Learning from Earthquakes

Preliminary Observations on the October 31-November 1, 2002 Molise, Italy, Earthquake Sequence

Ten days after the Molise earthquakes, EERI deployed a team of engineers and emergency management experts to document the geotechnical effects, the performance of buildings and lifelines, and the postearthquake emergency management by local authorities. The EERI team, which was led by Paolo Bazzurro of AIR Worldwide, San Francisco, CA, included structural engineers Sandro K. Kodama of ABS Consulting, Seattle, Washington; Joseph Maffei of Rutherford & Chekene, Oakland, California; Joshua Marrow of Simpson Gumpertz & Heger, Inc, San Francisco, California; and emergency management expert Barbara Foster of Barbara Foster Associates, Sausalito, California. The EERI team joined a group of Italian engineers whose active support and enthusiasm were critical for the success of this mission. The Italian team included Tito Sanò, formerly of the Italian Environment Protection Agency; Fabrizio Mollaioi of the Department of Architecture, University of Rome “La Sapienza;” Agostino Goretti and Adriano De Sortis of the Italian National Seismic Survey, and Alessandro Rasulo of the Department of Mechanical, Structural, and Environmental Engineering, University of Cassino, Italy.

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Introduction

At 11:32 am (local time) on October 31, 2002, a magnitude Mw 5.7 (Ml 5.4) earthquake struck the inland part of Molise, a small rural region in the southeastern part of the Italian peninsula (see Figure 1). The epicenter was located about 220 km southeast of Rome, but the earthquake was felt as far away as Naples and the Italian capital. This earthquake caused widespread damage in 50 villages and killed 30 people, 27 of whom were children trapped in the collapse of the elementary school in San Giuliano di Puglia.

The next day, November 1, at 4:08 pm (local time), an aftershock of similar magnitude — Mw 5.7 (Ml 5.3) — hit the same area, with an epicenter about 10 km to the west of the first event's. The aftershock seriously damaged many buildings whose stability was already impaired by the main shock, but it did not cause any additional casualties.

Tectonic Setting and Earthquake Parameters

The 2002 Molise earthquake sequence took place in the Apennines foretrench. This is a transition zone between the most external thrusts of the Apennines fold-and-thrust belt and its foreland, locally represented by the Gargano promontory (the “spur” of the Italian boot). While the Apennines and the Gargano are both characterized by intense, destructive, and historically well-documented seismicity, the area of the Molise events has traditionally been regarded as a transition realm affected by small earthquakes.

Thus, the Molise events were rather unexpected despite two foreshocks of M3.2 (01:25 am local time) and M3.5 (03:27 am local time) that preceded the main shock by a few hours and created great concern among the populace.

Figure 1 - Epicenters of the two main events of this sequence (stars) and of the main historical earthquakes (hollow squares) in this region (from Italy’s CPTI catalog). The rectangles identify seismogenic sources from the INGV database, while the dashed lines identify undifferentiated tectonic lineaments. The E-W fault on the Gargano Promontory is the Mattinata fault cited in the text. (Courtesy of INGV)
The first few hours after the main shock were punctuated by many aftershocks (Figure 2). This sequence culminated on November 1 with the shock comparable in size to the main shock. Significant aftershocks continued for about 10 days and then became very sporadic.

The occurrences of a discernible foreshock, of two similarly sized main shocks, and of the many relatively large-magnitude aftershocks make this unusual sequence more similar to a swarm than to a typical Apennines main shock-aftershock sequence. Similar behavior was observed during the May 5, 1990, Potenza (Basilicata region, southern Italy) earthquake sequence (M, 5.3).

Another interesting characteristic of the Molise sequence is its focal depth (Figure 3). With most hypocenters falling in the range of 15-20 km deep, this sequence differs substantially from typical Apennines sequences that normally take place in the uppermost 12-14 km of the crust. Again, the 1990 Potenza sequence had similar depth. This depth has both tectonic and ground-shaking implications:

- The Molise earthquakes occurred in the metamorphic basement underlying the Apulia platform, an extensive, 10 km-thick carbonate deposit that underlies the Adriatic margin of the Apennines. Fault activity in this deep complex structure was not considered likely prior to these earthquakes.
- The main shock was felt over a very large area (essentially along most of the peninsula down to Calabria), but the ground shaking in the epicentral region is thought to have been lower than that expected for shallower events of the same magnitude.

Figure 2 - Location of the epicenters and of the main known faults in the area. (Courtesy of INGV)

Figure 3 - Epicenters of the two main events and of the first sequence of aftershocks from November 3 until November 6. Focal mechanisms and hypocenter locations are also displayed. (Courtesy of INGV)
These two features may very well characterize the seismogenic faulting in this portion of the peninsula and they should be carefully considered in future seismic hazard analyses of the region.

The focal mechanism of the two main shocks and the alignment of aftershocks (Figure 3) strongly suggest that the earthquake rupture extends for 20-25 km E-W, on a dominantly strike-slip fault. Although the fault had not been previously identified in any of the existing compilations of faults and seismogenic sources, INGV’s Database of Italy’s Seismogenic Sources (Figure 1) shows that the sequence falls on the westward prolongation of the E-W Mattinata fault, the main active tectonic element of the Gargano Promontory.

These tectonic elements display a long-history of left-lateral activity, followed by right-lateral activity since Late Pliocene-Early Quaternary, in agreement with the fault kinematics shown by the focal mechanisms. The 2002 Molise earthquakes would hence comprise instrumentally documented evidence of a relatively recent change in tectonic regime (from NE-SW to NW-SE shortening).

**Historical Seismicity**

Figure 1 shows that historical seismicity also failed to delineate the earthquake potential of the 2002 Molise source area. After the fact, however, the joint interpretation of historical and tectonic evidence reveals a consistent and somewhat “predictable” pattern. The active faults in the Gargano promontory have produced many earthquakes, the largest of which (M~6.8 in 1627) occurred in the western foothills. The evidence offered by the 2002 Molise earthquake suggests that the 1627 event might have been generated by oblique (reverse and right-lateral) slip along a western buried extension of the Mattinata fault.

The intensity pattern available for the catastrophic 1456 event, which leveled a wide area, including three villages around the current location of San Giuliano, suggests that some of the lineaments discussed above may have been activated in that earthquake. Unfortunately, current catalogues “collapse” it into a single, highly unrepresentative epicenter.

**Ground Motion**

Before the two events of October 31 and November 1, the seismometric network in this area was not very dense (see flags in Figure 4) and no ground motion recordings close to the fault rupture are available. The closest station was about 27 km southwest of the epicenter and recorded a PGA below 0.02g. The largest peak ground acceleration (PGA) recorded for the main shock is about 0.07g at the Lesina Station (Figure 4), about 40 km northeast of the epicenter. The orientations of the iso-PGA lines, which are in agreement with the reported damage pattern after the main shock, seems to suggest a rupture that nucleated from the west and moved towards the east, causing significant forward directivity effects in the region east of the epicenter despite the somewhat limited magnitude.

No definite data are yet available to establish the direction of rupture of the November 1 event. More than 30 portable new stations were installed after the November 1 event and they were used to localize the aftershock hypocenters shown in Figure 3.

**Geotechnical Effects**

The ground motion triggered 111 cases of ground failure on hill slopes, with final ground displacements ranging from an inch to about a foot. Such phenomena were observed often on roads mainly southeast of San Giuliano and north of Colletorto. Some known paleo-slides triggered by the ground shaking are thought to be partially responsible for aggravating the damage to buildings in the towns of Ripabottoni, Castellino del Biferno,
and Casalnuovo Monterotaro. A more spectacular and quite unexpected slope failure—given the relatively large distance (34 km) from the epicenter—resulted from the second event near Trivento at Serre di Salcito. An existing landslide area with a front of about 0.5 km and a width of about 1.5 km moved downhill by about a foot at some locations (see Figure 5) and threatened a few private buildings and one of the major local roads.

As suggested by a preliminary study, soil amplification can be regarded as a significant cause of widespread damage in a very localized area of the badly hit town of San Giuliano. Most of the damage occurred along the main street which is located on a narrow hill-top ridge formed by a 10m-thick layer of talus and anthropic filling (shear wave velocity, $V_s$, ranging from 110m/s to 300m/s) underlain by a much harder layer of clayey marls ($V_s\approx550m/s$) (Figure 6).

The aforementioned study, which uses both the empirical Nakamura's microtremors approach confirmed by SHAKE amplification analyses, indicates that the soil formation underneath the main street has caused high amplification effects (to more than three times the bedrock motion) with peaks at 2Hz and especially at 5Hz. Besides the effect of the soft soil formation, the morphology of the narrow ridge may have also intensified the surface ground shaking.

Finally, as is usual for Italian earthquakes, the fault ruptures did not break the ground surface and no evidence of liquefaction was reported.

**Building Performance**

The Molise earthquake sequence damaged towns in the Campobasso Province in Molise and in the Foggia Province in Puglia. San Giuliano di Puglia, Bonefro, Santa Croce di Magliano, Ripabottoni, Castellino del Biferno, and Casalnuovo...
Monterotaro are the most affected towns. As of December 15, 2002, about 15,000 inspections had been made in Molise and about 2,000 in Puglia. In San Giuliano alone about 300 buildings have already been declared unsafe and will probably be demolished.

The inspection survey considered six tagging conditions: A (usable with no restrictions), B (usable with conditions); C (partially usable); D (to be inspected again); E (not usable); F (not usable because of damage to adjacent buildings). Tagging condition A can be associated with a Green Tag; conditions B, C, and D with a Yellow Tag; and conditions E and F with a Red Tag. The preliminary breakdown of the inspections in the six most affected towns are shown in Table 1.

The damage is also shown in terms of intensity levels in Figure 7. The scale used in Italy is the Mercalli-Cancani-Sieberg (MCS), which in this range of intensity can be approximately translated into the more customary Modified Mercalli Intensity (MMI) scale by subtracting a unit (thus, MCS VII = MMI VI).

**Building Stock:** All the towns in this area are located on hilltops, ridges, and steep sloping hills. The older, medieval buildings are almost always located on outcropping rock formations, while the newer developments are often on looser materials. The building stock in this area is rather homogeneous, but the building types are significantly different in the medieval and the newer parts. The older buildings have stone bearing walls and are usually 2-4 stories high. The stone walls are usually carefully crafted with local materials; reinforcing details, such as iron tie-rods or buttresses, are often seen in the facades of larger buildings. Small and far apart openings in the facades are common. The first floor is often vaulted either in stones and mortar, or bricks of different types. The roofs have a wooden structure with joists and purlins that often carry a grille of bamboo canes acting as roof sheathing for supporting clay tiles.

At the margin of the old towns, new developments arose mainly in the 20th century. Most of the buildings were constructed in the first part of the century as one or, more rarely, two-story bearing wall structures. The stones were often cut in small regular blocks for the exterior and interior parts of the walls, while the middle was filled with loose material. The mortar is either absent or scarce and of very poor quality. There are frequent cases of bearing walls of poorly cut 25-100 cm stones mixed with smaller irregular stone pieces and no mortar. Less common are buildings with regular blocks of “tufa” or filled bricks.

After World War II one or two additional stories were added to many of these buildings. Often the additions were made either by hollow brick bearing walls with elements of

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Table 1 - Postearthquake building inspections in the most damaged towns.

Figure 7 - The observed damage measured by the Mercalli-Cancani-Sieberg (MCS) intensity measure. (Courtesy of the Servizio Sismico Nazionale)
different shapes and dimensions, or by reinforced concrete frames with hollow brick infills with heavy pre-cast or cast-in-place ribbed slab with ribs at approximately 45-60 cm on center, and not more than 30 cm in depth with a flange depth of not more than 7-10 cm, with hollow clay tile infill between the ribs. Minimal or no provisions were made to ensure continuity with the already existing story. These buildings of mixed construction proved to be extremely vulnerable, as shown below.

The more recent structures are almost all engineered reinforced concrete frames with hollow brick partitions. Often the ground floor consists of pillars with no infill walls, a classic soft-story condition. The construction practice and materials used were observed to be fairly poor compared to modern standards, but, with a few exceptions, concrete buildings experienced minimal damage.

**Stone Bearing Wall Buildings and Buildings of Mixed Construction:**
Better construction practices and, probably, lower ground shaking made older buildings perform relatively well, with many fewer collapses than more modern construction. Some significant examples of damage to older buildings include out-of-plane failures of walls and failure of the roof-supporting structure (Figure 8). Some interior damage, with partial detachment of the façade from the exterior wall, was also observed in the historical part of Casalnuovo Monterotaro. Some of the collapses in the older buildings occurred in buildings that were abandoned and in an acute state of disrepair.

All the damage mechanisms typical of stone-wall and brick-wall buildings were observed in the relatively newer structures located in the developments outside the old town. The figures from 9 to 13 show some typical examples. The failure

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**Figure 8 -** Two partially collapsed buildings in the older part of San Giuliano. **Right:** Note the tie-rods in the facade that prevented the total collapse of the exterior wall.

**Figure 9 -** San Giuliano. Failure of the exterior wall not properly connected with the slab. **Left:** Note the two different construction types at the first and second story. **Right:** Note degraded mortar and poor construction material in foreground wall.

**Figure 10 -** San Giuliano. **Left:** Detachment and rigid shift of the top story in reinforced concrete from the stone wall at the bottom story. **Right:** Similar failure pattern, where the reinforced concrete structure supporting the roof rotated and shifted.
mechanisms follow directly from the characteristics of such buildings discussed in the previous section.

**Churches:** The observed damage caused to the monumental heritage has confirmed, yet again, that churches are particularly vulnerable to seismic forces. The intrinsic vulnerability was often exacerbated by questionable recent retrofits that proved incompatible with the natural vibration mode of the original masonry walls. Roofs made of reinforced concrete or steel, and the addition of very thick reinforced concrete tie-beams and floors, dramatically increased the inertial forces that could not be accommodated by the original structure.

An emblematic case can be found in Santa Croce di Magliano, where the two recently retrofitted churches of Sant’Antonio da Padova and San Giacomo suffered severe damage with partial collapses, while the abandoned Greek church, which was already cracked and in a bad

**Figure 11** - San Giuliano. Large diagonal shear cracks in the proximity of the large openings. The two stories above built more recently in reinforced concrete and hollow-brick infills are unscathed. The bottom story essentially acted as a base isolation system. The building is going to be demolished.

**Figure 12** - Collapsed school in San Giuliano di Puglia. Note the very heavy slab of the second story and the roof that was supported by a first story bearing wall of poor-quality stone, now collapsed (foreground).

**Figure 13** - Example of inadequate retrofit. The steel beam that has been added to support the vaulted slab is inserted directly in the stone wall. The hammering of the beam against the bearing wall has severely impaired the safety of this building.

**Figure 14** - San Giacomo church in Santa Croce di Magliano: the spire of the bell tower, recently reconstructed in reinforced concrete, has collapsed, leaving the original masonry bell tower below without any visible damage.
state of maintenance, shows only a slight worsening of damage.

About 75 churches in the epicentral and surrounding areas were systematically inspected to single out the different collapse mechanisms and the major causes of damage. The most common damage pattern includes cracking and collapse of the vaults (owing to their limited thickness and lack of tie rods); damage due to crushing and shearing of the masonry pillars (often because of the increased weight from reinforced concrete tie beams and slabs on the vaults); damage due to sliding or overturning of the spires on the bell towers (as a result of being more rigid and heavier); overturning of the gable roof of the façade; or damage in the apse (from reinforced concrete roofs).

**Reinforced Concrete Frame Buildings:** Overall damage to reinforced concrete frame buildings was minor throughout the region, with a limited number of localized damage pockets in San Giuliano di Puglia and Bonefro. Damaged buildings were located on soft-soil basins in both of these regions.

Three concrete buildings in the surrounding regions were observed to have sustained structural damage, while approximately 50 concrete frame buildings were observed to have had significant nonstructural damage to hollow-clay tile and plaster infill walls.

Concrete construction in this region is similar to that found in Turkey, consisting of poorly detailed, mildly reinforced concrete columns, beams, and slabs with hollow clay masonry tile infill walls between column lines. Concrete frame buildings suffered tremendous damage and collapse during the 1999 Izmit Turkey earthquake, but the Italian concrete structures suffered little damage, as they typically have fewer stories (four or less) and the

**Figure 15 – Left:** Two concrete frame apartment buildings in Bonefro. Construction of each building was identical, with the exception of the additional floor. The four-story building sustained major damage in the two events, resulting in a substantial collapse hazard. **Right:** Extensive damage at the ground level of the four-story building after the aftershock of November 1.

**Figure 16 – Left:** Ground level, east face of four-story structure following the first earthquake. The structure shed one wythe of a two-wythe hollow clay tile wall during the first shock. The interior wythe remained substantially intact. (photo: M. Mucciarelli and M.R. Gallipoli. Additional information available from http://www.mi.ingv.it/eq/021031/Molise/BonefroCA.pdf and http://www.mi.ingv.it/eq/021031/Molise/rlievo.html) **Right:** The same ground level wall after the second earthquake. These sequential damage photos offer a rare glimpse at the time-dependent damage mechanism of the structure. The lack of a plastic hinge at the top of the column on the first floor indicates the existence of a diagonal compression strut action in the hollow clay masonry wall. As the hinge forms during the second event, the compression strut shifts approximately two feet down the left column, resulting in a short column hinging failure at the top. **Inset** shows detail of hinged failure. (photos: J. Marrow)
ground motions in the Molise events were substantially shorter and less severe than those in Turkey.

Two buildings of particular interest were a pair of concrete frame residential apartment structures located in Bonefro (Figures 15 and 16). The two buildings, constructed in 1984, were founded in a valley, at the base of the historic portion of the town. Both structures were identical in plan and structural composition, but varying in height, one with three stories and the other four. The four-story structure suffered substantial structural damage at the ground level, focused mainly along the east elevation. The three-story structure suffered no structural damage and only minor cracking in the exterior plaster finishes.

The damage to the four-story structure is likely due to the additional mass of the fourth floor level. Italian researchers who studied these structures following the quake have theorized that the differential damage states can also be attributed to significant ground motion amplification around the fundamental period of vibration of this four-story structure (about 0.5s). Further study is required to verify the exact cause of failure.

**Lifeline Performance**

No damage of any significance has been reported to lifelines. The only exceptions were the local gas distribution system in San Giuliano di Puglia, where operations were disrupted after the events, and some local roadways around the same town that developed cracks but remained accessible to vehicles.

The Larino substation of the electric power distribution network, operated remotely by the utility company Terna, was on alert status during the earthquake shaking. However, the alarm did not shut down the substation. Some local power lines were slightly damaged and affected only a limited number of customers.

The local cellular phone network and part of the land phone network were somewhat disrupted in the epicentral area after the main shock, but were soon fixed. The main regional lines of the telecommunications network, consisting of coaxial cables running along main roads and point-to-point radio-bridges, were not affected by the quakes. No damage to the water supply or the sewage systems was reported.

**Rescue, Relief, and Rehabilitation**

The impact of the earthquake sequence (I MCS > V-VI) was felt in an area of approximately 1400 km², with 66,000 residents in 33 towns. The most severe damage (I MCS > VI-VII) was concentrated in 8 towns (see Table 1 and Figure 7) with an estimated population of about 16,000. Thirty people were killed and 173 sustained injuries requiring hospitalization.

The greatest losses were in the town of San Giuliano di Puglia (population 1163), with 61 injuries and all 30 fatalities. The fatalities included 27 children and one teacher who were killed when the primary school building collapsed, and two elderly women who were killed in their homes by falling debris. No fatalities and relatively few injuries were reported in the other towns.

The bulk of injuries and all of the fatalities occurred following the initial event on October 31, but another 56 people were injured during panicked evacuations following the second event on November 1. Following this aftershock, the entire town of San Giuliano di Puglia was evacuated by order of the Director of the Civil Protection Department (DPC), and approximately 4800 other individuals

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**Figure 17 – Left:** Hinged column failure of a reinforced concrete frame building in San Giuliano di Puglia. (photo: P.Bazzurro) **Right:** This modern concrete frame structure in San Giuliano di Puglia was under construction at the time of the earthquake. It had no structural damage, but the hollow clay tile infill walls were half built and not tied into the slabs above, and suffered an out-of-plane toppling failure. (photo: J. Marrow)
were evacuated from neighboring towns.

None of the hospitals in the area was damaged and no public health or sanitation problems were reported. The most significant impact was on the school system. All schools in the region were immediately closed after the initial earthquake for assessment of safety. Of the schools surveyed by the DPC, approximately 20-30% were deemed unsafe and not scheduled to be re-opened without structural intervention.

Given its agricultural nature, the area also contains a large number of farm animals, many of which were housed in old barns and other structures that collapsed or were seriously damaged.

Preliminary estimates of the economic losses due to this quake range from $250-$350 million.

Response: As so often occurs following major disasters, response was both planned and emergent. Immediately following the initial event, all attention was focused on the site of the collapsed school in San Giuliano, where bystanders began search and rescue until relieved two hours later by the fire brigade that used rescue dogs to help locate survivors and the dead.

At the local level (town and province), fire brigades began search and rescue operations and police provided access control. Pre-designated, nine-member fire brigade disaster response teams outside the impact area mobilized within 30 minutes of the first event and arrived in the Molise and Puglia regions within the first 24 hours. Members of the fire brigade were observed shoring up private buildings in several towns — not a common practice in the United States (Figure 18).

At the national level, pre-assigned personnel from the DPC in Rome mobilized automatically and within five hours of the earthquake established a primary Mixed Operative Center (Centro Operativo Misto, or COM) in the town of Larino. A second COM was established in San Giuliano, and a third in Casalnuovo Monterotaro in the Puglia region.

The location of the primary COM (Larino) had been designated prior to the earthquake, but telecommunications had not been installed. Within two hours of activation, 15 hard-wire telephone lines were installed, and 40 lines were in place within eight hours of activation. Five additional wireless communication sites were installed in the impact area within 48 hours.

Staff from the national DPC provided overall emergency management and coordination at the province level. At the local or town level, five Community Operative Centers (Centro Operativo Comunale, or COC), staffed by municipal staff and volunteers, provided emergency management services and logistical support. For example, the COC in Santa Croce scheduled which city blocks were to be inspected by professional crews every day.

Both COMs and COCs are organized around 16 emergency management functions, similar to the Emergency Support Functions (ESF) utilized by the Federal Emergency Management Agency in the United States. In accordance with existing emergency plans, three COM functions were implemented initially: fire brigade, police, engineers/technicians; emergency medical and local health services; and damage assessment.

On November 1, a state of emergency was declared in the impacted regions, allowing the use of all national resources to help in the emergency response. Ultimately, 5,000 emergency response personnel (600 fire, 2800 police/military, and 1,600 volunteers) responded to the impact area. Advanced Mobile Medical Units, staffed by Red Cross and military personnel, responded to the need.
and were still staged in the impact area two weeks following the initial event.

**Relief Operations:** Outdoor emergency shelters were established following the initial earthquake. There were not enough shelter beds to accommodate all of the displaced on the first night, so a number of people slept in their cars. The aftershock of November 1 doubled the number of displaced seeking emergency shelter and exacerbated fears of more quakes and damage.

As the aftershocks continued, the number of displaced rose to an estimated 6,000. People were afraid to stay in their slightly damaged or undamaged homes. In some cases, tents were erected right next to individual homes so worried owners could protect their property and belongings. Two weeks after the initial event, 60% of the displaced were still in emergency shelters. An unknown number of the displaced chose to stay in a hotel or with family and friends, rather than in a shelter.

Ultimately, 22 outdoor emergency shelters or “tent cities” (*tendopoli*) were established. Road signs throughout the region pointed in the direction of the nearest emergency shelter. The *tendopoli* (Figure 20) included large tents for meals and socializing, smaller, 8-bed sleeping tents, and several campers for the elderly and disabled. In cases where a sufficient number of campers were not available, the elderly and disabled were housed in hotels outside the impact area.

Each tent was equipped with portable, generator-powered heaters and lighting, and with hard modular grille floors. Public telephone booths were also installed at each shelter. Because people were not willing to send their children back to schools, school tents were erected in the tent cities.

The primary COM Logistics Chief indicated that there were no shortages of material resources, including generators and heavy equipment. The Interior Ministry maintains stockpiles of emergency supplies and equipment throughout the country and has contracts with private firms for heavy equipment, chemical toilets, showers and other equipment.

As seen in other disasters, there was an abundance of volunteers from the Red Cross and community agencies. The Red Cross in Italy is affiliated with the military and together one of their missions is to set up the outdoor emergency shelters.

**Rehabilitation Plans:** The main short-term priority established by the COMs for the initial recovery period is to provide temporary housing to the displaced. This involves moving the displaced whose homes are not damaged back into their homes, and moving the homeless from the tent cities to more stable, temporary housing. Prefabricated homes will be provided for those families whose homes were destroyed, while rebuilding occurs. Alternatively, each family will receive a housing allowance of about $400/month toward temporary housing of their choice.

Two weeks after the earthquake, grading had commenced at some sites on which prefabricated homes will be located. Another COM priority is to provide temporary structures for schools that were deemed to be unsafe following the earthquake. Prefabricated buildings are being considered to replace the unsafe schools while retrofit measures take place.

According to a representative of the DPC, it takes the government of Italy four to six weeks to compile damage figures and document damage before repairs can be made. Of particular concern to officials of the DPC was how to restore essential services in San Giuliano on an interim basis, and how to keep residents
from moving away permanently during the estimated three to four years it will take to rebuild damaged homes and businesses.

On November 4, the Interior Ministry made available approximately $50 million for the initial and most urgent emergency initiatives. Donated funds from public and private organizations will also play a significant role. For example, one of the major newspapers in the country raised roughly $12 million, a portion of which went toward the construction of a temporary school structure in San Giuliano.

Funds will be administered to repair any seismic-related damage for individual residences in the affected areas. Since virtually no earthquake insurance is available to individual homeowners in Italy, government and privately funded assistance programs are essential to the restoration efforts.

Pertinent to the reconstruction effort are the building codes in this area. The most current seismic hazard maps for Italy show the area affected by the earthquake to be a seismically active area with PGAs (approximately equal to 0.15g-0.2g at the 10% probability of exceedance in 50 years level) similar to those in zone 2B of the 1997 Uniform Building Code. Despite the suggestions of the 1998 ING-GNDT-SSN Working Group of classifying this zone as moderately seismic, most of the municipalities affected by these earthquakes were considered by past and current building codes to be aseismic.

Government officials have made public statements promising that all new buildings, especially scholastic buildings, will be built or retrofitted to the latest known seismic standards. However, until local jurisdictions decide to officially adopt more stringent design criteria for lateral loads, the performance level to which new buildings are designed will be left to the engineer and owner.

Conclusions

The extensive damage to buildings observed in Molise can be attributed mostly to poor quality construction practices and materials. Many of the buildings that suffered extensive damage or collapse (including the school) were not adequately engineered to withstand the seismic forces. The extensive damages to poor quality, non-engineered buildings were caused by the lack of seismic regulations for construction in this region. Amplification of ground motion due to soft soil conditions and topographic effects seems to have played an important role as well.

The older, medieval parts of towns that were built on surface hard rock formations sustained much less damage. Another contributing factor was the strong aftershock on November 1, which exploited the weaknesses of already damaged buildings.

Acknowledgments

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