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A seismic geotechnical hazard study in the ancient city of Noto (Italy)

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Abstract

South-Eastern Sicily has been affected in past times by several destroying earthquakes with high values of estimated magnitude. The aim of the seismic hazard microzonation studies performed at the City of Noto is to quantify the spatial variability of the site response on some typical historical scenario earthquakes that would be expected in the area. In order to quantify the expected ground motion, the manner in which the seismic signal is propagating through the subsurface has been defined. Propagation is particularly affected by the local geology and by the geotechnical dynamic ground conditions of the studied area. The data largely consist of the stratigraphic profiles obtained by in situ tests i.e. borings, MASW tests, Down-Hole tests, SDMT tests; some are accompanied by static and dynamic laboratory tests, such as Resonant Column, monotonic compression loading Triaxial tests and Direct shear tests. Processing of all these data allowed the ground response analysis at the surface, in terms of time history and response spectra, of some areas of the city using the linear-equivalent codes EERA, STRATA and DEEPSOIL, useful for microzonation of seismic geotechnical hazards.

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Keywords: Ground motion; shear modulus; damping ratio; site effects

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1. Introduction

The city of Noto, located in the South-Eastern Sicily, was affected in the past by several destroying earthquakes of about magnitude greater than 7.0. The area, belongs to the Ibleo-Maltese escarpment, is placed near the contact between the African and the Euro-Asiatic plates, and it is therefore a seismogenic area. According to the frequency and the importance of the seismic effects suffered in past times, Eastern Sicily must be considered one of the most seismic areas most at risk in Italy.

The central area is a densely populated territory; a huge patrimony of historical and monumental buildings is placed in the area. In situ and laboratory investigations have been carried out in order to determine the soil dynamic characteristics in the Noto tests sites. In the tests sites some boreholes have been performed and undisturbed samples were retrieved. In the boreholes a Down-Hole geophysical survey and MASW tests were performed. On the undisturbed samples static soil tests and dynamic soil tests were performed (Resonant Column Tests). Finally, accelerograms and synthetic seismograms of scenario earthquakes have been used to evaluate the local site response analysis at the surface. The ground response analysis at the surface, in terms of time histories and response spectra, has been obtained by some 1-D linear-equivalent models.

2. Seismicity of the area

Over the last 9 centuries the strongest earthquakes, with epicentral intensity falling within the interval VIII and XI MCS, are only 8, and the last of these with epicentral intensity of VIII MCS, dates back to 11 January 1946. Afterwards, the strongest earthquake, about 140 years later, is the Sicilian Earthquake of December 13, 1990, with the epicentre close to Augusta and maximum intensity of VII - VIII MCS. Figure 1 shows the interactive seismic hazard map of Southeastern Sicily with the city of Noto, in terms of PGA with the 10% probability of exceedance in 50 years. The star in the map shows the epicenter of the April 23, 2006 earthquake (M_L=3.9).

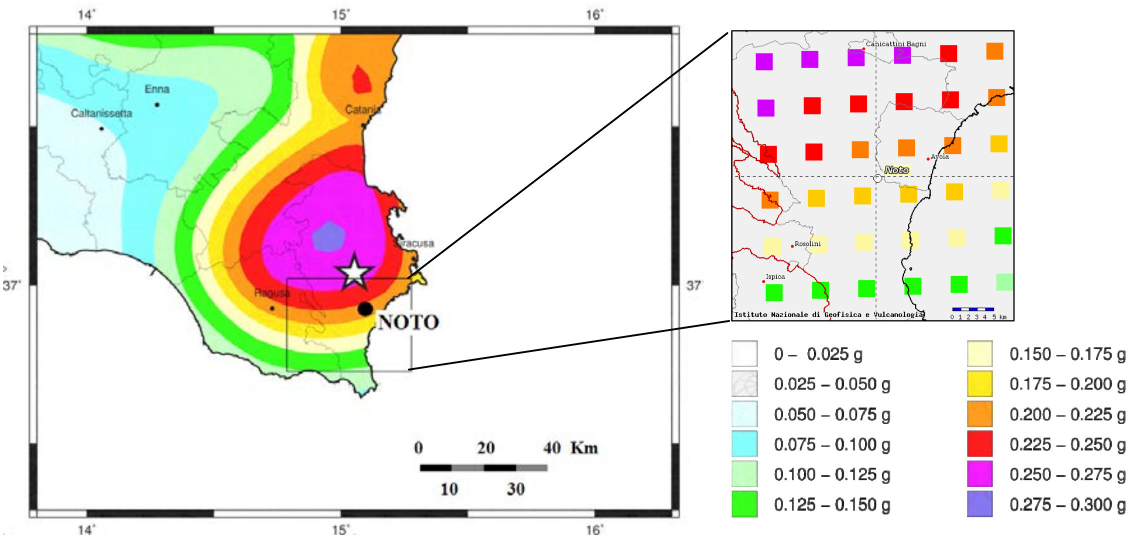

Fig. 1. Interactive seismic hazard map of the city of Catania with 10% probability of exceedance in 50 years (return period of 475 years).

The old city of Noto, few kilometers in the upper part of the city of Noto, was destroyed by the Val di Noto earthquake of January 11, 1693; the build-up areas suffered also heavy damages in occasion of the January 7, 1727 earthquake. The December 13, 1990 earthquake damaged several eighteenth century constructions in Noto and called the attention on need of safeguarding the artistic monumental patrimony of this city, maximum expression of

Sicilian baroque [1,2]. The epicentres of the historical scenario strong earthquakes which heavy damaged the cities of Noto, Augusta and Siracusa are reported in [3]. The strongest are those of 1169, 1542, 1693 and 1990.

3. Geological features of the Hyblean Region

The Hyblean region, in southeastern Sicily, represents the emerged portion of the NE-SW-oriented continental bulge of the African foreland [4] that buttressed the thrust front of the eastern Sicily collision belt, during the post-Tortonian NW-SE-oriented Africa-Europe convergence. In the Hyblean Foreland, two distinct tectonic domains, separated by the Tellaro River Valley, can be recognized: the Siracusa Plateau, to the east, and the Ragusa Plateau, to the west [5] (Figure 2). The Hyblean Foreland is made of a Late Cretaceous-Late Tortonian carbonate succession showing shallow water facies, to the east, and basinal facies, to the west, with intermediate carbonate ramp deposits developed between the two paleogeographic domains [6]. The stratigraphic succession of the Ragusa Plateau is exposed along the western flank of the Tellaro River Valley. Along the Tellaro River Valley, a sequence, made of basal marly clays covered by chaotic coarsegrained deposits, has been mapped in a discrete NW-SE elongated sector bordered by faults, immediately to the northeast of the river course. These terrains have been previously correlated to the stratigraphic sequence, including the Tellaro and the Palazzolo formations, exposed along the western border of the Siracusa Plateau. The youngest marine sediments cropping out in the investigated area are represented by whiteyellowish bioclastic Early Quaternary [7] calcarenites, cropping out near the village of Noto.

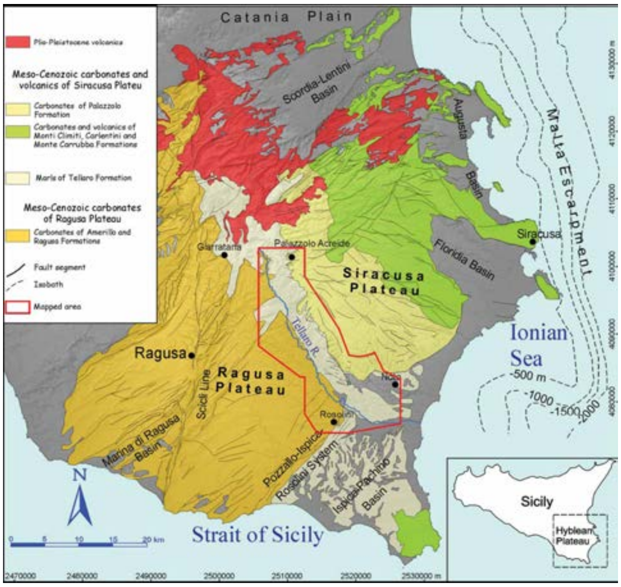

Fig. 2. Geological and structural sketch map of the Hyblean region, after [5].

The Quaternary deposits, unconformably covering different horizons of the Messinian-Pliocene sequence, infill a depocenter bounded by faults that caused the tectonic collapse of the southeastern sector of the Tellaro Basin [5].

4. Basic soil properties and soil response analysis

Laboratory tests have been performed on 55 undisturbed samples retrieved by boreholes in the central area of Noto by means of an 86 mm Shelby tube sampler. The Pliocene Noto deposits of Trubi Formation mainly consist of a medium stiff, over-consolidated lightly cemented silty-clayey-sand. For depths of about 15 m, DMT results show an OCR from 1 to 4.5 ($K_o = 0.5 \div 1.0$). The value of the natural moisture content wn prevalently range from between 12 - 37 %. Characteristic values for the Atterberg limits are: wl = 37 - 69 % and wp = 17 - 22 %, with a plasticity index of PI = 15 - 47 %. The obtained data indicate a low degree of homogeneity with depth of the deposits [8], [9]. Shear modulus G and damping ratio D of Noto soil were obtained in the laboratory from resonant column tests (RCT). The Resonant Column/Torsional shear apparatus were used for this purpose. Since the areas studied here appear rather flat and characterized by lithological units trending sub-horizontal, it was performed a one dimensional local seismic response analysis by EERA, STRATA and DEEPSOIL codes, to assess the ground amplification due to local stratigraphic conditions. 1-D columns having a height of 70 m and are excited at the base by the synthetic scaled seismograms of 1693 earthquake, with a PGA of 0.200-0.225g corresponding to a return period of 475 years. Further analyses have been performed using scaled accelerograms of 1990 earthquake in the Sortino recording station. Figure 3 shows the results obtained with the three 1-D codes i.e. for the soil column of site 1 respectively in terms of time history of maximum accelerations at the surface, in terms of maximum acceleration with depth and in terms of Arias intensity at the top soil layer, using as input the synthetic scaled seismograms of 1693 earthquake.

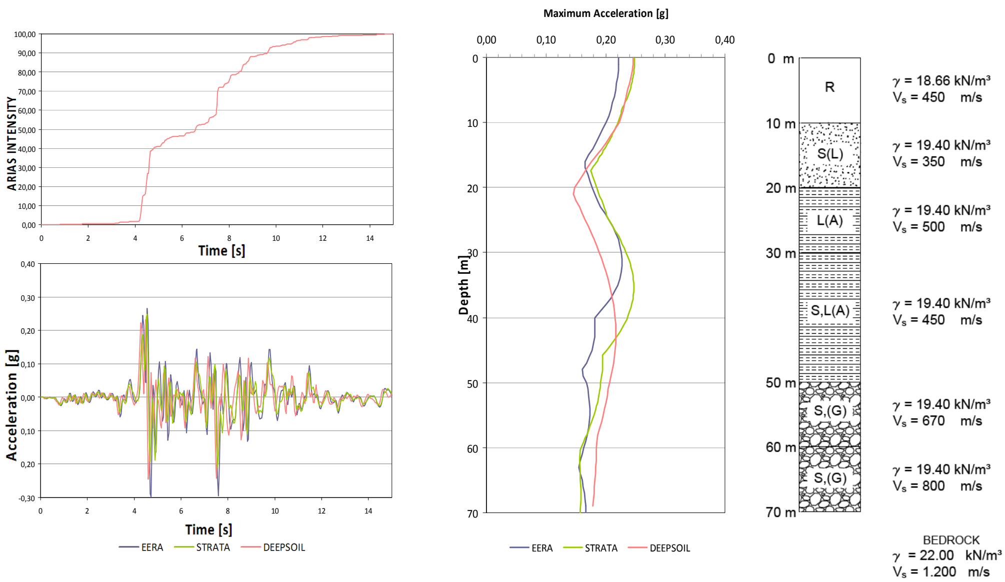

Fig. 3. Maximum accelerations at the surface, maximum acceleration with depth and Arias intensity using scaled 1693 seismograms in the soil column 1. R = fill and debris; S (L) = sands and silts; L (A) = silts and clays; S, L (A) = sands with silts and clays; S (G) = sands and gravels.

Figure 4 shows the results terms of amplification ratio and in terms of response spectra, using as input the synthetic scaled seismograms of 1693 earthquake. Figure 5 shows the results obtained with the three 1-D codes using scaled accelerograms of 1990 earthquake in the Sortino recording station. Similar studies have been performed for the zonation on seismic geotechnical hazards in the city of Catania (Italy) [10-19] and for the Abruzzo Region (Italy) during L'Aquila earthquake [20-23]. Results of site response analysis are useful for soil-structure interaction behaviour in the mitigation of seismic risk of buildings [24-26] and for the behaviour of landfills and piles [27-31].

5. Conclusions

The seismic response analyses have been performed using 1-D code, assuming a geometric and geological model of substrate as 1-D physical model. These analyses were carried out here with EERA, STRATA and DEEP SOIL codes, both linear equivalent codes operating in the frequency domain. The layers characteristic of the model have been carried out from geological surveys. Trough 1-D numerical analyses performed it has been possible to evaluate the influence of stratigraphic effects in seismic response of Noto central area. In some cases results show an important amplification of the seismic signal imposed on the basis of the model.

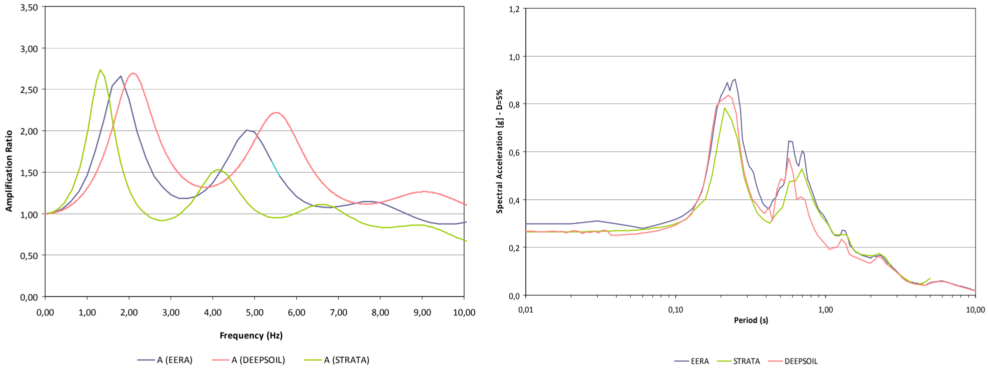

Fig. 4. 1-D results: amplification ratio and response spectra using scaled 1693 seismograms.

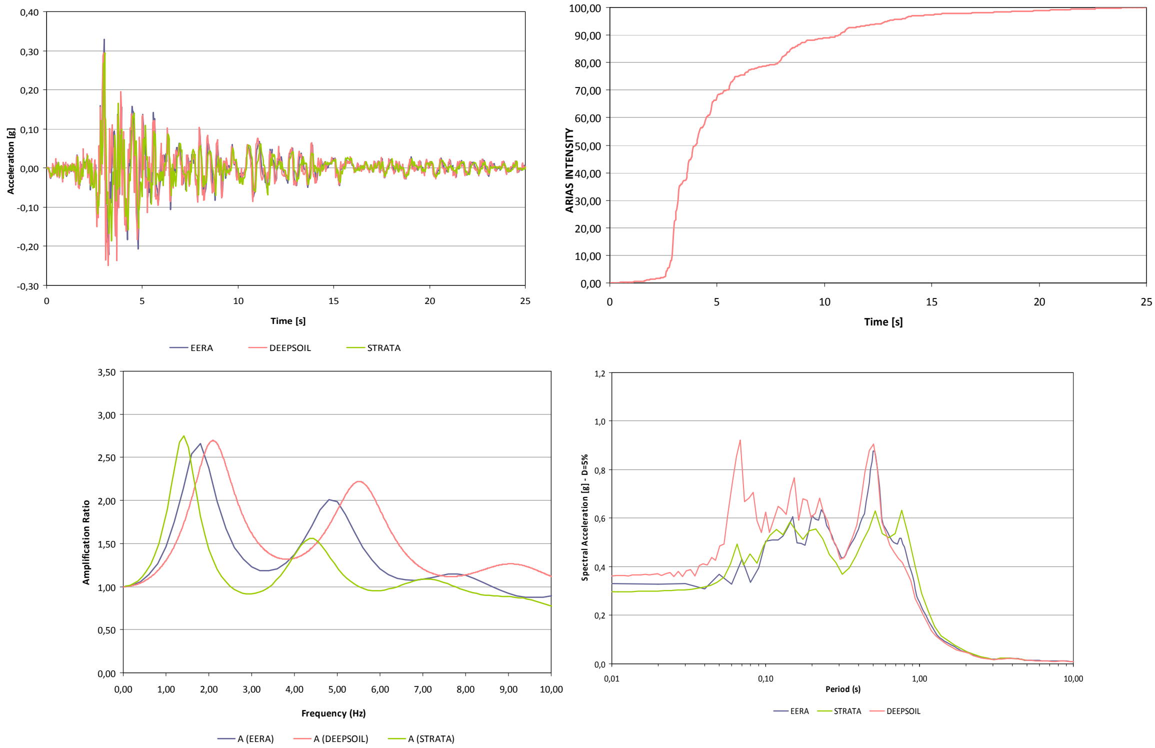

Fig. 5. 1-D results of soil response analysis using as input the scaled 1990 accelerograms in the Sortino recording station.

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