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HVSR and MASW seismic survey for characterizing the local seismic response: a case study in Catania area (Italy)

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***Abstract* – Many recent researches show that the site seismic response is strongly influenced by stratigraphic and topographic features. Site response can reduce or amplify the earthquake induced ground motion. An integrated approach based on passive (HVSR) and active (MASW) seismic surveys, was carried out at the Garibaldi Hospital, located in Catania downtown, in order to evaluate the seismic site response. Fourteen environmental noise records, located near some previously mechanical drillings, were carried out and processed by using the Horizontal to Vertical Spectral Ratio (HVSR) technique. Successively, two MASW prospections were performed at the northern and the southern sides of the Hospital building, following the information deduced from the stratigraphic characteristics of soil drillings. The data obtained from this coupled analysis, method and the information derived by mechanical drillings previously performed, allowed us to obtain the site transfer function which can be related to the H/V average spectrum. Such integrated approach, based on passive and active seismic prospections, showed to be a reliable and quick method to obtain information for a site seismic characterization. According to Italian code a Vs30 profile was achieved and the soil type category was determined**

I. INTRODUCTION

The town of Catania is located in the eastern coast of Sicily (southern Italy) at the south of Mt. Etna. The high level of seismicity that affects the city, together with the considerably high density of inhabitants living in its urban area, contributed to classify it as one of the town having the highest seismic risk in Italy. It is also not negligible the high potential damage to which its historic-architectural patrimony could undergo even at small magnitudes. The seismicity of this area is linked to the collisional processes between African and European plates. In the last 900 years, the east cost of Sicily has been struck by various disastrous earthquakes with MKS intensity varying in the range IX-XI, and estimated magnitudes ranging from less than 5.0 to greater than 7.0. In particular, the earthquakes occurred in 1169, 1542, 1693, 1818, 1908 and more recently in 1990, having intensity ranging between VI and XI MCS scale testify the high level of hazard in this area. The information on damage distribution during the past earthquakes is available for downtown Catania only.

Hospital "Garibaldi" is located in a populated area in the western side of Catania. The study area is located in one of the most seismically active zones of the Mediterranean area. Using the historical seismicity data available for the area, it is reasonable to assume as a maximum expected earthquake the repetition of the two M > 7 events which hit western Sicily in the past and destroyed Catania: the 1169 and the 1693 earthquakes. These catastrophic events were characterized by intensities equal to X MCS and XI MCS and estimated magnitudes equal to 7.0-7.4. According to Azzaro [1]the first level scenario event for the Catania area may be reasonably assumed as the January 11, 1693 earthquake that caused the largest seismic catastrophe in eastern Sicily. The most probable source of this event is located along the northern part of the Ibleo-Maltese fault and is commonly associated with rupture to a normally pure mechanism along the escarpment.

It is therefore evident the importance of evaluating the local seismic effects in the whole Catania area assessing the ground motion amplification and damage distribution during earthquakes having different magnitude and source-to-site distance. In order to assess the seismic risk in Catania, an extensive seismic characterization should be performed in the whole area and this can be done with HVSR and Masw surveys.

II. GEOLOGICAL SETTING

The "Garibaldi" hospital area is located in the historic center of Catania (Fig.1). Being a "strategic" building. the prevention of seismic risk is necessary so that the

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knowledge of characteristics of soil foundation are required.

The tectonics of eastern Sicily is quite complex. Available seismotectonic information and interpretations for south-eastern Sicily suggest the existence of two groups of possible sources for the seismicity that affected the town of Catania in different times. The sources are located either close to the Ionian coast (Messina Straits and Malta-Hyblean escarpment), or inland, both in the Hyblean foreland and Etnean areas. The Malta-Hyblean escarpment, a normal fault system trending NNW-SSE, is in particular considered as the possible source of the destructive earthquakes (M $\approx$ 7.0) that struck in past centuries the Catania area[1].

The geological map of the Catania urban area is shown in Fig. 1. This is the result of assembling information coming from data and surveys performed by several authors [6]. The surface geology of the town derives from the combination of three processes linked to the volcanic, tectonic and human activities. As a consequence of this, the main feature of the area is the presence of a complex sedimentary sequence interbedded between a clay basement and an upper volcanic formation made by lava flows and pyroclastic products that sometimes is surmounted by detritus and ruins due to past earthquakes. The bedrock of the area is composed of a Lower-Middle Pleistocene sequence of marly clays, having thickness up to about 600 m. In the upper part of this succession, sand and sandy clays levels are present frequently. These layers are followed upwards by some tens meters of fluvial-deltaic yellowish sandy clay, sand and coarse gravel.

The geological, geomorphological and topographical local conditions are usually very important sources of information for the assessment of the seismic potential hazard for ground failure; these factors play a fundamental role on earthquake ground motions and distribution of damage. This aspect becomes even more critical in areas with sharp transitions between stiff surface formations and softer soil materials. This condition is typical in a volcanic zone like Catania with lies at the foot of the Mt. Etna Volcano and was affected by many eruptions in historical times.

III. SITE GEOTECHNICAL CHARACTERIZTION

Main earthquakes that affected Catania in the past are mostly characterized by high magnitudes that caused extensive damage in different areas. Concerning the geological and geotechnical soil properties, in the built-up area of Catania several outcropping strata of talus materials, consisting mostly of pebbly elements and rock fragments, are found. From the geological point of view, the area is characterized by “lava unit” and by alternating layers of limestones and sandy-silt or clayey-silt matrix. In particular, in the Garibaldi area located on a “grey compact lava”. In any case the geological-structural features of the Catania soil have been strongly influenced by the long period of human activity, so that the building foundation soil frequently consists of talus materials.

To define the seismic behavior of “Garibaldi” site, a geotechnical investigation to deduce the seismic significant soil parameters was carried out. Seven boreholes were made as shown in Figure 2 where the locations of the boreholes and of the in situ tests carried out during the investigations are indicated.

The geotechnical profiles resulting from boreholes and shown in figure 2 were matched with the geological information to deduce the geotechnical cross-sections (figure 3). Four cross sections were developed using boreholes A1, A2, A3, A4, A5 and A7.

Generally, a thin layer of altered soil can be observed in the area with thickness ranging from few centimeters to about 1 m. Then, four different units can be recognized: a layer of medium-stiff “fractured lava” with thickness ranging from 2 m to 11m; a layer of very sandy gravel which was detected only in two boreholes with thickness about 11 m; a formation of brown silt with sand with thickness ranging from 50 cm to about 7 m; a recast soil with depth ranging from 50 cm to about 7 m .

IV. DATA ACQUISITION AND PROCESSING

Two MASW profiles and fourteen HVSR (Horizontal to Vertical Spectral Ratio) measures were performed. Figure 1 show the location of both MASW profiles and HVSR measurements. .

A. HVSR survey

The HVRS (Horizontal to Vertical Spectral Ratio) survey consists in the recording of natural and anthropic microtremors (noise). The technique is able to detect the resonance frequency due to local stratigraphic after processing the spectral ratio between the average horizontal and vertical components. Therefore the H/V ratio provides an estimation of the resonance frequency responsible of ground motion amplification when stressed by seismic waves. Such amplification is ascribable to tectonic or stratigraphic discontinuities or topographic effects [2][5][7][8].

Fourteen noise samplings were carried out in proximity of the borehole between July and August, 2015, but in figure 4 they have been represented only those with a minimum rms The survey were performed by means of a three components tromograph. The instrument is equipped with three electro-dynamic velocimeters orthogonally oriented, acquiring in the 0,1÷1024 Hz band. The environmental noise is recorded for _20 minute at a frequency of 128 Hz, the amplified and digitized in 24bit equivalent. The first step of data processing consisted in the subdivision of the recorded signal in 20 seconds windows (with a triangular smoothing of 10%) and in the “cleaning” of the track removing any anthropic disturb usually coming from sources located very close to the site of investigation. For each of the recording the statist tests performed according to the SESAME (2005) guidelines, highlighted how all the registrations and the analyses fitted the criteria of reliability even though the resonance peaks were not always clear and significant for all the six selected criteria.

Fig. 1. Geotechnical map of Garibaldi Hospital area and location of borehole and noise records (after modified Monaco and Tortorici 1999).

B. Multi-channel Analysis of Surface Waves (MASW)

MASW (Multichannel Analysis of Surface Waves) is a technique able to reconstruct the vertical shear waves (Vs) profile with depth by means of surface waves analysis in various sensors (accelerometers or geophones) placed on the ground surface. The major contribution to the surface waves is due to Rayleigh waves, which velocity is related to the rigidity of the medium in which they propagate [3][4][9][10].Two MASW profiles were performed by means of a multi-channel seismograph with a incremental signal in the northern and southern part of the study area, where the topographic and stratigraphic conditions could provide the best results. The temporal series recorded with the multi-channel system were elaborated in the frequency-phase velocity domain (slant-stack and Fourier transform) in order to discriminate the portion of energy ascribable to the Rayleigh waves.

The dispersion curve of the Rayleigh waves was obtained from phase velocity (m/s) – frequency (Hz) and slowness (m/s) – frequency (Hz) identifying the couple of values f-k related to the maximum spectral energy values (spectral density). The theoretic dispersion curve was calculated by the formulation of the profile of the vertical shear waves (V_s), conveniently modifying the thicknesses h, the V_s and V_p velocities and the densities ρ of the layers constituting the model of the ground. Vs and V_p profile are shown in figure 5.

V. CONCLUSIONS

The analysis of the spectra of theHVSR samplings reveal that the investigated site is stable even though some slight amplification are present and characterized by a H/V ratio ranging between for 0.5 and 2.5 in the frequency interval 0.1 ÷ 64 Hz. In the engineering frequency range (1 ÷ 20 Hz) the H/V ratio decreases below the value of 1, probably indicating the preponderance of the vertical component of motion with respect the horizontal one.

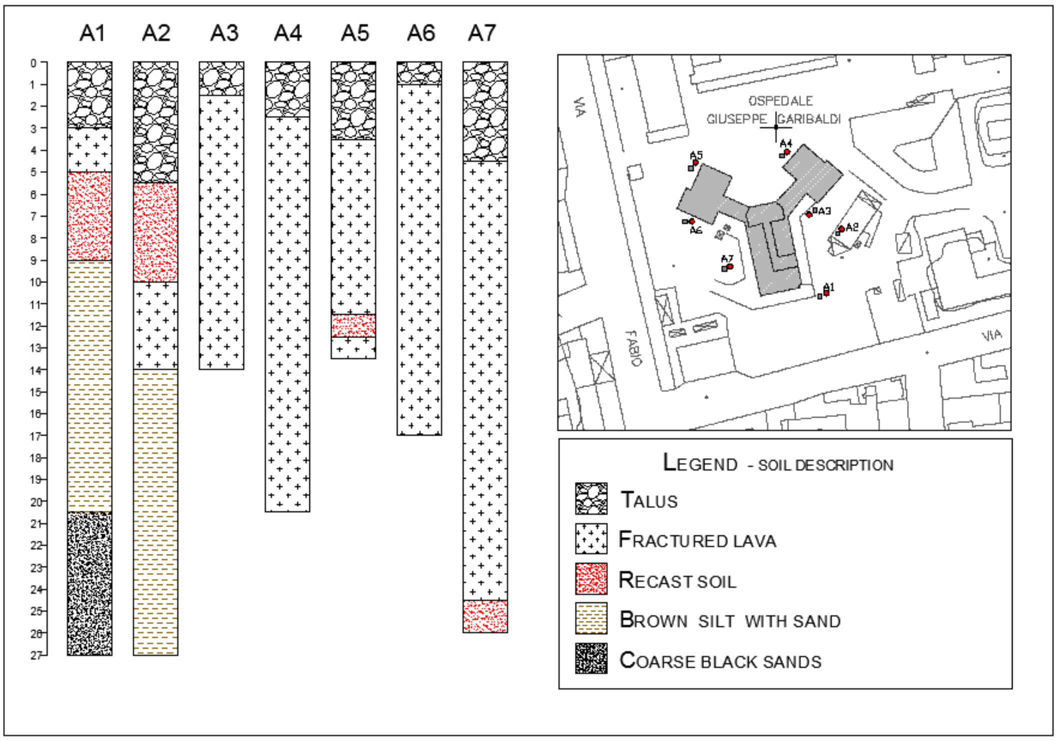

Fig.2. Geotechnical scheme of boreholes performed on Garibaldi Hospital area.

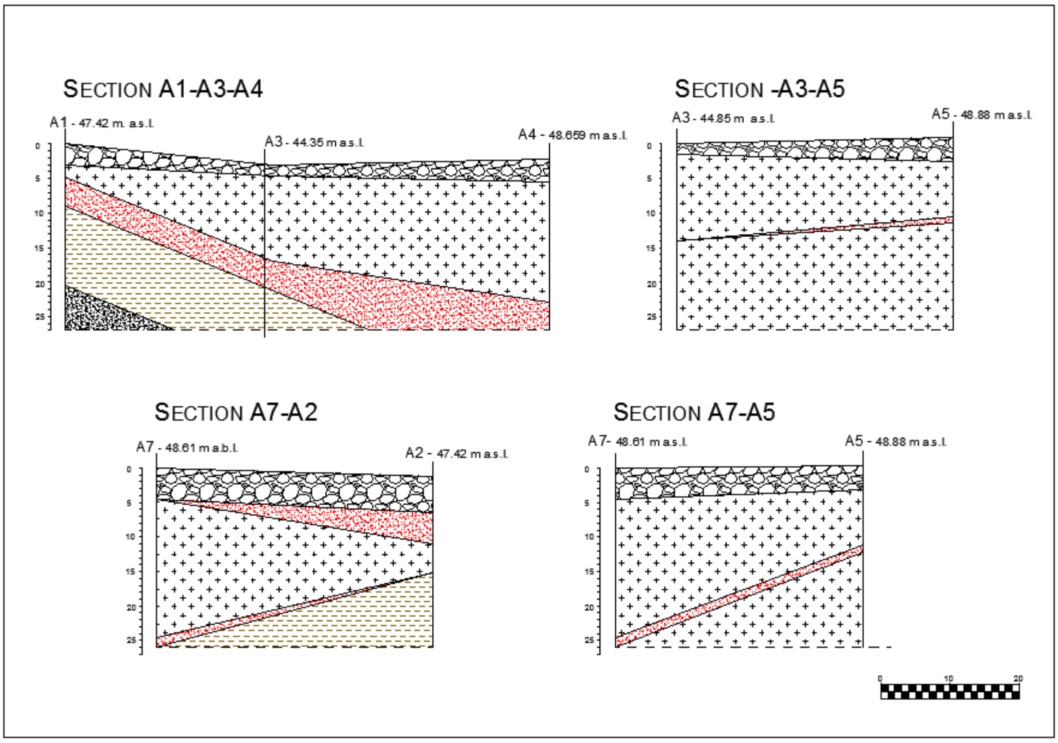

Fig.3. Geotechnical cross section developed using the results of performed investigation.

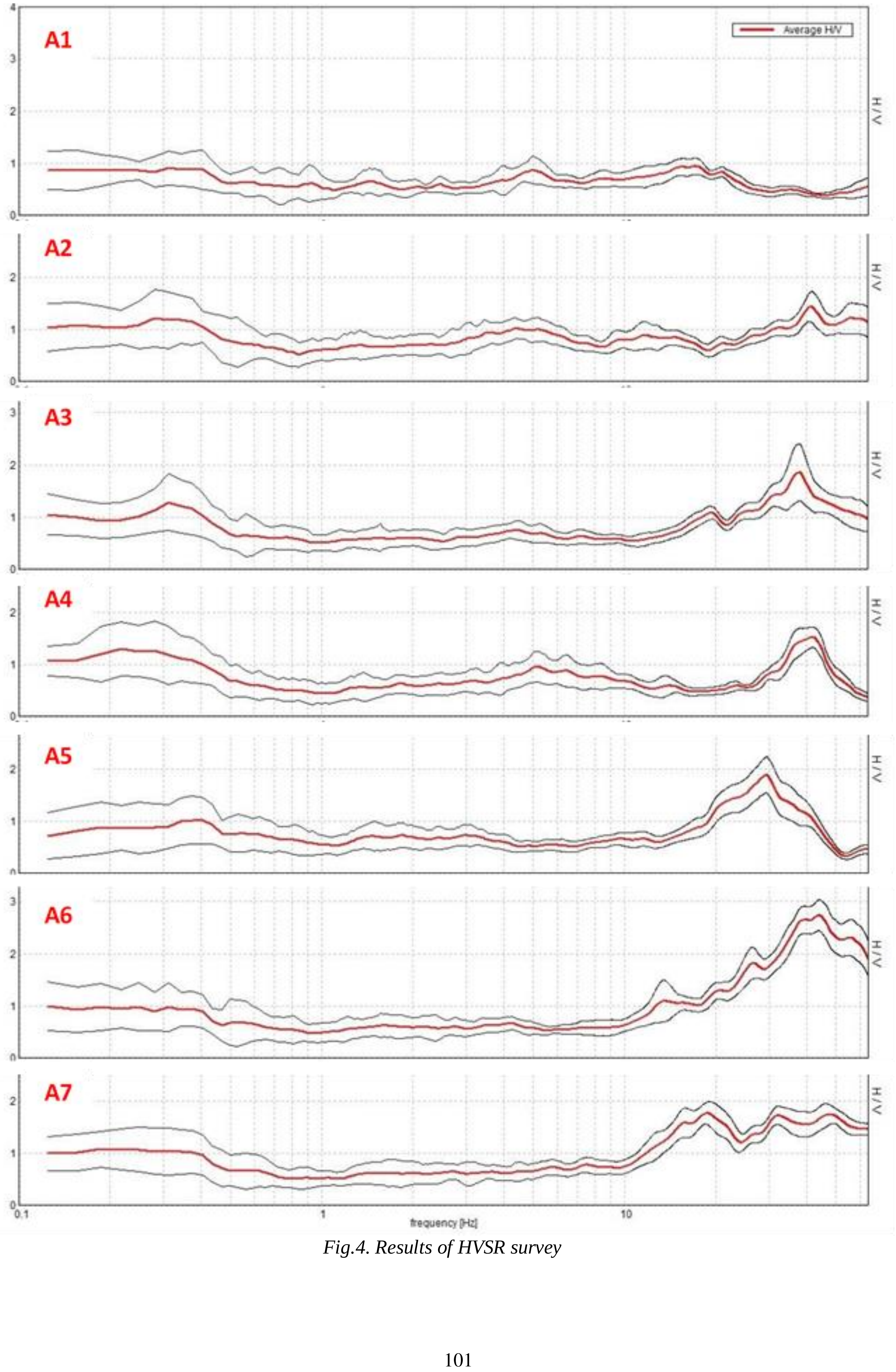

Fig.4. Results of HVSR survey

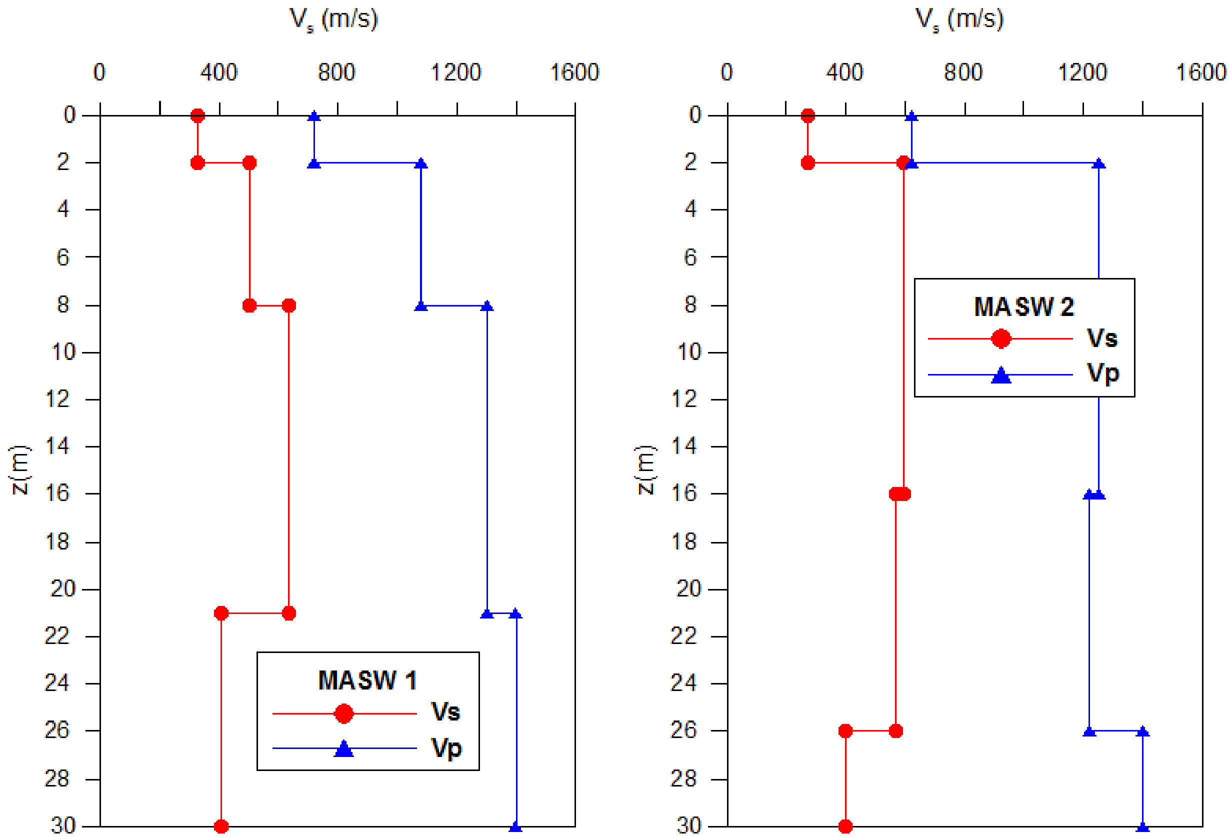

Fig.5. Profile of Vs and Vp vs depth by Masw survey

In particular, recordings made near the boreholes A1 and A2 show an almost complete flattening of the H/V curve and this could be ascribable to the underlying sedimentary soils. Conversely, the recordings near boreholes A3-A7 (revealing exclusively volcanic rocks and soils) show moderate peaks of amplification clearly related to the discontinuities between the superficial loose material and the underlying volcaniclastic layer and between this latter and the deeper massive volcanics.

The model was repetitively modified to obtain the best overlap between the experimental and the theoretic dispersion curves. Results show that the soil of the investigated area has an average Vs value of about 490 m/s along the first 30 m of depth. The estimation of V_p, of the dynamic Poisson coefficient, and of the density allowed to calculate the elasto-dynamic parameters and the young static modulus for the various layers.

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