

THE L'AQUILA, ITALY EARTHQUAKE OF 6 APRIL 2009

A PRELIMINARY FIELD REPORT BY EEFIT



The L'Aquila (Italy) Earthquake of 6th April 2009

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1.0 INTRODUCTION

An earthquake hit the Abruzzo region of Italy on the 6th April 2009 at 3:32am local time. This earthquake had a moment magnitude of 6.2 M_W and a shallow focal depth (~8-9 km, according to the Istituto Nazionale di Geofisica e Vulcanologia, INGV, 2009: www.ingv.it). The epicentre of the earthquake is located 95 km NE of Rome and 10km West of Aquila, the administrative capital of the region of Abruzzo. Aquila has a population of more than 68,000, and was devastated by the earthquake. The earthquake intensity was seen to have reached IX EMS-98 (see section 3) in the proximity of Aquila. In total the earthquake killed 299 people, injured over 1,500 people and approximately 34,000 people are reported to be living in emergency shelters. The total cost of damage to buildings is estimated to be 2Bn to 3Bn Euro (AIR Worldwide), whilst the insured loss to be in the range 200-400M Euro (AIR Worldwide). Though not of very high magnitude compared to some worldwide events, this is a significant magnitude for a European country.

The close proximity of the causative fault to the town of Aquila caused near total collapse of historical masonry buildings in its town centre, including the town hall, National museum of Abruzzo, and many major historic churches including that of San Bernardino. The earthquake also severely affected reinforced concrete structures of more modern construction. In particular the “Hotel Duca degli Abruzzi” and halls of residence belonging to Aquila University collapsed. Smaller villages within a radius of about 50km of the epicentre were also damaged. The affected buildings are representative of construction types in many European countries. This earthquake is therefore of particular interest to the UK earthquake engineering community.

The UK Earthquake Engineering Field Investigation Team (EEFIT) decided to mount a reconnaissance mission to the Abruzzo region of Italy following the earthquake. This report presents some of the preliminary findings of the team and is written on their immediate return from the field. Further images from the EEFIT Team field mission can be visualised on the Virtual Disaster Viewer (www.virtualdisasterviewer.com). This viewer development is an ongoing project supported by EEFIT and other International earthquake reconnaissance teams. It allows the visualisation of the geo-referenced photos taken by the team, with pre- and post-earthquake satellite images for the affected areas as well as mapped faults.

This report represents the preliminary findings from the earthquake and is aimed at helping further teams plan their reconnaissance and act as a means to disseminate the factual findings, including photographs and other exhibits. Further research on the findings will be published in due course by EEFIT members in peer-reviewed journals.

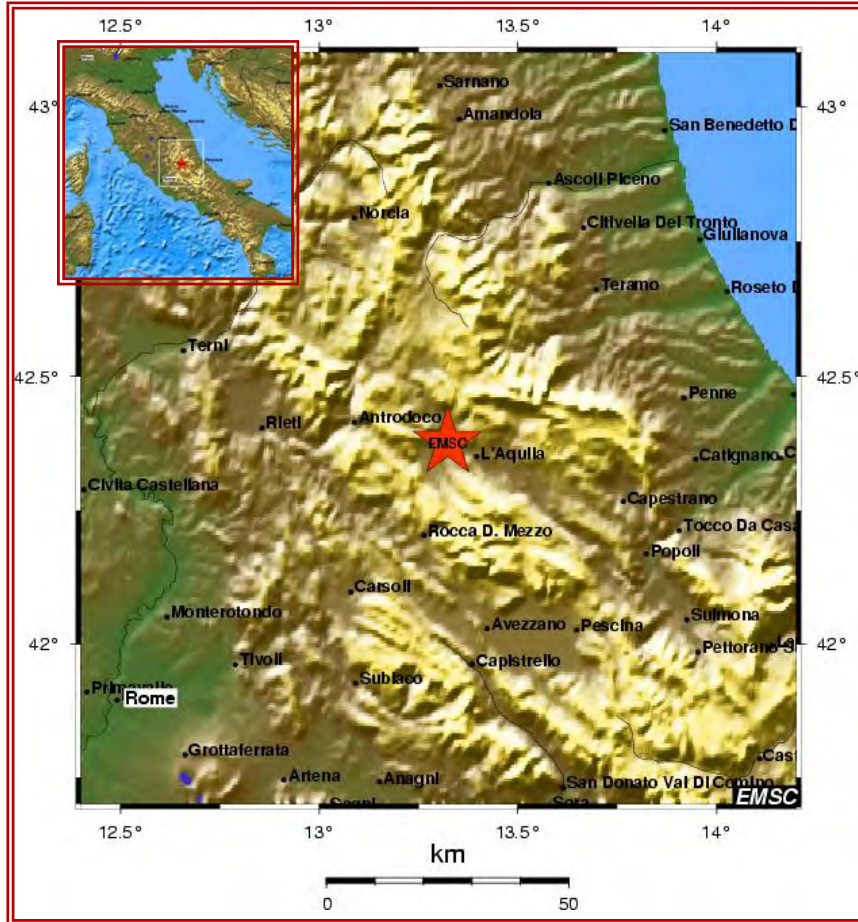


Figure 1: The epicentral location of the M_w 6.2 Aquila Earthquake of the 6th April 2009, (Source: EMSC: European-Mediterranean Seismological Centre).

1.1 THE EEFIT MISSION

An EEFIT committee decision to launch a mission to Italy following the Aquila earthquake was taken on the 8th April 2009. The selected EEFIT team left for Italy on the 17th April 2009 and spent six days in the disaster zone. The EEFIT Italy team was multidisciplinary, consisting of experts in structural and geotechnical earthquake engineering, geology and seismology, geohazards, GIS and remote sensing, special structures and infrastructure, risk modelling and human casualty modelling. The team members are presented in Table 1 and Figure 2.

In Italy the team was joined by Professor Peter Sammonds and Joanna Faure Walker of University College London for two days. They lent their experience of mapping faults in the Abruzzo region to the team. Agostino Goretti of the Italian Civil Protection helped the team gain access to restricted damage areas, and is thanked for his help. On Monday 20th April, Dr Goretti also organised a meeting between the different International teams in Aquila.

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Table 1: The EEFIT Aquila Team

Name	Role	Institution	Expertise
Tiziana Rossetto	Team Leader, Lecturer	University College London	Earthquake engineering, vulnerability of RC buildings
Navin Peiris	Lead Catastrophe Risk Modeller	Risk Management Solutions	Risk modelling, geotechnical earthquake engineering
John Alarcon	Research Associate	AIR Worldwide	Seismic hazard assessment, risk modelling
Emily So	Researcher	Cambridge University	Casualty modelling, earthquake engineering
Susanne Sargeant	Seismologist	British Geological Survey	Seismology, seismic hazard assessment
Domenico Del Re	EEFIT Chairman, Director modle management	Risk Management Solutions	Earthquake engineering, risk modelling
Victoria Sword- Daniels	Geologist	Arup	Geophysical hazards
Matthew Free	Associate	Arup	Geophysical hazards and earthquake engineering
Craig Libberton	Engineer	Sellafield Ltd.	Structural engineering, infrastructure and special structures
Enrica Verrucci	PhD student	University College London	GIS and remote sensing, resilience studies



Figure 2: The EEFIT Team in Abruzzo, Italy. From left: Emily So, Susanne Sargeant, Enrica Verrucci, Victoria Sword-Daniels, Craig Libberton, Navin Peiris, John Alarcon, Domenico Del Re and kneeling: Tiziana Rossetto (n.b. Matthew Free is missing from this photo)

1.2 THE MISSION OBJECTIVES

The main objectives of recent EEFIT missions can be summarised as:

- The detailed technical evaluation of the performance of structures, foundations, civil engineering works and industrial plant within the affected region.
- The collection of local geological and seismographic data, including strong motion records.
- Assessment the effectiveness of earthquake protection methods, including repair and retrofit, and to make comparisons of the actual performance of structures with the expectations of designers.
- The study disaster management procedures and socio-economic effects of the earthquake, including human casualties.

In addition to the above, in the context of the Aquila, Italy earthquake the mission also has the following objectives:

- To observe and review damage experienced by different building types, especially the hospital and historical masonry buildings in the centre of Aquila, and the distribution of damage (in relation to casualties, population and building density).
- To assess the effectiveness of earthquake protection methods, including repair and retrofit, and to make comparisons of the actual performance of structures with the expectations of designers.
- Collect information on strong ground motion and compare these to the seismic hazard maps and design criteria for the area.
- To observe and collect data on landslides and determine their damaging effects on infrastructure.
- To observe and review local construction materials and methods.
- To assess lethality rates of different types of collapsed and damaged buildings and also the survivability in these structures
- Obtain an understanding of the emergency recovery management in this earthquake, and how this can be linked to indicators of resilience.
- To report on the mission findings
- To improve the "Virtual Disaster Viewer", adapt it to the Aquila Earthquake case and provide a multi-source repository and dissemination system for spatially-based earthquake data.
- To train less experienced members of EEFIT on post-earthquake survey techniques.

For the latter objective, four EEFIT members with little experience in post-earthquake surveys were included in the Team (i.e. Craig Libberton, Victoria Sword-Daniels, Susanne Sargeant and Enrica Verrucci).

This report summarises the preliminary observations made in the field by the EEFIT Team and partially satisfies the objective of reporting the mission findings. This web report will be followed by a presentation at the Institution of Structural Engineers in London in May. The virtual disaster viewer (www.virtualdisasterviewer.com) also contains images from the mission, satellite images from before and after the earthquake as well as mapped faults.

2.0 THE AQUILA EARTHQUAKE

On 6 April 2009 (01:32 UTC) a shallow (circa 10 km), moderate-magnitude (6.2 M_w) earthquake occurred in central Italy. The epicentre is located near the city of L'Aquila, about 95 km north-east of Rome (see Figure 1). A summary of the principal event characteristics provided by local and international agencies is presented in Table 2.

The mainshock was preceded by a prolonged swarm-like sequence of foreshocks that began in December 2008 although this was not identified as a warning of a large event and is unlikely to have significantly increased the probability of the main event. There have also been numerous aftershocks (see Figure 3). There is a clear migration of aftershocks to the southeast and northwest. The main shock represents the southwest boundary of the aftershock activity. The five largest of these are listed in Table 3.

Table 2. Summary of the principal earthquake characteristics given by several agencies

Agency	Location		Focal depth (km)	Magnitude	
	Latitude	Longitude		M_w	M_L
INGV	42.33	13.33	8.8	6.2	5.8
EMSC	42.38	13.32	2.0	6.3	
ReNaSS	42.31	13.60	10.0	-	6.3
USGS*	42.423	13.395	10.0	6.3	

Notes: INGV – Istituto Nazionale di Geofisica e Vulcanologia

EMSC – European-Mediterranean Seismological Centre

ReNaSS – Réseau National de Surveillance Sismique (France)

USGS - United States Geological Survey

* USGS epicentral location as reported after the event. It was changed to that from the INGV

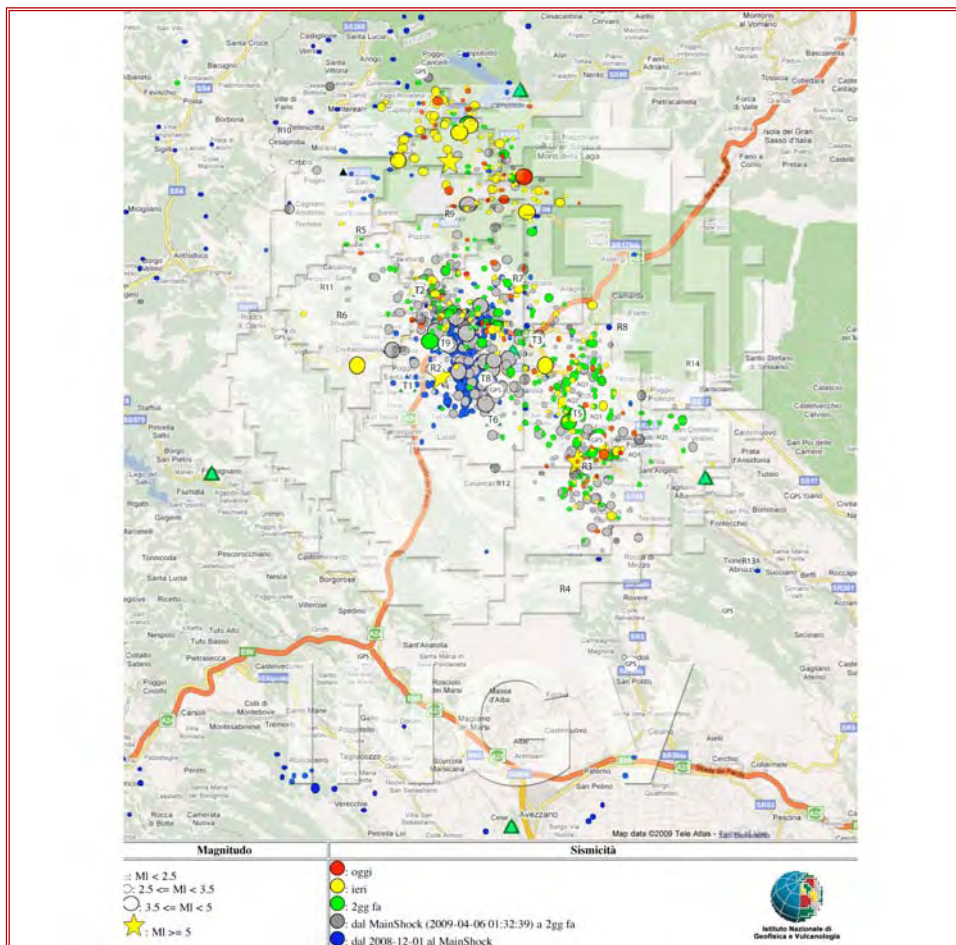


Figure 3: Seismicity in the Abruzzo region until 10 April (Source INGV).

The earthquake occurred in a zone of moderate seismic activity that is concentrated along the apex of the Apennines. This event is located 140km from the 5.9 magnitude earthquake of October 2002, 100 km from the Umbria, Marche earthquake sequence of 1997 and 240 km of the 6.8 M_s Naples earthquake of November 1980 (BGS). Significant historical earthquakes that have affected the region include the 1703 sequence (14 January Norcia, 2 February Aquilano). Figure 4 shows the historical and instrumental earthquakes recorded in Central Italy from 1005 A.D. with magnitudes larger than 5.0. The Paganica Fault has had two historical earthquakes assigned to it in 1461 (Intensity X, Mo 6.1) and 1762 (Intensity IX-X, Mo 5.5) (Pace et al., 2006)

Table 3: Source parameters for the five largest aftershocks (INGV)

Date	Time	Lat	Lon	Dep	ML	Location
06/04/2009	23:15:37	42.451	13.364	8.6	4.8	Gran_Sasso
07/04/2009	09:26:28	42.342	13.388	10.2	4.7	Aquilano
07/04/2009	17:47:37	42.275	13.464	15.1	5.3	Valle_dell'Aterno
09/04/2009	00:52:59	42.484	13.343	15.4	5.1	Gran_Sasso
09/04/2009	19:38:16	42.501	13.356	17.2	4.9	Gran_Sasso
13/04/2009	21:14:24	42.504	13.363	7.5	4.9	Gran_Sasso

Focal mechanisms from various agencies are broadly consistent and indicate normal faulting on a north-west – south-east trending fault plane, in line with the regional tectonic regime, which is dominated by east-west extension

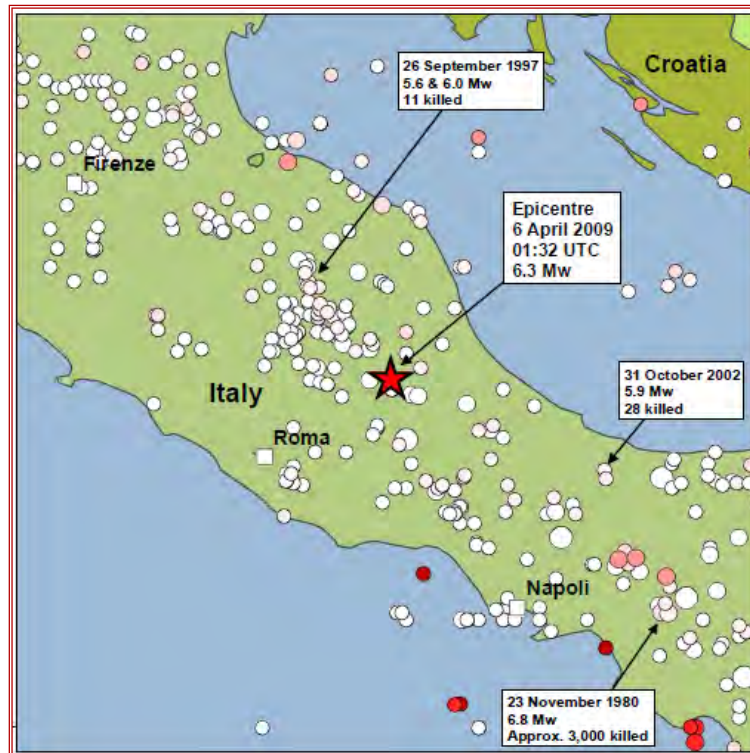


Figure 4. Historical and instrumental events with magnitudes larger than 5.0 recorded in Central Italy since 1005 A.D. Light colour events correspond to shallow events whilst dark colour earthquakes correspond to deep events (Source: BGS)

The USGS Shake-map calculated intensities (not reviewed) present a maximum MMI intensity of VIII. Since the earthquake, local agencies have been assessing intensity both in the field and using online macroseismic questionnaires. The EEFIT team carried out their own assessment of EMS-98 Intensity in the towns they visited (see Section 3)

Both INGV and the Protezione Civile Nazionale (PCN) operate strong motion networks in the area. INGV also deployed a network of temporary sensors following the mainshock. Table 4 presents the peak ground accelerations (PGA) recorded by the RAN (Rete Accelerometrica Nazionale) network of PCN within 50 km from the epicentre. Very high values of PGA (0.67g) were recorded near Aquila town centre, but as previously stated the site classification at recording stations is as yet unknown.

Figure 5 shows the PGA values as a function of the epicentral distance for the entire RAN network (56 recordings). For comparative purposes, Figure 5 includes the ground motions predicted using the Akkar & Bommer (2007) PGA predictive equations. Data about site classification at each station is not available yet. The Akkar & Bommer (2007) predictions are presented considering rock, stiff soil and

soft soil conditions. The distance measure was assumed to be identical to the epicentral distance and the Akkar & Bommer (2007) parameters were set to Normal faulting.

Table 4: PGA values recorded by RAN network within 50 km of the epicentre (Source PCN)

Station Code	Province	Lat N	Log E	PGA (m/s ²)	PGA (g)	Epicentral distance (km)
AQV	L' Aquila	42.377	13.344	6.626	0.675	4.85
AQG	L' Aquila	42.373	13.337	5.049	0.515	4.34
AQA	L' Aquila	42.376	13.339	4.780	0.487	4.69
AQK	L' Aquila	42.345	13.401	3.663	0.373	5.64
GSA	L' Aquila	42.421	13.519	1.489	0.152	18.01
CLN	L' Aquila	42.085	13.521	0.894	0.091	31.68
AVZ	L' Aquila	42.027	13.426	0.677	0.069	34.97
ORC	L' Aquila	41.954	13.642	0.644	0.066	49.30
MTR	L' Aquila	42.524	13.245	0.622	0.063	22.35
GSG	L' Aquila	42.460	13.550	0.292	0.030	22.60
FMG	Rieti	42.268	13.117	0.264	0.027	19.30
ANT	Rieti	42.418	13.079	0.259	0.026	22.93
CSO1	L' Aquila	42.101	13.088	0.183	0.019	32.89
LSS	Rieti	42.558	12.969	0.086	0.009	38.95
MMP1	Rieti	42.249	12.748	0.089	0.009	49.12

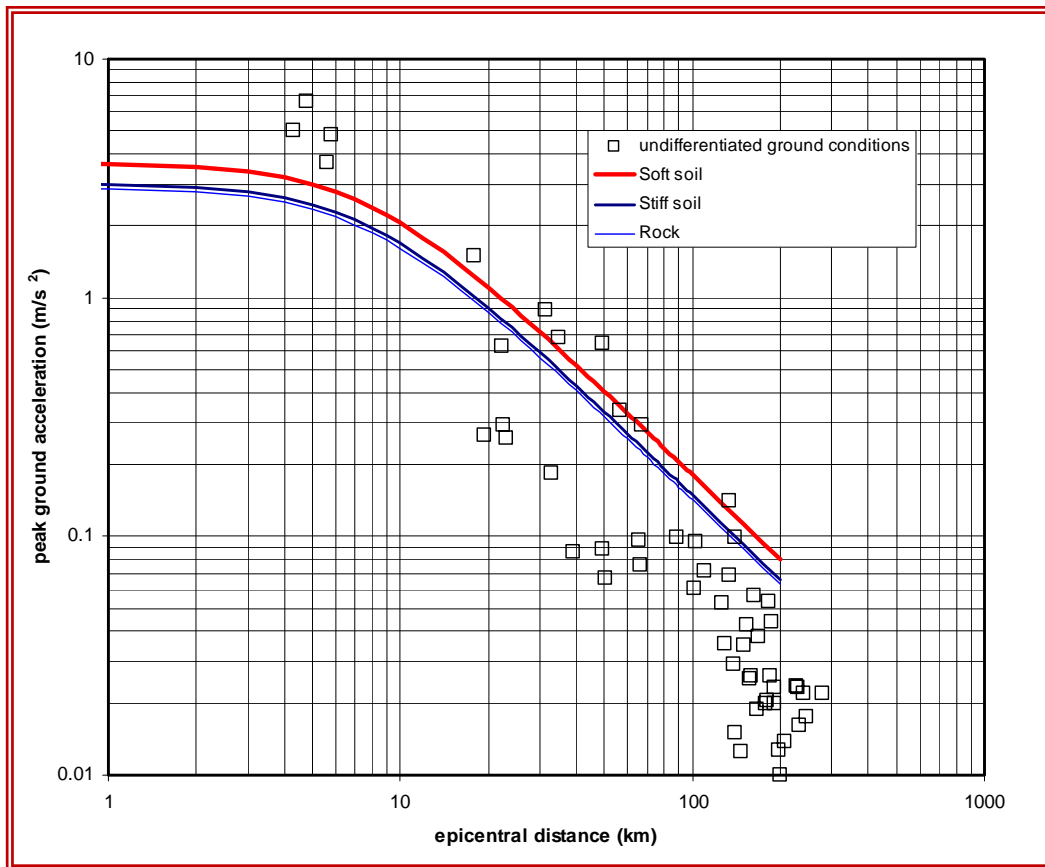


Figure 5. Recorded ground motions (squares) and Akkar & Bommer (2007) predictions for three site conditions (continuous lines).

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A zone of tension cracks was observed at Paganica near to the alignment of surface rupture predicted by InSar interferogram (see Figure 6). The predicted fault surface rupture model indicates the strike and dip of the fault plane to be 143 and 60 degrees respectively and is predicted to occur approximately 9km northwest of the INGV epicentre. This is consistent with a normal faulting model with rupture initiating at a depth of approximately 10km. The observed tension cracks extended over approximately 1km with individual cracks measured over 5 to 20m in length. A 700mm diameter high pressure water pipe, which crossed the alignment of the tension cracks at Paganica, is understood to have ruptured during or soon after the earthquake and was under repair at the time of the EEFIT visit to the area. 49 measurements of the tension cracks at 6 sites (a grassy slope, 2 tarmac roads, a cement floor, a soil bed and a concrete pavement) show the fault slip vector azimuth, plunge and strike of the fault is 219, 57 and 110 degrees respectively. An average of 50mm (maximum 90mm) horizontal and 50mm vertical displacement was measured at the surface, corresponding to 70 to 100mm of surface slip. These findings are consistent with preliminary results found using InSar, focal mechanisms of the main shock and with the regional tectonics which is dominated by northeast-southwest extension

The InSar shows the maximum subsidence occurred near the village of Onna, where some of the worst damage was observed (see Figure 6).

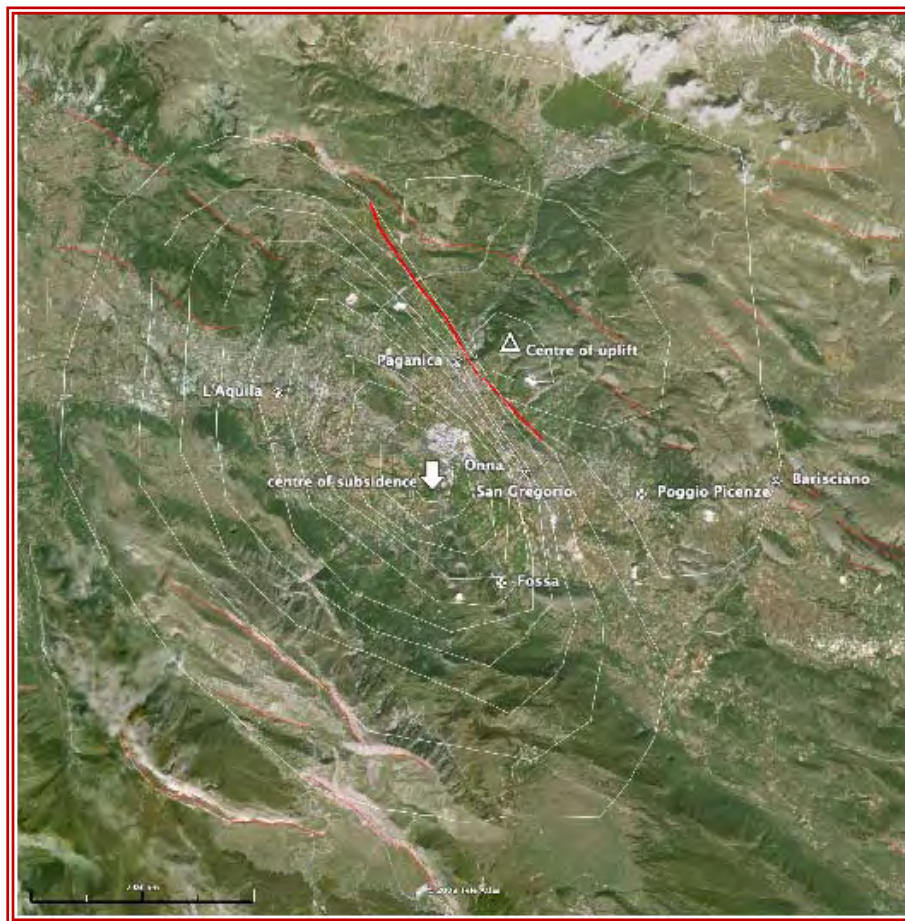


Figure 6: Interferogram fringes showing ground motion following the 6th April 2009 Earthquake (<ftp://ftp.earth.ox.ac.uk/pub/richardw/>). Each fringe represents 28mm of ground movement in the line of site of the satellite. Preliminary results show the strike and dip of the fault plane to be 143 and 60 degrees respectively and at depth there was 0.7m of slip.

3.0 OVERVIEW OF OBSERVED DAMAGE

The damage observed from the L'Aquila earthquake varied substantially depending on the location, building typology, age of construction and condition. Figure 7 shows the surveyed locations in and around L'Aquila with a summary estimate of the EMS-98 intensity in each city based on damage surveys carried out by the EEFIT team. These surveys were not comprehensive macro-seismic surveys and were carried out in a small time window, sometimes for only part of the village/town visited, with the purpose of gaining an overall understanding of the extent of the affected area. Detailed surveys are underway by Italian authorities. For the purpose of the intensity survey, masonry residential buildings have been assumed Class B vulnerability and reinforced concrete buildings class D, except for in locations of pre-code or old-code (pre-1974 to 1980) reinforced concrete buildings that were assigned to class C vulnerability. This figure shows that there appears to be more damage in the valley region of L'Aquila than over the sloping topography, and more damage east of Aquila compared to the west.

The pattern of damage is such that the historic stone masonry buildings without any restoration and retrofitting experienced substantial damage ranging from extensive damage to collapse. Those buildings with steel ties and RC ring beams performed relatively better with damage ranging from slight to moderate with some extensive damage. The RC construction generally performed well compared to masonry construction where majority of structures experienced slight damage particularly to the infill wall panels. The following sub-sections describe damage observed in Aquila and select towns with different values of intensity. Section 4.0 discusses specific structural details of buildings.

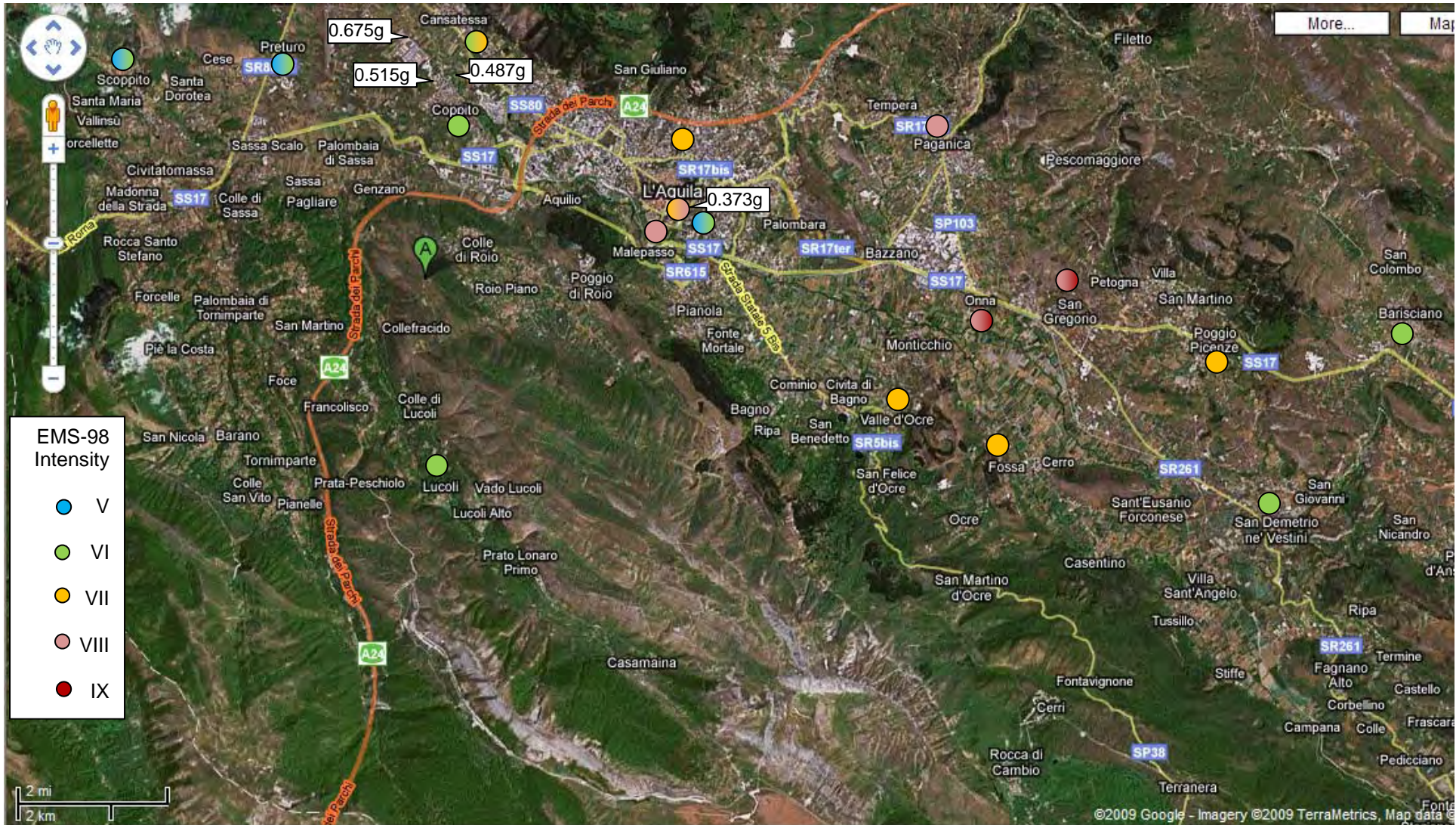


Figure 7: Surveyed locations in L'Aquila and estimated EMS-98 intensity. "A" indicates the location of the epicentre. Dots with two colours indicate the intensity lies between two values. The values in rectangular call-outs are the recorded PGA values at sites in and near Aquila (as reported in Table 4)

3.1 Aquila Town Centre (VII – VIII)

The city of Aquila is the administrative capital of the Abruzzo region in Italy. Surrounded by the highest mountains of the Apennines with the Gran Sasso to the north-east, Aquila is situated on the edges of an alluvial plain and is bounded by the Aterno River to the west, at an elevation of 2,150 feet (655 meters), and covers an area of 466 km². The oldest part of L'Aquila city centre is the walled city which straddles a hill and has dense housing, commercial and administration buildings in an area of less than 2km². The road network is on a grid where the city is flattest at the top of the hill, but the regular grids are lost on the slopes. The two main axes of the city are the Corso Federico II/Corso Emanuele, and the Via Roma/Corso Umberto. These main roads are little more than 7m wide, with roads in the rest of the city as narrow as 2.5m.

Aquila experienced a destructive earthquake in 1703. As a result, the majority of residential buildings in the walled city post-date 1703. The inner part of the city has a medieval layout with low rise masonry buildings and many historical monuments which include the important Church of Santa Maria del Suffragio (called Church of Anime Sante by locals) in the main square Piazza del Duomo. The Church of Anime Sante was built in 1713 by the fraternal order wedded to Santa Maria del Suffragio. The order chose Piazza Duomo for the construction of a new chapel after the 1703 earthquake which caused heavy damage to the prior chapel, situated to the rear of Saint Maxim Cathedral. The construction, designed by the architect Carlo Buratti, required many years and was completed in 1775. The central chapel of rectangular shape with barrel vault presents two smaller chapels on each side and a neoclassical dome designed to widen the area reserved to the presbytery. This dome collapsed in the April 6, 2009 earthquake (Figure 8).



Figure 8: Church of Santa Maria del Suffragio, which dome was damaged during the April 6, 2009 event.

Another important landmark is the 13th Century Fontana della Riviera. The fountain of 99 taps is one of the most ancient monuments in Aquila and is considered a symbol of the city. The fountain was not damaged by the earthquake.

In L'Aquila, the buildings are by vast majority stone masonry buildings. These were typically 2-4 storeys high with intersecting cut stone coins at the corners (Figure 10). The quality of the stone structural walls and mortar is seen to vary. Stone masonry walls are made of two withes of dressed rectangular stones of regular size with debris of smaller size used as fill ("a sacco" construction).

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Many, especially smaller buildings, have wythes which are instead made with uncut stone. Mortar is usually lime mortar and, roofs and floors are supported by wood beams or masonry vaults. What is evident from the surveys carried out in the city is that most of these 18th century buildings have been strengthened in some manner. The degree and quality of retrofit measures differ, ranging from traditional wall ties at floor levels, to anchors into the buildings and steel section lintel beams above openings. Based on the observation of external damage it can be estimated around 1 in 3 buildings in central Aquila experienced at least minor damage to the load bearing walls. Many also have internal damage in the form of collapsed internal walls and floors.



Figure 9: The Fontana della Riviera after the 6th April 2009 earthquake



Figure 10: Typical residential street in the historic centre of L'Aquila flanked by 2-3 storey stone masonry buildings



Figure 11: An example of a pre-1975 concrete frame reinforced concrete apartment block in L'Aquila, typically 5-8 storeys

In areas near to the walled city boundary, some housing is composed of reinforced concrete multi-storey frames, built from the 1970's to 1990's (Figure 11). Most such buildings suffered damage to infill walls, and three complete collapses were observed (see section 4.1).

At the time of the EEFIT visit, between 18th and 22nd April, the city was labelled Red Zone, it was not inhabited and access was exclusively under escort of the Fire Brigade. At the time of writing there is a lot of uncertainty about how long it will take to repair, reconstruct and make L'Aquila a safe and habitable city.

A PGA value of 0.373g was recorded in a car-park near the city of Aquila (as seen in Figure 8). A more detailed analysis of the EEFIT data is required in order to link the detailed surveys carried out by the team with PGA.

3.2 Pettino

Pettino is located in the North West suburbs of Aquila. The EEFIT team observed damage in a series of 6 residential blocks built in the 1980s extending up a hill-side. These buildings all consisted of reinforced concrete frames with hollow clay block infill (Laterizi). Two buildings suffered soft-storey failure (see Section 4.1). However, an adjacent block with open plan ground floor survived with negligible damage to lower storey columns. All suffered extensive infill panel damage.

At the top of the hill a 5-storey RC Frame with approximately 80m x 20m plan and built in 1990 suffered extensive damage to non-structural elements and moderate damage in structural elements. Shear cracks in connections were observed. Poor reinforcement anchorage and lack of ties were evident. New two storey RC villas had recently been completed in the vicinity and were undamaged.



Figure 12: Detail of the 5 storey residential block at the top of the hill at Pettino, showing shear cracks in beam-column connection and infill panel failure.

3.3 Onna (VIII-IX)

Onna is small town with a population of 350 located approximately 7.5km ESE of L'Aquila City on the north side of the Aterno River. There are only approximately 120 buildings in the town in total. The town is located within a broad valley adjacent to the river. The topography is flat and the ground conditions are expected to comprise recent alluvium deposits underlain by lacustrine deposits overlying limestone bedrock at hundreds of meters depth. At the time of writing of this report we have not been able to identify whether a strong motion station is located in close proximity to Onna and therefore we are unable to report on the level of ground motion at the site. The USGS ShakeMap indicates that the shaking is likely to have been very strong to severe (PGA in the range 1.8 – 6.5m/s²).

The building stock in the town is dominated by old, two to three storeys, stone masonry buildings with wood frame roofs covered with clay tiles. Many of these buildings have undergone alterations and the alterations have been constructed using clay brick, concrete block, wood board, or reinforced concrete. Steel beams were seen to have been used in a few of the altered buildings. In many cases these led to the buildings being a composite masonry construction (see Figure 14). These masonry and composite masonry buildings experienced a broad range of damage from moderate damage (Grade 2) with cracks in many walls to many cases of partial or total collapse (Grade 5). An old, stone masonry church located in the centre of the town experienced very heavy damage with failure of some walls and partial collapse of the roof (see Figure 15).

Two to three storeys, reinforced concrete frame buildings with clay brick infill walls are less common in the town. These buildings generally experienced lower levels of damage compared to the masonry structures (Figure 16). A school building comprising a single storey, reinforced concrete frame with clay brick infill walls structure experienced negligible to slight damage (Figure 17).

A systematic damage survey was undertaken in the town to obtain representative damage statistics. Forty-six buildings were surveyed and of these 44 were masonry and 2 were reinforced concrete frame. The survey results are presented in Table 5

Table 5: Surveyed distribution of building damage in Onna

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Town	Total number buildings surveyed	D0	D1	D2	D3	D4	D5
Masonry	44	0	2	7	2	16	17
R.C.	2	1	1	0	0	0	0
Total	46	1	3	7	2	16	17

The preliminary death toll after the main-shock is reported to have been 33, i.e. 9.4% of the total population.



Figure 13: View to south down Onna main road showing very heavy damage (Grade 4) and destruction (Grade 5) of typical masonry buildings.



Figure 14: View of total collapse (Grade 5) of masonry building showing composite nature of building materials.



Figure 15: View of very heavy damage to church with wall failure and partial collapse of roof.



Figure 16: View of partially collapsed masonry building (left) and negligibly damaged reinforced concrete building (right).



Figure 17: View of reinforced concrete frame with infill brick wall school building showing negligible damage.

3.4 Barisciano (VI)

Barisciano is located on the route SS17 southeast of L'Aquila. It has a population of 1400 and sustained 3 injuries and no deaths. This is consistent with the extent of damage observed within the town. The town centre is composed of 2-3 storey masonry buildings, with wythes made of uncut stone and filled with smaller rubble ("a sacco"). The damage seen on most of the buildings ranged from slight cracking to falling plaster. Very few modern residential buildings were observed in the town, however many of the old masonry buildings had been restored and strengthened with ring beams or ties. These seemed to be effective for the level of ground shaking experienced in Barisciano, as is shown in Figure 18 where a partially collapsed building that has not been strengthened (Figure 18a) stands beside a undamaged building that has been retrofit with a ring beam at roof level (Figure 18b).



(a)



(b)

Figure 18: Partially collapsed stone masonry, 2-storey, residential building (a), besides a similar undamaged building with reinforced concrete ring beam at roof level (b).

3.5 Poggio Picenze (VII)

Poggio Picenze consists of an old town centre with masonry structures of similar typology to those in Barisciano and Onna (Figure 19). Surrounding the town was an extended area of modern reinforced concrete moment resisting frame constructions (Figure 20). Both structural typologies are of 2 to 3 storeys in height. Approximately 70% of the masonry buildings in the town centre suffered some damage with 10% sustaining partial collapse. Some of the masonry properties were in the process of

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renovation with the addition of strengthening such as concrete ring beam at roof level, cross ties and mesh reinforcement in the render (Figure 21). It was observed that masonry structures that had been retrofit sustained substantially less damage than those that had not been retrofit. Approximately 5% of reinforced concrete frame structures suffered damage but this was non-structural damage to infill block-work panels and was generally rated as slight. The population of the town is 1100 and there were 7 fatalities



Figure 19: Reinforced Concrete frame structure with damage to infill panel



Figure 20: Collapsed masonry structure



Figure 21: Masonry Structure in Process of Strengthening.

3.6 San Gregorio (VIII-IX)

San Gregorio is located about 8.5 km to the Southeast of L'Aquila. The total population is approximately 600 people and the city sustained 9 casualties. A significant proportion of the houses in the centre are two to three storey stone masonry buildings, again similar to those described for Onna and Barisciano. During the field survey it was estimated that more than 60% of these structures had at least slight damage, with about 10% of the houses having total or partial collapse (Figure 22).



Figure 22. Example of masonry building damage in San Gregorio.

Two distinct features were observed at St Gregorio. The first of these being that San Gregorio is the farthest town from L'Aquila, towards the Southeast, in which reinforced concrete structures were observed having slight or moderate damage. The second particular feature is the finding of a soft storey collapse of a RC structure (see Section 4).

3.7 Paganica (VIII)

As in most other towns near Aquila, the historical centre of Paganica mainly comprises 2-3 storey, masonry buildings with wood beam roofs. A particular feature of these buildings is their use of steel beam floors supporting clay hollow bricks that have been screed with concrete (without steel mesh, hence unreinforced). The steel beams consist of I-sections with 100mm width and 150mm height. The beams are seated on stones in the wall of 30-50mm depth, or are placed all the way through walls and can be seen extending out 100mm from the exterior wall face. This differs from other towns where the floor systems adopted precast reinforced concrete beams instead of the steel beams, and commonly adopted steel mesh in the overlaying screed. The lack of seating of the beams caused the collapse of floors in buildings. This was seen to occur even where the external walls of the buildings sustained little damage.

Most (90%) of the observed masonry structures suffered Grade 4 or 5 damage. Uniform tie beams were seen to restrain exterior walls from falling out but did not stop floors from collapsing internally. The mortar used was observed to be of particularly low quality and no stone coins were present in the corners of buildings. Small changes in the quality of materials and even simple repointing was observed to make a large difference in reducing sustained damage. A recently restored stone masonry church was observed to have sustained no damage to its main structure, but some damage to its bell tower and its rose window.



Figure 23: Panoramic view of damaged masonry houses in Paganica



Figure 24: Recently restored masonry house in central Paganica that sustained no damage

Recently built reinforced concrete frame buildings with full clay brick or concrete block infill were present in the periphery of the old town centre. These constructions sustained slight to no damage (see Section 4).

4.0 OVERVIEW OF THE PERFORMANCE OF BUILDINGS

This section provides a preliminary overview of the performance of the different types of buildings as observed by the EEFIT Team. It brings together observations made in different areas in order to generalise performance of buildings by building class.

4.1 Reinforced Concrete (RC) Buildings

The first building code for reinforced concrete (RC) construction in Italy was published in 1939 (Royal Decree no. 2229). Subsequently updated several times through a series of Government Decrees and Circulars. Of special notice is Law no.64 of 1974 and subsequent Governmental Decree in March 1975, which for the first time introduce the concept of response spectra to the seismic design of buildings in Italy. According to the codes, two conditions of loading must be considered in the building design and verification: the “Normal” load case, which considers all possible gravity and live load combinations, and the “Exceptional” load case, which considers all possible seismic, gravity and live load combinations, excluding wind actions. A series of revisions follow the introduction of these codes, with major re-hauling of the code taking place in 1986, 1996 and 2003. A series of revisions to seismic hazard maps of Italy also accompany these building codes.

The main RC buildings observed in the affected region consist of 2 to 4 storey residential buildings and multi-storey (up to 8 storey) residential and office buildings. All these structures are moment resisting RC frames with either hollow clay brick infill or concrete block infill. The floor is composed of beam and block construction, where small RC precast beams with steel reinforcement in the bottom, support hollow clay blocks over which wire mesh and concrete screed is placed. Roofs often consisted of the same construction as the flooring, and sometimes of RC slab.

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In the majority of towns surrounding Aquila the reinforced concrete frames were undamaged with varying levels of damage to the infill panelling (e.g. Figure 25). This makes them easily repairable, but the extent of infill damage sometimes precluded immediate occupancy. At this stage we cannot comment on the appropriateness of this performance, as we cannot yet correlate observed damage to the ground motion experienced in the surveyed areas.



Figure 25: RC frame in Aquila Centre with severe damage to infill but intact structural frame.

Exceptions to this were three observed soft-storey failures in Pettino (2) and San Gregorio (1). In all these cases failure was precipitated by irregular stiffness in elevation. Poor detailing of reinforcement in connections was evident as well as lack of confinement in columns (see Figures 26 to 28). These structures date from the mid 1980s and should have contained a degree of seismic design.



Figure 26: Three storey RC frame with soft-storey failure in Pettino.

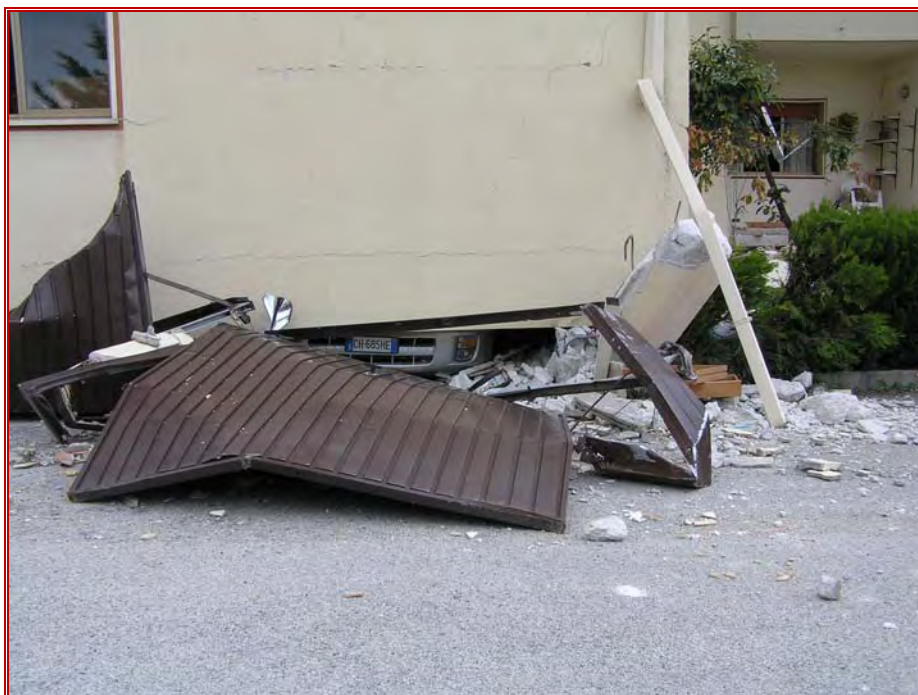


Figure 27: Detail of second soft-storey collapsed RC frame in Pettino



Figure 28: Detail of soft-storey collapse of RC frame in San Gregorio

Three major failures to RC frames were also observed by the EEFIT Team in Aquila Centre: the Aquila University halls of residence, a 5 storey (with basement) residential building (Figure 31) and the Hotel Duca degli Abruzzi (Figure 29). In all cases the buildings were constructed in the late 1970's, just after the introduction of the first seismic code for RC buildings was introduced in Italy. In each case a section of the building underwent total collapse indicating a lack of robustness and redundancy of members. The Hotel degli Abruzzi seems to have failed through a combination of soft-storey mechanism formation exacerbated by sloping topology. Poor detailing of column reinforcement was observed with smooth reinforcing bars and inadequate confinement steel (Figure 30) that seems incongruent with the requirements of the 1974 code. In the case of the halls of residence, it was not possible to identify the failure mechanism due to site clearance for rescue. However, from exposed connections and rubble, smooth reinforcement was again present. In the residential building one of the main problems is seen to be the lack of transverse reinforcement in columns and connections. Columns seem to have failed in compression before beam yielding. Despite these collapses, the majority of RC frame buildings in Aquila town centre were not structurally damaged but sustained extensive non-structural damage.



Figure 29: Hotel Degli Abruzzi in Aquila. Soft-storey failure of RC frame.



Figure 30: Detail of failed column from Hotel degli Abruzzi in Aquila



Figure 31: Residential building in Aquila on Via XX Settembre.

An example of modern good detailing was observed above the town of Paganica. A series of modern 3 storey residential houses were virtually undamaged by the strong ground shaking, despite being located near Paganica old town centre that suffered 90% damage to its masonry buildings. Figure 32 shows a three storey RC Frame with clay full brick infill that was built in 2001. Evidence of strong ground shaking was observed through falling objects in the house as well as radiator pull-out from wall and wardrobe pounding (Figure 33). However, the house suffered only minimal hairline cracking between infill and frame.



Figure 32: RC 2001 residential two-storey above Paganica Undamaged

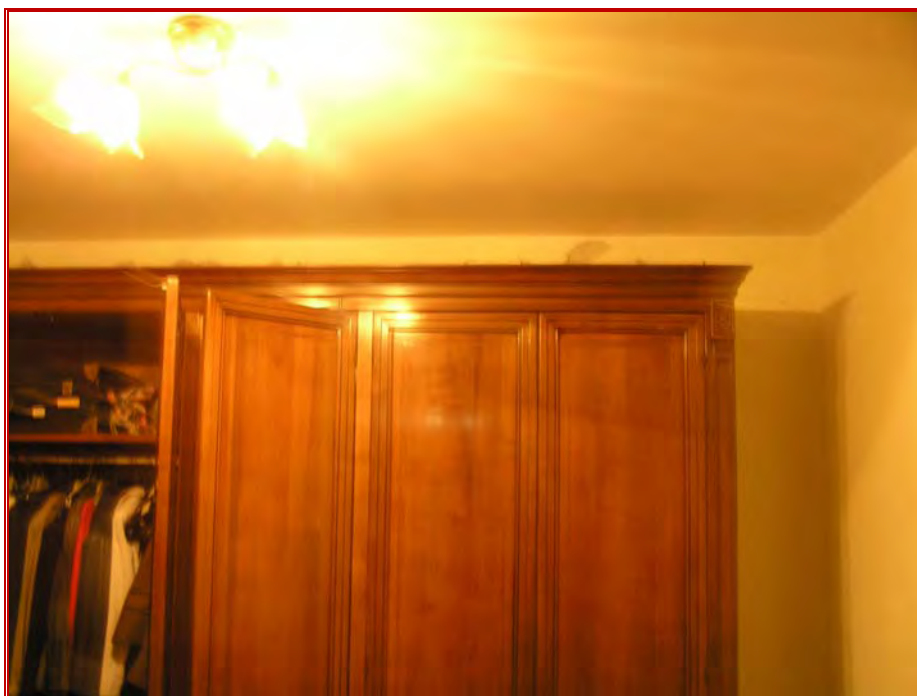


Figure 33: Inside of residential building in Figure 32. Evidence of strong ground shaking shown by wardrobe having damaged plaster through pounding.

Overall Reinforced concrete frames performed well structurally but sustained significant damage to infill panels especially when these were made of clay hollow block infill. These structures were mainly seen to perform better (in terms of life-safety) than masonry buildings observed in the same area.

4.2 Masonry Buildings (Residential and Historical)

Masonry construction is the predominant building type for residential housing in the affected area. The building material for the walls is local stone, with clay fired bricks used above openings and interspersed in the wall matrix. Within a single building, a range of masonry materials can be used: cut stone, rubble stone, terracotta tiles and bricks. In larger buildings the wall construction can exceed 500mm in thickness and the common form of wall construction called “a sacco” is used. “A Sacco” construction means that the walls are formed by two external wythes (skins) of cut stone and the gap between is filled with rubble pieces of smaller dimension. The true make-up of the masonry walls is often hidden by a render finish. When the render is well maintained and other improvements to the external appearance of the structure have been made, it can be difficult to distinguish a masonry building from a modern concrete low rise structure.

Floor structures vary significantly between adjacent and apparently similar buildings. Masonry vaulted ceilings are common, spanning in one or two directions in the older buildings (Figure 34). Other floor constructions include timber joisted floors, and more modern floors with concrete precast beams with clay hollow bricks spanning 1m between adjacent beams and sustaining a concrete screed layer reinforced with a steel wire mesh. A variation of the latter sees the precast concrete beams substituted with steel I-beams. Roofs are predominantly pitched at around 15 degrees and are timber-beam with clay tile covering, or in more recent constructions RC pitched floors are used that consist either of RC slabs or RC beam and block construction similar to that used in floors (Figure 35).



Figure 34: Building typologies - a major collapse opposite University Building in L'Aquila showing the typical masonry wall construction and vaulted floor construction.



Figure 35: Building typologies - building in Poggio di Roio with concrete slab roof. Falling render shows how the presence of concrete roof and slabs exists with stone masonry wall loadbearing walls

Historical buildings (e.g. churches and cathedrals) were observed in Aquila and several of the small towns visited by the EEFIT team. The quality of construction in these buildings was greater than that observed in the masonry residential buildings. Walls adopted larger cut stones, however the same “a sacco” technique of building was used for walls. Corner stone coins were always observed in these buildings, whereas they were not always present in residential masonry buildings. Furthermore, strengthening measures were commonly seen.

Over the centuries, various interventions have been made to maintain and improve the stability of masonry structures (residential and commercial) with techniques that are common in the whole of Italy and Southern Europe. The introduction of iron then steel ties and braces to restrain the walls from horizontal movement is a common method of strengthening that was observed in the affected areas, especially in the built up areas. Some homeowners have carried out strengthening that involves upgrading the floor through the addition of a layer of reinforced concrete, achieving a composite action with the existing floor, and achieving a floor deck with enhanced stiffness and connection with the external walls. Others have substituted timber floors with reinforced concrete slabs cast in-situ or pre-cast. RC ring beams were also observed on occasion at the roof level of masonry buildings. In the towns of Poggio Picenze and San Gregorio, several houses were seen to have had wire mesh and concrete screed also added to external masonry walls to enhance their strength.

Overall masonry buildings in the L'Aquila region were very vulnerable to ground shaking and many collapsed or suffered extensive damage. EEFIT has previously reported extensively on the vulnerability and the forms of collapse to masonry buildings in Central Italy in the report on the Umbria-Marche earthquake (available for download on the EEFIT website). Readers can find descriptions of the typical methods of damage and collapse to masonry structures in this report. Very similar observations apply to the L'Aquila Earthquake, and are summarised in the following paragraphs.

Masonry buildings in rural areas, with only one or two storeys suffered the greatest number of collapses. The poor quality mortar, masonry workmanship and materials all compound to cause the overturning of the walls panels. The more extreme examples of this are the collapses in the village of Onna (see Section 3.3). Cable ties, when present at all floor levels and in both horizontal directions, helped prevent or reduce out-of plane failure of external walls. The collapse of internal floors was commonly observed when concrete beam-clay hollow block floors (or steel beam-clay hollow block) floors were used, caused by the unseating of the supporting floor beams from the walls. Failure was

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more common (e.g. in Paganica) where no steel wire mesh was used to reinforce the concrete screed floor surface.

In massive buildings and monuments of L'Aquila, the tension forces that initiate collapse of masonry could only form in the upper storeys of the buildings, so parapets, top corners, and church timpani were the most severely damaged



Figure 26: Church in Paganica



Figure 37: Damage to corner of government building in L'Aquila

The largest concentration of masonry buildings is in the Centro Storico (old town) of L'Aquila. As well as the forms of severe damage and partial collapse described above, a large proportion of buildings suffered wide spread cracking, in the form of X-cracks due to in plane shear forces or cracking in the corners.



Figure 38: Typical minor to moderate damage to masonry buildings in L'Aquila

All visual inspection of damage was to the external envelopes of buildings. Access into building was deemed unsafe. Reports from the Fire Brigade point to extensive internal damage to partitions and internal load-bearing walls. These are reported even in buildings that present apparently undamaged facades. Another common and more catastrophic form of internal damage was the collapse of the floor structures, in particular the masonry vaulted floor plates. Floor collapses of this type were responsible for at least 3 of the 5 fatalities in the village of Fossa, and were the dominant form of damage in this village.



Figure 39: Example of collapse of vaulted floor in L'Aquila

4.3 Industrial Facilities

There are two industrial estates in the L'Aquila area: a few kilometres West of the City lies the Pile Nucleo Industriale and to the East of the city, off the SS17 the larger Bazzano industrial estate. Industrial sheds are built with precast RC frame and precast planks. There were no major collapses to these structures, and few cases of cladding collapse were observed other than in two industrial facilities. It is however stressed that the EEFIT survey in this case was not extensive and carried out from the roadside, Accounts from a local consulting engineer indicate that up to 20% of the structures suffered minor damage in the form of collapse to cladding panels. The EEFIT team was able to carry out a detailed visit to the Dompé pharmaceutical company in the Pile industrial estate where the worst reported damage to industrial buildings occurred. The building construction is in situ concrete frame and precast planks or T-beams. The major form of structural damage consists of short-column failure. The total cost of repair works are initially estimated to exceed €10 million



Figure 40: Dompe' Pharmaceutical Plant in Pile



Figure 41: Short-column failure in Dompe' Pharmaceutical Plant



Figure 42: Temporary office housing in Dompe' Pharmaceutical Plant

4.4 Schools and Hospitals

L'Aquila hospital, which is the main and largest medical centre in the area, was finished and began service in the year 2000. The hospital is formed by several blocks most of which are 4-storeys in height and some of which present irregular shapes in elevation and plan. The damage assessment presented herein corresponds to a survey carried out from the perimeter of the hospital as we were not allowed access to the structure interior.

The majority of Aquila hospital buildings are made of reinforced concrete moment-resisting frames, with either concrete block masonry or hollow clay brick infill. The areas mostly affected were observed in the northern side of the hospital where the top walls of the façade on the entrance collapsed (see Figure 43), and shear cracks were observed along infill walls (see example in Figure 44). The latter Figure also shows the horizontal displacement of about 3-5 cm of an infill wall from its original axis. The RC frames seemed to have performed well with no significant cracks being observed in columns or beams, though some minor fissures were observed on a ground floor column on a northern side building. A point worth noting is the fact that the dimensions of the top beam on the northern entrance seem to be larger than those of the columns. On closer inspection of the blocks towards the western end of the hospital complex, lack of cover was observed in the structural beams. The location of transverse beam reinforcement could be seen through the concrete cover. Moreover this reinforcement looked to have started to corrode.

Vertical sheet steel strips were observed to bridge between structural beams at the external face of infill walls. These seem to have been put in place in order to prevent out of plane displacement of infill if broken (Figure 45). However, the extent and frequency of this type of reinforcement could not be assessed.



Figure 43: Northern blocks of L'Aquila hospital. Note that the infill walls on the top floor of the entrance collapsed.



Figure 44. Shear cracks on the ground and first floors on one of the Northern hospital buildings. The concrete block infill wall on the right-hand-side of the photo was displaced from its axis about 3-5 cm.



Figure 45. Detail of reinforcement of an infill wall by means of steel strips

The faculty of Medicine and Surgery of Aquila University (Figure 46) is located to the northwest of the hospital complex. In this case the system seems to correspond to concrete shear walls, that although irregular in plan, behave much better than the hospital complex, with no structural or architectural damage observed.



Figure 46. The Faculty of Medicine and Surgery building of Aquila University, located northwest of the Aquila hospital. The structure is formed of shear walls and withstood the earthquake without any visible damage.

The hospital was still completely shut at the time of the EEFIT mission, with a camp set out in the grounds with medical facilities for the treatment of patients. On the 22nd April the local newspaper “Il

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Centro” reported that the hospital would be re-opened, but only very partially, the week of the 27th April, i.e. 21 days after the earthquake.

The EEFIT team observed several schools in the affected area. These were of both masonry and reinforced concrete construction. All schools observed by the EEFIT Team suffered less than grade 3 damage (e.g. Figure 47). One school in Lucoli was observed to have brackets and mesh placed at gutter level to stop any loosened roof tiles from falling (Figure 48). On the 22nd April, the newspaper “Il Centro” reported that of the 294 schools in Abruzzo 209 were open, 78 were closed and 12 were partially open. 2709 children below the age of 18 are living in temporary accommodation.



Figure 47: Elementary school in Aquila. RC frame building with infill, which sustained slight damage.



Figure 48: Detail of a school in Lucoli where brackets and wire mesh had been placed to prevent falling of roof tiles.

5.0 OVERVIEW OF THE PERFORMANCE OF INFRASTRUCTURE

This section provides a preliminary overview of the performance of infrastructure. Observations are limited to locations visited by the EEFIT team.

5.1 Roads

Many of the major roads pass over multi-span viaducts with expansion joints at each support. These roads were open to traffic with no evidence of any damage. There were no signs of damage to the bridge decks near expansion joints, nor any spalling of concrete at the beam ends, which would have been indicative of seismic pounding. Many road tunnels were present in the area but were all open, seemingly unaffected by the earthquake.



Figure 49: View of elevated highway in background.

Within Aquila a two span road bridge was closed due to displacement of the bridge deck at the propped cantilever expansion joint (Figure 50). A partial road closure was observed where a low masonry retaining wall had moved resulting in settlement of the supported road. At Fossa a single carriageway minor road bridge failed due to the support columns punching through the deck (Figure 51). Some minor rock falls were observed on rural roads in the mountains and one road was reported to have been blocked. Within the towns road access restrictions were in place where required due to building collapsed debris and unstable structures.

The road bridge over the railway which gives access to the retail and industrial area to the west of Aquila had sustained damage to the road surface at the expansion joints due to gap closure, this was non-structural and the road remained in use. Two further mass masonry arch bridges were seen by the Team. These had sustained no damage other than to slippage of the parapet coping stones.



Figure 50:View of propped cantilever bridge with displacement at connection.



Figure 51: Failed minor road bridge at Fossa

5.2 Buried Services

Only two instances of damage to buried services due to ground movement were observed by the EEFIT team: a water main and a gas pipe. The water main at Paganica was a 0.7m diameter high-pressure pipe which failed in an area where cracks in the ground surface were observed. This failure resulted in significant slope erosion caused by the water (at 40bar pressure) escaping the pipe. This resulted in the flooding of basements to properties below the site of the fracture. There was also a

buried gas pipe that failed due to ground movements at Madonna Del Ponte, in the outskirts of Aquila. Several elevated pipelines were observed to be undamaged.



Figure 52: Failed water main at Paganica

The electricity distribution network appeared to be intact with no pylon failures observed, the only damage being the local cables adjacent to collapsed properties. The rail network was still operational.

Generally the infrastructure network appears to have performed well with only isolated problems.

6.0 GEOTECHNICAL OBSERVATIONS

This section of the report provides a brief overview of the ground conditions in the areas visited relevant to the understanding of the seismic geotechnical effects observed. Geotechnical observations with regard to fault rupture, ground motion site response, liquefaction, and slope stability are also provided. Finally, observations on the response of geotechnical structures including; building foundations, retaining walls and buried services are also provided.

L'Aquila and the surrounding area occupy a broad valley which comprises alluvial deposits, lacustrine and slope deposits overlying the bedrock below. The valley is aligned approximately NW-SE, with an approximate elevation of 600m a.s.l. rising to over 1000m at the valley sides.

6.1 Fault Related Surface Rupture

Tension cracks, interpreted to be associated with offset on a secondary fault or faults, were observed in Paganica and Tempera. Detailed mapping of these features was undertaken by Peter Sammonds and Joanna of UCL who coordinated with the EEFIT team for two days. Detailed mapping was also undertaken by geologists based at the camp in Paganica. There remains some uncertainty as to the formation of these features and further analysis is required to investigate these.

At Paganica the strike of the tension cracks was approximately 120-300° and the apparent normal slip direction was toward 205-225°. Individual tension crack segments were typically 3 to 10m in length cracks roads, with maximum displacement in the order of 60mm horizontally and 60mm vertically. The tension cracks segments were aligned and could be traced over a length of approximately 600m. The width of the zone along which the tension cracks were observed was approximately 25m wide. The cracks were observed to cross open natural hillside, tarmac road pavement, concrete retaining walls,

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concrete slabs, exterior walls of reinforced concrete frame modern residential buildings and through the interior of the buildings where the tension cracks preferentially followed tile patterns or elements within the buildings (see Figures 53, 54 and 55). The tension cracks have been sub-categorised (tectonically induced, structurally controlled and settlement related) by geologists from the camp at Paganica. Creep displacement appears to be ongoing on some of the features. Extensometers have been installed at specific locations by the geologists at Paganica Camp to monitor the movement on the cracks. At Tempera cracking was observed crossing a tarmac single lane road at several locations. Individual crack lengths could only be traced across the width of the road for 3 to 4m with maximum displacement in the order of 50mm horizontally and 50mm vertically but more typically 5-10mm horizontally and 5-10mm vertically. At Tempera a set of 8 sub-parallel cracks were observed at roughly equal intervals over 200m.



Figure 53: Tension cracks passing through stone paving and single storey building at Paganica



Figure 54: Tension crack at Paganica



Figure 55: Tension crack in the hillside above Paganica Town

6.2 Ground Shaking and Site Amplification

The ground conditions within the valley comprise alluvium, underlain by lacustrine deposits and bedrock at depth. The bedrock is predominantly limestone and dolomitic limestone. (APAT, 2005). On the valley sides the ground conditions comprise slope deposits of conglomerate and breccia with limestone clasts that have been re-cemented and underlain by older limestone and dolomitic limestone formations (Figure 56). Local deep soil ground conditions within the valley appear to have amplified ground motions. The distribution of the level of strong ground motion is briefly discussed in Section 2 and analysis is ongoing. The amplified ground motions are reflected in the higher levels of damage encountered with the valley when compared to the valley side slopes where the thickness of soil is less. The distribution of earthquake intensities are also elongated mirroring the shape of the valley.



Figure 56: Re-cemented outcrop of slope deposits close to Lago Sinizzo

6.3 Liquefaction

No direct evidence of liquefaction was observed. Tension cracks and later spreads adjacent to rivers and a lake were observed but it was not possible from field evidence to determine whether the failure had occurred as a result of liquefaction or by failure of a low shear cohesive layer.

6.4 Earthquake Induced Landslides

The region is surrounded by mountainous topography with steep slopes. There is evidence of ongoing slope instability on steep slopes around the region prior to the earthquake. Slope instability induced by the earthquake is manifested in the form of rock falls, rock or debris slides, slumps and lateral spreads.

Small rock falls were observed throughout the region the region. At Fossa a rock fall of approximately 300m³ occurred from the steep rock slopes above the town with individually boulders of 1 to 2 m³ travelling down into the town and damaging buildings and cars and coming to rest within the streets of the town (Figures 57). Another large rock fall was passed on the road between Paganica and Camarda. This rock fall appeared to have blocked the road but had been cleared by the time of fieldwork. Typical smaller rock falls from natural and cut slopes were observed at many locations. An example of this type smaller 2 to 5 m³ rock fall feature occurred on a cut slope adjacent to Lago Sinizzo (Figure 58).



Figure 57: Rock fall in Fossa Town



Figure 58: Rock fall at Lago Sinizzo

Slumping of the ground around the man-made Lago Sinizzo was observed (Figure 59). Tension cracks were observed around the edge of the lake in the man-made deposits around the lake. The tension cracks could be traced for 5 to 20 m and formed arcuate features around the lake edge. The majority of the land sliding at this location was restricted to the opening of tension cracks and lateral movement of 0.5 to 1m with movement toward the lake. Tension cracks could be measured to extend to greater than 1m depth where the cracks were infilled with water. In some cases the sliding toward the lake was more extensive with travel distances of 5 to 10 m in two cases.

Stream flow downstream of the lake was interpreted to be above normal flow levels with downstream flows observed to flowing across vegetated areas. The increased flows were interpreted to be as a result of increased loss of water from the lake into the ground due to the tension cracks.

Tension cracks were also observed at Madonna Del Ponte, adjacent to a small bridge over the river. The cracks had opened at the maximum depth of the abutment fill deposits, extending diagonally from the termination of the bridge structure towards the free face, on both sides of the river (Figure 60).



Figure 59: Slumping in fill around the edges of Lago Sinizzo.



Figure 60: Tension cracks on the abutment adjacent to the bridge at Madonna Del Ponte

A ruptured water main was observed on the slope above the town of Paganica (Figure 52). The high pressure water had eroded a channel in the hillside, exposing the superficial deposits on the slope to a depth of approximately 4m. Soil depth here is deeper than seen in the surrounding area, up to a depth of 2-3m. Underlying the soil a colluvial deposit with a relatively weak matrix was observed. The soil erosion had flowed down gradient and partially infilled some deep basements in the reinforced concrete houses down-slope.

6.0 OBSERVATIONS ON DISASTER MANAGEMENT

The relief operations are coordinated by the Civil Protection of Italy with the support of the Italian police, military and fire service. Based near Coppito, to the northwest of the town of L'Aquila, the picture below shows the operation centre set up in the headquarters of the finance police and which now houses the Civil Protection, the Red Cross, the Army coordinating logistics and INGV, who have been monitoring the aftershocks since the event.



Figure 61: Photograph of the disaster management coordination centre at the Command Centre of the Finance Police

At the time of the visit, all residents from affected towns had been evacuated. Fire fighters from all over Italy had been drafted to help manage the rescue and aftermath of the earthquake. Since the earthquake, their operations have been divided into three phases. The first phase was that of search and rescue, which lasted a week during which the fire service was in operation 24/7. During this time they also secured all affected areas, not allowing entry into affected towns. The second phase required fire-fighters to be on 16 hours shifts, to escort residents into the towns and their properties to retrieve important items such as documentation and jewellery. Two weeks after the earthquake, the third phase had begun, where fire-fighters were required to again escort residents to their properties to retrieve essential items. The EEFIT team had to gain permission from the Civil Protection and then only visit affected towns under the escort of the fire-men.



Figure 62: Fire-fighters from around Italy have been involved in search and rescue operations and in escorting residents into their homes in affected areas

According to the Civil Protection, there are a total of 17,000 people displaced from their homes in this event. Camps were set up by the 7th April around the affected area, and there are 8 camps in L'Aquila city, located in stadiums, sports grounds and at the train station. The largest camp houses 4,500 people and is situated in the army barracks at Piazza D'Armi. In these camps, there are medical facilities, central catering and sanitation provisions. The Civil Protection has also arranged regular visits of psychiatrists to the camps.

A policy of "evacuate all" has been adopted by the Civil Protection, until buildings have all been inspected by qualified engineers with earthquake engineering experience. Over 1500 engineers have been deployed for this purpose, and are investigating lightly damaged buildings, and buildings of strategic importance first. Engineers from the Ministry of Cultural Heritage have also been sent to inspect churches and historical buildings in the area.



Figure 63: A camp outside the village of Tempera housing local residents evacuated from the town

A proportion of the affected people have been housed along the East coast of Italy. In the coastal town of Giulianova, 100km east of L'Aquila, around 1,000 are housed in hotels and Red Cross doctors with medical provisions have visited the area on a daily basis. Hotel managers were told after two weeks of the event by Civil Protection that 48 Euros will be paid for each adult housed per night and 7 Euros for each child for their accommodation and three meals a day. The figure below shows some of the notices on display at these hotels. Whereas those housed in campsites are all from the same communities, those housed in hotels are not. Despite the better accommodation, this has led them to feel isolated. Many have been returning to their homes every day to collect belongings and also to find out more information from the authorities.

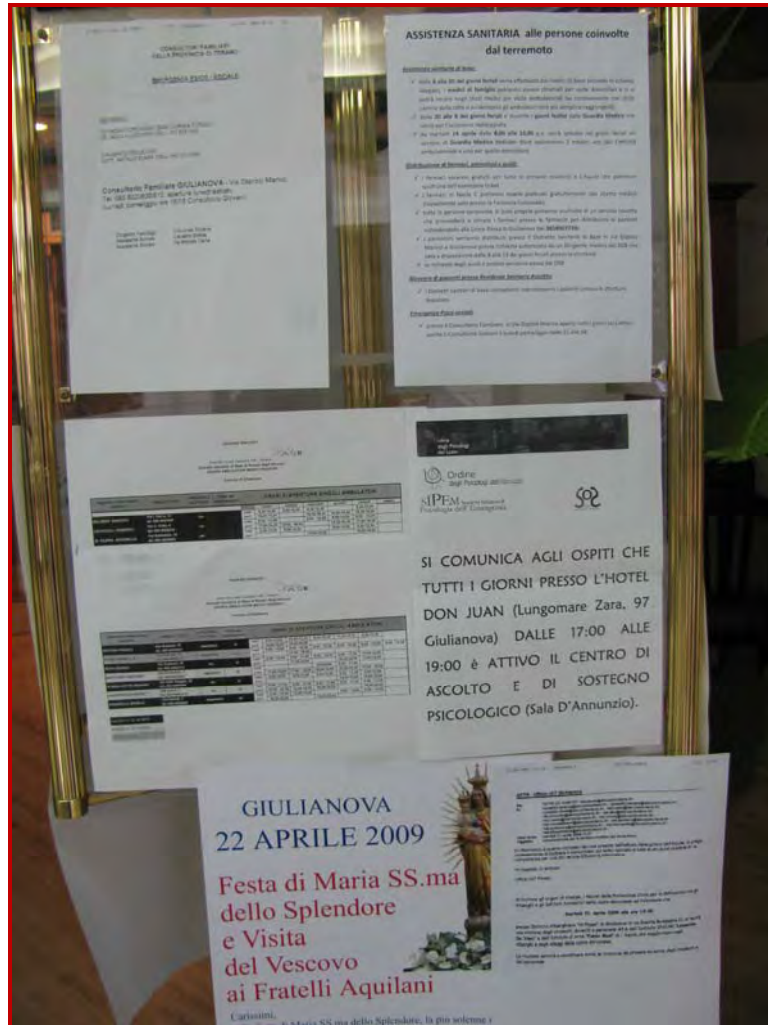


Figure 64: Notices posted at the lobby of the Parco dei Principi Hotel in Giulianova. In particular the notice in the middle on the right notifies the hotel residents of the location of a support centre for those affected by the earthquake in a nearby hotel.

6.1 Casualties

Overall, there are 299 reported fatalities and over 1,500 injuries. A breakdown of the fatalities by town is shown in the pie chart below:

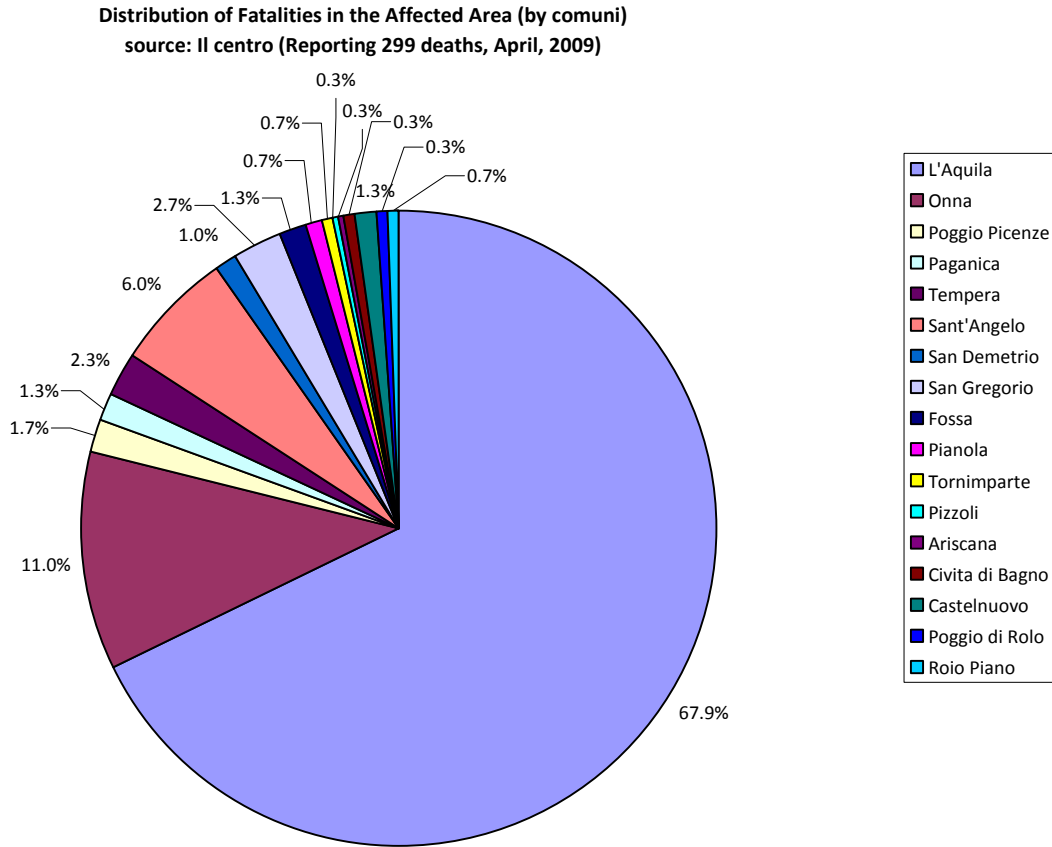


Figure 65: Graph showing the number of deaths in each commune (i.e. town district) in the L'Aquila region (source: Il Centro newspaper on 22nd April 2009)

Table 6: Dominant types of collapsed structure reported to have caused casualties in the towns visited by the EEFIT team.

Town/Village	Population (from 2001 census)	Fatalities	% Fatalities in population	Dominant collapsed building type causing fatalities
L'Aquila	68,500	203	0.3%	1970s RC frame 7-8 storey buildings and 2-storey masonry houses
Onna	350	33	9.4%	1-2 storey stone masonry-little evidence of wall ties
Paganica	661	4	0.6%	1-2 storey stone masonry with weak mortar
Poggio Picenze	1,011	5	0.5%	1-2 storey stone masonry with weak mortar
Fossa	661	4	0.6%	1-2 storey stone masonry inner floor collapse.

The team visited the following towns and villages during the field mission and was able to assess the dominant type of building which had collapsed, and therefore was most likely to have caused casualties in these towns. These observations are summarised in Table 6.

With regards to search and rescue, the Red Cross reported that very few were found alive. People were either able to escape on their own, with the help of neighbours or sadly died. The main hospital was substantially damaged during the event (see Section 4) so the injured had to be treated outside. Those hospitalised at the time of the event also had to be transported out to other large medical facilities. Those with more severe injuries were airlifted to Rome and nearby cities. The Red Cross are operating field hospitals at the camps as well.

6.2 Interviews

The EEFIT team conducted a few interviews of local residents to explore their actions and reactions during and after the event. The following interesting observations were made:

- At the town of Paganica, which had 5 fatalities despite the 90% D4-D5 damage to the building stock, residents cited feeling a foreshock at 1am on the 6th April. This made many of the people sleep in their cars and therefore they were not in their vulnerable housing at the time of the event.
- When asked about the characteristics of the motion felt, residents in L'Aquila who were in reinforced concrete frame buildings cited feeling a pull into their beds and there were also accounts of pianos and other contents being 'thrown' across the room by the motion.
- People in older masonry residential houses were only able to escape through windows on the ground floor as most cited jammed doors.
- The amount and magnitude of aftershocks continue to be a major concern for the affected communities and some who have left the area to stay with relatives elsewhere are afraid to return to the area.
- Although many of reinforced concrete frame buildings are structurally sound, the extent of damage to the infill walls has discouraged residents to return, fearful of further collapses in the future.
- A couple of those interviewed have mentioned being 'embarrassed' to seek help with the provided psychiatrists and also 'ashamed' to be staying in hotels whilst their neighbours were in tents.
- There did not seem to be a system of allocating temporary accommodation as this was done very quickly and people who registered on the two days following the earthquake were randomly assigned tents near their towns and villages or to hotels and hostels further outside the area. Though not immediately obvious, the availability of transport to the displaced may be a factor on the assignment.

7.0 SUMMARY

This report presents the preliminary observations made by the EEFIT Team during the 6 days they spent surveying the areas affected by the Aquila earthquake of the 6th April 2009. Despite the relatively moderate magnitude of the Aquila earthquake (M_w 6.2), large PGA values were recorded, and vast amounts of damage to towns in the surrounding area were seen. More analysis will be required to draw any conclusions from the recorded motions and attenuation of strong ground motion in the Abruzzo region. However, one major factor in the amount of damage observed is the high vulnerability of the poorly maintained residential masonry 1-2 storey buildings that are predominant in the affected town centres. The collapse of these buildings is seen to be the greatest cause of deaths in the region. Well maintained or strengthened masonry buildings are seen to perform much better, sustaining only low levels of damage. The observed reinforced concrete frame buildings were seen to

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perform well structurally. One of the main observations in regard to RC frames is the brittle nature of failure of clay block infill panels. It is recommended that in future construction such panels are tied into the frame to avoid out of plane collapse and potential injury. Infrastructure was observed to perform well, with very few closures of roads or reported pipe breakages. Management of the disaster was seen to be generally effective.

Further findings of the EEFIT mission will be published shortly. Pictures from the field together with pre- and post-earthquake satellite images can also be seen on the Virtual Disaster Viewer (www.virtualdisasterviewer.com).

8.0 REFERENCES

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ACKNOWLEDGEMENTS

Any visit to a disaster zone is a challenging experience and this mission was no different. The team members would like to thank the following organizations for their support to the mission. The EPSRC for providing the funding for the academic members of the party. The Arup External Research Fund for the support of the Arup members of the party. Sellafeld Ltd. AIR Worldwide and Risk Management Solutions for supporting their employee involvement. The Italian Civil Protection (Protezione Civile) is thanked for their support in gaining access to the affected areas.

The team would also like to extend their thanks to the following people. As always, Berenice Chan of the Institution of Structural Engineers has been outstanding in her support of EEFIT. Agostino Goretti of the Italian Civil Protection, Mr Aldo Eliseo for his help in the first day in the field. Gerald Roberts of Birkbeck University, Professor Peter Sammonds and Joanna of University College London. Thanks are extended to Ing. Cappelli, Director of Confindustria Provincia di L'Aquila, Ing. Beomonte and Ing. Martinoni, who allowed the EEFIT team access to the Dompé and Filmet industrial facilities respectively. Campedel Paolo, geologist, from the Servizio Provincia Autonoma di Trento is thanked for the information on local geology provided to the team. The team would also like to thank Romano Camassi of INGV and Alessandro Micchetti of Università dell'Insubria (Como) for their support.

Thanks are also extended to the Italian Vigili del Fuoco (Fire service) for escorting the EEFIT Team to the areas of greatest damage, in particular: Bonomi Ermes, Ravizza Giovanni, Panella Renato from the command at Sondrio; The command from Pisa, Rome and Trento who escorted the team to Aquila, Onna and Paganica, respectively; Azzalini Fabio, Conotter Renato and Giordani Mauro of Trento Fire Service.

Finally, the EEFIT Corporate Sponsors are thanked for their support over the years. They are: RMS, AIR Worldwide, Arup, Sellafeld Ltd, Buro Happold, CREA Consultants and Giffords.