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Quasi-Newton algorithm using Fresnel wavepaths and frequency increase for P-wave tomography inversion: application to a landslide in the South French Alps

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Seismic wave attenuation

The Super-Sauee landslide offers a promising context to study the effect of favoring on seismic wave attenuation. The amplitude of the first arrival was then exploited to recover the lateral variation of attenuation along the fore wall. The seismic attenuation is a good physical property because it is directly linked to porosity and to the presence of fractures in the soils. We choose to use the inversion method proposed by Watanabe and Sasao (1996) considering that in a homogeneous attenuating medium the amplitude of the spectral waves varies:

\[ A(f) = \frac{A(0)}{\sqrt{1 + \frac{2.2 f}{\omega_{0}}}} \]

Where \( A_0 \) is the amplitude of the source signal. Applying a logaritm to the equation, its become linear in \( \ln(\omega) \). The attenuation inversion is performed using the previous results of soil and of the W matrix in a gradient. We performed 5 iterations starting from a simple homogeneous media with an attenuation at \( f = 0.5 \text{ Hz} \). Comping the Fresnel wavepaths for matrices of different frequencies (30 Hz, 45 Hz, 60 Hz, 90 Hz, and 120 Hz) in order to link the attenuation map with surface cracking, we made an inventory of the favoring of the state of the soil along the seismo profile. We keep all the cracks wider than 5 cm and created a Surface Cracking Index (SCI) corresponding to the total length of cracks per linear meter. The SCI is then normalized (Fig. 5).

Application to the Super-Sauze landslide

The previously described algorithm was applied on a real dataset acquired on the Super-Sauze landslide. The seismic profile was parallel to the flyover axis (longitudinal profile). It was situated in the upper part of the landslide from the second component (transmit A, receive B). The main, crust to the centrifuge, and then only around 50 shots have beenachieved with a hammer every year 4 m. We used a roll-along system to translate the fluke and recorded only 48 traces per shot. The only vertical component of the seismic signal was measured. The initial length of recording is 1.5 s with a sample rate of 0.25 ms with a Geometrics Stratosphere seismic camera with 48 geophones of central frequency around 40 Hz. Active picking, differences between reciprocal traveltimes have been computed and pick a difference greater than 10 ms have been used for the inversion. The error in the quality of traveltime can be approximated by a Gaussian distribution with a standard deviation of 2.2 mm (Fig. 3).

The signal around 40 Hz is characteristic of surface wave signal but the first arrivals are clearly visible. The inversion has been performed with the GNQ algorithm on a 104x153 grid. Each square cell of the grid measures 0.67 m. The hammer source gave frequencies comprised between 30 Hz and 120 Hz with a dominant frequency of 40 Hz. Those values were considered as constant for each shot. For the first iteration, the frequency of the source was increased at each step to 45 Hz, 60 Hz, 75 Hz, 90 Hz, 105 Hz, until 120 Hz, so that after the eighth step, the frequency was kept constant.

Interpretation

Results from seismic P-wave inversion have been compared to dynamic penetration tests and to the 3D geological model of Travelliet and Malce (2012). The bedrock depths are comparable and the relationship between the SCI and the depth to bedrock is around 5 m. We also used an orthophotograph and a DEM of the area from 1996 before the landslide triggering to compare the paleoposition recovered on seismic and the old topography. We notice on the orthophotograph a slight bump of the topography followed by a depression and a second important bump created by a cret crossing the seismic profile as well as on the P-wave tomography, respectively at 90, 125 and 140 m. Near 180 m, one can see a zone of low velocities (< 400 m/s) in depth that we interpret as the path of a gully present before its covering, also visible on the orthophotograph of 1996 (Fig. 4).

Bedrock and landslide layer are well recovered by seismic attenuation and results are well correlated to surface cracking. The values obtained for the bedrock are around 10–13 Np/m, which corresponds to consolidated soils attenuation at 40 Hz. The attenuation of the landslide layer varies from 4 to 12 (10–3 Np/m), which are more characteristics of unconsolidated soils at that frequency. The litho heterogeneity of the attenuation is important. Areas of high attenuation show attenuation 3 times higher than others. The correlation between the SCI and the attenuation is very good, so that we can affirm that attenuation variations are mainly caused by cracking. Results obtained from seismic data are gathered inside an interpreted model (Fig. 6 b). We interpreted the three units visible in the P-wave tomography and cracks area determined by high attenuation zones. This interpreted geological model could improve the result in numerical modeling for a better hazard assessment.

References


Seismological and geophysical surface wave methods (1)

Fig. 1. Spatial correlation of earthquake seismograms spatially and temporally correlated with signals from occurrence of landslides (Gance et al., 2009).

Fig. 2. Inversion of spectral wave attenuation of vertical particle motion in a complex heterogeneous media (Watanabe et al., 1995)

Fig. 3. Inversion of spectral wave attenuation on vertical particle motion as a function of frequency (Watanabe et al., 1995).

Fig. 4. Seismic traveltimes and spectral wave attenuation rates for P waves and S waves among near and far area after triggering of landslides. The SCI is increased significantly by the landslide triggering (Watanabe, Matsukawa, and Ashida, 1996; Watanabe, T., 2012; Watanabe, T. et al., 2012).

Fig. 5. Spectral wave attenuation rates for P waves and S waves among near and far area after triggering of landslides. The SCI is increased significantly by the landslide triggering (Watanabe, Matsukawa, and Ashida, 1996; Watanabe, T., 2012; Watanabe, T. et al., 2012).