary houses have been built to accommodate the people that lost their houses and whom, in the aftermath of the earthquake, were initially hosted in tents first and later on hotels or with relatives. In Amatrice the need for 536

temporary dwellings was assessed and by November 2017, and 426 have been already completed and provided to citizens. The number of people that need to be accommodated in temporary houses can be estimated roughly as 2.5 the number of temporary dwellings, which results in about 1340 people. This corresponds to approximately 52% of Amatrice population.

A temporary elementary and middle school has been built immediately after the August earthquake to allow the regular start of the school year. A temporary high school that had moved to the Sport Centre after the August earthquake and made unusable after the October earthquakes, has also been built. All the temporary schools have been built with donations. The October earthquake changed many plans since people had to be relocated in some cases far away from their homes. A temporary health centre has also been built and a temporary food area was set up to relocate the restaurants that resulted unusable.

However, the historical core of Amatrice that was closed just after the August earthquake is still closed and ongoing activities are related to debris removal. Figure 7 shows the red area as it was after the October earthquake and as it was on October 2017, almost one year later. It is exactly the same.

30 October 2016 30 October 2017

Figure 7. Red area in Amatrice after the 30 October 2016 earthquake and one year later (https://www.comune.amatrice.rieti.it)

4.2 Norcia

In the municipality of Norcia, several temporary schools have been immediately built after the earthquake partially with donations and partially with national funds provided to Regions by the Civil Protection Department. Temporary houses have also been built to accommodate the people that lost their houses and that in the aftermath of the earthquake were initially hosted in big containers. In Norcia, the need for 602 temporary dwellings has been assessed. While waiting for the construction of the individual temporary houses, the first of three large size temporary containers (http://container.abc-online.it/) was delivered to the population, at the end of December 2016. The first 20 temporary houses have been provided on January 2017 to citizens that lost their houses in the October 2016 earthquake. By October 2017, 191 temporary houses had been already completed and provided to citizens. Similarly to Amatrice, the number of people to be accommodated in temporary houses can be estimated roughly as being 2.5 the number of dwellings, yielding a total of about 1505 people, about 30% of Norcia population. The ratio of temporary houses to the dwellings in use by resident is 30%, similar to the value found in Amatrice.

Short term countermeasures were implemented in the historical centre, initially by the Fire Brigades and later by private construction companies. As a result of these interventions, the red area, where people cannot have access without Fire Brigade personnel, has been reduced from January 2017 to nowadays. The reduction of the Norcia red area up to August 11th, 2017 is shown in Figure 8.

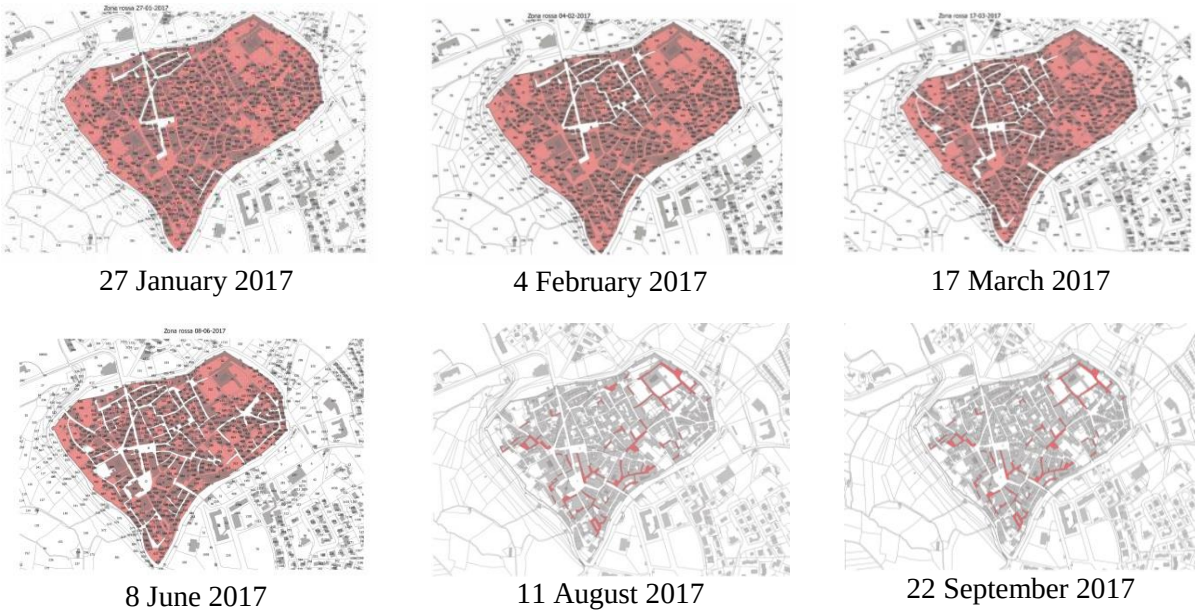

Figure 8. Reduction of the red area in Norcia from January 2017 to September 2017 (www.comune.norcia.pg.it)

The duration of time that buildings, roads and lifelines are not operational disturbs all livelihoods in the affected area, including economic activities. The longer this period is, the higher the likelihood that people won't come back. This may change social characteristics typical of some areas, losing part of the "character" of those zones. After many years into the future, when Norcia is repaired and Amatrice is rebuilt, and life resumes in both towns, there are high probabilities that social changes are higher in Amatrice, as the process will be much longer. In Norcia, these effects, if any, will tend to be much smaller.

5. LESSON LEARNT

The first major lesson from the comparison of the different performances of Norcia and Amatrice constructions is that, in seismic areas, prevention pays off. The seismic strengthening of constructions is able to avoid major collapses and, most important, to save lives. Other comparisons between the seismic performance of old strengthened and unstrengthened constructions, lead to the same conclusion. This inference was also found in events of other countries. Figure 99 shows one of those examples: two adjacent houses in the island of Faial (Azores, Portugal) stroke by a violent earthquake on the July 9th 1998 (Mw 6.1). Both houses are old, and none of the original constructions had been designed to resist earthquakes. However, the left hand side house had been strengthened against earthquakes and the other had not.

Figure 9. Difference of seismic performance between adjacent constructions

The houses were so close that there were no geotechnical differences between their locations and both were subjected to the same seismic action. The comparison is clear and straightforward: the figure shows that the strengthened house resisted the earthquake with minor damage and the unstrengthened house collapsed. Therefore, it is important to draw attention of decision makers and managers of programs of urban rehabilitation in seismic zones for the importance of seismic strengthening in the rehabilitation of constructions. In seismic zones, improvement of aesthetics and living conditions of old and unsafe houses should in general be accompanied by seismic strengthening.

Even though properly strengthened houses survive strong earthquakes, they vibrate and deform during the vibration. These may introduce relevant non-structural damage, part of which can be avoided by appropriate measures taken by common citizens, which is the subject of the KnowRISK project. Moreover, reducing non-structural damage reduces the probability of people getting injured by falling objects and reduces economic damage. Note that the reduction of economic damage is also important for the affected populations to resume their normal life. Figure 1010 shows a recent example in Norcia: during the August earthquake the television fell down and broke. After that, a new television was bought to replace the broken one, but was fixed with chains, as shown in Figure 10 (photo shot by the KnowRISK team on October 28th). With the chains, the television suffered no damage during the October 26th October earthquake. The above example has already been used by the Portuguese team in KnowRISK actions in schools, during which young students are taught how to reduce seismic risk from non-structural elements at school and at home.

Figure 10. Televisions connected to walls by chains to avoid toppling

6. CONCLUSIONS

The comparison between the damages inflicted to Amatrice and Norcia during the Mw 6.0 August 24th and Mw 6.5 October 30th 2016 earthquakes in Central Italy, led to the following conclusions:

- Although there are some differences in seismic intensities in Norcia and Amatrice, the large difference in building performance cannot be attributed to differences in seismic actions alone;

- The lower levels of damage in Norcia were due to the fact that during the last four decades the old constructions of Norcia were strengthened to resist earthquakes, while in Amatrice seismic prevention plans were much poorer;

- Strengthened and retrofitted constructions prevent major damages and save lives.

- To strengthen and retrofit constructions increases resilience. It is strongly likely that the repair and retrofit of damaged constructions in Norcia will be much faster than the reconstruction of Amatrice, leading to a much faster recover of the economy and livelihood of the town. Indeed,

at present time, the red zone of Amatrice is still the same as it was after the August 24th 2016 earthquake while in Norcia it has been reduced since January 2017;

- Long time for rehabilitation act on society and cultural roots. The longer the reconstruction and recovery takes, the higher is the probability of profound social changes, risking the complete loss of traditional traits, uses and customs of the region.

The above conclusions can and should be used for pedagogic purposes in other earthquake-prone areas to demonstrate that seismic strengthening is effective and it is worth the investment. In reality, strengthening not only saves lives and reduces economic damage, but also contributes to the preservation of the building cultural characteristics and the cultural identity of the population that lives in the affected areas as well as it allows a much faster recovery of the economy and faster resume of everyday life.

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