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“SEISMIC RISK EVALUATION FOR THE EMERGENCY MANAGEMENT”

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ABSTRACT

The recent advances in cloud computing have opened new opportunities in emergency management issues due to earthquakes. In this context, Geographic Information System (GIS) based solutions have been recently investigated, with the aim of the prevention and the reduction of seismic risk. The paper focuses on the results of the research project *PRISMA - cloud PlatfoRms for Interoperable SMArt Government* in which an innovative open source GIS system, based on the knowledge in the field of dynamic characterization of soil has been developed in order to assess the local seismic hazard and the seismic zonation of the Enna area in the south of Italy.

The paper describes how the application of prospecting and surveying techniques allowed a decisive improvement in the geological knowledge of the area, contributing to define the subsoil model for the purposes of seismic microzonation. The seismic geotechnical characterization has been performed with laboratory tests including the resonant column and cyclic torsional shear test on undisturbed samples. The interpretation of geophysical and geotechnical data and their correlation with geological units are presented as microzonatic map. Finally, a wireless sensor network has been used for structural monitoring at the aim to highlight the significant benefits when the time available for access is limited, by representing an effective way of managing risks.

All the data relating to the monitoring of the buildings and to the geological and geotechnical characterization are available on the web GIS platform, representing an important tool for the prevention and reduction of the seismic risk.

1. INTRODUCTION

In a high seismic hazard country, as Italy, with urban areas characterized by significant level of seismic vulnerability, the seismic zonation, monitoring local networks and earthquake early warning system, may allow the prevention and mitigation of the earthquakes effects [Castelli et al., 2013, 2016a, b, c; Castelli and Maugeri, 2008, 2013; Grasso et al., 2016; Grasso and Maugeri, 2014; Ferraro et al., 2016; Monaco et al. 2011].

Some recent examples of strong earthquakes in Italy include the central Italy earthquake of 24th August 2016, the L’Aquila earthquake of the 6th April 2009, the Emilia Romagna earthquake of the 29th May 2012, the St. Lucia earthquake of the 13th December 1990 occurred in the South Eastern of the Sicily. In particular, two major seismic areas there are in the South Eastern Sicily: 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). These normal faults were in the past sources of earthquakes with M up to 7.4 such as the 1169, 1693, 1818 and 1908 events. The seismic history of southeastern Sicily is characterized by several intense events, which, over the

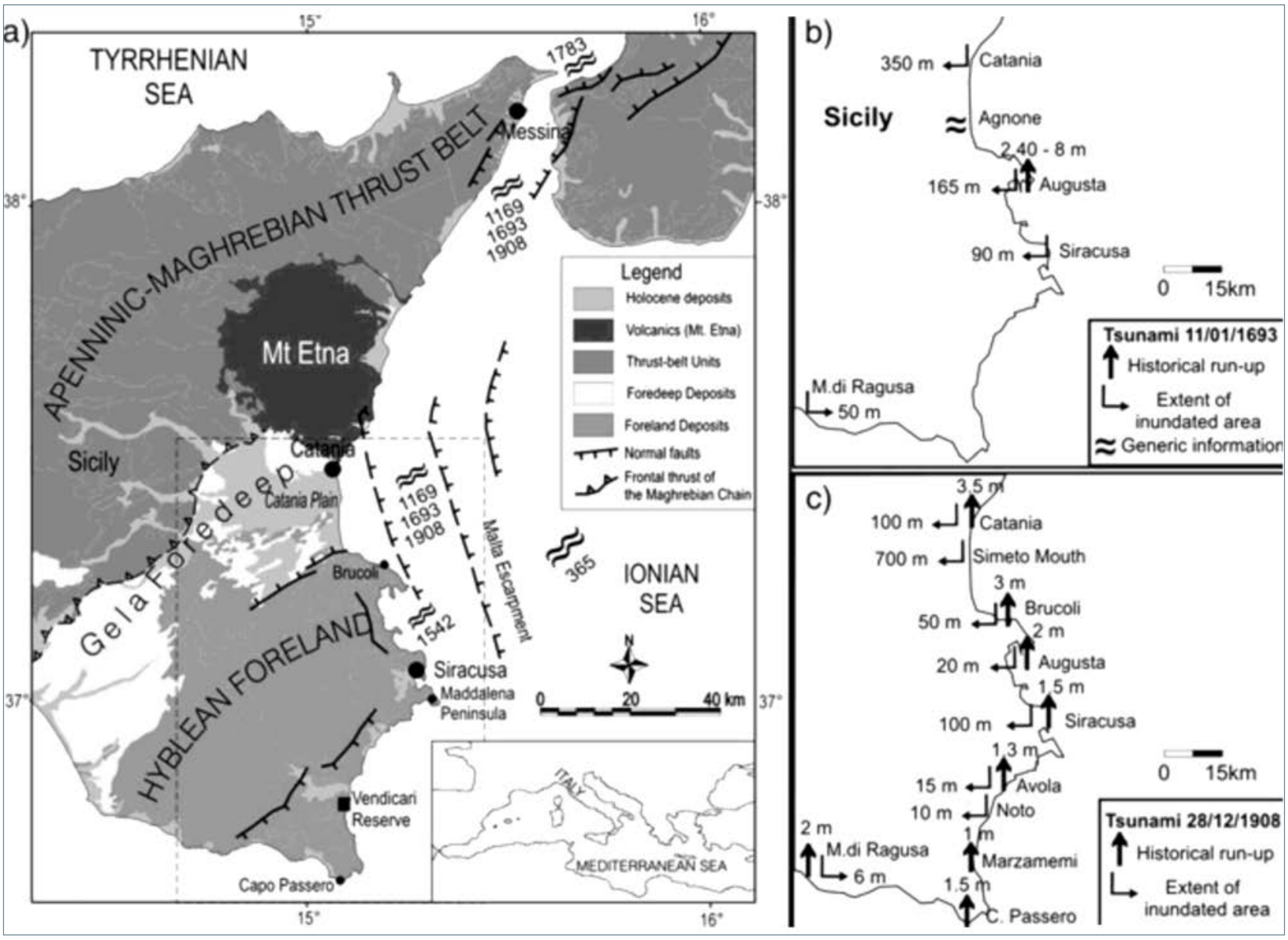

FIGURE 1. Map of seismotectonic features of South-Eastern Sicily, with indication of 1693 and 1908 historical tsunamis.

centuries, caused severe damages and, sometimes, razed entire settlements [Barbano et al., 2014; Pappalardo et al., 2016]. Some of these events generated also destructive tsunamis along the Sicilian Ionian coast (Figure 1).

Earthquakes in Sicily are often among the main causes of land-slides, with particular reference to rockfalls. Such phenomena represent, in turn, a further risk for population and for structures and infrastructures [Pappalardo et al., 2014; Pappalardo and Mineo, 2015].

While these sudden disasters result in deaths, injuries, and homeless people, a quick response from the corresponding governments may include different techniques for post-disaster recovery. One big challenge that arises with disasters is that the telecommunication services (e.g., cellular networks, third generation, long term evolution services and internet infrastructures) usually become interrupted or overwhelmed. This congestion can be, particularly, noticed immediately after the disaster because the inhabitants of the affected area might want to, at the same time, communicate with the rest of the world. In order to deal with this challenge, the topic of designing an efficient disaster resilient network has recently gained much interest. As a consequence, researchers have diverted attention toward an alternate technology, namely the wireless mesh networks (WMNs), in order to construct disaster zone networks [Liu et al., 2010, 2012; Ngo et al., 2013; Wishart et al., 2008]. Recent advances in the development of Wireless Sensor Networks [Asplund and Nadjm-Tehrani, 2009] reveal a new paradigm for monitoring structures and infrastructure health [Shibata et al., 2009; Ishizu et al., 2011] and environmental conditions [Fouda et al., 2012] owing to the availability of low powered millimeter-scale CPUs, highly integrated wireless transceiver circuits and various miniature sensors.

The paper focuses on the results of the research project *PRISMA - cloud PlatfoRms for Interoperable SMArt Government* in which a web-GIS platform, based on the knowledge in the field of dynamic characterization of soil and structural monitoring has been developed with the aim to provide the seismic zonation of the Enna area.

Experimental and research activities have been performed through the active involvement of the Department of Civil Protection. The activities regard:

i) geological and geotechnical characterization of the soil through in situ and laboratory test;

ii) wireless networks for monitoring strategic structures;

iii) collection of experimental data and their processing through GIS;

iv) implementation of data [Castelli et al., 2015, 2016d, 2017; Castelli and Lentini, 2010, 2012; Maugeri et al., 2013] on an open cloud platform.

Its architecture consists in a geospatial database system, a local GIS application for analyzing and modeling the seismic event and its impacts, a web-GIS module for sharing the geo-information among the public and private stakeholders and emergency managers involved in disaster impact assessment and response management. With this aim, data available by previous studies and investigations, as well as, those deduced by the studies carried out within the Project PRISMA, have been organized in a database and geo-referenced. A set of data and information needed for the evaluation of the seismic response are available on the web by the GIS platform, representing an important tool for the prevention and reduction of the seismic risk.

The data derived by geotechnical investigations have identified different soil types within the studied area and the geophysical surveys have provided information on the values of the shear wave velocity V_S in the different layers and on the position of the bedrock. The results of resonant column, torsional shear and cyclic triaxial tests have provided the dynamic characterization of the subsoil and the normalized shear modulus G/G_0-γ and damping ratio D-γ versus strain curves for an accurate seismic response of soil, taking into account the non-linear behavior.

2. RISK PERCEPTION

The analysis, assessment and mitigation of seismic risk, as well as developing smart technologies in support of these activities, must be accompanied by a careful study of the human factors involved in these processes. The active and aware involvement of population is necessary condition in order to achieve any successful intervention. In particular, analyzing perception of seismic risk by population, the trust among citizens and information or interventions implemented by institutions appear to be the key-issue. At the same time, Institutions must infuse trust in the population by policies activated to prevent and mitigate seismic emergencies. These considerations are not needed for an effective introduction of smart technologies aimed at granting safety in an area: technological systems for alerting properly work only if citizens perceive them as reliable and useful. In this context, the use of systems for the diagnostics of the subsoil, damage assessment, and monitoring [Castelli and Lentini, 2016] of urban areas and infrastructure, is an option with significant social and economic implications in terms of better ability to manage emergency situations.

The emergency management presents many criticalities due to various factors, like the human factor (reaction of panic, high number of victims, possible obstacles to the rescues), the environmental characteristics (presence of escape ways, extreme weather conditions, easy way or not to reach the interested area) and the coordination of the intervention itself (different agencies may use different procedures or may even evaluate the same situation in different ways, thus disagreeing on the kind of intervention).

Models and simulations of risk prevention and emergency alert have to take into account many risk factors, with different activation thresholds, and various typologies of reaction for all the stakeholders. This requires not only the trust of citizens towards institutions (that is, their trust in the structure of prevention) but also the trust of institutions in citizens (as sources of information and as responsible agents in preventing to catastrophes). However, trust attitude in the context of natural catastrophes is complicated by a variety of factors: the number, diversity and complexity of relevant actors, the actions and interactions that each of them is able to implement, often without any coordination. A comprehensive analysis of all these factors, as well as their interactions, allows to define and elaborate prevention rules with a high level of effectiveness. For all these reasons, success of intervention strategies during a natural catastrophe relies heavily on distributed delegation actions towards actors capable of guaranteeing full trustworthiness, based on their well-tested and widely acknowledged expertise.

3. ANALYSIS, ASSESSMENT AND MITIGATION OF SEISMIC RISK IN SICILY

Seismic zonation, monitoring local networks and alert systems may allow the promotion of appropriate policies for the prevention and mitigation of the earthquakes effects, especially in a region with high seismic risk, as Sicily, and with an urban area characterized by high levels of seismic vulnerability. However, for the reduction of seismic risk, the development of innovative experimental activities that enable the advancement of knowledge in the field of seismic geotechnical hazard assessment of sites and of the vulnerability of infrastructure and civil and industrial facilities is necessary. Geological and geotechnical aspects related to seismic prevention are particularly topical in Italy also in relation to the effects caused by the recent earthquakes in the city of L'Aquila [Monaco et al., 2013; Santucci de Magistris et al., 2013), in the Emilia region [Facciorusso et al., 2016] and in the central Italy. In the past, the study of these problems was often limited to the geotechnical characterization of the sites and to the analysis of phenomena such as, subsidence or local seismic amplification, not reaching consistent suggestions about the possibility to realize soil remediation to ensure the structures preservation. In contrast, the structural remediation is often separated from the geotechnical characterization of the sites, the geotechnical modeling of the soil foundation and the actions for the improvement of the foundations. To overcome the limits of these approaches, the research activity will aim the analysis of the phenomena regarding the soil in order to evaluate the influence that they exert on the seismic vulnerability of buildings and systems to secure the achievement of seismic improvement. These goals can be achieved through an innovative experimentation in the field of evaluation of soil, structures and infrastructure behavior subjected to seismic loads. Therefore, the establishment of a monitoring network of seismic action for the acquisition of site data and the comparison with seismic amplification factors required by national and international regulations and the procedures for the analysis of the seismic response [Cavallaro et al., 2006, 2008, 2012, 2013a, 2013b] in the case of difficult soil condition is expected.

For more realistic assessment of the seismic hazard of a test site, it is necessary in addition to geological surveys, to take into account the historical and instrumental seismicity of the area around the test site in order to better constrain the degree of regional seismicity. The aim of research activity is to realize a platform open cloud, based on the implementation of smart systems for monitoring characteristics of the environment. The data available on the platform allow the construction of seismic damage scenarios, the verification of the structural resistance of strategic buildings and the assessment of seismic vulnerability of the urban area, the verification of the practicability of the road system.

4. TEST SITE

The testing activities was taken place in Sicily, with particular reference to the municipality of Enna, in collaboration with the Regional Department of Civil Protection and the Regional Province of Enna.

Several prospecting and surveying techniques (geological surveys, down-hole, MASW, HVSR) and laboratory test for the static and dynamic characterization have been performed, allowing a decisive improvement in the geological and geotechnical knowledge of the area. For the purpose of seismic vulnerability assessment all buildings and houses of Enna have been classified by identifying the construction material (masonry or reinforced concrete), the construction period, the number of floors, the surface in m2 and the number of inhabitants (Table 1,2). Furthermore, two typical buildings (Figure 2) of the constructed reality were chosen: reinforced concrete and masonry buildings because these structural kinds represent over 90% of the built in Italy on the basis of the results of ISTAT census [2011].

A set of spectrum compatible synthetic accelorагrams for which was fixed a duration of 15 seconds have been generated. For each return period and for each generated signal a non-linear dynamic analysis with a FEM calculation code has been performed. Then for each return period, the probability of exceeding of each limit state has been evaluated and, consequently the fragility curves of the buildings. The synthetic accelerograms have been generated using the software REXEL-DISP [Smerzini et al., 2013] that allows to select suites of natural accelerograms compatible with displacement spectra of NTC'08. Records contained in REXEL-DISP are those of: Selected Input Motions for Displacement-Based Assessment and Design (SIMBAD).

Figure 3 shows the acceleration spectra corresponding to the synthetic accelerograms generated for the sites in which is located the Duca D'Aosta School and the building of the Province of Enna respectively for a return period equal to 475 years. In Figure 3 the red line is the average spectrum according to the Italian Technical Regulations on the Constructions.

The fragility curves have been re-calculated using natural accelerograms, selected in the strong-motion databank [Giardini et al., 2013]. The acceleration response spectra on rock and at ground surface, computed for the seven accelerograms selected, are shown in Figure 4 in which xa and ya are the waveform identification code of the acceloragrams.

5. SENSOR NETWORK

Earthquake Early Warning System (EEWS) are a rather recent development in seismology that allows to issue warnings to a site with a short lead-time about the impending arrival of the largest strong ground motion from an earthquake after the first wave arrivals have been detected nearer to the source by adequate sensors. Although the time interval between the warning and the arrival of the strong ground motion may be only of some minutes

	Code	Meaning
Material	1	masonry
	2	Reinforced concrete pilotis
	3	Reinforced concrete no pilotis
	4	other
Floor	1, 2, 3, 4, 5	if material =1
	1, 2, 3, 4, 5, 6, 7, 8	if material = 2, 3, 4
Period	1	< 1919
	2	1919 - 1945
	3	1946 - 1961
	4	1962 - 1971
	5	1972 - 1981
	6	1982 - 1991
	7	> 1991
no. houses		Number of houses within the group identified with material, floor and period
no. buildings		Number of buildings within the group identified with material, floor and period
surface (m2)		Surface in m2 within the group identified with material, floor and period
no. inhabitants		Number of inhabitants within the group identified with material, floor and period

TABLE 1. Code and meaning for buildings census.

or seconds it allows for some important security measures to be taken to secure life and property.

Among the activities performed in the context of research project there are: monitoring of strategic buildings, identification of the seismic input, definition of fragility curves by means of non-linear FEM analysis, collecting data for web-GIS platform. At this aim the two chosen buildings were instrumented for the structural monitoring. In particular, for the building of the Province of Enna, ultrasonic measurements and dynamic identification tests were performed. The dynamic identification tests were carried out using triaxial velocimeters with sensitivity of 400 V/m/sec according to two different configurations: the first for the characterization of the tower and the second for the identification of the periods of the remaining part of the structure. Nine velocimeters for the real-time structural health monitoring (Figure 5) and 4 velocimeters for the tower (Figure 6) were placed respectively. The recorded data regard the response of the structure to the natural actions such as ambient noise, wind, earthquake, etc.

At the acquisition of the signals is followed the step of processing of the data. In particular, through the processing of the data in the frequency domain of some parts of the acquired signals, the fundamental period of the structure has been evaluated. The performed recordings have permit the identification of probable frequencies and natural vibration modes of the structure equal to 4.125 Hz (0.24sec), 3.625 Hz (0.27sec) and 12.5 Hz (0.08sec). The recordings on the tower have provided a value of frequency along x direction equal to 3 Hz (0.33sec) and along the Y direction equal to 3.5 Hz (0.28sec). On the basis of the experimental monitoring and the study performed an Earthquake Early Warning System could be implemented in a web GIS platform on the basis of obtained results in terms of natural frequencies.

6. GEOTECHINICAL CHARACTERIZATION OF THE TEST SITE

To manage the seismic risk and to allow for effective and efficient management of communications during the alert and emergency phases, a desktop application for Local Authorities has been realized. The application consists of an advanced system which combines the experimental data provided by structural monitoring and

Material	Floor	Period	no. houses	no. buildings	Surface m^2	no. inhabitants
1	3	2	27	12	2860	55
1	3	3	42	26	4246	94
1	3	4	11	6	1166	13
1	3	5	1	1	140	3
1	4	2	3	1	392	6
2	1	2	8	3	730	10
2	1	3	5	5	471	16
2	1	4	51	33	5134	125
2	1	5	34	25	3907	78
2	1	6	35	31	4097	78
2	1	7	15	15	1822	32
2	2	2	3	3	293	4
2	2	3	8	5	894	11
2	2	4	23	15	2329	48
2	2	5	63	48	7006	155
2	2	6	40	27	5198	98
2	2	7	16	12	1763	38
2	3	4	34	7	3148	87
2	3	5	4	3	560	6
2	3	6	23	6	2601	45
2	3	7	2	1	176	5
2	4	2	1	1	150	2
2	4	4	45	6	3730	103
2	4	5	17	2	1496	32
2	5	4	7	1	537	19
2	7	4	46	4	3370	76
3	1	4	7	4	1015	14
3	1	5	8	5	720	16
3	1	6	7	5	1067	27
3	1	7	12	9	1337	38
3	2	2	10	6	755	24
3	2	3	36	15	3766	81
3	2	4	55	32	5197	140
3	2	5	31	19	3753	86
3	2	6	55	21	5569	157
3	2	7	95	54	11007	284
3	3	2	8	2	639	18
3	3	4	17	4	1647	43
3	3	5	74	9	6516	204
3	3	6	6	1	504	9
3	3	7	28	7	2801	82
3	4	4	2	1	180	3
3	4	5	19	2	1654	45
3	5	4	43	2	2885	87
3	5	5	198	8	13234	554
3	6	5	54	1	4303	149
4	1	1	2	1	200	6
4	1	2	2	2	260	4
4	1	3	5	4	578	12
4	1	4	6	6	459	7
4	1	5	3	3	303	6
4	1	6	1	1	80	4
4	2	1	5	4	456	8
4	2	2	7	5	764	16
4	2	3	44	39	3720	72
4	2	4	36	32	3232	64
4	2	5	6	5	444	8
4	2	6	2	1	205	6
4	2	7	2	2	292	5
4	3	2	10	6	1233	17
4	3	3	15	11	1812	33
4	3	4	22	14	1822	53
4	3	5	7	5	871	17
4	4	4	4	1	275	10

TABLE 2. Buildings census.

FIGURE 2. Reinforced concrete building: Duca D'Aosta School (a); masonry building: Palace of the Regional Province of Enna (b).

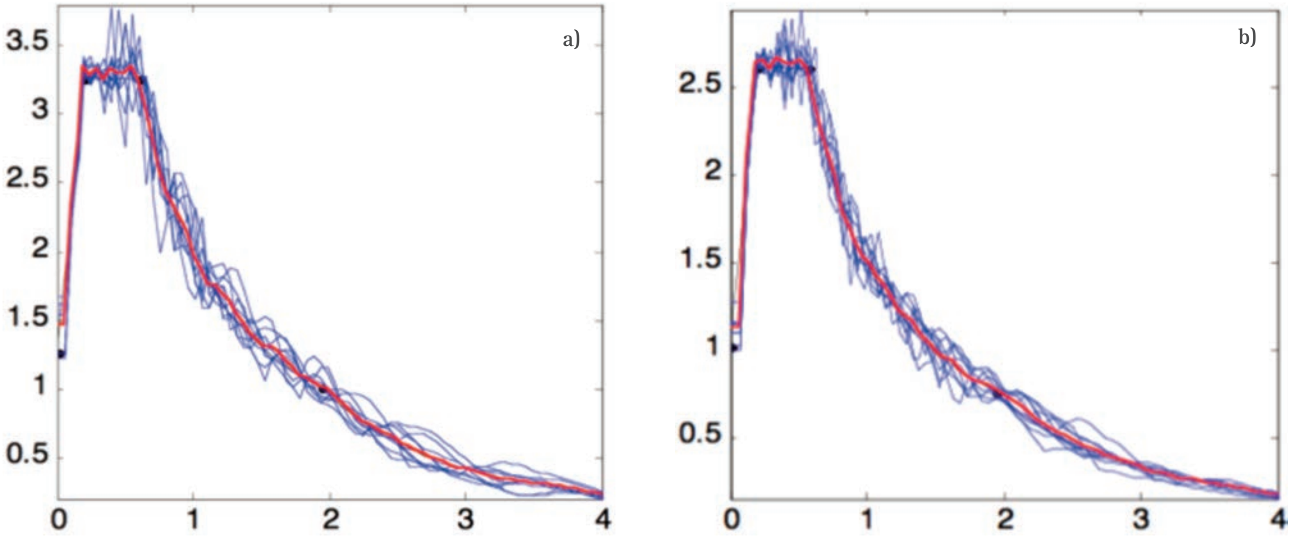

FIGURE 3. Response spectra for synthetic accelerograms for the sites of the Duca D'Aosta school (a), and of the Province of Enna building (b).

the available data derived from geotechnical investigation geo-referenced through the Geographical Information System (GIS) with the probable impacts on the territory, providing a forecast of the seismic risk.

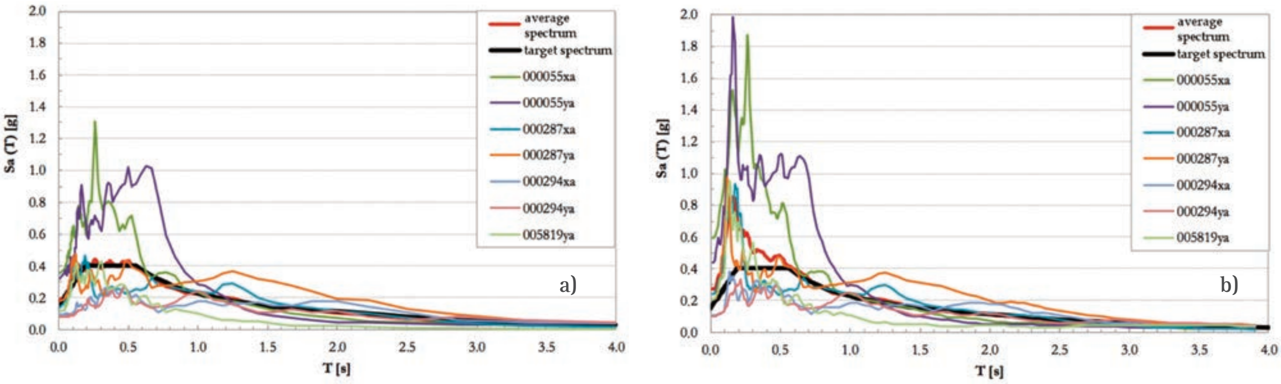

FIGURE 4. Response spectra of accelerograms on rock (a) and at ground surface (b).

At this aim a detailed survey, comprising in situ and laboratory tests have been performed and at the same time the data available related to geotechnical properties for several municipalities of the Province of Enna have been collected.

The collection and analysis of exiting data from previous geotechnical investigations was the first step in planning the site investigation program. For several municipalities of the Province of Enna are available Down - Hole (*DH*), Multichannel Analysis of Surface Wave (MASW), Horizontal to Vertical Spectral Ratio (HVSR), Refraction Microtremor (REMI) and electrical tomography tests (Table 3). A preliminary selection of results of in situ tests have been collected throughout the past years by the public administrations.

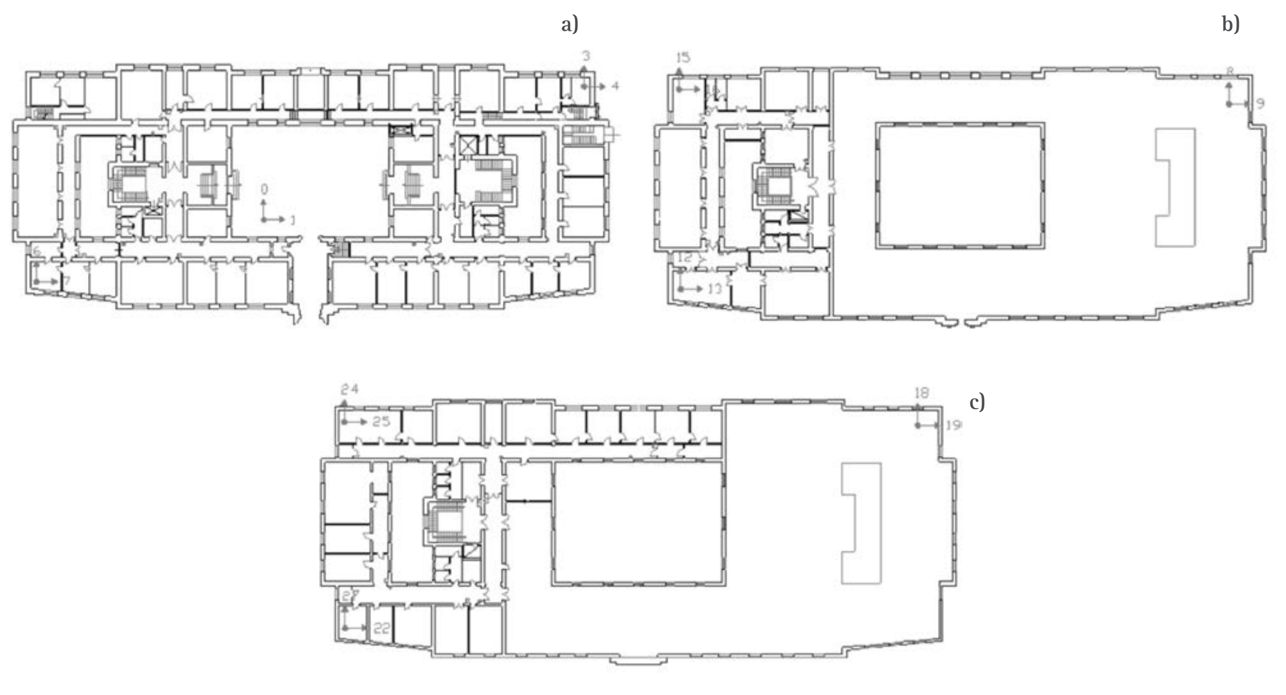

FIGURE 5. Structural monitoring system for the ground level (a), the first level (b) the second level (c) of the Province of Enna building.

For an accurate dynamic subsoil characterization of such sites, surface wave tests were planned in all of them. Down - Hole tests were carried out only in sites with apparently deep seismic bedrock.

In the paper, the results of geotechnical soil characterization exclusively of the municipality of Enna are reported. The geotechnical parameters of the soil foundation have been derived from the boreholes down to a depth of 30.0 m, equipped to perform Down Hole Tests (DH) to evaluate the propagation velocity of seismic compression V_P and shear V_S waves or with piezometers in order to monitor the water level.

To determine the propagation velocity of the body

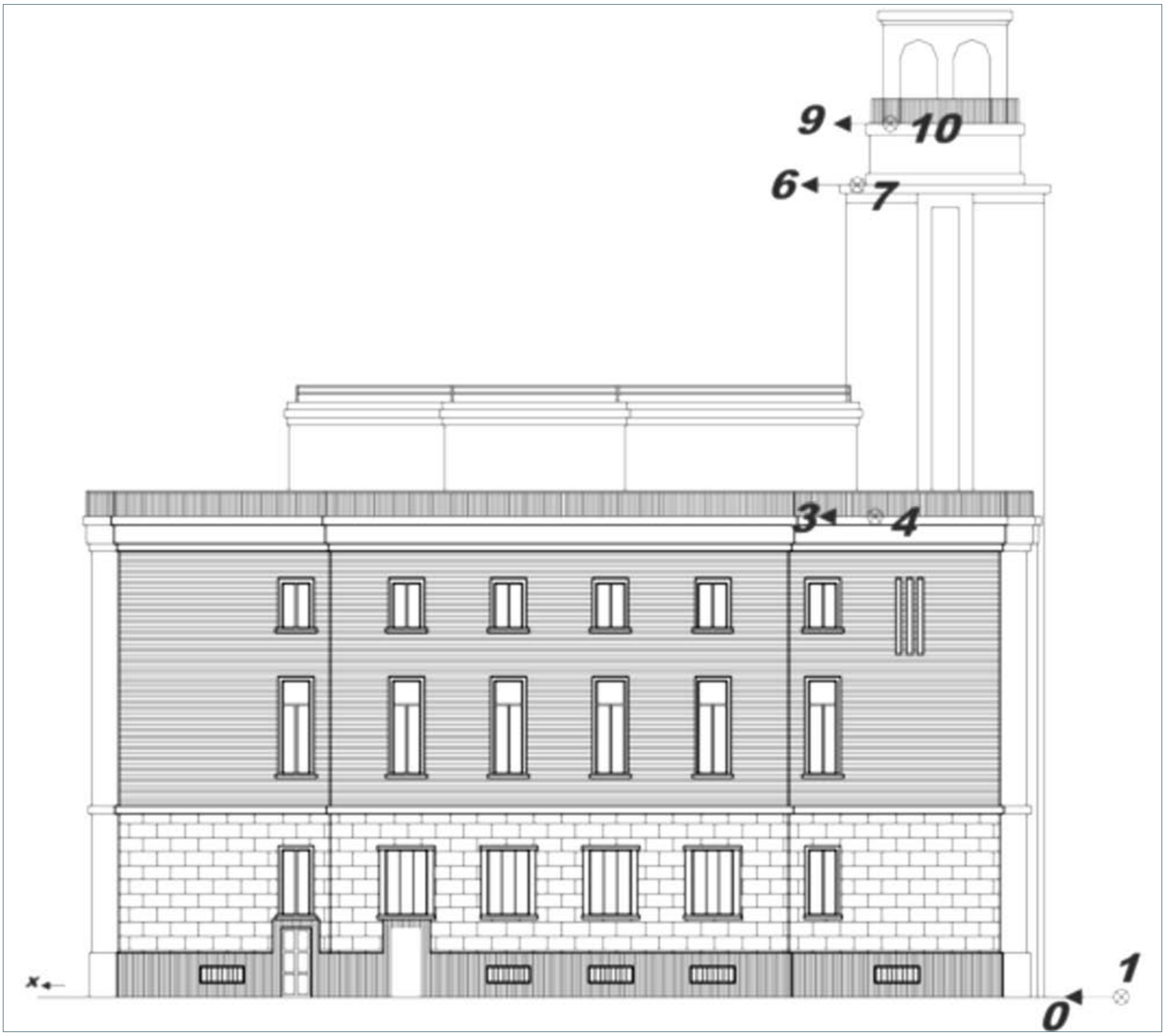

FIGURE 6. Structural monitoring system for the tower of the Province of Enna building.

waves *DH* tests has been carried out. The velocities profiles V_P and V_S shows a progressive increase with depth, within a range of about 120 and 400 m/sec for shear waves and about 200 and 2200 for compression waves (Table 4). In the investigated site, n.40 multi-receiver surface wave (MASW) tests were also performed (Figure 7).

The Surface Wave Method is used for evaluating shear wave velocity profile. It is based on the dispersion of surface waves in heterogeneous media: the velocity of each harmonic component of the surface wave depends on the properties of the medium affected by the wave propagation and its penetration depth is proportional to the wavelength. Dispersion curves (velocity versus waves frequency) can be extracted from field data, using processing technique. The shear wave velocity profile can be inferred by solving an inverse problem.

The MASW tests were performed using active acquisition technique. The Figures 8 and 9 report a set of trial profiles, including the best-fitting profile, and the dispersion curve respectively.

A first validation of the MASW shear wave velocity profiles was possible by means of the DH tests available in the test site. The shear wave velocity profiles obtained from the DH and MASW tests are compared in Figure 10 for all data available (a) in the city of Enna and for the C.da S. Panasia area.

It can be observed that DH and MASW test results are very in good agreement. Within the experimental activities of PRISMA n.80 single station measurements of microtremors have been performed in the city of Enna (Table 5).

Indeed, the experimental horizontal to vertical spectral ratio (HVSR) of ambient noise provide a rea-

Test	Enna	Agira	Aidone	Assoro	Barrafranca
DH	6	-	-	-	-
MASW	11	10	1	4	7
REMI	2	1	2	1	2
HVSR	2	1	1	1	7
Electrical Tomography	-	-	1	3	-

Test	Calascibetta	Catenanuova	Centuripe	Cerami	Gagliano C.to
DH	1	-	-	-	-
MASW	2	2	2	2	2
REMI	1	1	1	1	1
HVSR	1	1	1	1	1
Electrical Tomography	-	-	-	-	-

Test	Leonforte	Nicosia	Nissoria	Piazza Armerina	Pietraperzia
DH	-	1	-	-	-
MASW	1	2	1	4	1
REMI	3	1	2	1	1
HVSR	1	1	1	3	1
Electrical Tomography	1	-	-	-	-

Test	Regalbuto	Sperlinga	Troina	Valguarnera Caropepe	Villarosa
DH	-	-	-	-	-
MASW	5	1	1	2	1
REMI	1	1	2	1	1
HVSR	1	1	1	1	1
Electrical Tomography	-	-	-	-	-

TABLE 3. Summary of site tests available for the municipalities of the Province of Enna.

Soil	V_s (m/s)
Silty sand	500¸700
calcarenites	1200
Clay marnes	300¸400
Grey clay	200¸300
Chalky clay	700¸800
Chalk	1800¸2200

TABLE 4. Shear waves velocity for lithological units in the Enna area.

sonable estimate of the fundamental natural frequency of the site.

The results of in situ test were used to represent a thematic map in which are reported for Enna site the values of the parameter $V_{S,30}$, computed according to the Italian Technical Regulations on the Constructions (Figure 11).

6.1 GEOTECHNICAL PROPERTIES FROM ROUTINE LABORATORY TESTS

The geological survey [Pappalardo and Rapisarda, 2016] shows that foundation soils include in the first meter fine sand and/or sandy silt and at a major depth blue-grey silt clay.

The geotechnical characterization of the soil of the test site is carried out by routine laboratory tests.

The values of the main index properties and the percentage of grain size distribution are summarized in Table 6. Most of the samples are coarse-grained soils, classifiable as sandy silts to silt sands, showing a lower percentage of clayey material. According to the particle size distribution, the tested samples can be classified into two main groups on the basis of clay fraction: lower than 30% and higher than 30%. Physical parameters, in terms of water content w_n, soil unit weight γ, plasticity index *PI*, were derived from standard classification tests performed on the samples retrieved by geotechnical survey.

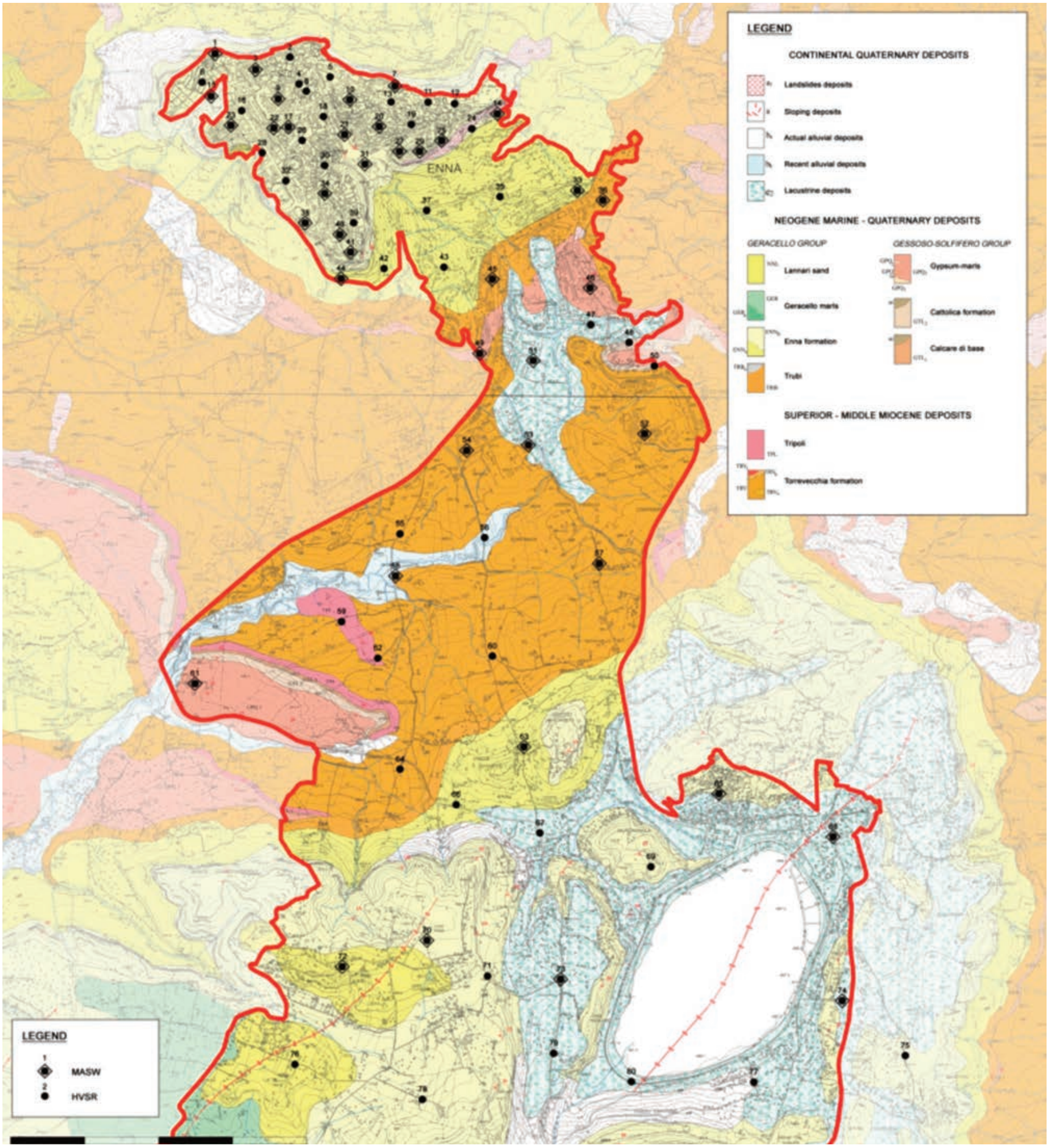

FIGURE 7. Geological map of Enna with location of the HVSR tests and MASW tests.

6.2 STIFFNESS AND DAMPING FROM LABORATORY TESTS

Soil non-linear behavior was analyzed by means of fixed-free Resonant Column/Torsional Shear (RC-CTS) devices. The specimens were consolidated isotropically to the estimated in situ stress. At the end of the consolidation stage, the cyclic and/or dynamic tests were performed with increasing shear load levels, to investigate the behavior of the soils for shear strains ranging between 0.0001% and 1%. As usual, the tests were interpreted in terms of linear equivalent parameters, i.e. shear modulus *G* and damping ratio *D*.

To evaluate the dynamic properties of the soil and in particular to determine the degradation law of shear modulus *G* and the increase law of damping ratio *D* several tests were performed with the Resonant Column/Cyclic Torsional Shear apparatus.

In *RC* tests, sinusoidal torsional forces are generally applied at high frequencies, so as to reach the resonance conditions. For low and medium levels of deformation

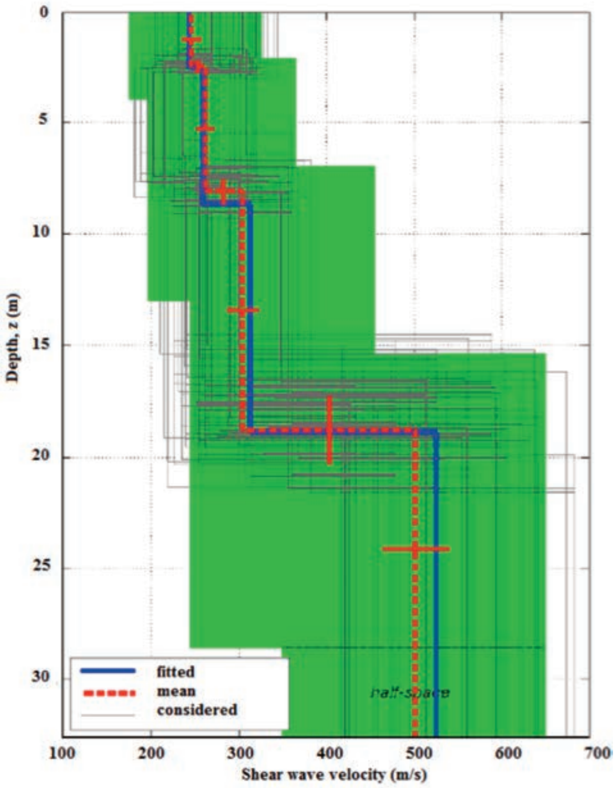

FIGURE 8. Best - fitting profile.

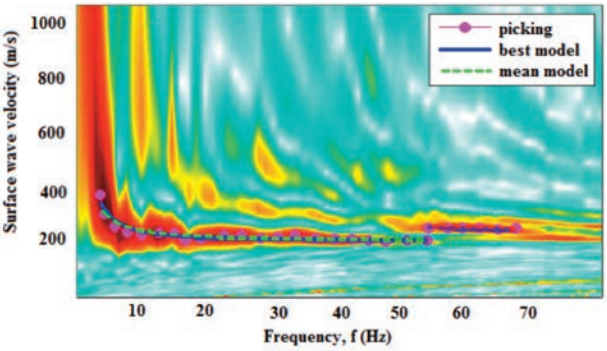

FIGURE 9. Dispersion curve.

torsional forces are generally applied at frequencies between 1 and 100 Hz. At higher levels of deformation, the frequency of torsional forces ranges from 0.01 to 1 Hz. *RC* and *CTS* tests have been carried out on cylinder soil samples with 50 mm of diameter and 100 mm of length, by the use of electromagnetic actuators, in order to perform both *RC* and *CTS* tests with the same equipment on the same sample.

Figure 12 shows the experimental results obtained from the resonant column and cyclic torsional shear test in terms of normalized shear modulus G/G_0 (Figure 12a) and damping ratio D (Figure 12b) versus shear strain γ. Experimental results have been compared in

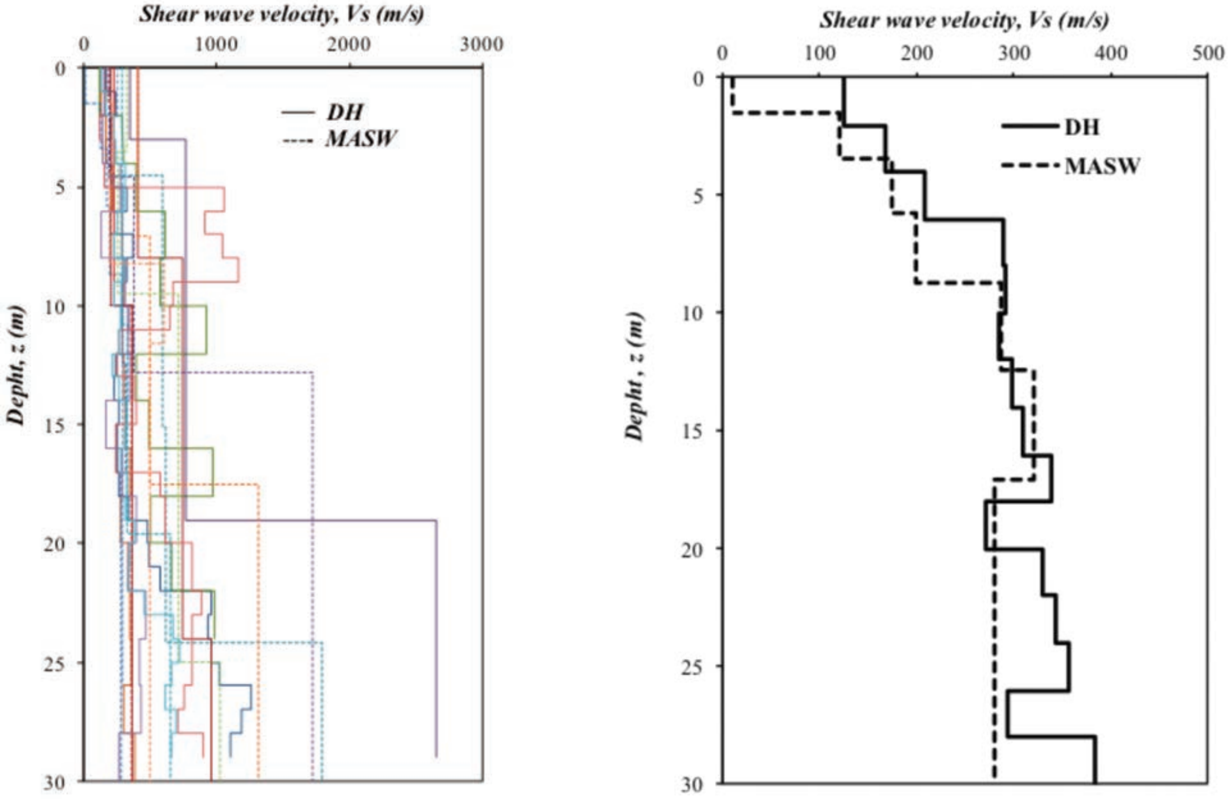

FIGURE 10. Enna site: comparison of shear wave velocity profiles obtained by MASW tests and Down-Hole tests.

Station	f0	A0	f1	A1	f2	A2	Bedrock depth (m)
TR1							7
TR2	4,69	2,11					7
TR3							7
TR4							22
TR5							7
TR6	10,72	1,7					10
TR7	31,72	6,25					9,8
TR8							7
TR9	2,5	2,8	4,2	2,1	24	2,7	32,2
TR10							7,3
TR11							15
TR12							15
TR13	31	2					7
TR14	5,5	2					19
TR15	12,95	2,2					16
TR16	2,5	2,71	3,5	2			26
TR17	5	2,1					37,4
TR18	35	2					6,5
TR19	5	2	7,92	2,9			7,7
TR20							7,2
TR21	1,23	2,3					28,6
TR22	3	2	4,52	2			17,9
TR23	5	2					26
TR24	0,53	1,8					19
TR25	16,72	1,73					7,7
TR26							16
TR27	27	3					7,7
TR28	0,44	3,5	5	2,8			20
TR29	20,63	2,2					8
TR30							20
TR31	2,8	3,5					20
TR32							18,5
TR33	7,2	6,8					17,2
TR34	4,2	2	5,2	2			18,4
TR35	2	2,3					76
TR36	19,83	4,2					21,7
TR37	1,28	2,5					50
TR38	5,94	2					18,5
TR39	14,38	2					12

TR40	5,77	2					12,1
TR41	0,92	3,68					22
TR42	1,7	2,3	24	3			50
TR43	2,66	4					50
TR44	2	2	12	2,9			66
TR45	4,63	4	19	2,1			42
TR46	20	2,2	38	2			15,5
TR47	3,4	2,2	35	2,5			15,5
TR48	3,7	3					15,5
TR49	6	2,2					48
TR50	1,55	1,83					15,5
TR51	2	4,25	26	2,9			26
TR52	1,39	2,35	2,5	2			42
TR53	3,09	2,68					58
TR54	2,2	3	31,09	3,6			44
TR55	2,2	3	4,63	3,2			40
TR56	2,3	2					50
TR57	2,81	3,32	7,2	2,7			42
TR58							50
TR59	1,3	2,6	4	2,5	15	3	35
TR60	2,6	2,8					42
TR61	4,5	3					41,3
TR62	1,5	2,6	4,02	3	17	2,2	27
TR63							25
TR64	1,6	2,5	2,8	2,6			42,4
TR65							23
TR66	0,66	2,4					25
TR67	3	2					40,1
TR68	2,02	3,6					55
TR69	2,81	1,8					50
TR70	1,52	4,8	10	2,2			24,7
TR71	2,19	2,4					20
TR72	2,61	3	33	2,8			46,44
TR73							47,7
TR74	22,03	1,6					27,3
TR75	1,95	1,5					25
TR76	2,5	2	20	3,8			22
TR77							22
TR78	2,3	2,5	4	3,2			20,2
TR79							48
TR80	3,75	3,4	22	3			48

TABLE 5. Single station measurements of microtremors.

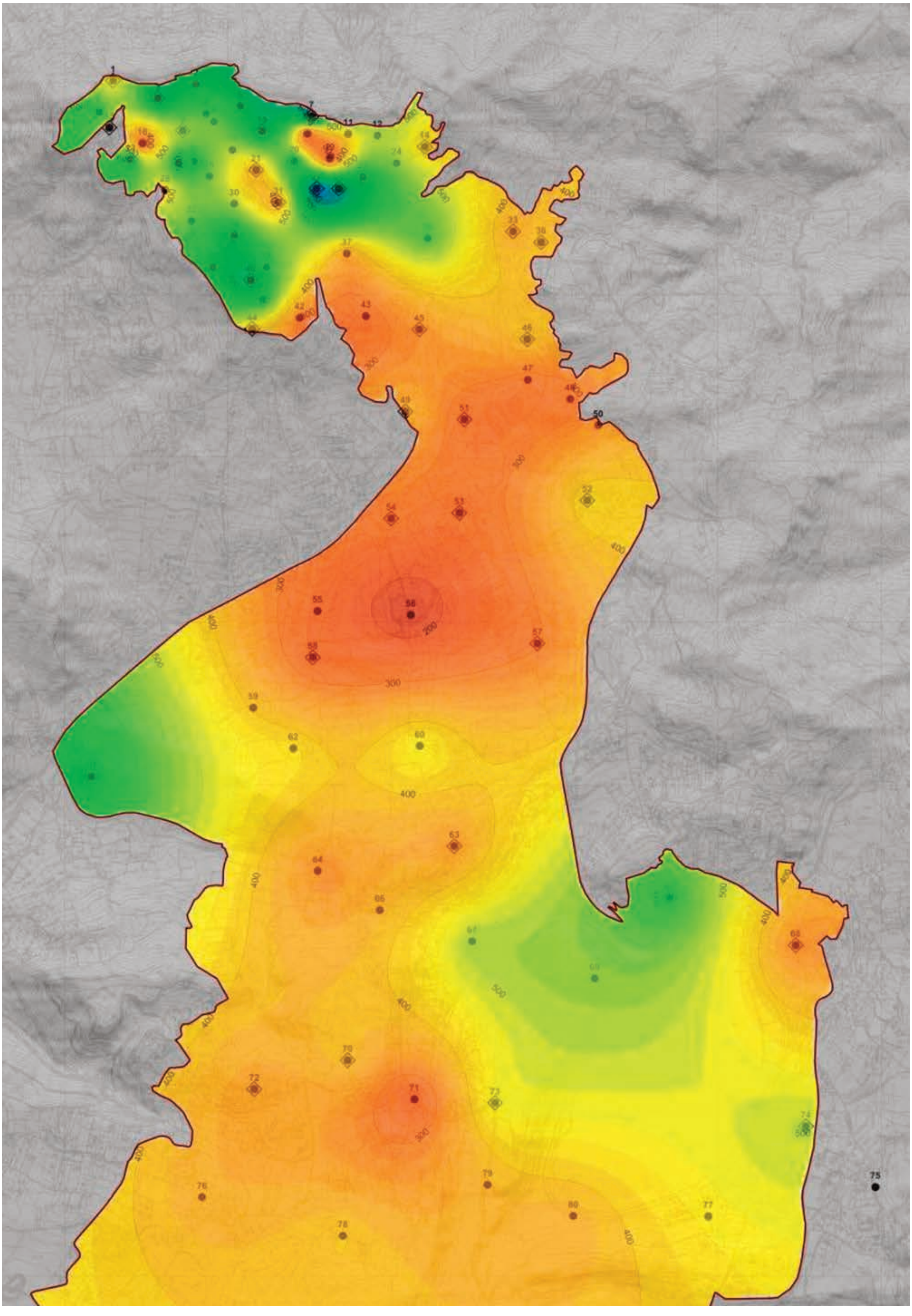

FIGURE 11. $V_{S,30}$ map for Enna site.

Site	Sample	Depth (m)	Clay (%)	Silt (%)	Sand (%)	γ (kN/m^3)	w_n (%)	I_p (%)	e_o
C.da Santa Panasia	S1/C2	6,00	39,36	41,31	19,32	20,21	19,90	-	-
	S2/C1	2,00	12,34	14,46	71,59	19,26	19,33	-	-
	S2/C2	5,50	30,73	39,50	25,61	19,66	31,26	33,47	0,731
	S2/C4	15,5	35,33	44,94	19,74	20,01	20,02	42,12	0,581
	S3/C1	1,50	11,75	17,97	64,41	19,01	20,99	11,58	-
	S3/C2	4,00	5,39	2,25	89,38	19,67	13,76	-	0,584
	S3/C3	8,00	20,60	27,07	52,29	20,26	20,27	8,58	0,569
	S3/C4	15,3	28,50	48,71	22,79	20,05	22,74	48,84	0,608
C.da S. Anna	S1/C2	8,00	10,15	30,01	46,11	19,27	24,74	14,80	-
	S1/C3	18,0	25,13	53,54	21,27	19,88	31,86	36,39	-
	S2/C1	3,00	23,35	43,79	25,63	20,02	21,97	19,97	-
	S2/C3	13,2	37,45	51,80	10,72	20,52	22,50	47,44	0,495
	S3/C2	5,70	26,24	34,80	36,44	19,25	28,18	22,79	-

TABLE 6. Geotechnical properties derived by laboratory tests.

Figure 13 with the curves proposed by Darendeli [2001] for soils with plasticity index equal to 30% and for mean effective confining pressure σ'0 equal to 100 kPa for soils tested in the range 75-150 kPa.

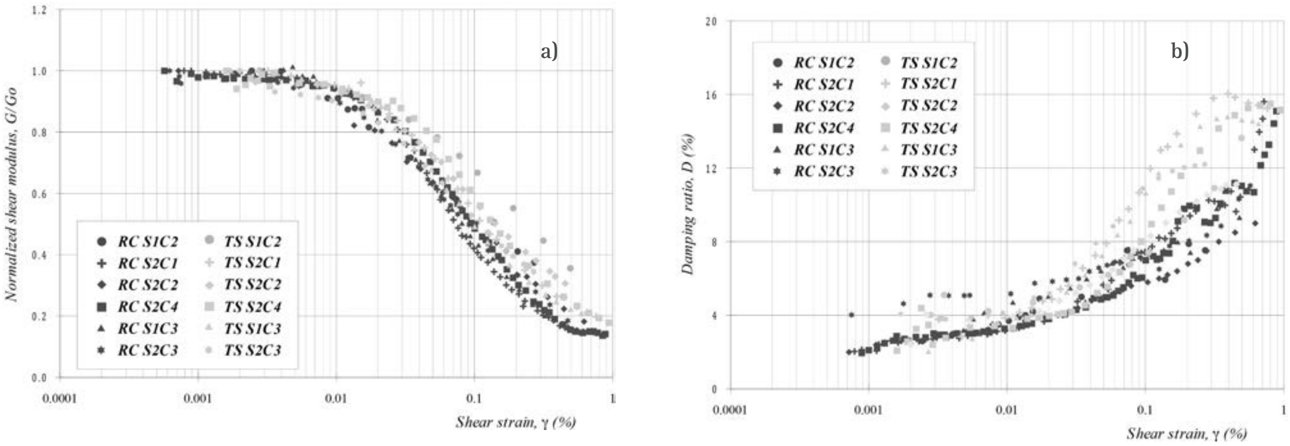

FIGURE 12. Normalized shear modulus (a) and damping ratio (b) vs shear strain from RC and CTS tests.

The comparison among the tested specimens reflected their differences in physical properties, confirming that clay fraction and plasticity index are key parameters to represent soil non-linearity. The curves relevant to silty-low plasticity soils define a range of linear behavior not exceeding a threshold strain level of the order of 0.005% beyond which the decay of stiffness and the increase of damping are quite pronounced. The

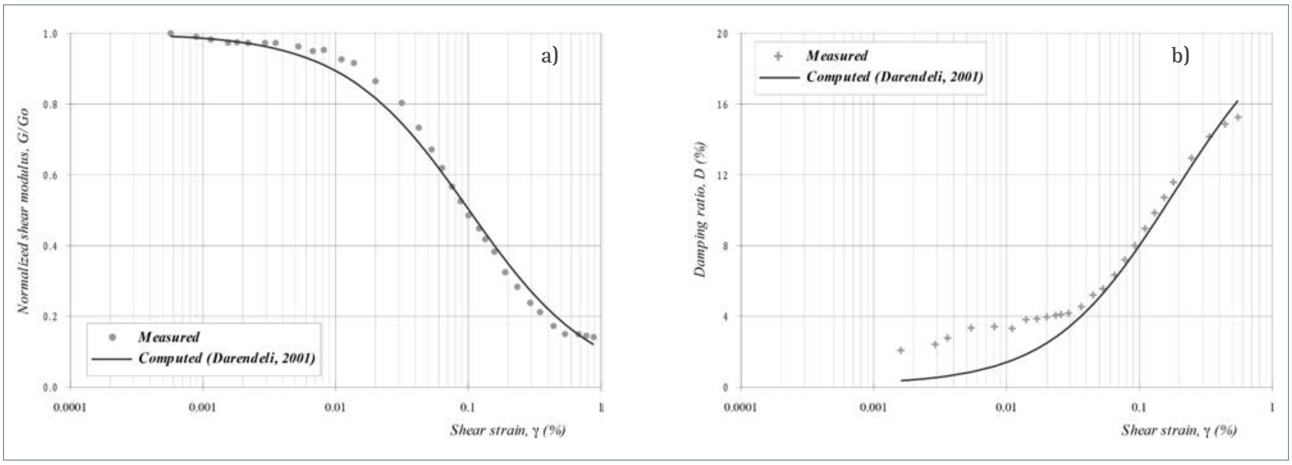

FIGURE 13. Normalized shear modulus (a) and damping ratio (b) vs shear strain from RC and CTS tests compared with literature curve by Darendeli (2001) for σ'_0 equal to 100 kPa.

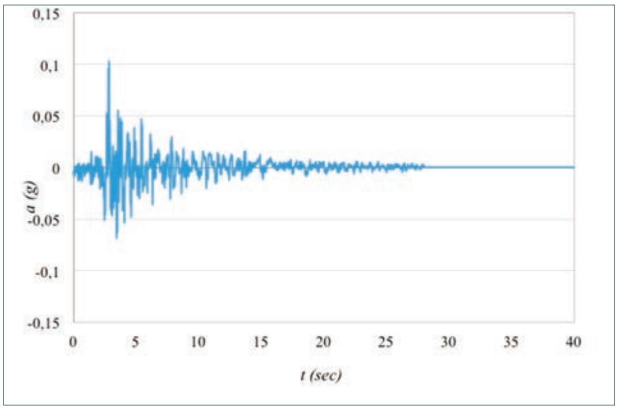

FIGURE 14. Input motion recorded to Sortino (SR) station during St. Lucia earthquake (13th December 1990).

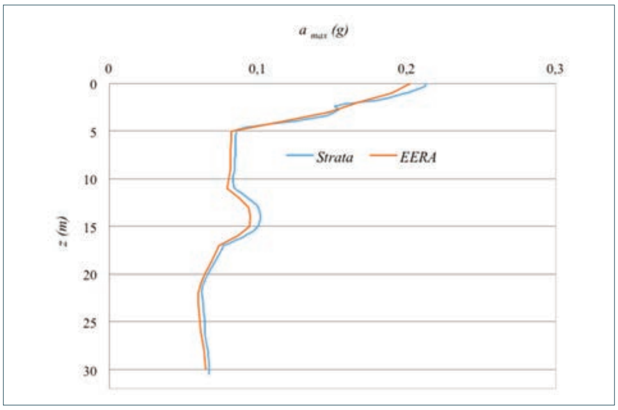

FIGURE 15. Peack ground acceleration versus depth for the bedrock depth at 30 m.

curves relevant to clayey-high plasticity soils are characterized by higher values of the linear threshold of the order of 0.01%, showing a less evident reduction of stiffness and lower damping values in the non-linear range.

7. SITE RESPONSE ANALYSIS

The study of topographic factors, with the information related to the surface morphology and to the mechanical properties of soil is fundamental for a reliable seismic response analysis. The paper proposes results from seismic analysis performed in 1D and 2D field based on geological, geotechnical and geophysical studies with reference to the Enna area.

The 1D numerical simulations were performed through the STRATA [Kottke and Rathje, 2008] and EERA [Bardet et al., 2000]. codes; the seismic bedrock depth was assumed at 30 m. The input motion (Figure 14) is the St. Lucia earthquake (13 December 1990) recorded to Sortino (SR). The results obtained from the two numerical codes in terms of peck ground acceleration (PGA) versus depth are presented in Figure 15, showing a good agreement. The maximum value of PGA obtained at the surface is equal to 0.203 g.

When the section is characterized by a ratio between the depth and the distance from the edges greater than 2, then the 1D analysis may give unreliable results [Lanzo and Silvestri, 1999]. For this reason, topographic effects on the hill of Enna have been studied through the QUAKE/W [Krahn, 2004] computer code.

The 2D simulations have been performed considering a cross section (Figure 16) that covers 2060 m in length and 280 m in elevation; the numerical method used is the finite element implemented is QUAKE/W. Rectangular shaped elements have been used in the finite element domain discretization. The boundary conditions applied to lateral boundaries are nodal zero vertical displacements and the boundary condition at the bottom of the model are nodal zero vertical and horizontal displacements (Figure 17). Finally, the input time history acceleration relating to St. Lucia earthquake (13 December

FIGURE 16. Cross section of Enna.

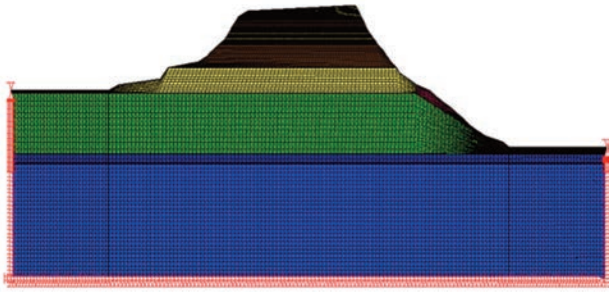

FIGURE 17 2D Boundary condition of the model.

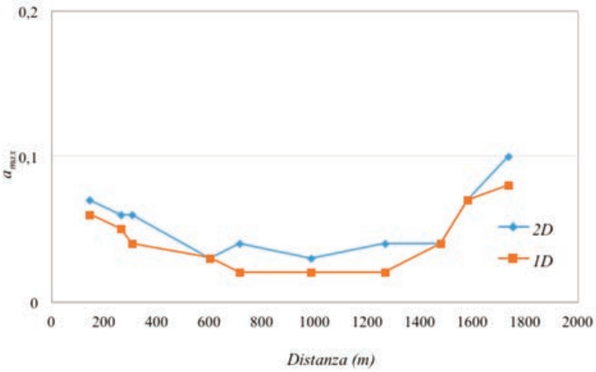

FIGURE 18 Comparison between 1D and 2D PGA.

1990) (SR) has been applied at the bottom of the mesh. The analyses were performed based on the soil properties derived from field investigation and laboratory tests.

For the purpose of this numerical study carried out along the cross section of Enna, this seismic bedrock model seems to be the most representative, provided that the input motion is the 1999 St. Lucia earthquake recorded at Sortino and accurate geotechnical and geological characterization of deep deposit is available.

Figure 18 shows the values of the maximum acceleration obtained by 1D (red line) and 2D (blue line) simulations. It is possible to note that the value of PGA on the crest are greater than those on the edges.

8. SEISMIC MICROZONATION OF THE AREA

The Seismic Microzonation is a cognitive tool aiming at the mitigation of seismic risk of an area. It should be conducted on the basis of the Guidelines for Seismic Microzonation that defines three levels of detail and the corresponding improvements of knowledge that should be carried out to achieve each one, depending also on the local hazard. Level 1 is an introductory level consisting of a collection of exiting data processed to define the subsoil model and a Seismic Microzonation map in which the territory is qualitatively classified into homogeneous microzones. Level 2 introduce the quantitative elements associated with the homogeneous zones, using additional investigations and a new Seismic Microzonation map is produced. Level 3 contains insights on topics and/or on particular areas.

All the considerations discussed above were integrated in a map of homogeneous microzones in seismic perspective (Figure 19) in which some areas were identified as homogeneous on the basis of main parameters as: lithological and lithotecnical characteristics, depth of bedrock, geomorphological conditions, etc.

The integration of geological, geophysical and geotechnical data allowed to distinguish n.29 zones characterized as stable zones but susceptible of local seismic amplification. In the same Figure 4 instable microzones can be distinguished.

9. CONCLUDING REMARKS

In the last years, strong earthquakes occurred in Italy have highlighted the ineffectiveness of prevention policies. To acquire a greater knowledge on the seismic risk affecting urban areas, geological and geotechnical characterization of the soil is the main step. Within this aim, smart technologies allow the management and sharing of complex information relating to the seismic vulnerability of exposed resources. The thematic maps are cognitive tools aiming at the mitigation of seismic risk of an area. The realization of a risk map is a complex task that involves the combination of data coming from different field of expertise, such as geology and geotechnical and structural engineering. The paper describes how the application of prospecting and surveying techniques allowed a decisive improvement in the

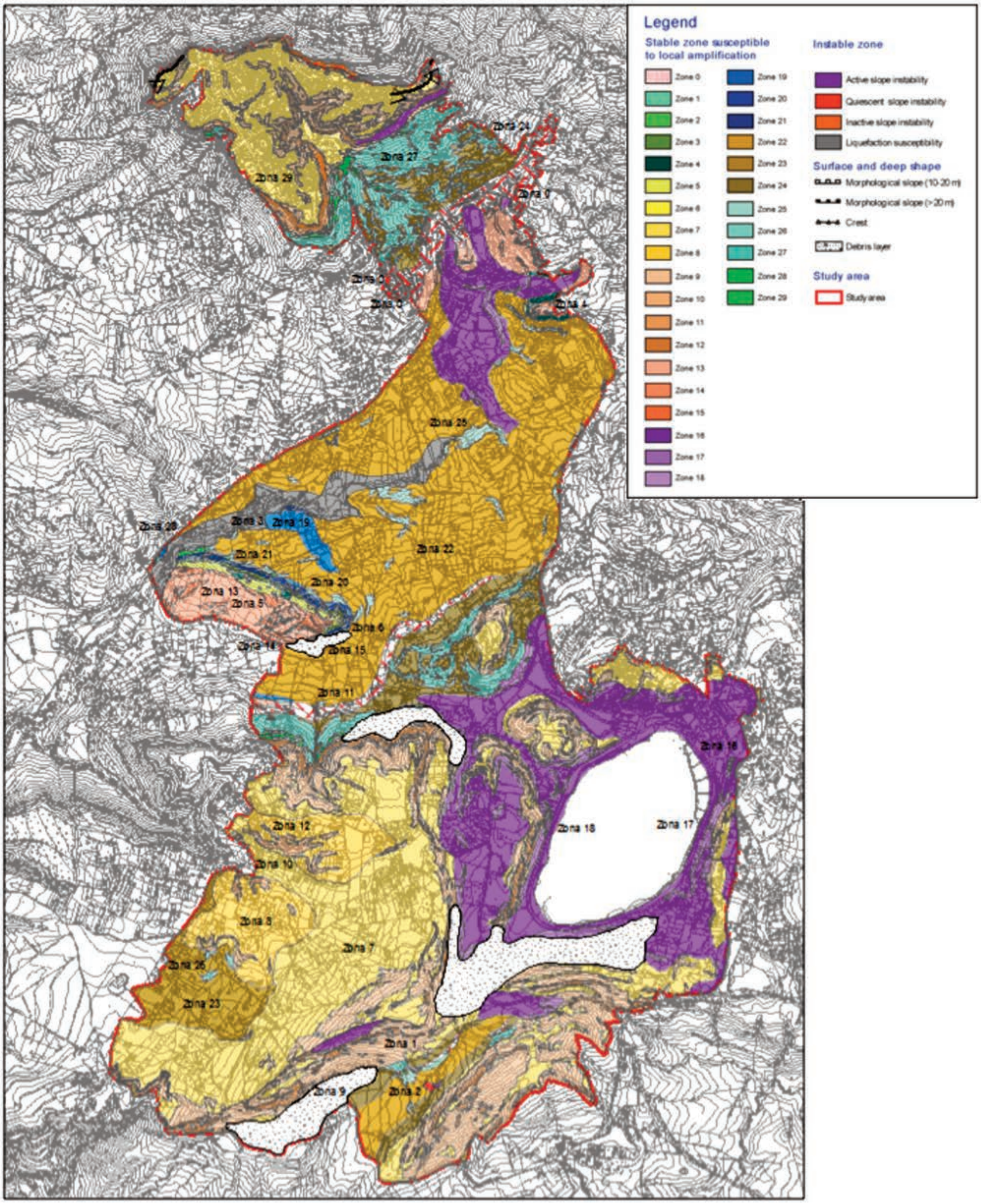

FIGURE 19 Map of homogeneous microzones in seismic perspective for Enna area.

geological knowledge of the test site, contributing to define the subsoil model for the purposes of seismic microzonation. The paper also reports the seismic geotechnical characterization performed with laboratory tests including the resonant column and cyclic torsional shear test on undisturbed samples. The results are summarized in terms of variation of stiffness and damping with shear strain. Finally, wireless sensor for structural monitoring have been used, having significant benefits when the time available for access is often severely limited and representing an effective way of managing risks once that an area of concern has been identified.

REFERENCES

Asplund M. and S. Nadjm-Tehrani (2009). A partition-tolerant many cast algorithm for disaster area networks. In Proc. of IEEE 28th International Symposium on Reliable Distributed Systems (SRDS), Niagara Falls, NY, USA.

Barbano M.S., G. Pappalardo, C. Pirrotta and S. Mineo (2014). Landslide triggers along volcanic rock slopes in eastern Sicily (Italy). Natural Hazards, 73, 3, 1587-1607, 2014. DOI: 10.1007/s11069-014-1160-1.

Bardet J.P., K. Ichii and C.H. Linn (2000). EERA, A computer program for Equivalent Earthquake site Response Analyses of Layered Soil Deposits. University of Southern California.

Castelli F. and V. Lentini (2010). Bearing capacity of shallow foundations on slopes: experimental analysis on reduced scale models. In Proc. 7th Int. Conf. on Physical Modelling in Geotechnics, (ICPMG 2010), Zurich, Switzerland, 685-690.

Castelli F, Lentini V (2012) Evaluation of the bearing capacity of footings on slopes. Int J Phys Mod Geot 12(3):112-119.

Castelli F and V. Lentini (2013). Landsliding events triggered by rainfalls in the Enna area (South Italy). In Proc. of Second World Landslide Forum, 2, 39-47.

Castelli F. and V. Lentini (2016). Monitoring of Full Scale Diaphragm Wall for a Deep Excavation. In Proc. of 1st IMEKO TC-4 International Workshop on Metrology for Geotechnics, Benevento, Italy, 103-108.

Castelli F., V. Lentini and M. Maugeri (2013). Stability Analysis of Landfills in Seismic Area. In Proc. of Geo-Congress 2103 March 3-7, 2013 | San Diego, California, United States, ASCE Geotechnical Special Publication, no.231, Stability and performance of slopes and embankments, https://doi.org/10.1061/9780784412787.124, Published online: March 28, 2013

Castelli F., V. Lentini and E.T. Dean (2015). Discussion: Evaluation of the bearing capacity of footings on slopes. Int. J. Phys. Mod. Geot. 15(3), 165-168.

Castelli F., A. Cavallaro, A. Ferraro, S. Grasso and V. Lentini (2016**a**). A seismic geotechnical hazard study in the ancient city of Noto (Italy). In Proc. of VI Italian Conference of Researchers in Geotechnical Engineering - Geotechnical Engineering in Multidisciplinary Research: from Microscale to Regional Scale, CNRIG2016, 158, 535-540.

Castelli F., V. Lentini and C.A. Trifarò (2016*b*). 1D seismic analysis of earth dams: the example of the Lentini site. In Proc. of VI Italian Conference of Researchers in Geotechnical Engineering - Geotechnical Engineering in Multidisciplinary Research: from Microscale to Regional Scale, CNRIG2016, Procedia Engineering, 158, 356-361.

Castelli F., A. Cavallaro, S. Grasso and V. Lentini (2016*c*). Seismic Microzoning from Synthetic Ground Motion Earthquake Scenarios Parameters: the Case Study of the City of Catania (Italy). Soil Dyn. Earthq. Eng., 88, 307-327.

Castelli F., E. Castellano, F. Contino and V. Lentini (2016*d*). A Web-based GIS system for landslide risk zonation: the case of Enna area (Italy). In Proc. of 12th Int. Symp. on Landslides, Napoli, Italy.

Castelli F., Freni G., Lentini V., Fichera A. (2017) Modelling of a debris flow event in the Enna area for hazard assessment. In: Proceedings 1st international conference on the material point method (MPM 2017), Delft, Procedia Engineering 175 (2017), 287–292

Castelli F. and M. Maugeri (2008). Experimental Analysis of Waste Compressibility. In Proc. Of GeoCongress 2008 March 9-12, 2008 | New Orleans, Louisiana, United States, doi.org/10.1061/40970(309)26, Published online: June 20, 2012.

Castelli F. and M. Maugeri (2013). Postearthquake analysis of a piled foundation. J. Geotech. Geoenviron., 139(10), 1822-1827.

Cavallaro A., S. Grasso and M. Maugeri (2006). Volcanic Soil Characterisation and Site Response Analysis in the City of Catania. In Proc. of 8th National Conference on Earthquake Engineering, San Francisco, 2, 835-844.

Cavallaro A., A. Ferraro, S. Grasso and M. Maugeri (2008). Site Response Analysis of the Monte Po Hill in the City of Catania. AIP Conference Proceedings, 1020(1), 583-594.

Cavallaro A., A. Ferraro, S. Grasso, M. Maugeri (2012). Topographic Effects of the Monte Po Hill in Catania, Soil Dyn. Earthq. Eng., 43, 97-113.

Cavallaro A., S. Grasso, M. Maugeri and E. Motta (2013*a*) An innovative low-cost SDMT marine investigation for the evaluation of the liquefaction potential in the Genova Harbour, Italy. In: Int. Conf. on Geotechnical and Geophysical Site Characterization 4, Coutinho & Mayne (Editors), Taylor & Francis Group, London, 637-644.

Cavallaro A., S. Grasso, M. Maugeri and E. Motta (2013*b*). Site characterisation by in situ and laboratory tests of the sea bed in the Genova Harbour, Italy. In Int. Conf. on Geotechnical and Geophysical Site Characterization 4, Coutinho & Mayne (Editors), Taylor & Francis Group, London, 415-422.

Facciorusso J., C. Madiai and G. Vannucchi (2016). The

2012 Emilia earthquake (Italy): Geotechnical characterization and ground response analyses of the paleo-Reno river levees. Soil Dyn. Earthq. Eng., 86, 71-88.

Ferraro A., S. Grasso, M. Maugeri and F. Totani (2016). Seismic Response Analysis in the Southern Part of the Historic Centre of the City of L'Aquila (Italy). Soil Dyn. Earthq. Eng., 88, 256-264.

Fouda M.N., H. Nishiyama and N. Kato (2012). A novel heuristic based traffic distribution method for disaster zone wireless mesh networks. In Proc. of 1st IEEE Int. Conf. on Communications in China (ICCC), Beijing, China.

Giardini D., J. Woessner, L. Danciu, G. Valensise, G. Grunthal, F. Cotton, S. Ak-kar, R. Basili, M. Stucchi, A. Rovida, D. Stromeyer, R. Arvidsson, F. Meletti, R. Musson, R.K. Sesetyan, M.B. Demircioglu, H. Crowley, R. Pinho, K. Pitilakis, J. Douglas, J. Fonseca, M. Erdik, A. Campos-Costa, B. Glavatovic, K. Makropoulos, C. Lindholm and T. Cameelbeeck (2013). Seismic Hazard Harmonization in Europe (SHARE).

Grasso S. and M. Maugeri (2014). Seismic Microzonation Studies for the City of Ragusa (Italy). Soil Dyn Earthq Eng, 56, 86-97.

Grasso S., F. Castelli, M.R. Massimino and V. Lentini (2016). In Situ Measurements for Evaluating Liquefaction Potential under Cyclic Loading. In: Proc. of 1st IMEKO TC-4 Inter. Workshop on Metrology for Geotechnics, Benevento, Italy, 79-84.

Ishizu K., H. Murakami and H. Harada (2011). Cognitive wireless network infrastructure and restoration activities for the earthquake disaster. In Proc. of 14th Int. Symp. on Wireless Personal Multimedia Communications (WPMC), Brest, France.

Kottke A.R. and E.M. Rathje (2008). Technical Manual for Strata - PEER 2008/10. University of California, Berkeley, California.

Krahn J. (2004). Dynamic modeling with QUAKE/W. Geo-Slope International Ltd.

Liu R., I.J. Wassella and K. Soga (2010). Relay Node Placement for Wireless Sensor Networks Deployed in Tunnels. In Proc. of IEEE 6th Int. Conf. on Wireless and Mobile Computing, Networking and Communications, Chengdu City, China.

Liu W., H. Nishiyama, N. Kato, Y. Shimizu and T. Kumagai (2012). A novel gateway selection method to maximize the system throughput of wireless mesh network deployed in disaster areas. In Proc. of 23rd IEEE Int. Sym. on Personal, Indoor and Mobile Radio Communication (PIMRC), Sidney, Australia.

Monaco P., G. Totani, F. Totani, S. Grasso and M. Maugeri (2011). Site Effects and Site Amplification due to the 2009 Abruzzo Earthquake. In Proc. of 8th Int. Conf. on Earthquake Resistant Engineering Structures, WIT Transactions on the Built Environment, 120, 29-40.

Monaco P., G. Totani, S. Amoroso, F. Totani and D. Marchetti (2013). Site characterization by seismic dilatometer (SDMT) in the city of L'Aquila. Rivista Italiana di Geotecnica, 3, 8-22.

Ngo T., H. Nishiyama, N. Kato, Y. Shimizu, K. Mizuno and T. Kumagai (2013). On the throughput evaluation of wireless mesh network deployed in disaster areas. In Proc. of Int. Conf. on Computing, Networking and Communications (ICNC), San Diego, USA.

Pappalardo G., S. Mineo and C. Monaco (2016). Geotechnical characterization of limestones employed for the re-construction of a UNESCO world heritage Baroque monument in southeastern Sicily (Italy). Engineering Geology, 212, 86-97, 2016. DOI: 10.1016/j.enggeo.2016.08.004.

Pappalardo G. and S. Mineo (2015). Rock-fall Hazard and Risk Assessment: The Promontory of the Pre-Hellenic Village Castelmola Case, North-Eastern Sicily (Italy). In G. Lollino et al. (eds.), Engineering Geology for Society and Territory – Volume 2, 1989-1993, 2015. DOI: 10.1007/978-3-319-09057-3_353.

Pappalardo G., S. Mineo and F. Rapisarda (2014). Rockfall hazard assessment along a road on the Pe-loritani Mountains (northeastern Sicily, Italy). Nat. Hazards Earth Syst. Sci., 14, 2735–2748, 2014. doi:10.5194/nhess-14-2735-2014.

Pappalardo G. and F. Rapisarda (2016). Hydrogeology and geochemistry of surface water and groundwater in the Site of Communitarian Im-portance of the endorheic Pergusa basin (Sicily). Ital. J. Geosci., Vol. 135, No. 3 (2016), pp. 503-511.

Santucci de Magistris F., A. d'Onofrio, L. Evangelista, S. Foti, M. Maraschini, P. Monaco, S. Amoroso, G. Totani, G. Lanzo, A. Pagliaroli, C. Madiai, G. Simoni and F. Silvestri (2013). Geotechnical characterization of the Aterno valley for site response analyses. Rivista Italiana di Geotecnica, 3, 23-43.

Shibata Y., Y. Sato, N. Ogasawara and G. Chiba (2009). A disaster information system by ballooned wireless adhoc network. In Proc. of 3rd Int. Conf. on Complex, Intelligent and Software Intensive Systems (CISIS), Fukuoka, Japan.

Smerzini C, C. Galasso, I. Iervolino and R. Paolucci (2013). Ground motion record selection based on broadband spectral compatibility. Earthquake Spectra. DOI 10.1193/052312EQS197M.

Wishart R., M. Portmann and J. Indulska (2008). Evaluation of wireless mesh network handoff approaches for public safety and disaster recovery networks. In

Proc. of IEEE Australasian Telecommunication Networks and Applications Conference (ATNAC), Adelaide, Australia.

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