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Seismic microzonation studies for the city of Ragusa (Italy)

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ABSTRACT

The seismic history of the city of Ragusa (Italy), the geotechnical characterisation of the subsoil and the site response analysis should be correctly evaluated for the definition of the Seismic Geotechnical Hazard of the city of Ragusa, through geo-settled seismic microzoning maps. Basing on the seismic history of the city of Ragusa, the following earthquake scenarios have been considered: the *"Val di Noto"* earthquake of January 11, 1693 (with intensity X–XI on MCS scale, magnitude M_W=7.41 and epicentral distance of about 53 km); the *"Etna"* earthquake of February 20, 1818 (with intensity IX on MCS scale, magnitude M_W=6.23 and epicentral distance of about 64 km); the Vizzini earthquake of April 13, 1895 (with intensity I=VII–VIII on MCS scale, magnitude M_W=5.86 and epicentral distance of about 26 km); the *"Modica"* earthquake of January 23, 1980 (with intensity I=V–VI on MCS scale, magnitude M_W=4.58 and epicentral distance of about 10 km); the *"Sicilian"* earthquake of December 13, 1990 (with intensity I=VII on MCS scale, magnitude M_W=5.64 and epicentral distance of about 50 km). Geotechnical characterisation has been performed by in situ and laboratory tests, with the definition of shear wave velocity profiles in the upper 30 m of soil. Soil response analyses have been evaluated for about 120 borings location by some non-linear 1-D models. Finally the seismic microzonation of the city of Ragusa has been obtained in terms of maps with different peak ground acceleration at the surface; shaking maps for the central area of the city of Ragusa were generated via GIS for the earthquake scenarios.

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1. Introduction

The Val di Noto earthquake of January 11, 1693 is the best documented among the ancient sicilian earthquakes. The seismic sequence started at 9 p.m. of January 9: at the first shake many buildings collapsed and were badly damaged in all of the towns in the south-east of Sicily spanning from Catania to Noto [1]. But the real destructive shock hit two days later, on January 11 at about 2 p.m. [1]; the area was already been stricken and so the result was that two earthquakes overlapped causing great damages over an area of 14,000 km square. Due to the huge number of people died (nearly 60,000) and the extent of the damage (more than 45 towns and small villages) this seismic event may be considered alongside the one that stroke Messina in 1908 the strongest earthquake ever occurred in Sicily in historic times. The shock of January 9 hit the main cities of Lentini, Augusta and Catania, with an intensity of VII on MCS, while that of January 11 (situated at sea but not far from the coast) hit Augusta with an intensity of XI on MCS, as it resulted from the buildings destroyed and the persistent damages on the soil; this earthquake hit Ragusa with an intensity of IX–X on MCS (Fig. 1). In the city of Ragusa, with 9946 inhabitants at that time, about 5045 victims were registered.

The *"Etna"* earthquake occurred on February 20, 1818 was one of the highest ever occurred at the Etna Volcano and its effects were noticed over a vast area. In fact, this quake was sensed in Eastern Sicily and in the south of Calabria [2]. The quake occurred at 18:20 (G.M.T.) and destroyed many villages on the south-east side of Mt Etna. A total amount of 72 people died because of the great number of houses collapsed. The isoseismal map (Fig. 2) explained that the earthquake heavy damaged many cities of Eastern Sicily, from Siracusa to Noto. Probably at Ragusa major damages were caused by the aftershock of March 1, 1818 with epicentre located near to the city (M_W=5.51, I=VII–VIII on MCS). The *"Modica"* earthquake of January 23, 1980 (M_W=4.58) with epicentre near to the city of Ragusa represents the "medium" event.

The earthquake of December 13, 1990 occurred at the end of a period of seismic dormancy of the Ibleo-Maltese fault system, with a moment magnitude M_W=5.64 and a focus depth of about 6–12 km. Even if it was internationally recognized as a *"moderate"* earthquake it caused serious damages to many buildings. The analysis of the available data showed that the greatest effects of the earthquake were felt in Augusta (near Siracusa) with an intensity of VIII MCS causing considerable damages even in modern r.c. buildings (Fig. 3).

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Moreover, the recorded acceleration at Sortino located on rock was 0.1 g, while the acceleration recorded at Catania, located on clayey soil was 0.24 g, although they are located at the same distance of about 30 km from the epicentre (Fig. 3). Thus the accelerations recorded are influenced by significant local amplification phenomena.

In the south-eastern Sicily there are two seismic areas: the first along the Ionian coast (earthquakes of magnitude $M > 7.0$) and the second in the hinterland area (earthquakes of magnitude lower than 5.5). There are evidences from the late Quaternary period that the Ibleo-Maltese fault system is the most probable source for the great earthquakes that struck the region (1169 and 1693 earthquakes). This fault system is mainly made up of normal faults NNW–SSE oriented, divided into three segments of fault, the most northern of which continues on the ground up to the Etnean area (Timpa of Acireale), the central segment reaches the Gulf of Catania while the most southern part lies at sea between Augusta and Siracusa.

The Hyblean foreland may be considered as part of the northern margin of the African continental crust, which is bounded to the north by the thrust front of the Apennine allocthonous units.

2. Seismic hazard estimation of the city of Ragusa (Italy)

Fig. 4 shows the seismic history of the city of Ragusa in the last millennium [3]; it is possible to observe that there is a low frequency of occurrence for seismic events with MCS intensity $I > 5$–6; for those with $3 < I < 5$–6 the occurrence is reported more specifically in the last 300 years, while the older seismic events are not well documented and so have not been reported. Seismic catalogues have been used to estimate the return period (Fig. 5) and probability of occurrence (Fig. 6) of earthquakes in Ragusa using the approach proposed by Ref. [4]. The approach takes into account the ordinal and discrete character of intensities, trying to avoid misleading results due to the assumption that intensity can be treated as a real number (continuous distribution estimators, attenuation relationships, etc.). The proposed formulation is based on the use of a distribution function describing, for each earthquake, the probability that site effects can be described by each possible intensity value [4].

From Figs. 5 and 6 it is possible to observe that return period is low for intensity classes $I=6$ and $I=7$ (moderate damage). For higher intensity classes ($I=8$, $I=9$, $I=10$, heavy damage), the return periods are high, so that the probability of occurrence is very low. In Fig. 5 are also quoted the uncertainties in evaluating the return period for each intensity class. Historical maps of the city of Ragusa allowed to reconstruct the damage frame of the city for the earthquake scenarios. Damage scenario for the Val di Noto earthquake of January 11, 1693 is represented in Fig. 7, reporting the damage of the city of Ragusa, with a typical *"forma piscis"*. Among the correlations between intensity and peak ground acceleration reported in (Fig. 8 [5–8], the correlation used was that obtained by Ref. [5], which is the median of the tested correlations and is related to the italian soil.

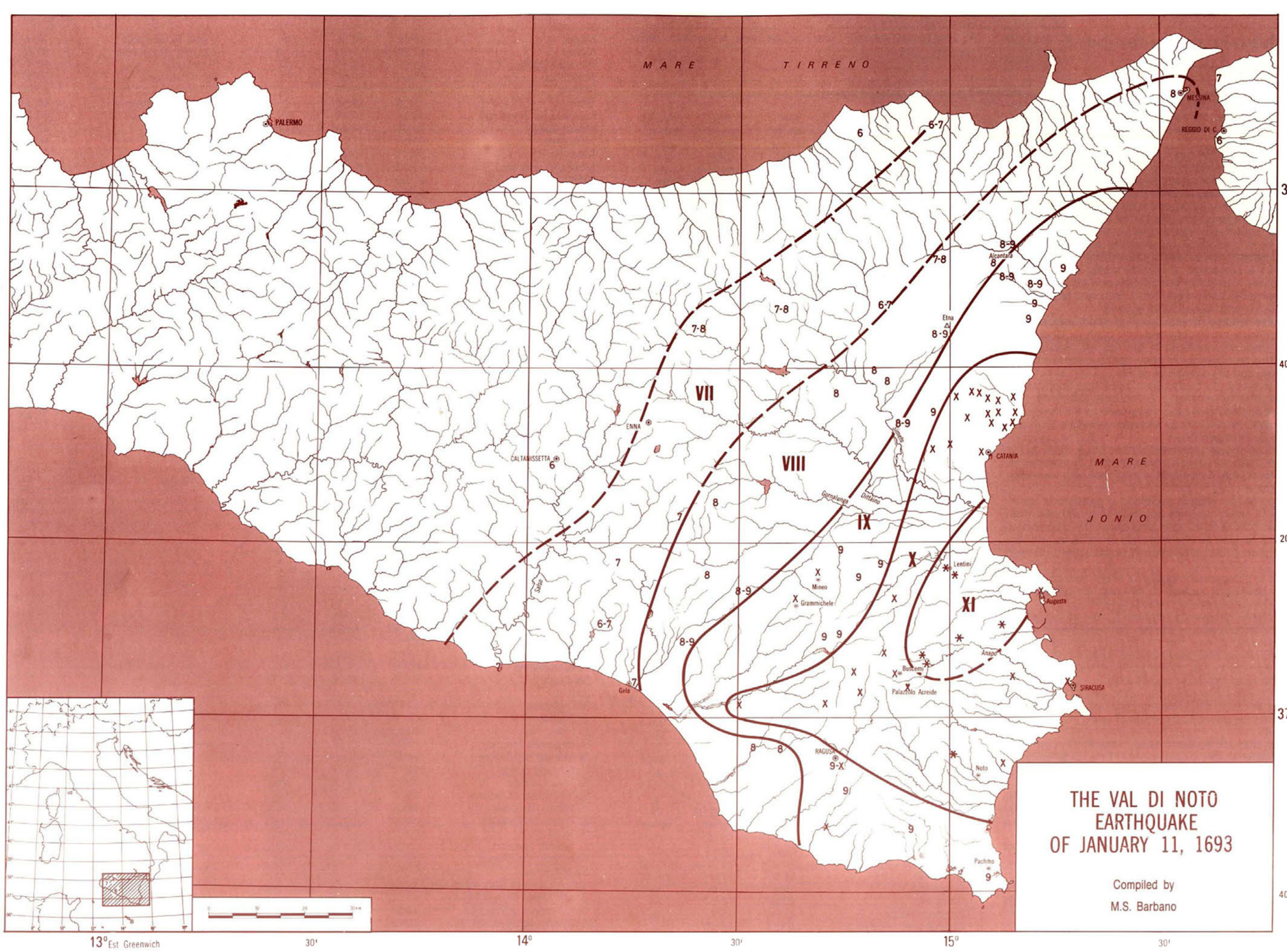

Fig. 1. Isoseismal map of the "Val di Noto" earthquake of January 11, 1693.

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