COLFIORITO 1997 EARTHQUAKES DAMAGES SEVERITY OBSERVATIONAND SITE EFFECTS

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SUMMARY

September 1997 registered the onset of a seismic sequence effecting the Umbria-Marche region (Central Italy), in which earthquakes up to IX MCS degree caused diffused damage over a large area. With respect to villages settled in an intermountain basin near the epicentral area, the resulting damage pattern is investigated to give a better understanding of future local ground motion sensitivity, from a qualitative point of view. Macroseismic survey data are collected and compared with the surface geology of 15 villages and hamlets within a restricted area. It emerges that among these 15 settlements, six individual groups are discernable showing a gradual variation to the damage severity, inside a relatively small area. Such abrupt damage variation is influenced by modest scale lithological transitions. In particular, major effects occurred within the basin in villages settled close to border faults. These observations support models existing in literature, which maintain that edge effects and the generation of diffracted waves in soft basins contribute to a strong shaking at site.

INTRODUCTION

Many different elements determine the seismic shaking of an inhabited center and it is difficult to evaluate the individual significance of each factor. However, local surface geology, together with dwelling characteristics, are those most commonly claimed. The crucial role of near surface geology in site amplification has been demonstrated by many authors, both from theoretical and observational points of view [Borcherdt, 1970; Borcherdt and Glassmoyer, 1992; Moczo and Bard, 1993; Tertulliani and Maramai, 1998; and many others]. The idea that geomorphology and geology might influence the damage pattern during an earthquake is not new. One of the most famous of eminent forerunners, the German philosopher I. Kant [1756], argued when discussing the Lisbon earthquake of 1755 that more damage generally occurred along rivers. By the end of the nineteenth century, seismologists considered the correlation between effects and soil composite to be a fatal element when considering the safety of buildings [i. e. Milne and Burton, 1891; Baratta, 1910; Oddone, 1916]. It is now known that there exist many geo-morphological situations that can contribute to amplification of the ground motion; those exhibited by topography or lithology, edge and basins effects and all lithological contacts where the impedance contrast is high. We can generally believe that geological rather than engineering factors play a greater role where severity of damage is concerned, as shown by the recent destructive earthquakes of Michoacan, 1985, Loma Prieta, 1989 and Kobe, 1995. Besides significant amplification effects have been observed also for low intensity shaking in very little alluvial valleys as in the case of Rome (Cifelli et al., 1999).

This work attempts to separate and then to itemize reasons for the differing levels of heavy damage suffered in the Colfiorito area (Central Italy), during an earthquake sequence which started in September 1997. Disturbance factors that may be considered responsible for eventual site amplification have been observed during the field survey and compared with local geology for a group of localities. The goal of this paper is to show a set of detailed observational data, inferred from the macroseismic survey, that can be considered as an useful tool for further modeling or empirical practices to study the earthquake hazards of a done area.

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Figure 1. Landscape of Colfiorito basin from the top of Mt Pennino (photo of the author).

2. GEOLOGICAL SETTING AND DATA COLLECTION

The Colfiorito basin is situated within a mountainous region of the Central Appenines (fig. 1), associated to a fault array with main N-S orientation and bordered by NW-SE to NNW-SSE trending faults. Some of those show recent activity in continental deposits (sandy clays of Upper Pliocene) [*Cello* et al., 1997]. The epicentral area of the September 1997 earthquakes is characterized by small intermountain basins (Figure 2), filled with continental deposits (lacustrine) since Pleistocene and Holocene. Numerous debris fans mark the boundary of the basins, outcropping on the bedrock (Meso-Cenozoic limestone and marls). The thickness of the basin has still to be investigated, but it is reasonably estimable around 100 meters in the deeper part Differences in lithology enhance the contrast of impedance, with an evaluation of around 5 for that between the limestone and lacustrine deposits.

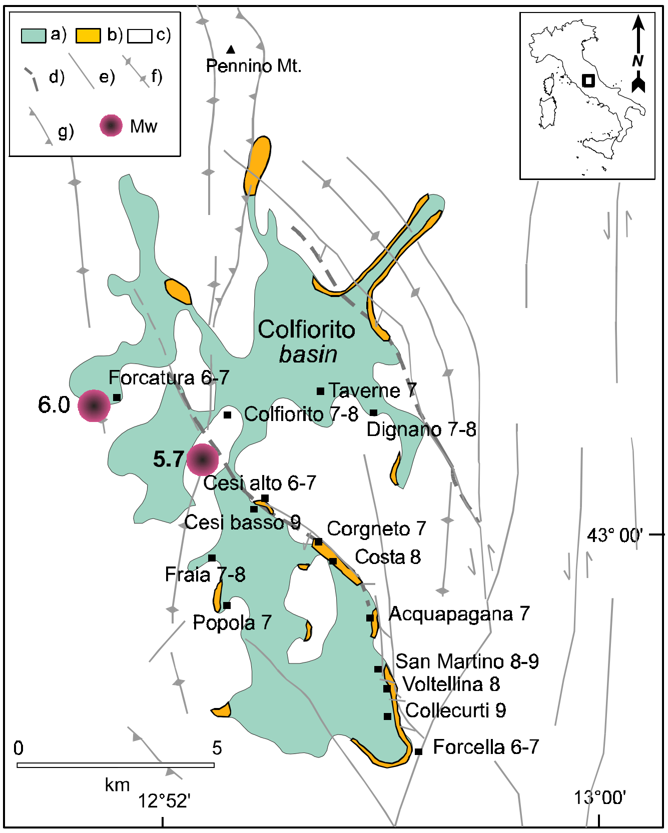

Figure 2. Epicentral area of the September-October 1997 earthquakes. Map of the Colfiorito basin. Main shocks are indicated with dark circles. a) recent alluvium filling; b) debris; c) Ceno-Mesozoic limestone formations; d) ground deformation and/or fault reactivation; e) Quaternary faults; f) Anticline axis; g) Miocene thrusts. (Modified after Cinti et al., 1998).

The Colfiorito (Central Italy) earthquake sequence caused diffused heavy damage over a large area, with a maximum MCS (Mercalli-Cancani-Sieberg) intensity I=IX in some villages near the epicenter. The largest shock, ML=5.8, (MW= 6.0) occurred on September 26 (h 09.40 GMT) and was preceded by an event with ML=5.5 (MW= 5.7) earlier that day. Important artistic and historical sites such as Assisi, Foligno and many others suffered severe damage with heavy concussion to the cultural heritage of the region. As the sequence, lasted from September 1997 to April 1998, was characterized by several shocks with magnitude larger than 5, it was difficult to distinguish the damage contribution from individual shocks. The data here presented were collected at the beginning of October 1997. Subsequently, the scenario of destruction becomes obviously and dramatically more severe. In this paper, only hamlets and villages settled into or neighboring the Colfiorito Basin (Figure 2) were studied, where the heaviest damage occurred. Data were collected by means of direct field investigation and were then integrated with information coming from macroseismic surveys performed by the Istituto Nazionale di Geofisica (ING), the National Defense Group Against Earthquakes (GNDT) and the European Seismological Commission (ESC) Working Group in Macroseismology [Tosi et al., 1998; Camassi et al., 1998; Stucchi, 1998]. The damage data set has been organized according intensity, occurrence of total collapse and type of substratum (see Table 1). Building types present in the epicentral area have homogeneous characteristics, typical of central Italian settlements where most of the dwellings are built using simple stones with poor mortar, or non-reinforced squared stones and blocks (Fig. 4). Furthermore, many old buildings have been badly renewed, by loading structures, for example with concrete roofs. Vulnerability due to type, material, geometry and state of maintenance can be considered very similar for the sample of buildings studied. On the contrary, the morpho-geological situations where the villages are settled, show evident differences. Within the 15 cases shown, six site types can be discerned, for which different responses are evidenced (Figure 3). Table 1 lists the characteristics, severity of damage and intensity at each location

Table 1. List of studied sites. In the substratum column the settlement type of Figure 3 is also indicated (between brackets).

LOCALITY	TOTAL COLLAPSES %	SUBSTRATUM	DISTANCE FROM THE EDGE m (*)	INTENSITY
Cesi basso	~ 50	Alluvium (a)	50	9
Collecurti	~ 50	Alluvium (a)	50-100	9
San Martino	20	Alluvium (a)	150	8-9
Voltellina	5-10	Alluvium (a)	150	8
Costa	5-10	Debris (b)		8
Dignano	5	Bedrock (f)		7-8
Colfiorito	-	Bedrock/Alluvium (c)		7-8
Fraia	-	Bedrock/Alluvium (c)		7-8
Taverne	-	Alluvium (e)	> 350	7
Popola	-	Bedrock (f)		7
Corgneto	-	Debris (b)		7
Acquapagana	-	Debris (b)		7
Cesi alto	-	Bedrock/Debris (d)		6-7
Forcatura	-	Bedrock (f)		6-7
Forcella	-	Bedrock (f)		6-7

(*) distance from edge is measured only for localities settled on alluvial sediments

3. DISCUSSION AND CONCLUSIONS

The variations in damage severity in the studied villages are not justifiable in terms of source effect, because of their closeness. In such a small area (Figure 2), with a hypocentral depth of about 10 km or less, the source contribution should be represented by pure vertical incidence. Also the simple association of alluvium with amplification is not enough to explain some cases, but it needs to be included in the overall evaluation. From Figure 2 we can deduce that most of the heavy damage occurred in hamlets settled on alluvial deposits near to the edge of the basin, with a border fault to mark the bedrock limit. In fact, it emerges that the occurrence of major damage (total collapses up and over 50 %, and heavy damage to reinforced concrete structures) coincides with settlements founded on alluvial deposits close to the basin edge (distance < 150 m), bordered by outcropping faults. If we consider the pattern of effects in detail, we can further observe that the severity gradually decreases as we move to villages settled on debris and on a bedrock-debris transition. We can find, in the recent literature, reasonable explanations of such behavior.

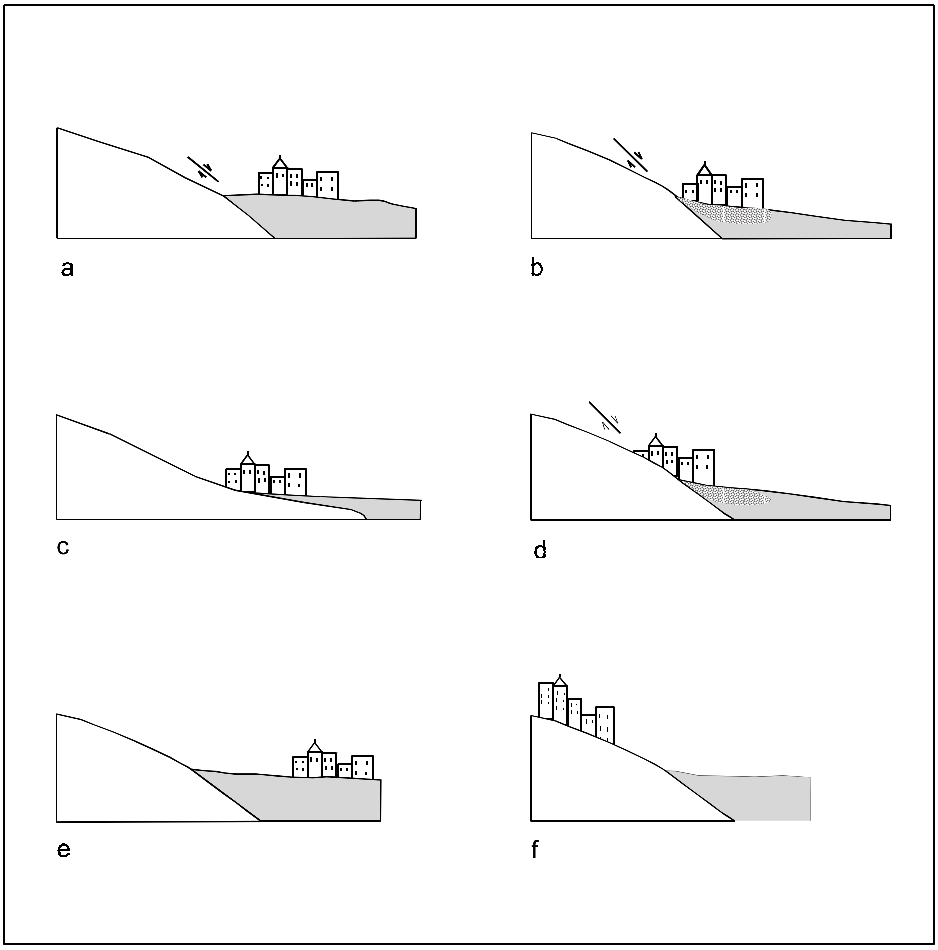

Figure 3. Simplification of the settlement types within the sites studied. a) on alluvium near the basin edge; b) on debris; c) on the bedrock-alluvium transition; d) on the bedrock-debris transition; e) on alluvium far from the basin edge; f) on bedrock. From the observations the *f* and *e* settlements result to be the safest ones, while *a* and *c* are the settlements with a major exposition.

Concentration and/or sharp variations in the severity of damage are commonly attributed to transitions between soft and rock lithologies. Numerical models and real case histories have shown strong correlation between damage and surface geology [i.e. *Moczo and Bard,* 1993; *Spudich and Ida*, 1993; *Kawase*, 1996; *Riepl* et al., 1998]. An increase of significant effects has been evidenced near the edge of soft basins [*Rovelli* et al. 1995; *Cifelli et al., 1999*; *Kawase*, 1996], particularly if bordered by faults which can induce abrupt amplification [*Pitarka* et al., 1997; *Pitarka* et al., 1998; *Marra* et al., 1999]. Preliminary analyses of strong ground motion have already been performed on sites affected by the Colfiorito sequence, both by the Nakamura technique [*Mucciarelli* et al., 1997] and from data collected with a dense array of instrumental stations installed within the basin area [*Caserta* et al., 1998]. In the second case a concentration of diffracted waves generated close to the edge of the basin was observed, which would have contributed to local ground motion characteristics. This phenomenon seems to coincide with that shown in the same area, and for the same seismic sequence, by *Caserta* et al. [1998], using a dense array of stations, and by *Pitarka* et al. [1998], regarding the Kobe earthquake. However the only observation of the intensity variation

Figure 4. Example of collapse in San Martino village. The building type is characteristic for the whole area. The irregular masonry texture of sample stones is clearly visible. Note the concrete roof in the house on the right. (photo of the author).

is not here a sufficient element to allow a hypothesis coupling source and basin-edge effects [*Pitarka* et al., 1998].

In conclusion, we can synthetize the observations here shown in some statements:

- the variability of an earthquake damage pattern is often linked to slightly differing geological features within a small area, which create a leopard stain effect;
- such behavior has been emphasized by the characteristics of surface geology, the vicinity of the seismic source and the geographical distribution of hamlets;
- settlement shaking seems to increase as we move from the inner to the outer parts of the basin, being greatest towards the edge where the presence of very local factors lead to the amplification of the ground motion;
- villages at greatest risk result those settled on alluvium at a short distance (< 150 m) from the basin edge controlled by faults (*a* in Figure 3);
- another dangerous condition is for villages built on the alluvium-bedrock transition (*c* in Figure 2), where heavier damage occurred in buildings settled on alluvial deposits side (see Fraia and Colfiorito sites in Figure 3 and Table 1);
- the safest settlements are based on bedrock (*f* in Figure 3) and on the inner part of the basin (distance from the edge > 350 m) (*e* in Figure 3);
- intermediate risk conditions are related to variable surface geology where the presence of debris beds and the transition between debris and bedrock are apparent (*b* and *d* in Figure 2).

This view supports the observation that diffracted waves generated at the edge of soft basins cause constructive interference with S-waves coming from the bottom of the basin itself [*Kawase*, 1996; *Pitarka* et al., 1997; *Pitarka* et al., 1998], suggesting a their important role in the damage pattern in the area.

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