The Umbria (Central Italy) earthquake series of September 26, 1997

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Abstract

The earthquake of 26th September 1997 caused reactivation of NNW-SSE striking faults, much destruction in buildings, and the deaths of 11 people. The site effects observed in the affected area were seismic fractures, landslides, rockfalls, local aquifer level changes, as well as damages to buildings. The site effects extended over a significant area. The type of damage for various types of buildings is described.

1 Introduction

On Friday 26th September 1997, at 9:40 (GMT), a strong earthquake of Ms=5.9 magnitude, produced severe damage and casualties in the area of Umbria, Central Italy. The epicentre of the quake was 43.00N and 12.80E; the focus was 10 km deep, and was located in the broad area of Cesi- Colfiorito villages, which suffered severe damages (Fig. 1). The villages are 50 km east of the town of Perugia (Central Italy). Moreover the populated areas that suffered most damages were Colfiorito, Annifo, Collecurti, Costa, San Martino, Verchiano, Arvello, Aggi, Casenove, etc., which the intensity exceeded the IX of EMS 1992 (Fountoulis,[1]).

According to official information, 11 people were killed, 150 injured, while about 10,000 people became homeless and 100,000 temporarily homeless. The total number of populated areas that suffered significant

damages exceed 60, which are scattered in a mountainous area and which stretches roughly 1,000km^2.

Finally, it is noteworthy that the most significant consequences of the earthquakes were on the historical monuments, some of which are priceless. Among others, significant damages were inflicted on the temple, the Vassilca of San Francisco, the medieval monuments of Assisi, (the historic centre of Nocera Umbria), Santa Maria of Spoleto and Santa Maria of Camerino, (the historic centre of Foligno).

2 Geotectonic framework

The epicentral area occupies part of the mountainous area of the Apennines, which constitutes the axial mountain range of Central Italy (Fig. 1).

From the geological point of view, the epicenter, as well as the broader area, consists of folded and thrusted limestones, cherty limestones, marly limestones, marly clays and marls, belonging to the Umbria-March unit. The above mentioned formations outcrop in elongated occurrences of broad N-S orientation, they have an Upper Triassic - Lower Miocene age, and constitute the bedrock. Locally the recent formations lie over the Umbria-March formations uncomfortably. The recent formations are mainly from continental deposits of Upper Pleistocene - Holocene age, and occupy commonly the topographical lows troughs of the mountain range (Centamore,[2]).

In the broad epicentral area, the geological formations are cut by a number of faults generally striking NNW-SSE, parallel to the main direction of arrangement of the formations, most of which are normal to the dip of shift of both sides' blocks (Barberi,[3] Boccaletti,[4]). Additionally there is a second system of faults with a transversal strike and important horizontal component of movement. According to the actual facts and particularly to the focal mechanism and the field observations, the first system of normal faults of general orientation NNW-SSE has an immediate connection with the particular seismic activity.

3 Seismicity

Eastern Umbria has suffered numerous high intensity (modified Mercalli VII or above) localized earthquakes. The areas in which earthquakes have occurred are the valleys between mountain ranges, such as the Tiberina valley and the eastern edge of the Umbra valley; and in the Martani

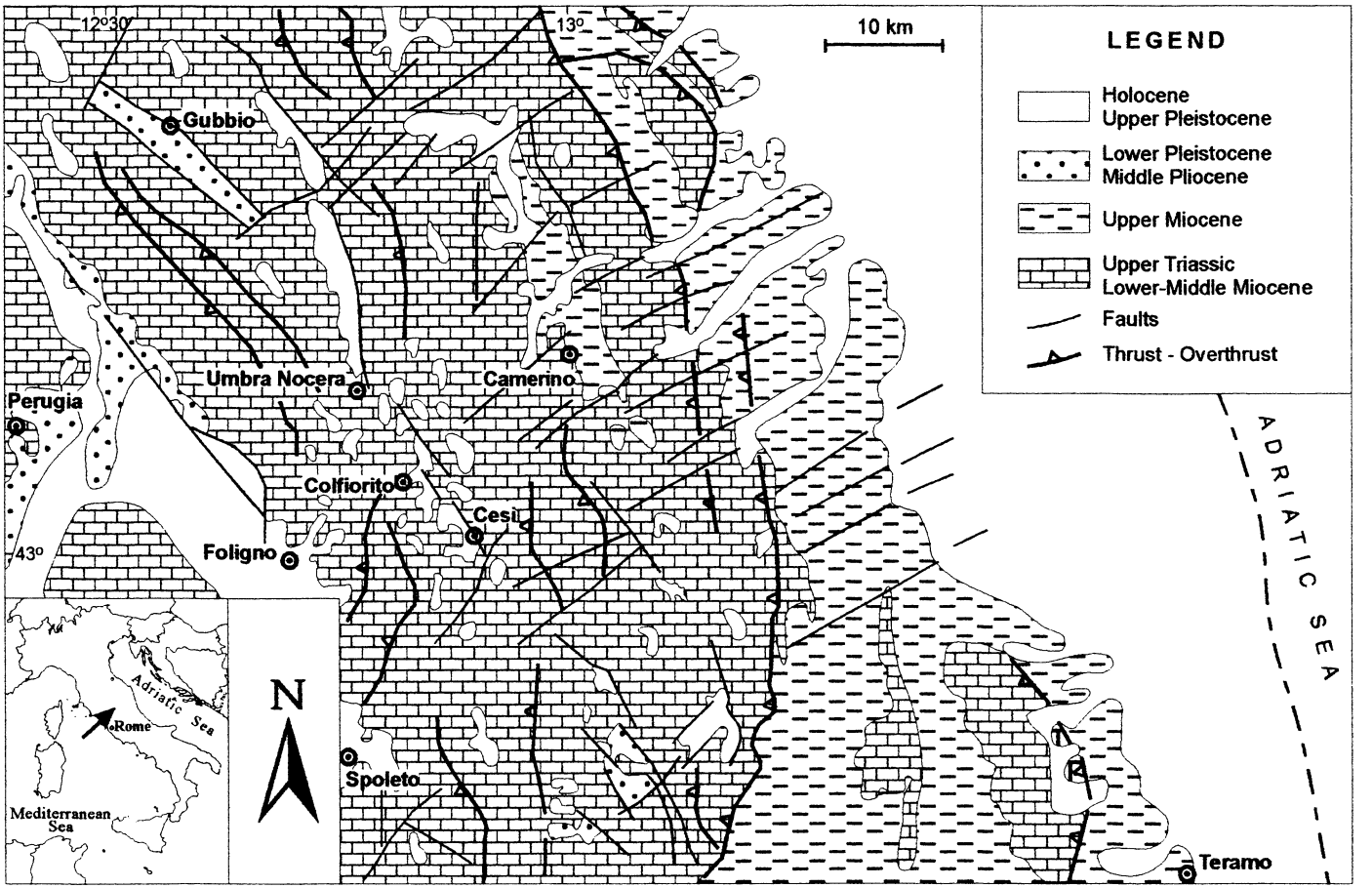

Figure 1: Geological sketch map of Umbria (after Fountoulis,[1])

mountains and the high Nera valley to the southeast, where Norcia is located (Cello,[5]).

Norcia and Cascia have sustained repeated strong earthquakes including shocks in 1328, 1567, 1703, 1730, 1859 and 1910. Multiple earthquakes struck Gubbio between 1465 and 1466 and again in 1736. Norcia was leveled in 1703. Gualdo Tadino and Nocera Umbra were both badly damaged in 1751. Assisi suffered major earthquakes in 1832, 1854 and 1915; Foligno in 1831 and 1832; and Spoleto in 1246, 1277, 1571, 1594, 1667, 1767, 1833, 1853, 1895 and 1957 (Stucchi,[6]).

The serial array of shocks should have been no surprise. Multiple tremors have occurred before in Umbria, even in recent memory. On the morning of October 17th 1982, the inhabitants of the zone between Gubbio, Gualdo Tadino, and Assisi felt the first of a series of earthquakes with epicenters in Valfabbrica.

Three years before, in 1979, in the zone of Valnerina, a similar series occurred. Between September 19 and 20, 1979, numerous shocks were felt, the worst having an intensity of VIII or IX on the Modified Mercalli scale, with a magnitude of 5.8. The small towns of Norcia, Cascia, Preci, Sellano, Valle di Nera, Pioggiodomo, S. and Scheggiano were badly damaged. 881 buildings were destroyed or demolished, and another 1,731 were gravely damaged. As in the earthquake under discussion, stone masonry structures suffered the most from these repeated shocks.

4 Site effects

During the earthquake of the 26th of September 1997, a number of site effects were caused. A number of faults in the epicentral locality and nearby the villages of Costa and Cesi were noticed especially. The faults have a general orientation NNW-SSE and display a variable vertical displacement, which ranges from 2cm to 15cm and separated the limestones from the recent formations. Surface ruptures were observed south of Colfiorito, striking mainly NNW-SSE and displaying a vertical displacement up to 10cm. In some cases they were open up to 10cm. Locally the ruptures displayed a left lateral horizontal component of displacement of a few centimeters.

Both during the main shock as well as the pre-seismic and the post-seismic activity significant site effects were not noticed. More specifically, a restricted number of landslides were recorded; rockfalls mainly along the road axes or artificial slopes. These are low magnitude landslides of materials which are not characterized by satisfying values of the geomechanical properties, which occur, for instance, in the roads

Nocera Umbria - Corfiorito, Casenova - Volpelino, and Cesi-Rasenna, however without causing any problem (Fig. 2).

Settlement apparently occurred in the town of Assisi, where significant cracks had opened in the Piazza Inferiore di S. Francisco. The west side of the outcrop on which the old town of Nocera Umbra is built appears to be slipping.

In the aquifer some small changes of local character were noticed, mainly in the area of the springs, which were the result of limited changes in the superficial formations. The change that was recorded from the springs of metallic water, in the area of Bagnata – Noccera was notable.

5 Description of the damage

In 65 towns and communes in the region of Umbria, 8.396 private buildings were structurally damaged and made uninhabitable. Inspection of public buildings, schools, and churches from 18-22 towns in the region showed that 24% of public buildings and 17% percent of the schools were seriously damaged, while more than half (54%) of the churches were unusable because of severe damage. The cost of the damage for approximately 900 private buildings in Assisi, was estimated around $ 1 billion. The overall value of damage for roughly 9,000 private buildings was approximately $ 10 billion, excluding the cost of repair of the public buildings and churches.

As far as the engineered structures are concerned the observed damage was limited in buildings with typical residential structures, some with commercial uses on the first floor. The type of damage was cracking between different materials and was minor overall. No cases of out-of-plane movement of the hollow clay tile infill were noted. In Fabriano, in the Marche region, several four- to six-storey structures had this type of damage and the buildings had been vacated. Vertical crack was also observed in a column which might have been a pending spall. Such vertical cracks are rare.

Most of the concrete buildings were a significant distance from the epicenter. The magnitude and frequency of the shaking was too small to cause damage to these buildings. The construction of the concrete frame buildings using the infill masonry could potentially create a short column condition under a big earthquake. Most of the damaged concrete buildings appeared to have been constructed in the 1960s or early 1970s.

Extensive damage was observed in buildings of Vernacular architecture. Such constructions are relatively consistent having stone masonry bearing walls with a wood roof structure. In some cases only

Figure 2: Small-scale landslide along the road Umbria Nocera – Annifo

Figure 3: Collapse of the two-story building rubble masonry, in the settlement of Cesi

individual structures were damaged. In other cases the extent of the damage in the community was so great that the entire town was vacated. Nonstructural damage usually included the loss of roof tiles of the low roof at the exterior wall. Moreover plaster spalling from the exterior walls was also observed. Such conditions created a situation where the sidewalk, street, or highway adjacent to the buildings was blocked off. The observed structural damage included many items that would result in a threat of life. The typical failure was in the outward movement of the wall, due to the deflection of the diaphragm pushing the wall outward. This, coupled with inadequate anchorage between the walls and roof, resulted in the wall collapse. In some cases portions of the walls were blown outward. Such type of collapse caused roof collapse too. Many structures had earthquake tie rods visible on the exterior walls (Fig. 3, 4).

From the monumental structures, the churches of Umbria exhibited a consistent pattern of damage despite their diverse designs, periods of construction, or even retrofit history. They are constructed of limestone, ashlar, and rubble masonry, 3 to 5 feet thickness. The major cracks or failures appeared at the junction of facades and naves, or naves and crossings where difference in building stiffness occurred. The most dramatic damage happened in the Basilica of S. Francisco in Assisi and its convent nave. The worst damage occurred at the ceiling and the roof levels. On the vault, the priceless Cimabue frescos crashed to the floor killing four people. Down the nave the webbing of the quadrant of the vault in front of the crossing, the supporting cross vault, and the webbing of the east quadrant of the crossing vault, all fell. The church of S. Chiara exhibits the same damage pattern as S. Francisco, only less severe. There is a crack between facade and nave arch, and the quadripartite vault of the nave is badly cracked on all webs. Large vertical cracks occurred at the sides of the nave walls below the vault.

The church of S. Pietro had cracks between the front arch and facade from which stones and mortar had fallen near the interior front portal of the church. Large vertical cracks ran down the walls of the facade and diagonal cracks appeared in the top bell tower. The Cathedral of Assisi, S. Rufino church also suffered very badly from the earthquake. A major crack runs down the center of the arches of the three bays from the facade to the crossing. The entire nave vault is severely damaged.

In the Basilica of S. Maria degli Angeli cracks were observed between the facade and the nave which had not moved in unison. Similarly in the

Figure 4: Partial collapse of two-story building in the settlement of Annifo.

Cathedral of S. Maria Assunta in Spoleto (1198) the interior nave arch has dislocated from the facade and there is a significant crack. Plaster is falling from the dome and apparent water damage can be seen.

To summarise, all the convents and monasteries that were examined were severely cracked. The Sacro convento of S. Francisco suffered major damage where the southeastern pediment had collapsed and the northwestern facade was badly cracked. The southwest support arches were likewise cracked. The vaults in interior rooms were damaged, frescos on the ceiling fell, and cracks appeared in cells of the southeastern side of the complex. S. Pietro's Benedictine abbey had severe diagonal cracks and was perhaps subsiding down the hillside.

Moreover there is limited evidence of significant damage in engineered structures and this is attributed to the high modern design standards. Stone vernacular buildings behaved much similar to any other vernacular structures around the world, where failing occurred due to inadequate anchorage of walls to roofs, with heavy roofs and chimneys pushing outward. However, most damaged buildings can be repaired but not upgraded significantly. By contrast, monumental structures and particularly churches, have already been through a number of earthquakes

and consequent maintenance attempts in their long lifetime. Although extensive intrusions by engineers may be considered unwarranted in monumental buildings, current thinking suggests that historic buildings must be strengthened to achieve a higher level of protection than ordinary buildings. However it seems clear that heavy engineered interventions will alter the traditional forms. Certainly efforts to preserve the priceless art work on walls and ceilings must be undertaken, and it is recommended to be done with concern not to harm the paintings in the long run.

6 Conclusions

The earthquake of the 26th of September 1997, in Umbria, Central Italy took place in an area that is characterized by not so high seismic activity and especially by seismic events, which have relatively high magnitudes but which take place at long intervals.

The seismic activity is generated by normal type stretching faults within the tectonic plate, due to release of tensional stress-field.

The site effects were observed in a significant area in which there were dispersed numerous small settlements and towns. Except for the geological and geotechnical factors, the type of the damage depends on and the age of the buildings.

7 References

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