

# THE $M_w$ 6.3 ABRUZZO (ITALY) EARTHQUAKE OF APRIL 6<sup>TH</sup>, 2009: ON SITE OBSERVATIONS

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## SUMMARY

On April 6<sup>th</sup>, 2009, at 3:32 am local time, a  $M_w$  6.3 earthquake struck the Abruzzo region in Italy. This earthquake killed 305 people, with a further 1,500 people injured and approximately 15,000 buildings damaged. Many buildings of significant historical and architectural value were destroyed and several modern buildings were also severely damaged with some having fully collapsed.

The authors visited the disaster zone one month after the earthquake. The most badly affected areas in L'Aquila historical centre and three other villages – San Gregorio, Pagánica and Onna – were inspected.

The main observations made during this reconnaissance trip are briefly presented, highlighting the relevant lessons for engineering practice in New Zealand and Australia.

## INTRODUCTION

On April 6<sup>th</sup>, 2009, at 3:32 am local time (01:32:39 UTC), an  $M_w$  6.3 ( $M_l$  5.8) earthquake struck the Abruzzo region in Italy. This earthquake killed 305 people, with a further 1,500 people injured, and approximately 15,000 buildings destroyed or damaged, forcing the temporary evacuation of more than 70,000 persons [1]. The epicentre of this earthquake was located 7 km north-west of L'Aquila (population 72,000) and 85 km north-east of Rome (Figure 1).

The authors visited the disaster zone one month after the earthquake. The most severely damage zones (red zones) in the historic centre of L'Aquila and three other villages were visited: San Gregorio, Pagánica and Onna (Figure 2). The intensities recorded at these locations were VIII-IX on the Modified Mercalli scale. L'Aquila and Onna have the sad record of the highest death toll during this earthquake, with 203 and 37 victims, respectively.

## SEISMOTECTONIC SETTING

The affected region is tectonically and geologically complex, involving subduction of the Adria micro-plate beneath the Apennines range from east to west, continental collision between the Eurasia and Africa plates, and the opening of the Tyrrhenian basin to the west. The evolution of this system has caused the expression of different types of tectonic faults acting at the same time in a broad region surrounding Italy and the central Mediterranean [2]. The April 6<sup>th</sup>, 2009 earthquake was related to normal faulting having a 15 km long NW-SE strike and SW dip. More than 30 aftershocks with magnitude greater than 3.5 followed the main event, with two aftershocks having magnitudes greater than 5.0 ( $M_l$  5.3 on April 7<sup>th</sup> and  $M_l$  5.1 on April 9<sup>th</sup>) [3].

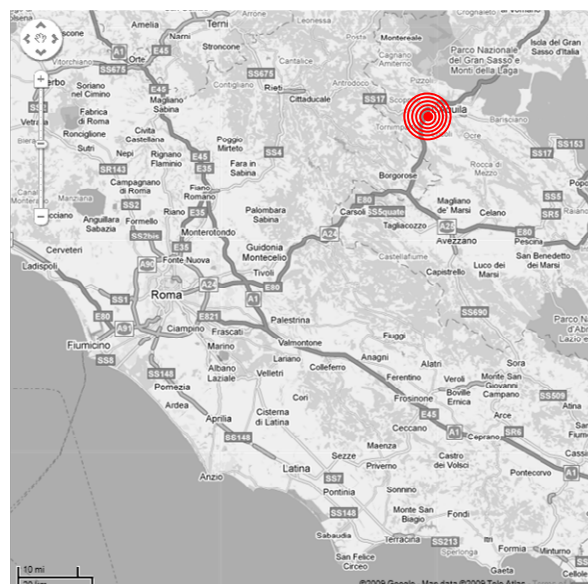


Figure 1: Abruzzo earthquake epicentre location.

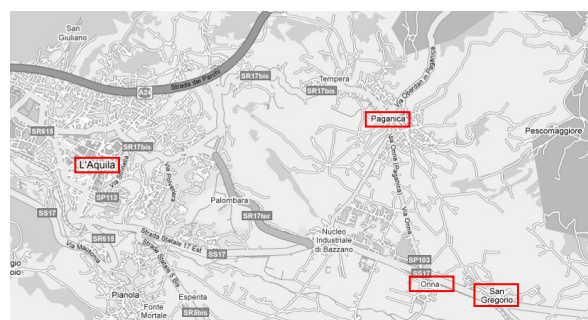


Figure 2: Urban centres visited.

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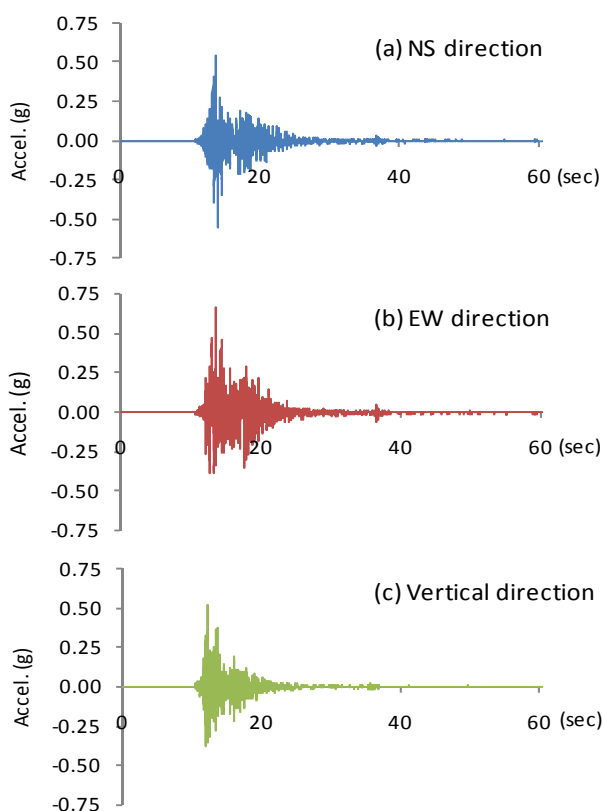
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## GROUND MOTION RECORDS

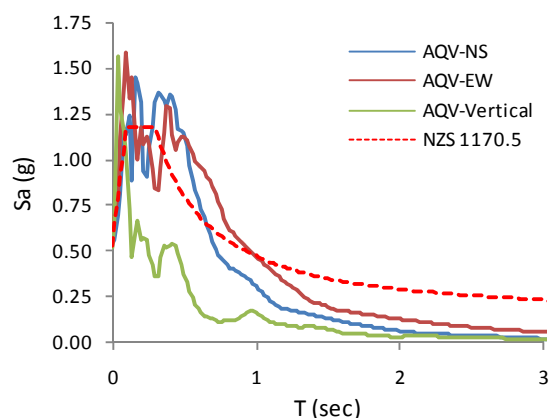
The main shock of this earthquake was recorded by 56 stations. A detailed analysis of these records is presented in reference [4] and the time series of these records are available in the RAN [5] and ITACA [6] websites. Four of these stations are located at a distance of less than 10 km from the epicentre and recorded peak ground accelerations (PGA's) exceeding 0.35g (Table 1). The acceleration time series for the AQV station are presented in Figure 3 and the response spectra are compared with the design spectrum [7] defined for Wellington/Soil C in Figure 4.

**Table 1. PGA recorded in stations with epicentral distance ( $R_{epi}$ ) less than 10 km.**

Code	Station	$R_{epi}$ (km)	PGA (g)
AQA	L'Aquila – V. Aterno – F. Aterno	4.6	0.44
AQG	L'Aquila – V. Aterno – Colle Grilli	4.4	0.52
AQK	Aquil Park Ing.	5.6	0.35
AQV	L'Aquila – V. Aterno – Centro Valle	4.9	0.66



**Figure 3:** Station AQV acceleration time series.



**Figure 4:** Station AQV acceleration response spectra.

## EFFECTS ON HISTORIC BUILDINGS

Typical unreinforced masonry (URM) construction in the region consisted of:

- stone masonry walls, 300 – 500 mm thick, which were often rubble filled and with timber or light concrete/masonry floor systems and timber with clay tile roofs;
- clay masonry walls, 300 – 500 mm thick, with timber floor systems with light concrete topping.

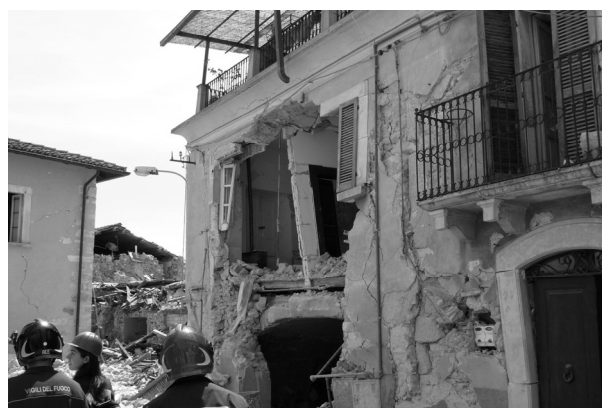
Hence, the most common failure modes observed were associated with out-of-plane failures of parapets, gable-ends and in some cases entire walls (Figures 5 and 6). In-plane failure modes, such as shear cracking and failure of panels adjacent to door or window openings (Figure 7) and shear failure of spandrel beam sections above openings (Figure 8), were also observed, but in most cases did not lead to complete building collapse.

It was particularly interesting to note that in some cases, URM buildings with good horizontal diaphragm action performed poorly (Figure 9). This was thought to be due to the large concentration of inertia force at the floor/roof levels exceeding the capacity of the connections to the vertical in-plane wall elements, resulting in large deformations being imposed on the out-of-plane walls. This damage concentration at diaphragm level was also observed in some buildings that had concrete ring beams (Figure 10) at floor and roof levels installed to 'tie the building together'.

There were also many examples of damage to neighbouring buildings and vehicles parked in streets due to falling masonry (Figure 11), owing to the lack of good cross-ties between the inner and outer faces of stone masonry walls.



**Figure 5:** Out-of-plane failure of walls (San Gregorio).



**Figure 6:** Out-of-plane failure of walls (Onna).



**Figure 7:** *Damage adjacent to openings (San Gregorio).*



**Figure 8:** *Damage in spandrel (San Gregorio).*



**Figure 9:** *Damage concentration at diaphragm level (Onna).*



**Figure 10:** *Collapse of walls with R/C ring beam at roof level (Onna).*



**Figure 11:** *Damage to vehicles because of bricks falling (Pagánica).*

### EFFECTS IN MODERN BUILDINGS

The most common failure mode in more modern buildings (post-WWII for example) seemed to be failure of masonry infill panels and failure of exterior masonry veneer panels. In both cases this was observed to be due to deformation incompatibility between the building frame (typically concrete) and the masonry infill.

Masonry cladding was typically a thin veneer clay masonry brickwork with no positive, mechanical fasteners to the structure. The veneer brickwork simply sat on the floor slabs and was poorly 'fastened' to the structure through some adhesion to the columns. Many examples of the veneer failing out-of-plane were seen (Figure 12). Less common, but still sufficient to cause concern, was the out-of-plane and/or in-plane failure of masonry infill walls (Figure 13). These walls were commonly constructed with perforated clay block units with the perforations running horizontally, where the masonry infill was not supporting any vertical gravity load.

There were several examples of complete collapse in L'Aquila, such as the building shown in Figure 14. Many of these collapses appear to be due to failure of the columns in lower storeys, either due to shear or flexure. Plain round reinforcement bars were found in most of the collapsed concrete frames and failed concrete columns (Figure 15). It was common to observe a lack of confinement, such as transversal reinforcement spaced in excess of 250 mm, and poor cross-section detailing, e.g. 90 degree hooks in the shear ligatures.

Another observation in many of the collapsed or partially collapsed buildings was the use of perforated masonry diaphragm systems. These systems continue to be used in modern construction in Italy and feature perforated masonry units (clay bricks or concrete blocks) which are supported by inverted concrete T-beams that span between the primary concrete or steel girders (refer Figure 16 for typical details). The perforated clay units are topped with concrete but do not appear to have any mechanical connectors with the topping concrete to ensure good monolithic diaphragm behaviour and hence have limited structural benefit when subjected to seismic loading (Figure 17).

It was interesting to see column hinges in one new concrete frame building under construction in Onna, even though the masonry infill was not yet in place. Figure 18 shows damage at the top of one column in the bottom (not basement) storey, where it can be seen that a horizontal failure plane has occurred at the top of the column where it meets the bottom of the beams (i.e. at a construction joint). It appears that at this location the concrete cover has spalled and the compression reinforcement has buckled.



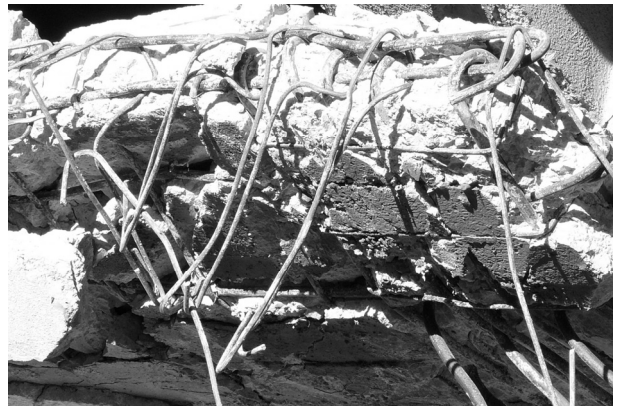
**Figure 12:** *Veneer out-of-plane failure (L'Aquila).*



**Figure 13:** *Masonry infill out-of-plane failure (L'Aquila).*



**Figure 14:** *Collapsed R/C frame building (L'Aquila).*



**Figure 15:** *Plain round reinforcement bars found in collapsed building (L'Aquila).*



**Figure 16:** *Photo of perforated masonry diaphragm system (courtesy of Sanja Hak).*



**Figure 17:** *Damage due to deficient performance of perforated masonry diaphragm system (Onna).*



**Figure 18:** *Plastic hinging and reinforcement buckling at the top of a column (Onna).*

### ENGINEERING ASSISTANCE RECOVERY OPERATIONS

While the search and rescue operations were well over by the time of the visit (four weeks after the April 6<sup>th</sup> earthquake), there was much evidence of propping and shoring of damaged structures by the emergency services personnel (typically firemen). Some of this work was still ongoing during the visit.

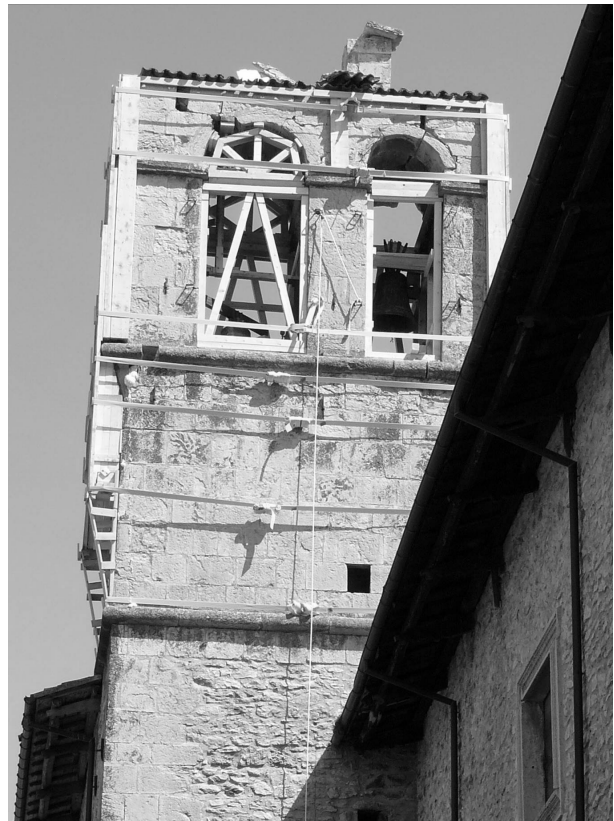
For example, fire brigades (*"Vigili del Fuoco"*) from throughout Italy assisted with the initial search and rescue and subsequent recovery operations. In each of the four townships that we visited, there were many examples of walls that had been shored/propped (Figure 19), columns that had been stabilized (Figure 20), and churches that were being secured (Figures 21 and 22 showing the tower of the *"Chiesa del Castello"* in Pagánica and the *"Chiesa di San Bernardino"* dome in L'Aquila). The availability of large sections of timber and the presence of structural engineering capability in the fire brigades meant that this work was of a high standard.



**Figure 19: Propped structure to prevent the collapse of masonry wall (Onna).**



**Figure 20: Damaged column stabilized with belts (L'Aquila).**



**Figure 21: Tower of "Chiesa del Castello" secured by belts and timber props (Pagánica).**



**Figure 22: Firemen securing the Dome of "Chiesa di San Bernardino" (L'Aquila).**

### LESSONS FOR NEW ZEALAND AND AUSTRALIA

The most significant problems observed in reinforced concrete frame construction were attributable to poor detailing. This situation is very common in buildings designed and constructed prior to 1970, and observed details appeared to be very similar to those found in buildings of comparable vintage in New Zealand and Australia.

Although confined masonry is not common in either New Zealand or Australia, steel and concrete frame construction with clay brick and/or concrete block masonry infill walls are routinely encountered in both countries. As mentioned previously, this type of construction demonstrated a systematic damage pattern associated with in-plane shear failure due to deformation incompatibility between the building frame and infill, which did not necessarily compromise the structural stability of the building. Unfortunately, whilst the damage mode typically did not lead to loss of structural integrity, it is expected that this damage will be expensive to repair.

The use of clay brick for exterior veneer walls remains common in New Zealand and Australia. Although these veneers do not contribute to the structural resistance of the system, damage to neighbouring structures, vehicles or persons, because of falling bricks was regularly observed. In L'Aquila, injury to pedestrians was minimised owing to the fact that the earthquake occurred at 3.32 am, when few people were outside buildings. Had the earthquake occurred during business hours when the streets would have likely been more crowded, the death toll might have been significantly higher. This is a significant issue, considering that in many cases construction details do not include mechanical fasteners between the structure and the brick veneer, and in other situations, the mechanical fasteners have often corroded with time, as observed during the 1989 Newcastle earthquake in Australia. Similar injury and damage due to falling brickwork from the masonry veneer of older buildings would be anticipated in New Zealand and Australia, although this form of construction is encountered to a much greater extent in Australia.

Some buildings, having reinforced concrete ring beams or stiff floor diaphragms, were observed to fail and it was noted that this was most likely due to inadequate strength of the connection between the in-plane walls and floor diaphragms. However, it appeared that the failure mode was still much improved over the many out-of-plane wall failures where little connection or diaphragm action was present. Hence, it was concluded that masonry buildings which were well connected (at wall intersections and between walls and horizontal elements such as floors and roof) performed much better than those having poor connections between structural elements.

Perforated masonry diaphragm systems performed poorly, primarily because of both deficient monolithic diaphragm behaviour and the inadequate diaphragm-to-wall connection, which generated an important mass concentration at floor/roof level, but not necessarily a structural benefit. However, this form of construction (see Figures 16 and 17) is not common in New Zealand or Australia.

Finally, special emphasis is given to the role taken by engineers and architects, not only in rehabilitation tasks immediately after the disaster, but also the efforts made to improve the seismic performance of existing structures and to protect the historical and architectural heritage of the country. In comparatively young nations such as New Zealand and Australia, this is still a "task to do", and the responsibility of preserving this legacy for future generations is partially in the hands of our professional community (architects, engineers and builders).

#### ACKNOWLEDGEMENTS

The authors wish to acknowledge the generous support of the New Zealand Society for Earthquake Engineering for this technical visit. In addition, we express our gratitude to local authorities and colleagues that collaborated with us during this site inspection: Prof. Francesco Benedettini (University of L'Aquila); Prof. Giorgio Monti (University La Sapienza of Rome) who facilitated our visit and access to L'Aquila; Ms Livia de Andreis (PhD Student, University La Sapienza of Rome), who acted as our guide and interpreter (Figure 23); and the various fire brigades (VF Firenze, VF Roma, VF L'Aquila) that escorted us during our visits into the "red zones" (Figure 24).

#### REFERENCES

1. Bazzurro, P., Alexander, D., Clemente, P., Comerio, M., Sortis, A.D., Filippou, F., Goretti, A., Jorjani, M., Mollaioli, F., Mosalam, K., Price, H.J. and Schotanus, M. (2009). "The Mw 6.3 Abruzzo, Italy, earthquake of April 6, 2009". Learning from Earthquakes. *Earthquake Engineering Research Institute*. June 2009.
2. USGS (2009). *Magnitude 6.3 - Central Italy 2009 April 06 01:32:39 UTC*. [cited 23 June 2009]; <http://earthquake.usgs.gov/eqcenter/eqinthenews/2009/us2009fca/>.
3. Istituto Nazionale di Geofisica e Vulcanologia (2009). *The L'Aquila seismic sequence - April 2009*. [cited 23 June 2009]; <http://www.ingv.it>.
4. Ameri, G., Augliera, P., Bindi, D., D'Alema, E., Ladina, C., Lovati, S., Luzi, L., Marzorati, S., Massa, M., Pacor, F. and Puglia, R. (2009). "Strong-motion parameters of the Mw=6.3 Abruzzo (Central Italy) earthquake". *Istituto Nazionale di Geofisica e Vulcanologia*.
5. Rete Accelerometrica Nazionale (2009). *Terremoto Abruzzo: registrazioni della Rete Accelerometrica Nazionale e rapporto dell'Osservatorio Sismico delle Strutture*. [cited 23 June 2009]; [http://www.protezionecivile.it/minisite/index.php?dir\\_pk=1046&cms\\_pk=15425](http://www.protezionecivile.it/minisite/index.php?dir_pk=1046&cms_pk=15425).
6. Istituto Nazionale di Geofisica e Vulcanologia (2009). *Italian Accelerometric Archive (ITACA)*. [cited 23 June 2009]; <http://itaca.mi.ingv.it/ItacaNet/>.
7. SNZ (2004). "NZS 1170.5:2004 - Structural design actions. Earthquake actions". 2004 ed. Wellington, New Zealand: *Standards New Zealand*.



**Figure 23: Reconnaissance team visiting L'Aquila centre.**  
From left: Michael Griffith, Livia de Andreis and Claudio Oyarzo-Vera.



**Figure 24: VF Firenze Brigade based in San Gregorio.**