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# INFLUENCE OF LOCAL SOIL CONDITIONS ON INTENSITY DISTRIBUTION IN CESI (ITALY) DURING THE UMBRIA EARTHQUAKES (SEPTEMBER 1997)

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## SUMMARY

Umbria (Central Italy) was hit by a 5.8 ($M_L$) earthquake on 26 September 1997, the epicenter of which was located very close to the small village of Colfiorito. Several people were killed, while thousands of buildings in the broader area were severely damaged; among them, unfortunately, were invaluable historical monuments as the chapel of San Francisco di Assisi. Over eighty-five urban units were damaged, while the distribution of macroseismic intensity presented a selective pattern from one unit to another. This differentiation is mainly attributed to local geological and geotechnical conditions, given that building type is more or less uniform throughout the meizoseismal area. Differentiation in intensity distribution was observed on both regional, among urban units, and local, within the same unit, scale. Specifically, our recordings of damage showed that within one single village the intensity would range between two to three degrees of EMS-92. This observation was confirmed by instrumental recordings, which showed that within a single urban (Cesi) unit amplification values were locally four times greater than in the surroundings. In this village we conducted detailed damage recording, following the guidelines of EMS-1992, which incorporates building type in the evaluation of damage. The locations of significant intensity differentiation coincided with the outcrops of geotechnically distinct geological formations. The main outcome of our survey is that geological and geotechnical factors affect greatly the distribution of damage throughout the meizoseismal area, and are responsible for significant variations not only on regional, but also on local scale.

## INTRODUCTION

The earthquake sequence was located in Umbria, an area about 60 km east of Perugia (Figure 1). The first shock ($M_L$=5.5/$M_w$=5.7) of the earthquake sequence, which lasted for about more than a month, was located at 43º01.75'N, 12º.51.08E and occurred on 26 September 1997 at 02.33 local time. The epicentre of the largest shock ($M_L$=5.8/$M_w$=6.0) was located near the village of Colfiorito.

The same village lay approximately at the epicentre of two more serious tremors, one on 3 October ($M_L$=5.1/$M_w$=5.3) and another one, four days later. On 12 and 14 October two more important shocks were reported ($M_D$=4.5 and $M_L$=5.4/$M_w$=5.7 respectively) located near Sellano village.

## GEOTECTONIC SETTING

The epicentral area is located within the Apennine mountain chain, which runs roughly north-south in central Italy. The outcropping rocks are limestones, cherty limestones, marly limestones, marly clays and marls, which form part of the Umbria-Marche unit. The age of the formations is from Upper Triassic to Lower Miocene and occur in elongated occurrences because of frequent folds and trusts that have deformed the strata.

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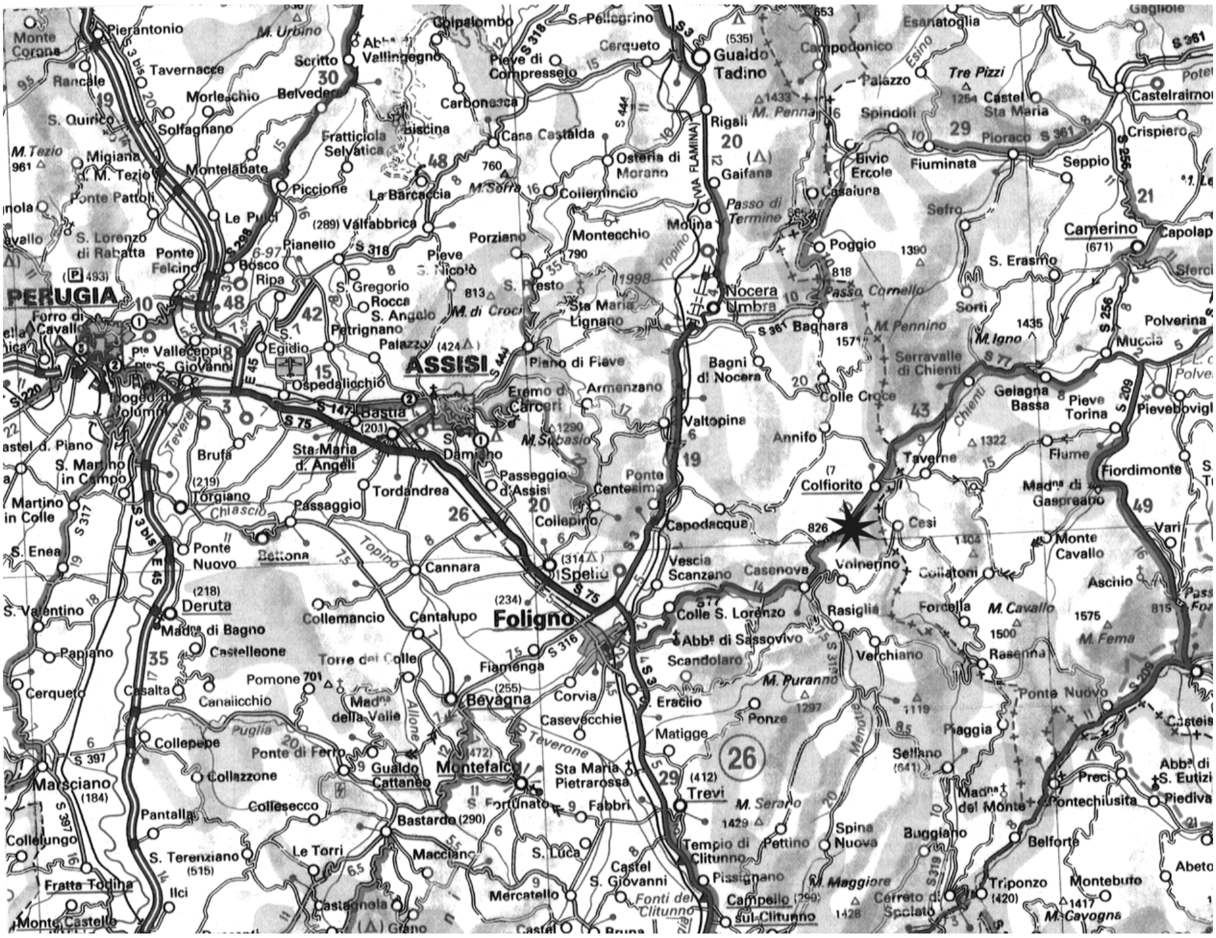


**Figure 1: Geographical map of Umbria area in Central Italy showing the earthquake epicenters in Colfiorito and Cesi.**

Unconformably over the above-mentioned occurs a series of Late Pleistocene- Holocene clastic deposits. They outcrop in the low altitudes areas and intermontane valleys [Barberi et al., 1993, Boccaletti, et al., 1985, Calamita et al., 1986] (Figure 2).

**Figure 2: Pleistocene-Holocene deposits forming an almost plain relief and overlying uncomformably the basement**

A system of NNW-SSE striking faults occurs in the broader epicentral area, almost parallel to the elongated outcrops of the geologic formations. This system was responsible for the earthquake sequence, as shown by their geometric, kinematic and dynamic characteristics, which are consistent with the focal mechanism solutions [Fountoulis & Lekkas, 1998]. Besides, a second, transverse fault system occurs in the area, with important component of lateral movement.

## SEISMIC HISTORY

Eastern Umbria has suffered numerous serious earthquakes ($I_o$=VII or higher) in the past centuries. Locations hit by seismic activity were mainly the intermontane valleys (Gubbio, Cualdo, Tadino, Nocera), the eastern edge of Umbra valley (Folingo, Trevi, Spoleto), in Martari mountains and the high Nera valley to the southeast, where Norcia and Cascia are located.

The latter two have suffered the repeated blows of earthquakes, in 1328, 1567, 1703, 1730, 1859 and 1910. Gubbio was hit by tremors in 1465/1466 and 1736. Norcia was razed by a disastrous event in 1736, while Assisi was struck in 1832, 1854, 1915. Foligno fell victim to earthquakes in 1831 and 1832, and Spoleto was hit in 1246, 1277, 1572, 1594, 1667, 1767, 1833, 1853, 1895 and 1957 [Tobriner et al., 1997].

## OVERVIEW OF DAMAGE

The Umbria earthquake of 26th September 1997 induced extensive damage within an extended area in central Italy. Based on official reports, out of 32.865 private houses checked, 9.182 collapsed, were severely damaged or rendered inhabitable. According to official records, in about 20 villages and/or settlements, 25% of public buildings and 20% of schools were rendered demolishable, while 55% of churches received an important amount of damage (Figure 3).

**Figure 3: Construction partially collapse in the epicentral area.**

No high-rise buildings, with modern design and construction exist in the epicentral area while, generally speaking. Low amount of damage was observed in all the lower earthquake-proof constructions. On the contrary, many old buildings and churches, most of which are historical monuments, suffered serious damage.

Based on extended researches throughout the epicentral area, the intensities recorded in certain settlements displayed significant differentiation. The main cause of this, except for the position and the epicentral distance of each settlement, was the foundation formations which might lead to differentiation greater than three degrees of E.M.S.-1992 [Fountoulis & Lekkas 1998].

## INTENSITY DIFFERENTIATION IN URBAN AREAS

Except the intensity differentiation displayed among various settlements within the epicentral area and the outskirts of it, similar differentiation also appeared within each single settlement. The most important differentiation was observed in Cesi, Aniffo, Collecuri, Arvello, Costa, San Martino, Casevove, Valtopina, Cassete, Verchiano, e.t.c., where the intensities ranged within 2 to 3 degrees of E.M.S.-1992 [Grunthal, ed., 1993] within the villages. Variation in construction type was not responsible for the differentiation of damage distribution within the same settlement, as constructions are more or less uniform in the whole of each community. The main reasons for this were the morphological, geotechnical, geological and tectonic conditions that differed from place to place within the same settlement.

## THE CASE OF CESI

The most representative example of intense differentiation was in Cesi village, which lies about seven kilometers south of Colfiorito (Figure 1), located on the earthquake epicenter. The village comprises about 300 residences and some public buildings founded at the foot of a small hill (Figure 4). The western part of the village occupies an almost flat expanse which corresponds to the outcrops of post-alpine formations and specifically to 10-20 meters thick terrestrial deposits consisting of coarser and finer, loose and semi-cohesive, red-brown colored clastic material. These overlie uncomformably the alpine basement (Figure 5).

**Figure 4: View of Cesi from the west.**

The eastern half of the village lies on the highest parts of the area and is built on the alpine NW-SE folded formations such as marly limestones, carbonate marls, etc.

Most of the constructions of the village are usually two and single (rarely three) story and roof-tiled buildings. They are built of masonry, bricks and more rarely of structural elements of reinforced concrete. The residential area, except some locations, is sparsely built; only around the northern entrance of the village are buildings dense. The overall image though is that there is a similarity in the construction type, the height and density of buildings, a essential fact which proved quite useful for results to be reached concerning the unequal damage distribution within Cesi settlement.

After the damage for each construction was recorded, it became clear that the damage was particularly serious in the western lower part of the village. Several buildings were collapsed totally or partially, while most of them had their walls and roofs seriously damaged, making the residences uninhabitable (Figure 6). The intensity in that part of the village were $I_{EMS92}$=IX+ [Grunthal, ed., 1993].

**Figure 5: Recent terrestrial deposits, south of Cesi village.**

**Figure 6: Damage and collapse in the west, low-lying flat part of Cesi.**

The damage gradually decreased towards the eastern side of the village, built on the hilly part, where only partial collapses were noted.. The intensity for this part was $I_{EMS92}$=VII.

Our observations could be verified and interpreted by instrumental data (Figure 7) compiled immediately after the main shock [Mucciarelli et al., 1977]. Specifically, measurements show that the amplification values are 4 times greater, for the frequency neighborhood of 2Hz, in the western part of the village, which is built on the plain and where the intensities were high, than in the eastern part, located on the hilly part and where the damage was significantly less.

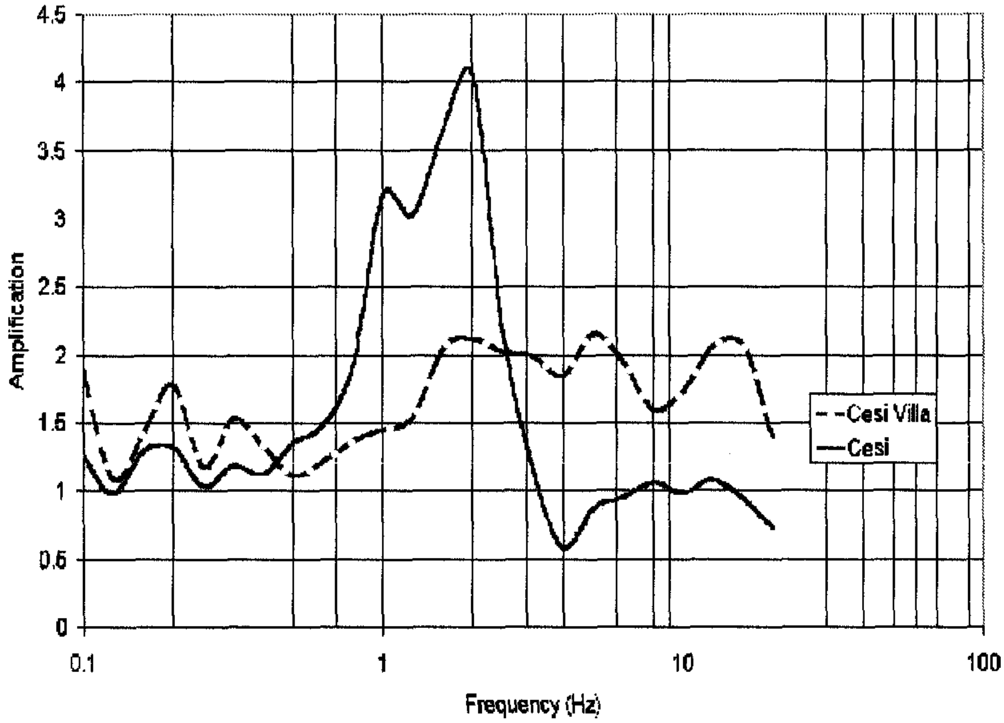


**Figure 7: Frequency – Acceleration Amplification diagram. Dashed line represents lower part of Cesi and continuous line the upper one.**

## CONCLUSIONS

The Umbria earthquake on 26 of September caused extensive damage in numerous settlements and urban units of the broader area. It could be observed that despite the structural similarity there was a significant variation in the damage and the evaluated intensities. This fact is mostly attributed to geological and geotechnical conditions regardless the location, epicentral distance and azimuthal position [Fountoulis & Lekkas 1998].

Such variations were observed not only on regional but also on local scale, that is to say within some urban units, where intensity differentiation exceeded 2 degrees (E.M.S.-1992), attributed to notable discrepancy in geological and geotechnical conditions.

Cesi, which is the most characteristic case, is divided into two parts with VII and +IX intensities respectively. Instrumental data showed that amplification values were 4 times greater for the frequency neighborhood of 2Hz.

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***LESSONS FROM RECENT EARTHQUAKES,*** *Earthquake damage, Earthquake ground motion, Site effects, Umbria (Central Italy)*