APPLICATION OF SURFACE WAVE METHODS FOR SEISMIC SITE CHARACTERIZATION

CONDOMINIO EX ATER - GEMONA

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1 Introduction

In this report a summary of the results obtained for the characterization of the site of the temporary accelerometric station Condominio Ex Ater (Gemona del Friuli) within the project PRIN 2007 “Prediction of ground motion and generation of shaking maps in the near-fault region of an earthquake” is presented. The analysis was performed using active surface wave method.

The map and the site location are shown in Figure 1 and Figure 2.

According to little a priori geological information available, gravels deposits are expected for tens of meter of depth below ground surface.

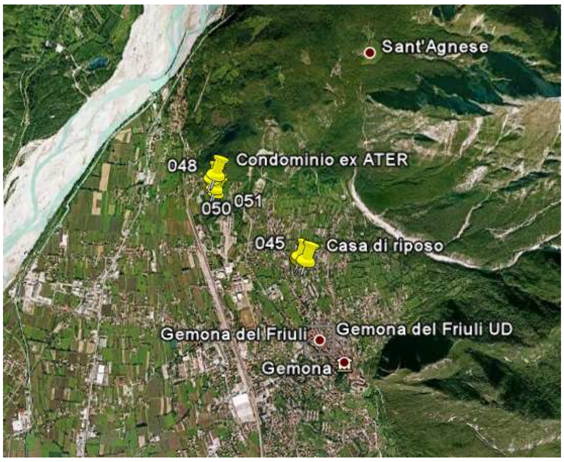

Figure 1 Gemona del Friuli: map

Figure 2 Condominio Ex Ater: site location

Goal of the seismic tests is the estimation of the S-wave velocity profile of the subsoil.

The primary use of surface wave testing is related to site characterization in terms of shear wave velocity profile. The V_S profile is of primary interest for seismic site response studies and for studies of vibration of foundations and vibration transmission in soils. Other applications are related to the prediction of settlements and to soil-structure interaction.

With respect to the evaluation of seismic site response, it is worth noting the affinity between the model used for the interpretation of surface wave tests and the model adopted for most site responses study. Indeed the application of equivalent linear elastic methods is often associated with layered models (e.g. the code SHAKE and all similar approaches). This affinity is also particularly important in the light of equivalence problems, which arise because of non-uniqueness of the solution in inverse problems. Indeed profiles which are equivalent in terms of Rayleigh wave propagation are also equivalent in term of seismic amplification (Foti et al., 2009).

Many seismic building codes introduce the weighted average of the shear wave velocity profile in the shallowest 30m as to discriminate class of soils to which a similar site amplification effect can be associated. The so-called $V_{S,30}$ can be evaluated very efficiently with surface wave method also because its average nature does not require the high level of accuracy that can be obtained with seismic borehole methods.

In the following a methodological summary of techniques and the description of the results is presented.

For further explanation of surface wave methodologies, see document: Project S4: ITALIAN STRONG MOTION DATA BASE, Deliverable # 6, Application of Surface wave methods for seismic site characterization, May 2009.

2 Surface wave method

Surface wave method (S.W.M.) is based on the geometrical dispersion, which makes Rayleigh wave velocity frequency dependent in vertically heterogeneous media. High frequency (short wavelength) Rayleigh waves propagate in shallow zones close to the free surface and are informative about their mechanical properties, whereas low frequency (long wavelength) components involve deeper layers. Surface wave tests are typically devoted to the determination of a small strain stiffness profile for the site under investigation. Consequently the dispersion curve will be associated to the variation of medium parameters with depth.

The calculation of the dispersion curve from model parameters is the so called forward problem. Surface wave propagation can be seen as the combination of multiple modes of propagation, i.e. more than one possible velocity can be associated to each frequency value.

If the dispersion curve is estimated on the basis of experimental data, it is then possible to solve the inverse problem, i.e. the model parameters are identified on the basis of the experimental data collected on the boundary of the medium. The result of the surface wave method is a one-dimensional S wave velocity soil profile.

The standard procedure for surface wave tests is reported in Figure 3. It can be subdivided into three main steps:

1. acquisition of experimental data;
2. signal processing to obtain the experimental dispersion curve;
3. inversion process to estimate shear wave velocity profile at the site.

It is very important to recognize that the above steps are strongly interconnected and their interaction must be adequately accounted for during the whole interpretation process.

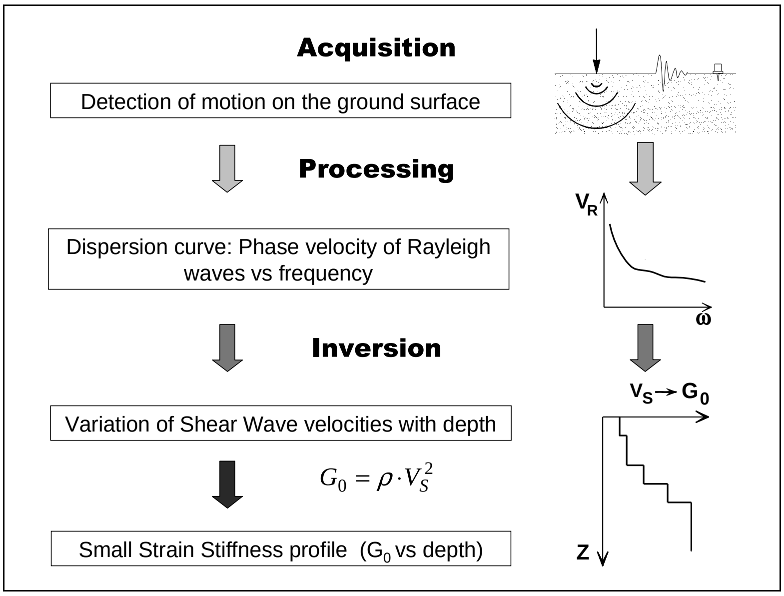

Figure 3 – Flow chart of surface wave tests.

2.1 Acquisition

Active surface wave tests (MASW) tests at Condominio Ex Ater have been performed in September 2009.

Characteristics of sensors are reported in Table 1.

Test	GEOPHONE TYPE	NATURAL FREQUENCY	GEOPHONE NUMBER
MASW/Refraction	vertical SENSOR SM-6/U-B	4,5 Hz	48

Table 1 Condominio Ex Ater: receiver characteristics

The total length of the array is 141 m. The source is a 5kg sledge hammer. Geometry parameters are summarized in Table 2.

Test	GEOF. N.	SPACING	SOURCE TYPE	ACQUISITION WINDOW	SAMPLING INTERVAL	STACK
MASW	48	3.0 m	Hammer	T = 2 s	$\Delta t = 0.5$ ms	20

Table 2 Condominio Ex Ater: acquisition parameters

2.2 Processing of surface waves

The processing allows the experimental dispersion curve to be determined.

Multichannel data are processed using a double Fourier Transform, which generates the frequency-wave number spectrum, where the dispersion curve is easily extracted as the location of spectral maxima.

2.3 Inversion of surface waves

The solution of the inverse Rayleigh problem is the final step in test interpretation. The solution of the forward problem forms the basis of any inversion strategy; the forward problem consists in the calculation of the function whose zeros are dispersion curves of a given model. Assuming a model for the soil deposit, model parameters of the best fitting subsoil profile are obtained minimizing an object function.

The subsoil is modelled as a horizontally layered medium overlaying a halfspace, with constant parameter in the interior of each layer and linear elastic behaviour. Model parameters are thickness, S-wave velocity, P-wave velocity (or Poisson coefficient), and density of each layer and the halfspace. The inversion is performed on S-wave velocities and thicknesses, whereas for the other parameters realistic values are chosen a priori. The number of layer is chosen applying minimum parameterization criterion.

In surface wave analysis it is very common to perform the inversions using only the fundamental mode of propagation. This approach is based on the assumption that the prevailing mode of propagation is the fundamental one; if this is partially true for normal dispersive sites, in several real cases the experimental dispersion curve is on the contrary the result of the superposition of several modes. This may happen in particular when velocity inversions or strong velocity contrasts are present in the shear wave velocity profile. In these stratigraphic conditions the inversion of the only fundamental mode will produce significant errors; moreover all the information contained in higher propagating modes is not used in the inversion process.

The use of higher modes in the inversion can be helpful both in the low frequency range, in order to increase the investigation depth and to avoid the overestimation of the bedrock velocity, and in the high frequency range in order to provide a more consistent interpretation of shallow interfaces and increase model parameter resolution.

In this work a Monte Carlo Global Search Method (GSM) has been adopted to perform the inversion, in order to reduce the possibility of falling in local minima. The Monte Carlo approach used exploits a particular property of the solution and permits to increase the efficiency with respect to traditional Monte Carlo approaches (Socco and Boiero 2008). Ranges for the inversion have been chosen, for the different sites, based on the experimental dispersion curves.

The results of the inversion are reported as the ensemble of the shear wave velocity profiles selected accordingly to experimental data uncertainties and degrees of freedom of the problem at a certain level of confidence through a statistical test (Socco and Boiero 2008). In the figures reported a representation based on the misfit is adopted for velocity profiles, so that the darkest colour corresponds to the profile whose dispersion curve has the lowest misfit and better approximation to the reference one; the same holds for the corresponding dispersion curves.

2.4 Numerical code

The numerical codes used for processing and inversion of surface waves are non commercial codes, implemented at Politecnico di Torino.

3 Condominio Ex Ater – Surface wave results

In Figure 4 an example of the f-k spectrum of the data collected at Condominio Ex Ater is presented.

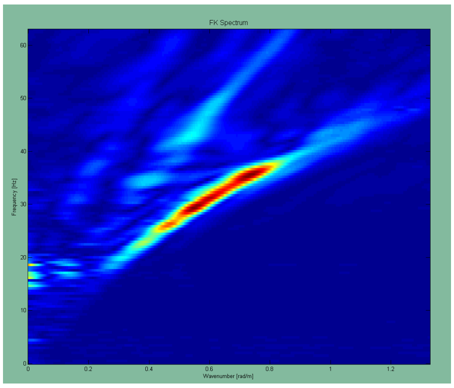

Figure 4 Condominio Ex Ater – example of f-k spectrum

From the f-k spectra, several dispersion curves can be retrieved. From all these curves an average curve is estimated (Figure 5).

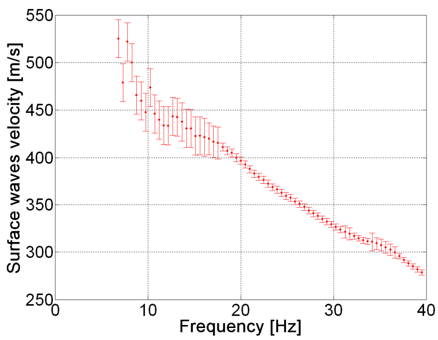

Figure 5 – Condominio Ex Ater -Average apparent dispersion curve

Observing the dispersion curve larger uncertainties can be observed in the low frequency range with respect to higher frequencies, due to weaker signal to noise ratio at low frequencies.
The best fitting profiles resulting from the Monte Carlo inversion at a confidence level of 1% (Socco and Boiero 2008) are plotted in Figure 6a, profile colour depends on the misfit, from yellow to blue (best fitting profile). In Figure 6b the corresponding dispersion curves are represented. In Figure 7 the experimental dispersion curve is compared with the dispersion curve of the best fitting model.

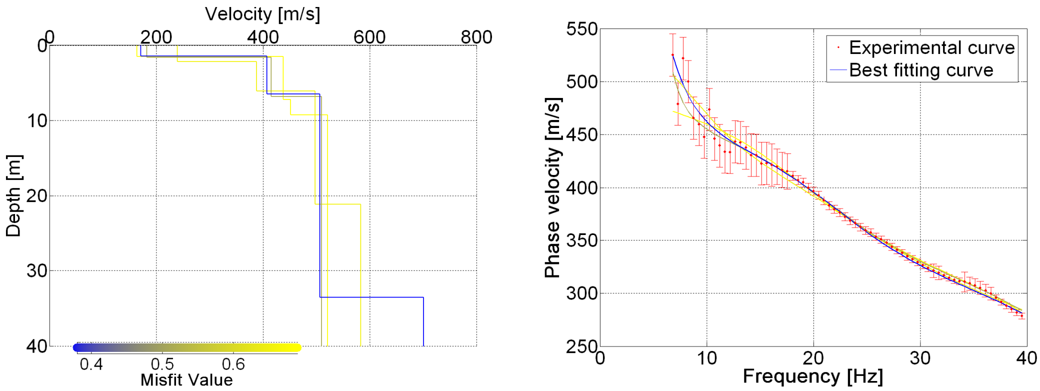

Figure 6 Condominio Ex Ater – a) final profiles (from yellow to blue) b) corresponding dispersion curves.

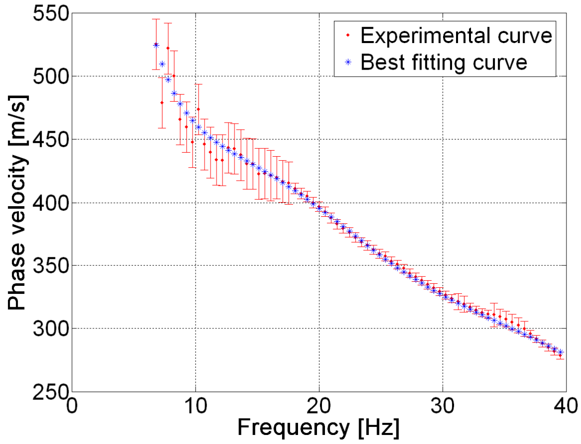

Figure 7 Condominio Ex Ater – Experimental dispersion curve compared with the best fitting curve

The parameters of the best fitting profile are summarized in Table 3.

Vs (m/s)	Thickness (m)	Poisson coefficient	Density (t/m^3)
171	1.5	0.25	1.8
407	5.0	0.33	1.9
507	27	0.45	2.0
701	-	0.45	2.0

Table 3 Condominio Ex Ater: subsoil parameters of the best fitting profile.

References

Project S4: ITALIAN STRONG MOTION DATA BASE, Deliverable # 6, Application of Surface wave methods for seismic site characterization, May 2009.

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