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The role of aftershocks in the liquefaction phenomena caused by the Emilia 2012 seismic sequence

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ABSTRACT

Extensive and spectacular phenomena of soil liquefaction were observed during the Emilia seismic sequence that struck northern Italy on May–June 2012. A back-analysis with simplified procedures based on empirical correlations reveals a small liquefaction potential, which apparently underestimates the observed surface effects. Multiple and close-in-time events were a peculiar aspect of the sequence but cannot be accounted for within the simplified procedure. This study investigates their possible role in excess pore pressure build-up and hence liquefaction triggering. Results of a numerical analysis suggest that aftershocks played a determinant role, leading liquefaction phenomena to such a great extent as observed in the field. This evidence is to be considered when assessing the results obtained with empirical correlations.

1. Introduction

The Emilia seismic sequence that struck northern Italy on May–June 2012 had a relevant social, cultural, emotional and economic impact and caused severe damage in many localities, especially to historical centres and factories [1]. 27 victims were ascertained, hundreds of people got injured and at least 40,000 evacuated [2]. From the scientific point of view, the sequence represented an important case study and the whole geophysical and engineering community focused its attention on it [1]. Surficial ground effects (and in particular liquefaction occurrences) were spectacular in some sites and absolutely unusual in the Italian context of the recent past years [3]. Several factors may have contributed to produce such widespread liquefaction phenomena, which were mainly located along the former stream of diverted rivers [3]. In particular, this study focuses on the role of aftershocks, as accelerometric stations recorded several close-in-time events.

Specific geologic settings with liquefiable layers confined by low permeability layers may cause significant delays in excess pore pressure dissipation. In such conditions, pore pressure build-up caused by subsequent shocks may produce significant effects. This peculiar behaviour cannot be accounted for in simplified empirical procedures for liquefaction triggering assessment, which take into account only the effect of the main shock. Evidence of pore pressure accumulation and build-up by repeated shocks are reported in the literature, for example in the case of the 2011 Great East Japan Earthquake. Observations of liquefaction phenomena in Urayasu city suggested a relevant role of an aftershock that struck about 30 min after the mainshock [4]. Numerical analyses have shown that indeed the small aftershock reactivated liquefaction phenomena as excess pore water pressure associated to the mainshock were not yet dissipated [5].

This paper reports a back-analysis of liquefaction phenomena observed in the municipalities of Sant'Agostino and Mirabello, where the most and largest liquefaction effects were observed. After a brief description of the subsoil within the interested area, a reference seismic ground motion is computed considering the strong motion records at the nearest accelerometric station. The conventional empirical procedure is then applied to verify the soil liquefaction potential [6]. Finally, a numerical non-linear analysis is performed to evaluate the influence of aftershocks on the pressure build-up process.

2. The 2012 Emilia seismic sequence and related liquefaction effects

The 2012 Emilia seismic sequence was characterized by two mainshocks (May 20th and 29th, 2012), with local magnitudes slightly less than M_L 6.0 and five more shocks with $M_L > 5.0$. Overall, about 2500 shocks were recorded [1]. The seismic events were responsible of many and variegated surficial ground effects in the epicentral area (mainly Ferrara and Modena provinces, see Fig. 1). In particular, several liquefaction induced phenomena were observed [7]: sand eruptions from water wells; sand boils or vents, sometimes

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accompanied by sinkholes; surface ruptures and graben-like fissures; lateral spreads and small collapses on slopes. Hydrological anomalies were also observed in the epicentral area. A relevant increase in the water-table level of water wells (from 3÷4 m up to 8÷9 m) was noticed immediately after the shocks [8]. Overall, more than 500 ground effects have been surveyed over a wide area (about 500 km^2), which extended up to 20 km from the epicentres [7]. About 400 effects were located in the eastern and northern sectors of the affected area and were induced by the first mainshock (May 20th, M_L 5.9) and following close-in-time aftershocks (mainly in the Ferrara area). More than 100 ground effects have been related to the May 29th, M_L 5.8 earthquake and relative aftershocks (in particular in Modena and Mantova areas). Some liquefaction-type phenomena that were triggered by the May 20th earthquakes were reactivated by the May 29th events [8]. Observations indicate that most of the liquefaction occurrences follow the sinuous path of abandoned rivers and their sandy deposits, which have patterned the location of towns and modern infrastructures, with ridges and levees. Liquefaction phenomena, indeed, mainly involved the ancient levees and the old bed deposits of the Reno River [7].

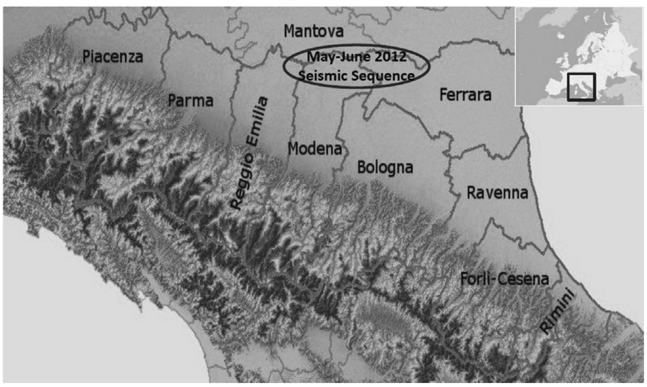

Fig. 1. Geographical location of the May–June 2012 seismic sequence.

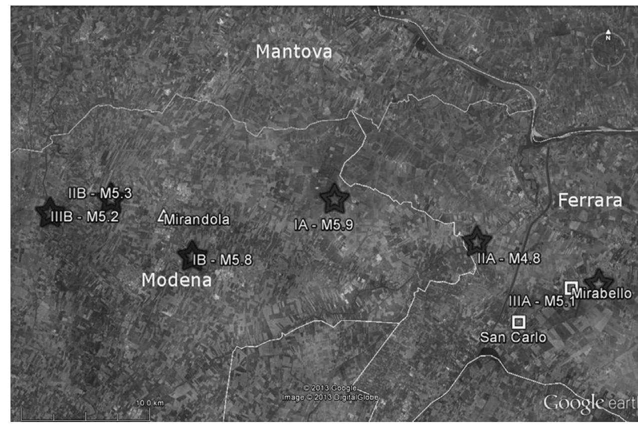

Fig. 3. May, 20th events (IA: mainshock, 02:03:53 UTC time; IIA and IIIA: aftershocks, 02:06:30 and 02:07:31 UTC time) and May, 29th events (IB: mainshock, 07:00:03 UTC time; IIB and IIIB: aftershocks, 10:55:57 and 11:00:25 UTC time).

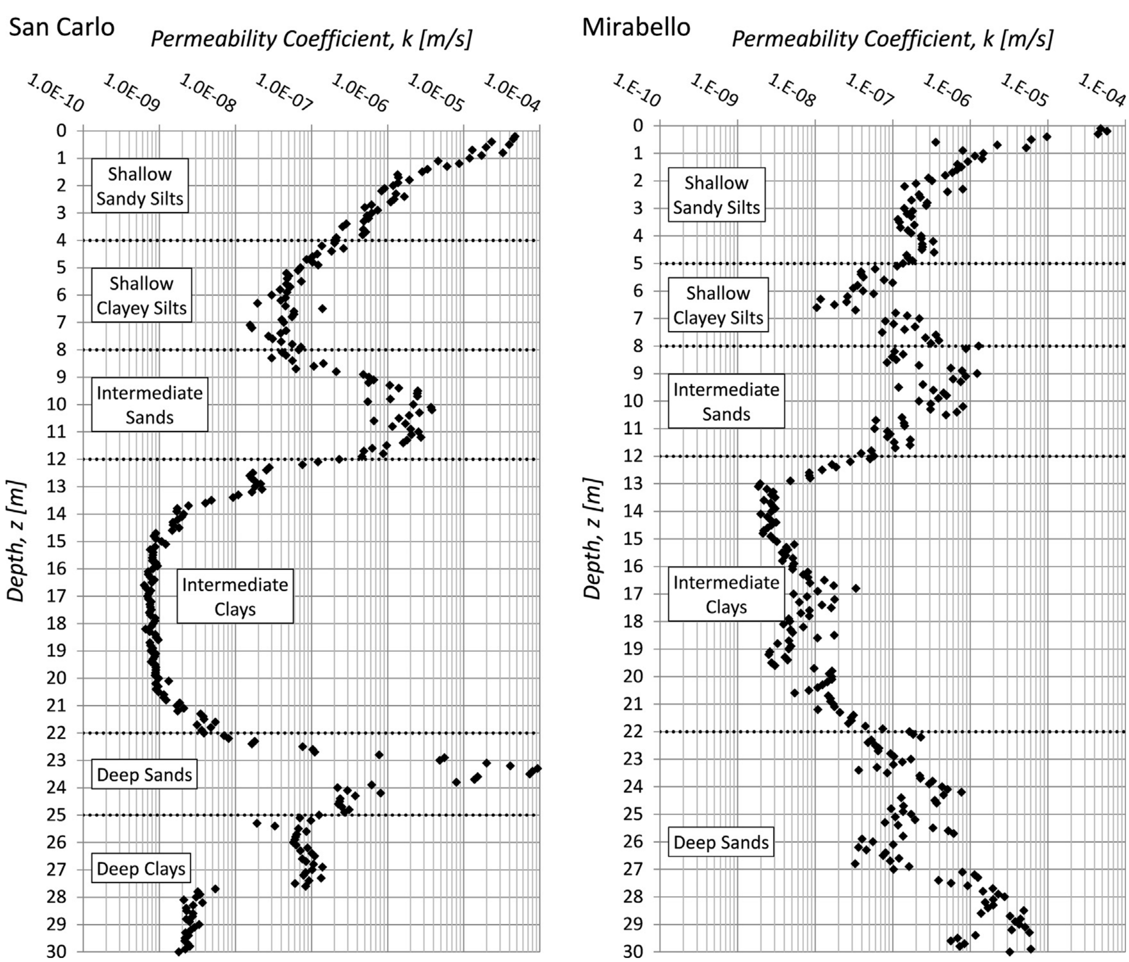

Fig. 2. Estimates of permeability coefficient from *CPT* correlation [17] for San Carlo and Mirabello sites.