Case History

Some aspects of the M6.3 April 6 2009, L'Aquila, Italy, earthquake

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On April 6th 2009, 03:32 local time, a strong earthquake hit the town of L'Aquila on the Appenninic chain in central Italy (Fig. 1). The sequence started in December 2008 as a series of small earthquakes and reached its climax in April 2009. Three events above M5 took place on April 6, 7 and 9 which devastated the town and its vicinity. An international team sponsored by GEER project and several Italian-only teams sponsored by AGI and ReLUIS project performed reconnaissance of the event. Most of this note is extracted from their reports ([1] and [2]).

Figure 1. Geodynamic model for the central Mediterrannean (Devoti et al., 2008) and location of L'Aquila earthquake (adapted from [1])

The city of L'Aquila and several small towns along the Aterno river valley suffered severe damage. About 300 people died as a result of the earthquake and several tens of thousands were left homeless. Most of the deaths took place in vulnerable masonry houses which were subjected to unusually strong motions – mainly due to proximity to the fault. In the days following the earthquake, a large number of researchers visited the area. A preliminary report on the main features of the recorded ground motions was compiled by a group of Italian investigators [2] under the umbrella of Italian Geotechnical Association (AGI) and the National Network of Earthquake Engineering Laboratories (ReLUIS) project. A detailed report on seismological and geotechnical aspects of the earthquake was produced by an international group of researchers [1] sponsored by the Geo-Engineering for Extreme Events Reconnaissance (GEER) project. The brief note at hand refers to geotechnical damage and is based on the above works. Information about structural damage is available at ReLUIS web site (www.reluis.it) and elsewhere.

According to Italian Institute of Geophysics and Volcanology (INGV), the main shock took place along a normal fault oriented NW-SE, with local magnitude M_L = 5.8 and moment magnitude M_W = 6.3. The hypocentral depth was estimated at approximately 10 km. Four accelerometric stations (AQV, AQA, AQG, AQK) were located within the surface projection of the fault and recorded peak values ranging from 0.4 to 0.6*g*. Peak computed ground velocities were estimated at around 35 cm/s. All stations were located in the Aterno river valley, NW of L'Aquila city and in the city itself (Fig. 2).

Figure 2. RAN accelerometric stations in the meizoseismal area around the city of L'Aquila (image from GoogleEarth)

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The moderate-size event of April 6 took place at shallow depth and produced severe ground shacking in the near-fault area, which was limited to approximately 250 km^2. The city of L'Aquila happened to be within this zone with catastrophic consequences. As shown in Figs. 3 to 5, the recorded motions are characterised by short durations (less than 10s) and high peak accelerations both in the horizontal and vertical directions. In some cases, peak vertical accelerations are higher than the horizontal ones. Also, the strong portions of vertical and horizontal motions occurred almost simultaneously due to the short travel paths of P and S waves from the fault to the ground surface. This is evident in Fig. 4, where the severe horizontal motion appears to start only about 1s after the vertical one, with a predominant period of 0.4-0.6s. These features can be particularly damaging to weak non-ductile systems, such as the old masonry structures in the area.

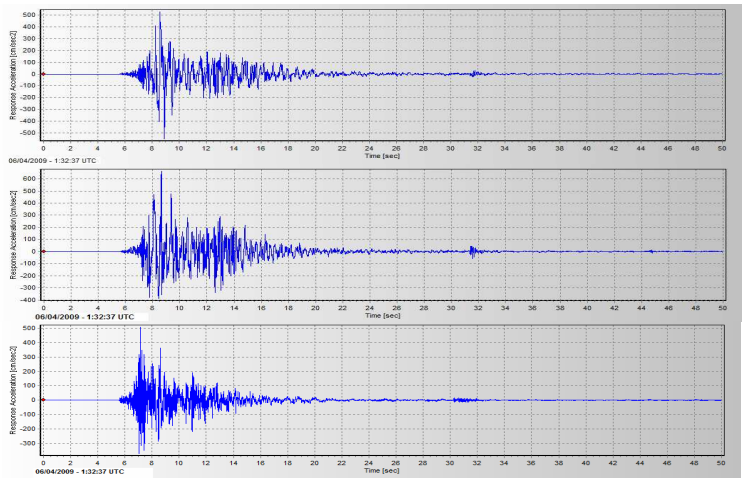

Figure 3. Accelerometric data of AQV station (42.377N; 13.344E), R_E 4.8 km, R_{JB} = 0.
From top to bottom: NS, EW and V components.
Uncorrected data by RAN (Rete Accelerometrica Nazionale) of the Italian "Protezione Civile"

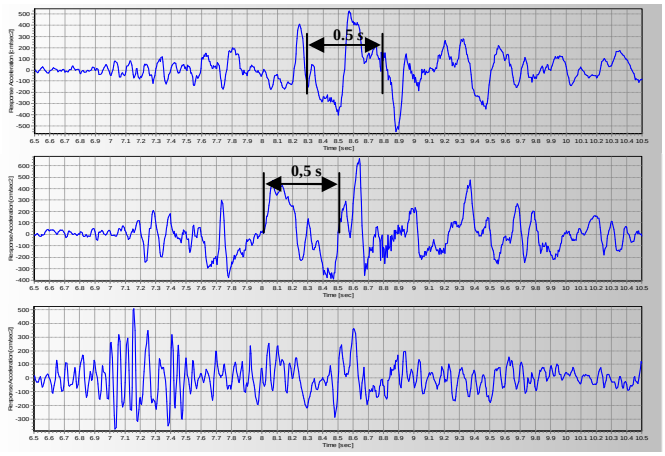

Figure 4. Details of acceleration recordings at AQV station, between approximately 6.5 and 10.5s. From top to bottom: NS component (PGA = 550 cm/s^2, t=8.88s); EW component (PGA= 663 cm/s^2, t=8.64s); V component (PGA= 508 cm/s^2, t=7.16s). (adapted from [2])

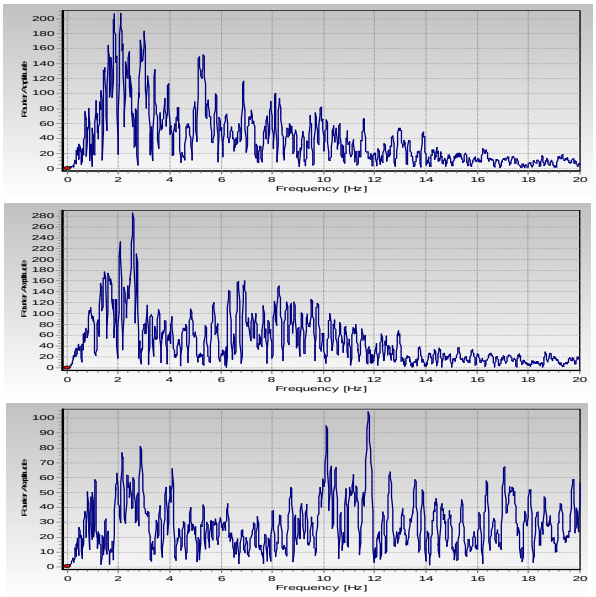

Figure 5. Fourier spectra of AQV station recordings
From the top to bottom: NS, EW, Vertical component
(adapted from [2])

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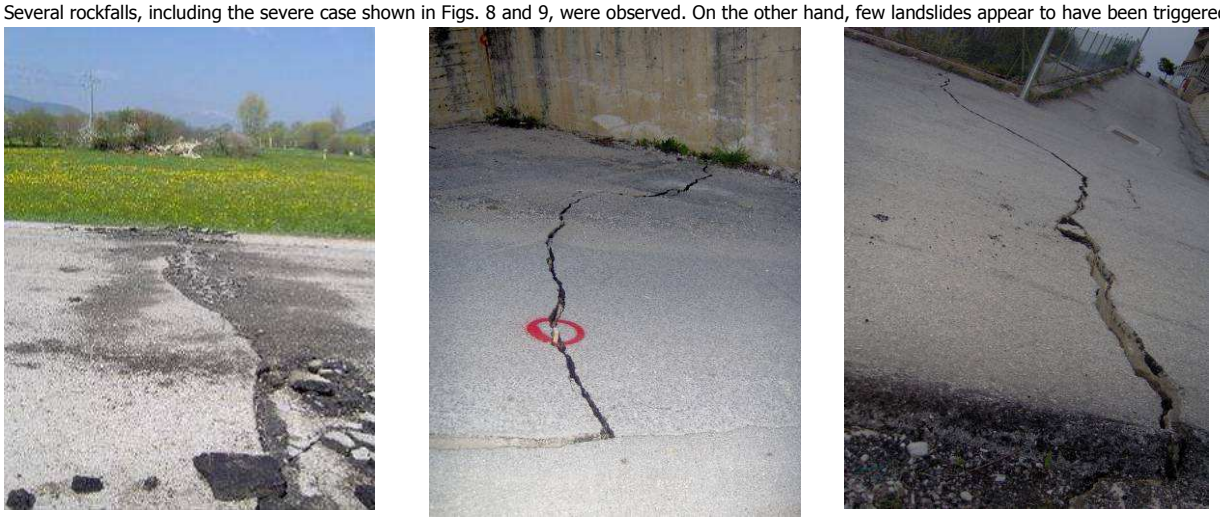
Geotechnical damage was widespread in the meizoseismal area. Here a selection of damage pictures is shown; most of the photos are taken from works [1] and [2]. A wide pattern of ground cracks, in soil and (especially) in road pavements was observed, as evident in Figs. 6 and 7. No conclusive evidence of co-seismic ground rupture has been presented to date. References of possible co-seismic rupture have been made at Paganica and Onna regions.

Several rockfalls, including the severe case shown in Figs. 8 and 9, were observed. On the other hand, few landslides appear to have been triggered.



Figures 6. Cracks in road pavements: near Onna (left) and Paganica (centre and right).

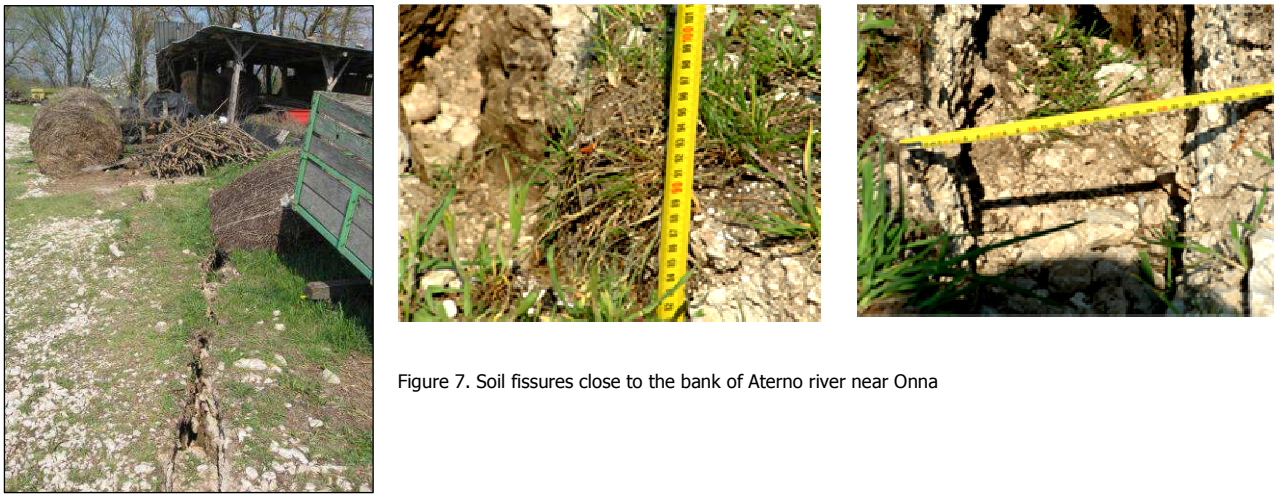


Figure 7. Soil fissures close to the bank of Aterno river near Onna

Figure 8. Rockfall at Caves of Stiffe: last impact mark prior to impacting the building (left); the rock fall impact against the building wall (above)

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An interesting case of ground failure was observed at Lake Sinizzo, near the small town of San Demetrio ne' Vestini, SE of the city of L'Aquila. Almost 80% of the perimeter of the lake collapsed towards the water, exhibiting large sliding and rotational movements (Fig. 10). The lake behaved essentially as a "sink-hole", being situated in a Karstic natural depression. Bathymetric and Lidar measurements are currently in progress to document and monitor the evolution of the phenomenon. Note in this regard that near-surface soil is cohesive and that no sand ejecta were observed.

Only minor liquefaction effects were triggered by the earthquake, none of which caused damage. Retaining walls behaved well, although some failures were observed on unreinforced RC walls. Finally, no damage was observed in 4 water-retaining dams around L'Aquila.

Figure 9. Rockfall at Fossa: the rock fell from the hill on the right, crossed the garage and stopped across the street.

Figure 10. Lake Sinizzo near San Demetrio ne' Vestini. Ground cracks and large displacements along the eastern perimeter (above, left), northwestern perimeter (above, right) and western perimeter (below, left). Submerged trees along the western perimeter (below, right)

References

[1] Stewart, J.P. (Ed.), Di Capua, G., Kayen, R.E., Scott Kieffer, D., Button, E., Biscontin, G., Scasserra, G., Lanzo, G., Tommasi, P., Pagliaroli, A., Silvestri, F., d'Onofrio, A., Simonelli, A.L., Puglia, R., Mylonakis, G., Athanasopoulos, G., Vlahakis, V. - GEER Association Report No. GEER-016, (Version 1. May 6, 2009), "Preliminary Report on the Seismological and Geotechnical Aspects of the April 6 2009 L'Aquila Earthquake in Central Italy", www.geerassociation.org.

[2] Simonelli, A.L., Sica, S., Moccia, F., Penna, A., Lucadamo, C., Mitrione A., Mosca, P., Moscato, T., Rotella, M., Spatola, M.G., Zarra, S. (2009) "Rapporto preliminare sugli effetti indotti sull'ambiente fisico dalla sequenza sismica dell'aquilano - Ver. 1.5", Working group AGI-ReLUIS, www.reluis.it.