The impact of the 6th April 2009 L'Aquila earthquake (Italy) on the industrial facilities and life lines. Considerations in terms of NaTech risk

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The impact of earthquakes on industrial facilities and life-lines may trigger events that could produce relevant hazardous scenarios or critical inoperability of safety facilities. Further side-effects of the seismic event, such as the disruption of communication lines, may cause important delays in the emergency response. This work presents an overview of the impacts that the recent earthquake of L'Aquila made on the industrial facilities and life-lines as they appeared to the rescue services immediately after the event. In particular the authors comment on these impacts through a list of considerations in terms of lessons learned useful for the purposes of NaTech risk assessment and preventative mitigation.

1. Introduction

On April 6, 2009, at 3:32 a.m. local time, a 6.3 M_W earthquake occurred in central Italy. The epicenter was in Tornimparte, a little village located 7 km North-West of the town of L'Aquila. This earthquake occurred on normal faulting on the Apennine mountains and was a shallow event with an epicentral depth of approximately 8 km. The main shock was followed by many aftershocks. Since the seismic waves associated with shallow quakes can reach the surface without losing much energy they produce stronger shaking and significant damage. In fact high values of PGA were recorded in near field (0.675 g UD component at AQV RAN station located 4.85 km from the epicenter) while smaller values (< 0.150 g) were recorded at just 20 km from the epicenter.

Therefore, even if this earthquake is classifiable as being of a moderate magnitude, the position of L'Aquila and its surroundings in the near field area of the earthquake have been affected by a level of ground motion able to provoke significant damage to industrial facilities and life-lines present in that area.

A few days after the earthquake researchers of the University of Udine, with the support of Italian National Fire Department engineers, were on the ground in the affected area, to investigate and analyze the damage. In this work the authors focus on the seismic damage of both industrial facilities and essential utilities.

The analysis of the damage has permitted an individuation of the major and recursive criticisms. The following sections describe the damages for the main categories of elements at risk, in order to obtain useful lessons learned for safety improvement.

2. Industrial Facilities

In the surrounding area of L'Aquila there are three main industrial zones (Bazzano-Paganica, Pile and Sassa) hosting high-tech, pharmaceutical, construction, mechanical and manufacturing industries. The most diffuse typology of building is represented by precast concrete buildings using precast panels, reinforced frames with concrete block walls and steel or light metal frames with precast panel walls.

2.1 Typical damage observed on industrial facilities

The surveys on the industrial buildings in the affected area permit an outline of some general considerations:

a) the damage observed was mainly concentrated in nonstructural elements (e.g., partitions and ceiling tiles) and contents. The criticisms were related to connections between the secondary elements and the structure. The collapsed walls of the precast-concrete buildings were a direct result of inadequate anchorage between the wall panels and the roof and floor framing members.
b) some structural damage to beams and columns was observed. The criticisms were related to the weakness of the joints and in particular to unseating effects (noticeable movements of the beam and column corbel support were observed).


Figure 1. Collapses on precast concrete buildings and weakness of connections between primary and secondary elements.

Other common damages observed were related to the fact that the equipment of the industrial plants was generally unanchored or inadequately braced to avoid relative movements during the earthquake. The equipment moved and/or collapsed, causing major business interruption.
Other criticisms observed are: as ground floor ceilings were much higher than the upper floors, they showed heavy damage on the beam-pillar connections evidencing a "soft-story" condition that could leading to a building collapse in case of a stronger earthquake. Collapses were recorded on structures with variety of building construction

materials. Heavy precast-concrete frames with precast walls and roof panels (typology of construction very common in Italy and in other countries in the Mediterranean region) show that, if not properly designed for earthquakes, buildings could likely suffer extensive damage or collapse in case of strong earthquakes.

2.2 The case of VIBAC facility

A particularly interesting case of damage was observed at the Vibac factory. This is a chemical facility located in the Bazzano-Paganica industrial area, 7 km South of L’Aquila town. The main building has a two-story reinforced concrete frame, engineered in 2003 and constructed in 2006. The exterior is primarily a glass windowed wall with hollow clay tile infill at the stair core and back of the building. It is adjacent to a one-story precast warehouse. The damage observed was:

a) column shear failures, rupture of the column tie reinforcement, cracking and falling of the hollow clay tile infill and collapse of the window wall glass.
b) in the warehouse, a precast girder collapsed along with one span of roof slab.
c) three tall steel silos storing polypropylene beads suffered damage.

During the earthquake the three silos which were full, either collapsed or suffered extensive damage. The silos collided with the adjacent precast warehouse partially crushing the concrete wall and leaving an impact imprint. The silos also crumpled at their bases. In addition serious damage was caused to pipelines and electricity cables. Consequently business was completely interrupted.

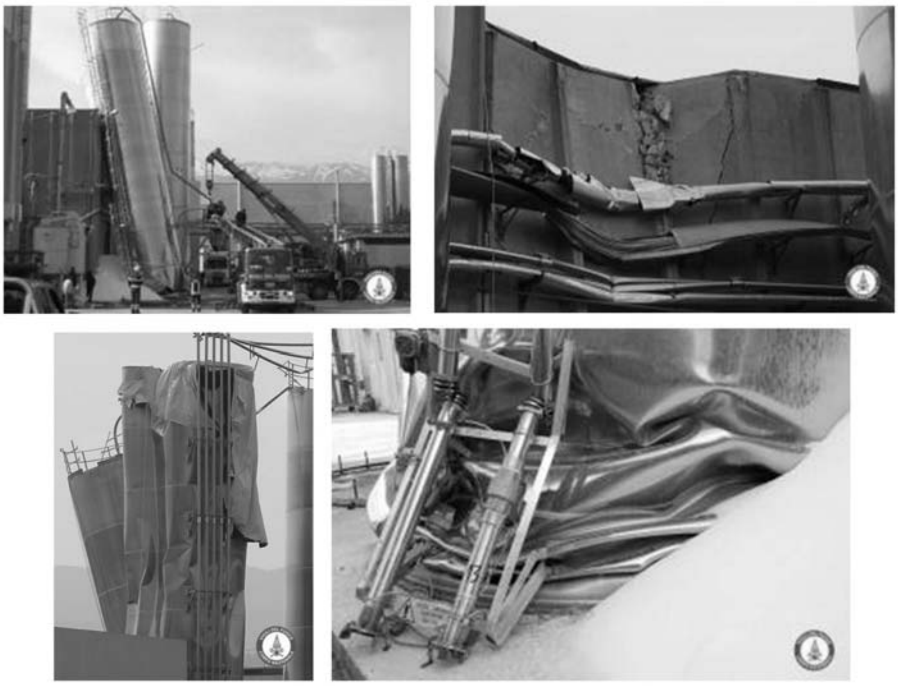

Figure 2. Damages to, and caused by, silos at VIBAC facility in the Bazzano industrial area, 7 km South of L’Aquila town.

3. Transportation facilities

Transport infrastructure damage in the earthquake-affected area was minimal. The affected area is crossed by the highways A24 and A25, connecting the Tyrrhenian and Adriatic coasts of Italy. Many parts of the A24 consist of elevated dual carriageway, constructed by simply supported single-span bridge segments on reinforced concrete piers of varying heights. Following the earthquake, both the A24 and A25 were closed for inspection, but reopened to passenger vehicles a few days later. In several locations, spans moved off their bearings; these stretches of highway were closed to enable repairs to take place. The only collapsed bridge structure was over the Aterno River along a secondary road to Fossa (AQ). The bridge was a reinforced concrete construction with three continuous spans. The collapse of the bridge was probably induced by failure of the columns. Slight damage to a few other bridges was also reported. A number of regional and provincial roads were partially closed, mainly as a result of earthquake-induced land and rock slides and settlements. The railways crossing the area affected by the earthquake were inspected immediately after the event and most of them were reopened in time to have no more than a minimal impact on the service. Full service was restored by April 9, three days after the earthquake. Minor landslides throughout the mountainous region also blocked some roads.

Figure 3 Bridge collapsed on the Aterno river, near Fossa (AQ) and disruption of embankment of carriageway of a road in the affected area.

3.1 Typical damage observed on transport facilities

Observations permitted by the earthquake showed that the criticisms were mainly derived from landslides on carriageway, embankment deformations, bridge or viaduct collapses or disruptions. As consequence the interruption caused by all this damage caused connection and transit difficulties for the emergency rescue services.

4. Life-lines and Utilities

Utility networks for water, electricity and phone services were all briefly interrupted by the earthquake, but the damage was localized and after minor repairs and reconfigurations all services were fully functional within a day.

The most important damage to the water system was a pipe break in the aqueduct from Gran Sasso (the main water supply of the area). A high pressure water pipeline broke at the crossing of the Paganica fault, due to a co-seismic movement within the main event. There were also a number of pipe breaks in the distribution system, and many had to be repaired in order to provide water to emergency shelters and temporary accommodations.
Phone services were only briefly interrupted because of power failure. Problems were typically solved by putting emergency generators into service.
Natural gas and electricity supplies were cut-off in the areas of severe damage, like downtown L’Aquila and Onna, and several users remain disconnected because of severe damage to their buildings. Many gas pipelines were damaged or broken by the earthquake. The gas supply was immediately interrupted by the Gas Company covering the whole area. Natural gas services to the areas with significant damage were interrupted as safety precaution as a result of request from the fire department.

Figure 4 Damage on gas pipelines caused by heavy damage to stone walls (at left) and of RC (at right) residential buildings

4.1 Consideration on gas distribution damage

The damages observed on life-lines highlighting primary criticisms related to gas distribution. A lot of gas pipelines were damaged or broken because the buildings were heavily damaged. Many RC buildings suffered high deformation caused by the plasticization of the beam-pillar connections, and some of them, with a “soft-story”, collapsed completely.
Since the majority of flats, houses and apartments were served by autonomous boilers a lot of gas pipelines were installed outside the building on the perimeter walls. As a consequence, many of the external gas pipelines were broken or damaged. This caused significant releases of gas, but fortunately, no fires started.

In comparison with the past the probability of release of gas increased and also the possibility of subsequent fires. This suggests the introduction of specific fire precaution measures.

5. Conclusions

The L'Aquila earthquake, despite the moderate magnitude, caused relatively extensive damage to industrial facilities and life-lines.

The industrial buildings were represented by nonductile concrete and new precast construction that suffered damage on structural and nonstructural elements and equipment. This typology of industrial buildings, therefore, presents significant seismic vulnerabilities. Since this system is widely diffused in Italy similar failures could be experienced in future earthquakes in other parts of the country.

Considering this scenario, a question in terms of NaTech is: What would happen if an industrial or chemical plant with a high risk of major accidents were to be located in the epicentral area of an earthquake? This question should generate thinking because the greater part of Italy is in a seismic region and a lot of vulnerabilities exist in the field of seismic protection of this type of facilities. In particular it is necessary to highlight the low seismic resistance of precast-concrete buildings, and non structural and equipment criticisms. More stringent seismic design is needed for these structures.

Following the collapse, in 2002, of a school due to a 5.4 magnitude earthquake in San Giuliano (South of Italy), attention was focused on a better seismic design for these important structures. It is hoped that industrial seismic damage observed during the L'Aquila earthquake, even if it was relatively slight, will suggest a better integration of seismic aspects in the Seveso directive plants design and reinforcements in order to control and reduce possible NaTech risks for such facilities. In particular, major attention must be aimed to design effective connections between primary and secondary elements in the precast concrete buildings and to control the relative deformation of different parts of the buildings structures. It is also necessary to implement more precautions on the anchorage of equipment. Finally, in order to reduce the risk of fire, the outside of each building should have installed automatic valves triggered by accelerometer for the immediate blockage of the gas supply in case of strong earthquakes.

References

Italian National Fire Department, The Earthquake in Abruzzo and the firefighter's work. www.vigilfuoco.it.