MULTIDISCIPLINARY INVESTIGATIONS USING HISTORICAL DATA, SPECIFIC EXPERIMENTAL SURVEYS, NUMERICAL SIMULATIONS AND EARTHQUAKE DATA TO ASSESS SEISMIC HAZARD IN A DENSELY URBANIZED CITY: THE STUDY CASE OF PALERMO

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Topic 3 - Propagation and local effects on the seismic destruction

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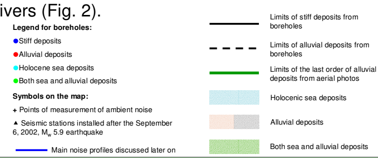
Introduction: The aim of this poster is to present the geological and seismological studies performed in downtown Palermo, a densely city of Southern Italy (Fig. 1) that was severely damaged in the past by moderate-magnitude earthquakes. This study case shows how the hazard of a complex urban environment can be approached with multidisciplinary investigations.

Fig.1 – Map showing the location of Palermo

Geological setting: The main feature of the geology in downtown Palermo is the presence of Holocenic sea deposits and alluvial deposits of two rivers, Papireto and Kemonia, completely hidden by urbanization [7]. The analysys of aerial photos and of more than 2000 borehole data organized in the City-GIS of the University of Palermo [8] overcomes the difficulties of a surface geological survey and reveals the paleo-valleys of the rivers (Fig. 2).



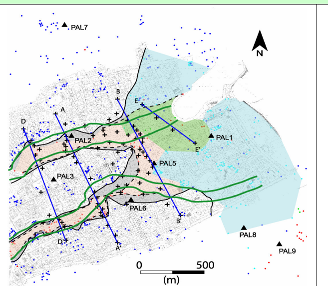


Fig. 2 – Geological interpretation from borehole data and aerial photos. Location of seismic stations is also shown.

Historical damage: The study of Guidoboni et al. [9] showed the crucial role played by the two river valleys and sea deposits in controlling the damage distribution during earthquakes (Fig. 3).

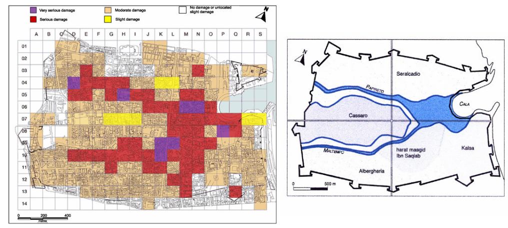
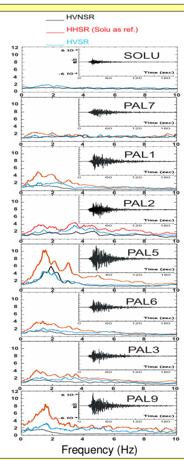


Fig.3 – **a)** Map of downtown Palermo with the cumulative damage of three past earthquakes (September 1, 1726, Me 5.7, Is VIII-IX; March 5, 1823, Me 6.0, Is VIII; January 15, 1940, Me 5.3, Is VII). The color scale indicates the prevalent maximum level of damage (above 50%) of the three earthquakes, occurred within the existent buildings in a 100x100 m² cell [9]; **b)** Historical map showing the flow of the two old rivers, Papireto on the north and Kemonia on the south.



Weak motion analysis: On September 6, 2002 a Mw 5.9 earthquake occurred in the southern Tyrrhenian sea, 40 Km off the coast of Palermo. After the event, 9 sites within downtown were monitored with portable seismic stations. We selected about 30 out of 300 aftershocks to perform: i) S-wave spectral ratio between the horizontal components at the studied site and reference (rock) site (HHSR on earthquakes); ii) S-wave spectral ratio between horizontal and vertical components at individual sites (HVSR on earthquakes); iii) the spectral ratio between horizontal and vertical components using ambient noise (HVNSR).

Moreover, we estimated the S-wave velocity of the different soils by comparing the empirical transfer function and the 1D transfer functions of S-waves using the Haskell-Thompson approach [6].

The analysis shows (Fig. 4) the strict correlation between ground motion amplification and variation of nearsurface geology [6].

Fig. 4 - Average of horizontal spectral ratios, referred to Solunto (SOLU) rock site (located 15 km east from Palermo), and H/V on earthquakes compared with the H/V on ambient noise. In particular, PAL5 site suffered the greatest level of damage during the Sept. 6, 2002, earthquake.

Strong motion synthetics: Since real data of the Mw 5.9 mainshock were not recorded in Palermo we estimated ground motion accelerations of the mainshock through aftershock recordings by using different methods (Fig. 5).

Rock stations in the region were used to compute seismic moment, local magnitude, corner frequency, and stress drop for the events of the sequence.

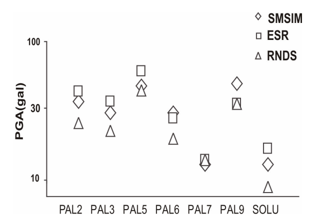


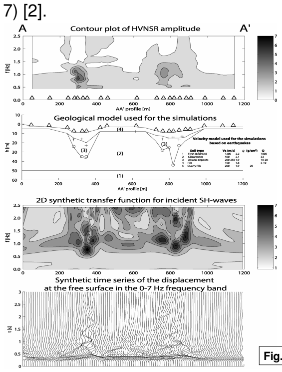
Fig. 5 – Ground accelerations in Palermo as estimated for the Mw 5.9 earthquake. The symbols represent the average value of each technique: stochastic point-source simulations (SMSIM), empirical spectral ratio (ESR) and random summation of aftershocks (RNDS).

The low level of shaking and the felt intensities of the mainshock rule out the occurrence of significant effects of soil non-linearity.

The resulting PGA values (Fig. 5) range from 11 ± 4 gals for the stiffest formations up to 51 ± 14 gals for the marine and lacustrine deposits (PAL5), where soils with the poorest mechanical properties outcrop. Therefore, a large variability, controlled by the local geology, is likely to have occurred within different zones of the city [1].

Microtremors survey: to test the feasibility of using H/V spectral ratios on ambient noise (HVNSR) for evaluating the resonance frequency of a site and for recognizing the presence of alluvial deposits in a urban environment, we performed a large microtremor measurement campaign across several profiles (see Fig. 1 for details) [4].

The profile A-A' was selected for a tentative comparison with 2D simulation of SH-waves (Fig. 7) [2].



HVNSR analysis evidences a peak around 1 Hz corresponding to the valleys of the two rivers.

We used a simplified geological model as input for the 2D simulation.

The fundamental resonance frequencies of 2D simulations reproduce fairly well the HVNSR peaks. However, the spatial position of the peaks is not coincident. This is probably due to uncertainties of the geological reconstruction.

Fig. 7

Correlating damage with HVNSR: Multivariate statistical (factor and canonical correlation) analyses [5] have been applied to microtremor and damage data. The HVNSR computed at each site has been digitized into nine 0.5-Hz-wide frequency intervals, from 0.5 to 5.0 Hz. We considered the damage of two events (1726, 1823) and the cumulative effect studied by Guidoboni et al. [9] (Fig.3). The factor analysis shows that two independent factors likely reflect the most of the variance of the two sets of data (Fig. 8a and 8b).

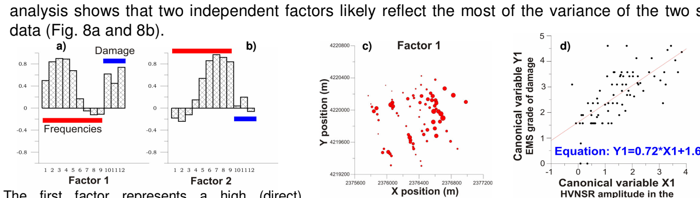


Fig. 8

The first factor represents a high (direct) correlation between HVNSR amplitudes in the 0.5-3.0 Hz frequency band and all seismic damage variables (Fig. 8a). The second factor shows that the amplitude peaks in the higher frequencies interval (2.5-5.0 Hz) have no correlation with damage (Fig 8b).

The geographical distribution of factor 1 over all the sites indivuates once again the zone of fluvial deposits (Fig. 8c).

A further canonical correlation analysis [5] allows to extrapolate a functional relation among damage and HVNSR amplitudes in the low-medium frequency band (Fig. 8d).

Inferences on response spectra in Palermo: the aftershock recordings allow a comparison (Fig. 6) with statistical expectation of response spectra for the Italian territory [10] and Eurocode 8 [3]. Data have been scaled according to the results of the synthetic ground accelerations.

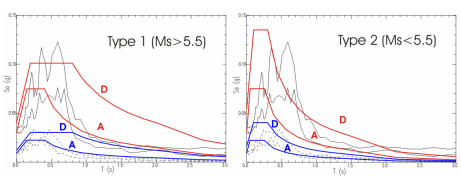


Fig. 6 - Elastic 5% dumped acceleration response spectra (Sa) for class A and D as prescribed by EC8 for low (Type 2) and high seismicity (Type 1). Superimposed are the response spectra of the Mw 5.9 mainshock computed for the simulations of PAL9 and SOLU (continuous and dashed curves, respectively). These curves are the mean ± 1 standard deviation (average of horizontal components with larger PGA) over the three selected events. Red lines are EC8 spectra constructed with ag = 0.009 g that is the average PGA of synthetics used for the horizontal ground motion at SOLU. Blue lines are EC8 constructed with ag=0.03 g, that is the the Sabetta and Pugliese expectation.

Response spectra reveal variations between class A and class D that are significantly larger than those expexted on the basis of the statistical predictions by Sabetta and Pugliese [10] and the EC8 prescriptions [3]. However, the EC8 spectra anchored to the PGA of Sabetta and Pugliese are well above the maximum envelope inferred from observations [6].

CONCLUSIONS:

The September 6, 2002, Mw 5.9 earthquake offered the opportunity of applying different methods to estimate parameters that control the seismic hazard of the city of Palermo. The study dealt with organization of geological and geotechnical data through a GIS, macroseismic investigations of both past and present time earthquakes, recording of weak earthquakes and modelling of strong motions in the city, and micrtremor measurements. Multivariate statistical analyses established reliable correlations in downtown Palermo between the spectral properties of the H/V ratios of microtremor and damage variations as a function of local geology. The approach seems to be successful in predicting relative variation of damage, for intensity VII to IX MCS.

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