ESTIMATION OF NEAR-SURFACE SEISMIC ATTENUATION THROUGH VSP SURVEYING

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Introduction. Seismic attenuation is definited by the loss of elastic energy contained in a seismic wave, while it propagates. We used two well-established methods for ours *Q* estimates, Spectral Ratio and Rise time. In the Spectral Ratio (SR) method, the determination of attenuation is based on the standard assumption of exponential amplitude decay in the frequency domain. When Q_P is considered to be frequency-independent, the inverse problem is generally stable, and it can be linearized and solved for all of these three parameters:

$$ln\left[\frac{S_2(f)}{S_1(f)}\right] = -\frac{\pi \Delta tf}{Q_P} + ln\left[PG\right] \qquad (1\text{-}1)$$

Where and are the amplitude spctrum of two seismic traces. The left-hand side of the equation is called Reduced Spectral Ratio. The slope term, , is called Differential Attenuation (Teng, 1968). The Rise Time (RT) method is based on the assumption that the pulse rise time increase linearly with the distance of propagation (Gladwin & Stacey, 1974). An attenuative impulse will satisfy the equation:

$$\tau = Ct^* \qquad (1\text{-}2)$$

where τ is the rise time of the resultant pulse and *C* is a constant.

Acquisition & survey geometry. From 2nd to 8th August 2017, as part of the investigation and study activities related to the level III Seismic Microzonation (MS) of the Municipality of Rieti (RI), in Campomoro (Borgo S. Antonio), a continuous core drilling was carried out, up to 45 meters, and equipped for the Downhole geophysical test. Below are the description data related to drilling:

Tab. 1 - Parameters for field data acquisition.

Survey	Acquisition detalis
Geognostic survey	*Lat:* 42°,402415, *Long:* 12°,866859 *Material:* PVC pipe with a 3” diameter and 0.5 cm thickness; *Cementation:* consisting of water, cement and bentonite
Near-surface VSP	*Geophones:* 8 + 2 hydrophones (4.5 Hz) 1 m spaced *Source:* 6 kg hammer weight *Device:* 1 seismographs Geode Geometrics

For the attenuation analysis, a geophone downhole string was used to perform a near-surface, VSP survey, consisting of n°8 single-channel hydrophones (the hole was previously fill of water) with a 4,5 Hz natural frequency, spaced 1 meter apart and progressively lowered down 5 meters for each measure, resulting in an overlap of three traces between two subsequent acquisitions. Two additional geophones was mounted on the ground to assure control over the absolute time. The seismic source consists of a 6 kg sledge-hammer operated manually on an aluminium plate (30 cm of radius) fixed on the ground. The sampling interval is 0.03125 ms, so that the sampling rate is 32000 Hz. The number of samples recorded is 16384 for a total recording length of 512 ms. The n-traces recorded can be combined into n-1 non-redundant pairs.

Data processing. The assessment of seismic attenuation values from VSP data is done essentially by measuring changes in amplitude and broadening of compressional P-wave first arrivals corresponding to direct travel path from source to receivers position.

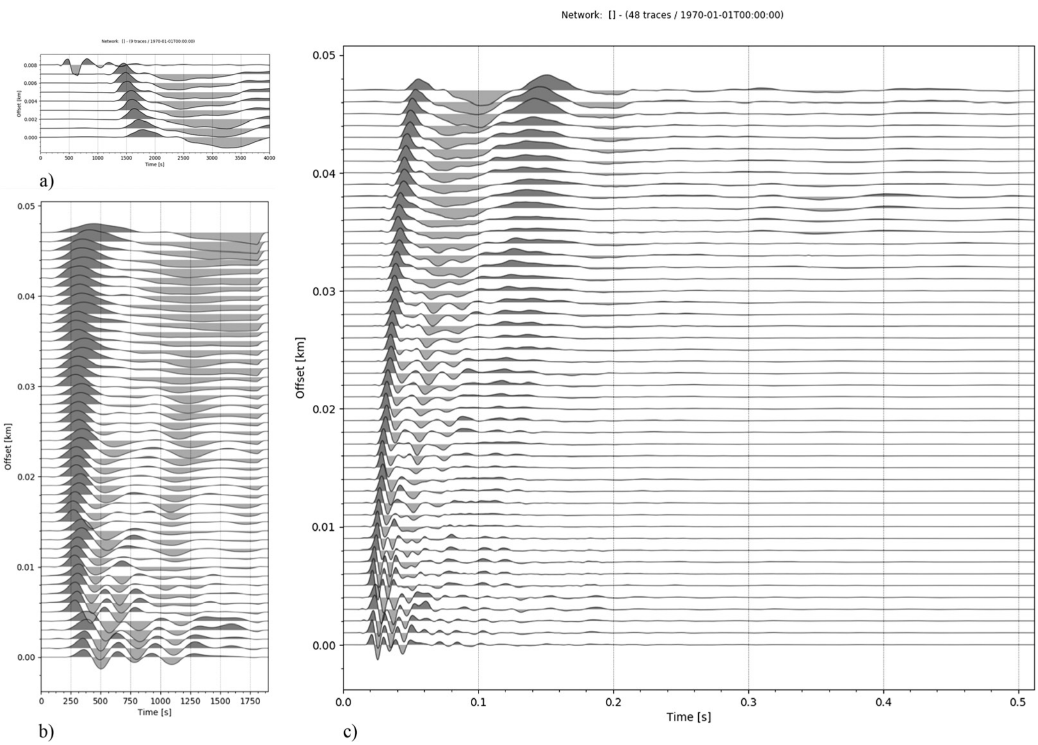

Fig. 1 - (a) One shot traces visualization (shot n. 9, depth 39-47 m.). (b) Vertical Seismic Profile after conditioning operations (c) Complete Vertical Seismic Profile.

The visualization of the traces in the fig.1b shows a significant dispersion of the pulse with increasing depth. For this reason the RT method seems to be particularly suited for this dataset. The key-point of the SR method is the identification of the first cycle of the signal over which perform Fourier Transform. I've firstly carried out a pack of operation technically called conditioning operations. These operations are usefull to improve the quality of the seismograms in relation of our studies, and their related spectra. After stacking, the primary objective is to identify and isolate the part of the seismogram relative to the passage of the P-waves and eliminate the contribute of slower waves and multiples in seismogram. Another difference between a classic VSP data and a near-surface VSP is even the different processing and conditioning operations. The downgoing wavefield was extracted using a wave-by-wave separation approach considering the near-surface wavefield observed (only Downgoing). A 300 Hz lowpass filter is applied in order to decrease interference and noise at higher frequencies. Then we performed a windowing operation using a Blackman Window function. In the end, we applied a polynomial function in order to remove significant trends of each seismic signal. We operated an FFT to estimate amplitude spectra of each trace. The natural logarithms of the spectral ratios between the reference signal and the arrivals recorded at subsequent geophones were then computed and plotted as a function of frequency to estimate the slope of the logarithm spectral ratio, alpha, which, according to Equation (1-1), is a function of Q and the travel time between the two arrivals. We can see on Fig.2 (a-b-c) the reduction in the spectral amplitude due to the attenuation of the signal in depth. The slope was plotted and obtained over a frequency band of 15-150 Hz, when the spectrum shows the peak of energy.

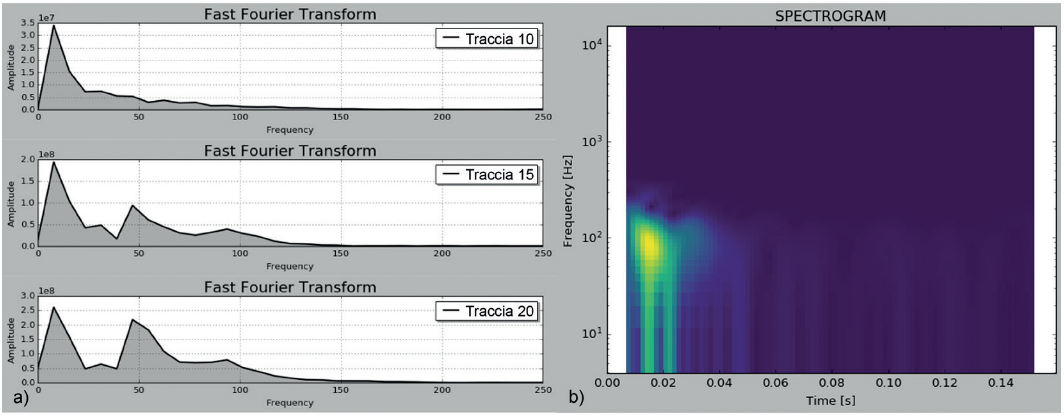

Fig. 2 - (a) Fourier spectra of seismic traces at 10-15-20 meters depth, (b) Spectrogram of 15th trace.

Data results. The key parameter used for Q_P estimate for SR method is , the slope of the regression (Equations (1-1). The spectral ratios show a very good linear trend between 15 and 150 Hz, especially for deeper ratios. Once this threshold is exceeded, a drastic change in slope is noted (Fig.3a). The slope values obtained from these ranges are equal to the differential attenuation . As we expected, plotting the differential attenuation values vs depth, we see an increasing. Some deviating values, most in the first layers, can essentially be due to scattering phenomena. The same is observed in the RT values (Fig.3c), which increase in depth, and vary from 0.069 to 0.33 ms. The slope values are divided by a minimum of 3.165×10^{-3} up to a maximum equal to 2.622×10^{-2} recorded in the last meters. At this point it is possible to obtain, with reference to the formulas (1-1) and (1-2), the values of the quality factor for the compressional P-waves for both of methods (Fig.3d). For the Risetime method, 3 different intervals were considered in relation to layers observed before. The results of the tests, comparing the values obtained from the two methods, show an excellent correspondence and a minimum error. Values of Q_P from SR method are included from 0.78 to 8.26. In general, the calculated values with the Risetime method are higher, considering mean values. The authors attribute this discrepancy to mode conversions, scattering around the borehole (Morozov, 2008), and signal dispersion with depth. For obvious technical issues, the values obtained with the RT method can only be relative to depth ranges, as it is not possible to obtain punctual values. The following Table 2 shows the values obtained with the two different methods, averaging the values obtained for the SR method with respect to the intervals.

Tab. 2 - Parameters for field data acquisition.

	Quality Factor (QP)	
Depth range (m)	Spectral Ratio (mean)	Risetime
0-8 (terreno da riporto e sabbie medio-fini)	1.41	1.93
8-32 (ghiaie)	2.69	3.59
32-47 (sabbie ghiaiose)	4.31	6.88

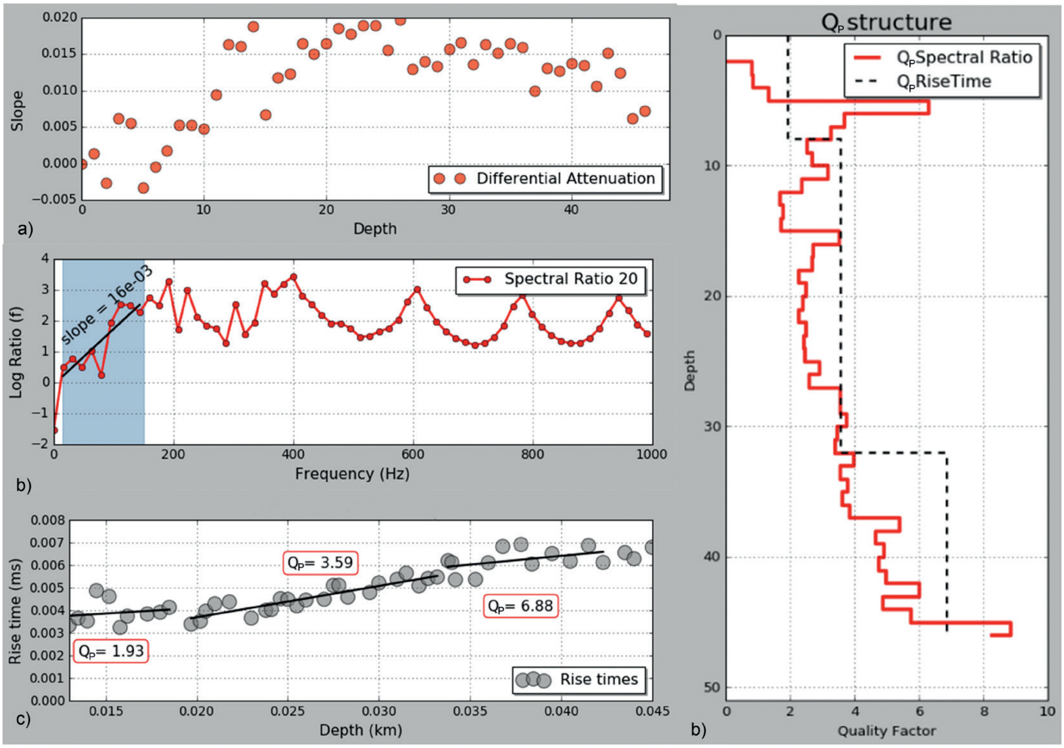

Fig. 3 - a) Spectral Ratio (15 meters depth) obtained using the left side of equation 1-1, b) Risetimes vs depth. c) Risetimes vs depth with Q_P values at each interval, d) Comparison of near-surface Q_P factors estimates using Spectral Ratio and Risetime methods.

Conclusions. The application of the methods for Q estimation using near-surface surveys is essential to provide an additional and important geophysical data for site characterization and seismic modelling. The medium-small depth (<100 m), which is generally correlated with a great seismic attenuation (low Q), requires an accurate study on the choice of the method to be applied. In this case the dispersive nature of the seismogram suggest to the application of the Rise time method, still not used in the medium-small depth. In order to have a confirmation of the reliability of the data, that show an high attenuation (Q<5), the results were compared by applying even Spectral Ratio method, showing a good correlation between the results, although the SR method is more influenced by problems related to waveform and frequency content of the seismic signal.

References

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