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Seismic response analysis in the southern part of the historic centre of the City of L'Aquila (Italy)

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ABSTRACT

This paper deals in the 2011 extensive site investigation by means of boreholes up to a depth of 80 m, Down-Hole (D-H) tests, Seismic Dilatometer Marchetti Tests (SDMT), Multichannel Analysis of Surface Waves (MASW) tests in the area of via XX Settembre of the city centre of L'Aquila (Italy), to obtain a detailed geotechnical model. Results of site investigations showed a marked variability of shear wave velocity V_s profiles, especially in the upper 5–10 m, where different soil types are commonly encountered, all characterised by low values of V_s.

In this paper the main features of the April 6, 2009 L'Aquila Earthquake ($M_L=5.8$; $M_W=6.3$) are also discussed. The earthquake caused 308 casualties and heavy damage in the city of L'Aquila and in the surroundings villages. Some accelerometric stations were located across the Aterno River Valley, while only one station (namely AQK) was located in the city centre of L'Aquila. The peak acceleration values ranged from 0.35 g recorded in the city centre to 0.65 g recorded in the middle Aterno valley. The recorded time histories were characterised by short durations and high peak accelerations both in the horizontal and in the vertical directions.

The area of via XX Settembre (southern part of the historic centre of the city of L'Aquila) was severely damaged by the earthquake. This area, located at a very short distance from the city centre, includes also some reinforced concrete frame buildings, mostly 5–7 storey high, built between 1950 and 1965. Old masonry buildings and some of these r.c. buildings collapsed or suffered severe damage due to the main shock, causing several tens of victims. The peculiar subsoil conditions locally detected down to about 40 m depths in this area include fine-grained soils interposed within, or placed above, *"Brecce dell'Aquila"* (typical of L'Aquila) and man-made fills. Low and variable shear wave velocity V_S values in the upper portion of the subsoil have locally originated major amplification of the ground motion during the main shock.

Therefore the paper deals also in specific one-dimensional numerical seismic response analyses performed. Significant amplification effects related to local subsoil conditions, bigger than the amplification factors given by the Italian Building Code NTC 2008, have been discovered by the seismic response analyses carried out at the site. The results of soil response analyses were compared with the occurred damage in the area.

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1. Introduction

The city of L'Aquila was struck by the 2009 seismic sequence, with the main shock on April 6, 2009, at 03:32 local time ($M_L=5.8$; $M_W=6.3$). The city of L'Aquila and the surrounding small villages along the Aterno river valley suffered severe damage: 308 casualties, 1600 injured, 40,000 homeless occurred. Most of the deaths took place in vulnerable masonry houses which were subjected to unusually strong motions. Detailed reports were also produced by the Geo-Engineering for Extreme Events Reconnaissance (GEER) project [1] on seismological and geotechnical aspects of the earthquake and by Aydan et al. [2a–c] on the occurred damage. An extensive report was made by the Italian Research Group [3] under the supervision of the Italian Geotechnical Association (AGI) and of the National Network of Earthquake Engineering Laboratories (ReLUIS) project. The geotechnical aspects of the earthquake are related to seismic amplification [4], fractures, large

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Fig. 1. Aerial view of the investigated area and location of geological section A-A reported in Fig. 5.

deformations, rock falls, sink holes and liquefaction. A soil liquefaction phenomenon occurred at the village of Vittorito, as reported in detail by [5]. Here the authors discuss about the ground recorded motion and compare the evaluated local site response with that predicted according to the Italian Building Code [6]. The subsoil conditions were reconstructed based on geological information and on a large amount of results of geotechnical and geophysical investigations carried out in the years 2009–2010, as well as on data from previous investigations. Basing on the results of site investigations, a ground model was obtained for the city centre of L'Aquila, where the damage was more severe (Fig. 1). In particular the investigated area is that near the via XX Settembre, a main road which borders the Southern part of the old city centre. The ancient part of L'Aquila centre includes most of the historical heritage and several old masonry buildings; the area facing Via XX Settembre, located at a very short distance from the city centre, includes also some reinforced concrete frame buildings, mostly 5–7 storey high, built between 1950 and 1965. The huge concentration of damage within this area created speculation for both poor design and construction techniques of the buildings, also related to inadequate evaluation of the seismic action provided by the Italian building Code in use at the time of their construction. In addition, possible significant amplification effects related to local subsoil conditions were devised. Basing on the ground model, the site response analysis was carried out and the results obtained were used to explain the occurred damage in the area.

2. Ground motion

The epicentre (latitude 42.3476, longitude 13.3800) of the main shock was located at few Kilometers W-SW from the city of L'Aquila. Maximum MCS intensity was: I=X at Onna and I=IX at L'Aquila (73,000 inhabitants). According to Italian Institute of Geophysics and Volcanology (INGV), the main shock took place along a normal fault oriented NW–SE, with local magnitude M_L=5.8 and moment magnitude M_W=6.3. The hypocentral depth was estimated at approximately 10 km from the ground surface. Some accelerometric stations (AQG, AQA, AQV, AQM, AQF, AQP) were located across the Aterno river valley, belonging to the Civil Defence (DPC) array, and recorded peak values ranging from about 0.33 g to 0.65 g. The time history of AQG station, located on weathered rock, the recorded PGA was: N-S =0.51 g, E-W =0.47 g, UP =0.24 g. As regards the AQK station, located on stiff soil on the city of L'Aquila near to the area of via XX Settembre, the recorded PGA was: N-S =0.35 g, E-W =0.33 g, UP =0.37 g. It must be stressed that L'Aquila is located in the vicinity of the normal fault, and because of this the recorded vertical PGA (UP component) is slight bigger than the horizontal one in N-S component.

It is interesting to compare the recorded PGA accelerations with those predicted by the Italian Building Code [6] for 10% probability of exceedance in 50 years, at L'Aquila city. According to this Code, the PGA, which is the acceleration with 10% probability of exceedance in 50 years, is a_g=0.261 g at the ground surface (outcrop stiff soil), as can be read in the specific site by the Code.

To compare the PGA recorded at the surface with the acceleration given by NTC (2008) at the ground surface (outcrop stiff soil), it must be evaluated the stratigraphic amplification factor S_S, which depends on the soil type. Evaluating the average shear wave velocity V_{s30} in the upper 30 m of soil, the soil type is B for AQG and AQK stations. In particular it has been evaluated a V_{s30}=680 m/s for AQG station by V_s profile given by Down Hole test [4]; for AQK station the V_{s30} is lower (V_{s30}=480 m/s) than the case of AQG station, where the soil is similar to that of via XX September, which is characterised in the next paragraph. The stratigraphic amplification factor S_S for soil type B varies in the range 1.00–1.20. In particular, for the reference ground motion with 10% probability of exceedance in 50 years, the computed value for AQG and AQK stations is S_S=1.15. Hence the maximum value of ground acceleration predicted by the Italian code for 10% probability of exceedance in 50 years, for the soil where AQG and AQK stations are located gives the maximum acceleration at surface a_g=0.300 g for both stations. Comparing the design acceleration values predicted by the code for 10% probability of exceedance in 50 years with the recorded ones at AQG (N-S =0.51 g, E-W =0.47 g) and at AQK (N-S =0.35 g, E-W =0.33 g), it clearly appears that in the case of AQG the recorded ones are quite higher than that predicted by NTC 2008 for 10% probability of exceedance in 50 years; in the case of AQK the recorded ones are quite similar to that given by the code. By the way, the acceleration at the conventional seismic bedrock underneath the AQG station can be evaluated by the deconvolution of the recorded time history at the surface, using the EERA code [7]. According to [5], the deconvoluted time history (Fig. 2) at the conventional seismic bedrock (25 m depth), for the N-S component, gives the maximum acceleration a_g=0.316 g.

Similarly, the deconvoluted time history (Fig. 3) at the conventional bedrock (50 m depth), for the N-S component of the AQK station, gives the maximum acceleration a_g=0.243 g.

The basic information on the two accelerograms recorded in AQK and AQG stations, are reported in Table 1, as well as the information of the two deconvoluted accelerograms.

The maximum deconvoluted acceleration at the AQK station located in city of L'Aquila (a_g=0.243 g) is lower than that of the

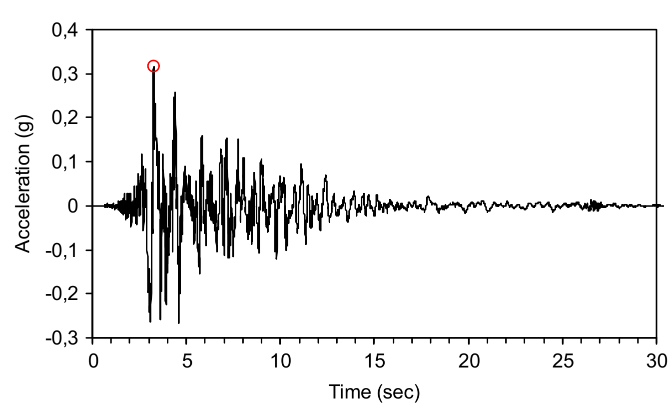

Fig. 2. Time history of the AQG recording for the N-S component deconvoluted at the conventional bedrock located at 25 m depth.

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