The role of Rayleigh waves ellipticity in mode misidentification

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Outline

1. Intro: Surface wave methods and modes misidentification

2. Rayleigh wave ellipticity and osculation

3. The Multi-components Analysis of Surface wave: real and synthetic cases

4. Results and conclusions
Multi-channels Analysis of Surface wave methods (MASW, Park et al. 1999) are nowadays common practice in geophysical surveys to infer Vs profile of the subsoil.

Common applications are vertical multi-channels controlled source or passive acquisitions. Usually surface waves dispersion properties are identified as energy density maxima in transformed domains as F-k or F-v domains. The assumption of the energy maxima as belong of the fundamental mode is common, but often not verified.

Modes mis-identification can seriously affects Vs profiles results, defined as the solutions of an erroneous assumption (Socco & Strobbia 2004; Maraschini et al. 2010)
1. Surface wave methods and modes misidentification

In the common case of strong impedance contrast in the subsoil the so call OSCULATION phenomenon takes place. Osculation frequency $F_0$ is where the energy peak shifts at low frequencies from the fundamental to the first higher mode. With the limited k resolution of the everyday engineering practice Osculation is not identifiable and the spectrum maxima are associated all to the fundamental mode. This misleading behaviour can lead to a serious overestimation of the deeper layers velocities.

Example of Osculation in f-k and f-v domains for a 5m soft layer on a bedrock (48ch array)
2. Rayleigh wave ellipticity and impedance contrast

Osculation takes place only in certain subsoil conditions. It is known it happens especially when energy is transmitted through internal waveguides. A strong impedance contrast is then needed to create the osculation singularity which ‘kiss’ fundamental and 1st mode at the frequency $F_0$.

Three modal curves models with varying impedance contrasts: 200 m/s layer 6m thick on a half space of respectively 300 m/s (blue), 400 m/s (black) and 500 m/s (red).
Rayleigh wave ellipticity and osculation

If we look in such cases of strong impedance contrast also ellipticity of Rayleigh wave present singularities. At frequency $F_V$ the horizontal particle motion vanishes, and the Rayleigh wave is purely vertically polarized, while at frequency $F_H$ the vertical particle motion vanishes, and the polarization becomes horizontal. These singularities are also the points where the direction of the elliptical particle motion changes: from counter-clockwise to clockwise and to counter-clockwise again.

$F_V$ ellipticity singularity is nearly the same frequency of $F_0$ osculation singularity.

Why?

Modal curves and vertical ellipticity of the fundamental mode
Monte Carlo simulation of 2000 models with high velocity contrast. The dots represent the pairs \( f_{osc} - f_h \) and \( f_{osc} - f_v \) color-coded to indicate the velocity contrast at the bedrock interface.

The ratio between \( f_v \) and \( f_{osc} \) is above 1.5, and the ratio between \( f_{osc} \) and \( f_h \) is below 1.5.
2. Rayleigh wave ellipticity and osculation

It means above the Osculation Frequency $F_0$
Fundamental mode particle motion is predominantly \textit{Vertical}
while below Osculation Frequency $F_0$
Fundamental mode particle motion is predominantly \textit{Horizontal}

Since 1st higher mode still remains predominantly vertical below $F_0$ energy seems to shift from the fundamental to the 1st higher mode simply cause we are looking only to vertical geophones !!!

If we look only on the vertical components we suffer the osculation phenomenon
3. The Multi-components Analysis of Surface wave McASW

If we record both the components of motion (vertical and radial) we are able to follow the fundamental mode still below the osculation frequency $F_0$.

We can clearer identify the osculation phenomenon avoiding a misleading picking of the dispersion curve.

In Osculation cases we must adopt a Multi-components Analysis of surface waves!

Only vertical comp. MISLEADING WAY
osculation not identifiable

horizontal components
osculation identifiable

f-k spectra for 6m soft layer on a bedrock

Boaga et al., Geophysics, 2013
3.

The Multi-components Analysis of Surface wave synthetic case: 5m 300/s over a bedrock with 1100m/s
3. Osculation Frequency and Resonance Frequency

H/V ratio peak

Resonance Frequency
The Multi-components Analysis of Surface wave
a real case in the Alps (NE Italy)

- 24 Vertical geophones
- 24 Horizontal geophones
- 5kg hammer

Belluno site
4.5 m of silty clay on Sandstone

Boaga et al., Geophysics, 2013

GNGTS 2013 - 19-21 Novembre 2013
The Multi-components Analysis of Surface wave a real case in the Alps (NE Italy)

Measured Ellipticity at Belluno site, HVSR single station measurement

Oscillation frequency $F_0$ is expected near after resonance frequency (20 Hz)
3. The Multi-components Analysis of Surface wave
a real case in the Alps (NE Italy)

F-v spectrum for vertical components
(in red points the maxima)

F-v spectrum for horizontal components
(in red points the maxima)
4. Results

- Modes misidentification known as Osculation phenomenon can lead to a serious overestimation of deeper structure Vs, particularly dangerous in a-seismic design.

- Osculation, which takes place in presence of strong impedance contrast, is strictly related to the ellipticity of Rayleigh waves.

- Below a certain frequency, function of the structure resonance, Rayleigh fundamental mode is predominantly horizontal, while 1st higher mode presents predominant vertical motion: this causes the shifting of the energy responsible of modes misidentification.

- If we adopt joined acquisition of vertical and horizontal geophones we can clearly identify Osculation phenomenon and avoid misinterpretation.

- For all these critical subsoil condition, verifiable with a-priori detector as HVSR analysis, a Multi-components Analyses of surface waves must be adopted (McASW).
Conclusions

In natura non vi è nulla di anomalo, siamo noi ad osservarla con lenti sbagliate

Guy de Maupassant
Main References


- Park C.B., R. D. Miller and J. Xia, 1999, Multichannel analysis of surface waves. Geophysics; June 1999; v. 64; no. 3; p. 800-808;