Abstract

This dissertation deals with the in situ characterization of the small-strain shear-wave velocity and damping ratio from the interpretation of Multi-channel Analysis of Surface Waves (MASW) surveys. Indeed, low-strain parameters dramatically affect the ground response under dynamic loading. Due to their remarkable role, an in-situ estimate of these quantities is highly recommended. A promising way to obtain soil stiffness and dissipative parameters relies on the MASW scheme. This approach is based on the interpretation of the propagation characteristics of Rayleigh waves, namely the phase velocity and the phase attenuation.

The first goal of this research was to identify and quantify uncertainties affecting the estimated Rayleigh wave parameters, with a focus on phase attenuation. For this purpose, a suite of synthetic wavefields and in situ measurements were considered, thus obtaining a benchmark for understanding the issues in the estimate.

The study focused on modeling epistemic uncertainties affecting the Rayleigh phase attenuation. On the one side, the influence of the processing technique was addressed. In this context, a novel technique (named Frequency-Domain BeamForming-attenuation, FDBFa) is proposed. This technique incorporates an explicit modeling of the geometry of the wavefield, and it allows to isolate different Rayleigh propagation modes, through a filtering scheme. Therefore, it returns reliable attenuation estimates even in the presence of multi-mode wavefield, which is typical of complex stratigraphy conditions. Then, the study focused on the sensitivity of the Rayleigh wave parameters to the acquisition setup, in terms of the type of the active source and the recording device. As for source characteristics, results show that low-energy sources (e.g., a sledgehammer) return reliable estimates of the phase velocity and attenuation, albeit with larger variability. This result demonstrates the possibility of retrieving reliable attenuation data also in ordinary MASW surveys, in which the sledgehammer is commonly used. As for the sensing device, estimated phase velocity and phase attenuation data obtained from geophone and fiber-optic DAS data were compared. The latter represents an innovative technology in seismic measurements and monitoring, of which use in geophysics is still limited but promising. Indeed, also existing fiber-optic networks for telecommunication can be used for the acquisition of seismic data. The high degree of matching between observed data demonstrated that the DAS technology can be successfully used to jointly estimate the phase dispersion and attenuation data, obtaining the same level of reliability as an "ordinary" geophone array.

Furthermore, this dissertation proposed a statistical scheme to model aleatory variabilities in the estimated phase velocity and attenuation data. Indeed, various models have been proposed to quantify the dispersion variability, whereas no scheme was explicitly demonstrated for attenuation data. The model describes the variability in experimental data according to a bivariate lognormal distribution, although the observed low correlation allows using lognormal marginals for the statistical characterization. The lognormal scheme is preferred to the Gaussian model to describe highly variable data (as the phase attenuation) without including negative values. This assumption ensures greater consistency, from the physical point of view.

Then, the research focused on mapping the experimental Rayleigh wave parameters into soil models describing the profiles of shear-wave velocity and damping ratio with depth. A robust inversion algorithm was developed for this purpose. This technique is a Monte Carlo, global search

algorithm, which implements a smart sampling procedure. This scheme exploits the scaling properties of the solution of the Rayleigh eigenvalue problem to modify the trial earth models and improve the matching with the experimental model. Thus, a reliable result can be achieved with a moderately small number of trial ground models. In general, estimated soil models exhibit well-defined shear-wave velocity profiles, whereas the damping ratio profile is affected by remarkably large scatter, although a trend can still be identified. This difference is the effect of the high variability characterizing experimental attenuation data, the limited wavelength range at which reliable values of these parameters can be retrieved, and the sensitivity of attenuation data to both damping ratio and the S-wave velocity. However, the resulting response to the ground motion is affected by moderately small variability, and it consistently matches in situ observed data. The result stresses the effectiveness of using damping ratio estimates from in situ surface wave data, as an alternative to other characterization techniques.

Overall, this research shows the feasibility of retrieving both stiffness and attenuation parameters from surface wave testing, highlighting also the issues related to the uncertainties and the different level of reliability affecting these two quantities. In general, great care is required when modeling the geometric features and the multi-mode nature of the wavefield, as well as model incompatibility effects. Indeed, these features dramatically affect the estimated attenuation. On the other side, under proper modeling of wavefield conditions and adopting robust inversion procedures, a reliable and accurate prediction of the actual behavior can be achieved.